

# **CROCODILES**

## **8th Meeting**

### **1986**

**Special Reprint of the Proceedings of the  
8th Working Meeting  
of the Crocodile Specialist Group**

**of the Species Survival Commission of  
IUCN - The World Conservation Union**

**convened at**

**Quito, Ecuador 13 - 18 October, 1986**

**(Unedited and Unreviewed)**

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**SPECIES SURVIVAL COMMISSION**

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**Proceedings of the 8th Working Meeting of the Crocodile Specialist Group  
of the Species Survival Commission of the International Union for  
Conservation of Nature and Natural Resources convened at**

**Quito, Ecuador**

**13 to 18 October 1986**

**International Union for Conservation of Nature and Natural Resources**

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1989

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## FOREWORD

This volume is a record of the presentations and discussions that occurred at the 8th Working Meeting of the Crocodile Specialist Group in Quito, Ecuador, 13 to 18 October 1986. Its publication was supported by contributions from Professor Harry Messel and the University Foundation for Physics, University of Sydney, Australia; the Griffiths Wildlife Conservation Fund of the University of Florida Foundation, Gainesville, U.S.A.; and Jacques Lewkowicz of Société Nouvelle France Croco, Paris. The opinions expressed herein are those of the individuals identified and are not the opinions of the International Union for Conservation of Nature and Natural Resources or its Species Survival Commission. Phil Hall was scientific and managing editor, Rhoda Bryant was copy and style editor.

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The International Union for Conservation of Nature and Natural Resources (IUCN) was founded in 1948, and has its headquarters in Gland, Switzerland; it is an independent international body whose membership comprises states, irrespective of their political and social systems, government departments, and private institutions as well as international organizations. It represents those who are concerned at man's modification of the natural environment through the rapidity of urban and industrial development and the excessive exploitation of the earth's natural resources, upon which rest the foundations of his survival. IUCN's main purpose is to promote or support action which will ensure the perpetuation of wild nature and natural resources on a world-wide basis, not only for their intrinsic cultural or scientific values but also for the long-term economic and social welfare of mankind.

This objective can be achieved through active conservation programs for the wise use of natural resources in areas where the flora and fauna are of particular importance and where the landscape is especially beautiful or striking, or of historical, cultural, or scientific significance. IUCN believes that its aims can be achieved most effectively by international effort in cooperation with other international agencies, such as UNESCO, FAO, and UNEP, and international organizations, such as World Wild Fund for Nature (WWF).

The mission of IUCN's Species Survival Commission (SSC) is to prevent the extinction of species, subspecies, and discrete populations of fauna and flora, thereby maintaining the genetic diversity of living resources of the planet. To carry out its mission, the SSC relies on a network of over 2,000 volunteer professionals working through 100 Specialist Groups and a large number of affiliate organizations, regional representatives, and consultants, scattered through nearly every country in the world.

## SUMMARY OF THE MEETING

The 8th Working Meeting of the IUCN/SSC Crocodile Specialist Group (CSG) was convened in Quito, Ecuador, from 13 to 18 October 1986. The meeting was hosted by the Pontificia Universidad del Ecuador and the Fundación Natura, and would not have been possible without the tireless efforts of Drs. Eduardo and Ana Cristina Asanza who handled local arrangements, and numerous university students who assisted with registration and operated the audiovisual equipment used during the sessions.

The meeting was open to anyone actively involved in crocodilian conservation or farming. More than 60 participants registered for the meeting and delivered a total of 48 papers and audiovisual presentations on the status of crocodilian populations, management problems and successes, legal and illegal trade, and the latest research developments; 17 of the papers were submitted for publication and appear below (see Table of Contents).

Dr. Julio Terán Dutari, Rector of the Pontificia Universidad Católica del Ecuador, opened the meeting at the university and welcomed the participants. Additional welcoming comments were delivered by Sr. Manuel Kakabadse, Director of the Dirección Nacional Forestal, Ministerio de la Agricultura y Ganadería; Dr. Tjitte de Vries, Director of the university's Department of Biology; Sr. Roque Sevilla, President of the Fundación Natura; and Dr. Luis Romo, President of the Comunidad Científica Ecuatoriana.

Following two days of sessions, the participants traveled by plane and boat to Limoncoche where two days were spent observing the *Melanosuchus* and *Caiman* population being studied by Eduardo Asanza. The final working session, the business meeting, was held on the Orellana floating hotel during the return trip to Quito. A summary of the business session deliberations follows.

### PUBLICATIONS

Publication of Commercial Volume on Crocodile Biology and Conservation. Although the CSG members had agreed to contribute to a commercial volume on crocodilians at the 1984 working meeting, and a number had signed agreements with the publisher, 60% of the chapters still had not been submitted despite the deadline having passed months ago. The chairman indicated that the chapters that had been turned in would be returned to the authors or compiled into a special volume to be published in the IUCN series on crocodiles.

CSG Newsletter. The members commended the format and currency of the Newsletter, and recommended that Peter Brazaitis and Myrna Watanabe continue to serve as editors. To ease the work load, Lehr Brisbin was asked to serve as assistant editor for business matters.

Catalogue of American Amphibians and Reptiles. The chairman, who had just become the editor of the crocodilian accounts in the Catalogue of American Amphibians and Reptiles published by the Society for the Study of Amphibians and Reptiles, asked if any people present were working on accounts. Records from the previous editor were incomplete and do not indicate who has been asked to write accounts. Several members indicated they were writing accounts and provided a list of prior assignments.

### FUNDRAISING FOR CSG OPERATIONS

The cost of CSG operations such as publication of the Newsletter, postage and telephone expenses, and travel has been borne by the chairman's and editor's offices, however, assistance is needed. In addition there are other costs not presently being covered, such as travel assistance for getting students and members from tropical nations to meetings, and funding for special projects. Following some discussion the members agreed that, provided the Group's ethical standards remained high and uncompromised, it was appropriate to ask the international hide trade to contribute to support of the CSG. It was recommended that a fundraising committee be appointed.

## RECOMMENDATIONS TO THE CITES SECRETARIAT

Transfer of Nile Crocodile Populations from CITES Appendix I to Appendix II under an Annual Quota. The members were unanimous in opposing transfer of any crocodile populations from Appendix I to Appendix II without supporting data to justify the transfer. Support was expressed for removal of quotas from any nation that, by the time of the 1989 CITES Meeting of the Conference of the Parties, has not developed the management and monitoring programs promised at the Buenos Aires meeting. However, the CSG also recognized the need to assist nations in developing and implementing monitoring and ranching programs to replace the quotas. John Hutton pointed out that wildlife officials in many African nations do not know what data are needed to justify downlisting of crocodile populations or how to generate the data. As a remedy, John Hutton drafted a,

### PROJECT FOR THE ASSISTANCE OF SADCC MEMBER STATES WITH CROCODILE MANAGEMENT AND UTILIZATION

#### Introduction

The Nile crocodile, *Crocodylus niloticus*, occurs in suitable habitat throughout the SADCC (Southern Africa Development Cooperation Conference) region and frequently comes into conflict with legitimate human interests. Extensive human fatalities have been reported from Malawi, Mozambique, and Zimbabwe. The level of this conflict is increasing which reflects, at least in part, the recovery of crocodile populations from over-exploitation in the 1950s. In several SADCC countries crocodiles are now sufficiently numerous to be a valuable natural resource promoting conservation.

For 20 years Zimbabwe's wild crocodiles have supported such a harvest. Eggs collected from the wild, hatched and the young crocodiles raised for their skins. In 1985 this industry earned approximately U.S. \$1,000,000.00, all in foreign exchange, and provided a conspicuous incentive for the conservation of wild crocodile populations. The success of this policy resulted in Zimbabwe's crocodiles being downlisted from "endangered" under CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), allowing unrestricted trade. A similar, largely untapped potential for crocodile utilization exists in neighboring states.

Five other SADCC countries (Botswana, Malawi, Mozambique, Tanzania, and Zambia) have, either through SADCC or the CITES forum, indicated that they intend to undertake crocodile utilization. In 1984 an "African proposal" was presented to the 5th Meeting of the Conference of the Parties to CITES by Malawi, supported by 25 other African countries and a consultancy report, asking that the status of the crocodile be moved from Appendix I (Endangered) to Appendix II (Threatened) - the prerequisite for utilization. Only certain populations were downlisted and an export quota system was adopted. Botswana did not request a quota at the time (it has since done so by postal vote) but the other SADCC countries received quotas as follows at the CITES meeting in Buenos Aires: Malawi (500), Mozambique (1,000), Tanzania (1,000), and Zambia (2,000).

Quotas are due to be reviewed in April 1987 and supporting data will be required. Member countries have few resources to dedicate to submissions of the type required for downlisting of species by the CITES Parties, and a second round of quotas is anticipated. This shortage of resources requires that SADCC states wishing to initiate sustainable crocodile utilization be assisted in some or all of the following areas:

- a. Pre-feasibility studies (harvesting potential of wild populations, production options);
- b. Policy and legislation (adaptation of legislative and institutional frameworks to allow efficient and controlled utilization);

- c. Feasibility studies (identification of potential production sites, evaluation and quantification of the factors inherent in utilization, production plans and a working document);
- d. International requirements for trade (the research and drafting of CITES submissions, documentation and tagging);
- e. Census and monitoring (technical advice for the derivation of simple and appropriate schemes, training of local manpower);
- f. Technical aspects of crocodile propagation in captivity (planning, extension, management training); and
- g. Marketing.

### Programme

The programme is divided into two parts:

1. Feasibility, policy and preliminary surveys (a,b,c, and d above).
2. Implementation - technical assistance with captive propagation, census and monitoring and marketing (e,f, and g above).

The first part of the programme is designed to give each country a clear indication of its options, a policy for utilization, a plan for its implementation and an unequivocal document for submission to CITES before April 1987.

The second stage is intended to transfer technical skills within the SADCC region to result in a coordinated regional production and marketing system which is efficient and sustainable, together with a system of monitoring.

### Programme details

1. Feasibility, policy and preliminary surveys.

As a general principal, egg collection and "farming" will yield more skins than cropping of wild crocodiles, but this advantage can be offset by the expense of such factors as food supply or initial capital investment. The choice of a utilization strategy requires a detailed investigation of both crocodile abundance (exploitation potential) and propagation potential. Following this, farm sites, the availability (and economics) of the supply of food and water, the suitability of the environment and the availability of management skills will be assessed.

It is neither simple nor inexpensive to census crocodile populations, but the problems must be faced. In the "African proposal" only Mozambique and Zimbabwe submitted recent census data and that for Mozambique was inadequate to allow discrimination between the utilization options. In this part of the programme preliminary surveys will be carried out using any existing database, critical localities will be identified and the requirement for census and monitoring under Part 2 assessed.

Assistance will be given in the formulation of a clear Government policy on crocodile management and on the required institutional framework. Private involvement in exploitation usually necessitates controlling legislation. Government involvement may require the establishment of a managing body with responsibility for revolving funds, foreign exchange matters

and the training of management and other manpower. The required safeguards will be built into the policy.

Based on the recommended magnitude of exploitation, preliminary utilization plans will, at this stage, allow economic assessment and prediction.

When Government is satisfied that it has identified a management scheme suited to its aspirations, the correct submissions and undertakings will be made to ensure problem-free international trade. Preliminary marketing suggestions will be made.

## 2. Implementation.

The technical input required in implementation will vary between countries depending on existing skills and management policy. It is envisaged that detailed structural and management plans will be provided where private enterprise is not extensively involved. Even where private investment is paramount, Governments will initially find it advantageous to provide extension services of the kind found in Zimbabwe. Experience has shown that even with good facilities, the success of crocodile utilization depends on the quality of management. Management training will be provided within the SADCC region.

In almost all circumstances the necessary surveying and monitoring will strain fully committed wildlife budgets. The rapid identification of census priorities in Part 1 will be followed up by detailed surveys to provide baseline data and correction factors on which subsequent simple, inexpensive monitoring will be based. Local skills will be created as appropriate.

The expertise required in this programme is available within SADCC, principally within Zimbabwe.

John Hutton also prepared a budget for this proposal, but it is not included here.\*

Transfer of the Botswana Nile Crocodile Population from CITES Appendix I to Appendix II under an Annual Quota. The CSG submitted to the CITES Secretariat a lengthy critique of the report Botswana submitted in support of its postal petition for transferring its Nile crocodile population to Appendix II under an annual quota, which the CITES Secretariat summarized and transmitted to the CITES Parties as:

"The Group will oppose the proposal until the Government of Botswana certifies to the CITES Parties that:

- a) it has limited and will continue to limit the exploitation of the Okavango crocodiles to the collection of wild eggs and hatchlings;
- b) it has and will continue to ban the exploitation of wild crocodiles over 2 meters in length, except for problem crocodiles that threaten humans and livestock;
- c) by protecting from all exploitation geographically widespread populations in national parks and wildlife reserves, it will conserve the biotic diversity of the Botswana crocodiles at a level that will allow them to perform their natural function in the ecosystem;
- d) it will establish a programme for monitoring (censusing) the status of crocodile populations similar to the programmes of Zimbabwe and Papua New Guinea; and

\* Following the CSG meeting this proposal was funded by World Wildlife Fund U.S.A. and a meeting of wildlife officials from SADCC nations was convened in Harare, Zimbabwe, under John Hutton's leadership prior to the July 1987 Meeting of the Conference of the Parties to CITES in Ottawa, Canada.

e) it will implement a marking system for legal crocodile hides and products, ...

If these things would be agreed and implemented by the Government of Botswana, then the CSG could support the modified proposal."

Prior to notifying the Parties, the Secretariat transmitted the CSG comments to the Botswana authorities, who responded with additional information on items a) and b) above. However, they indicated no plans to develop monitoring or hide tagging programs, items d) and e) respectively. After considering the comments of the various Parties, the CSG, and the Government of Botswana, the CITES Secretariat recommended that the Parties support the petition. As a consequence the postal vote probably will approve Botswana's petition.

Report on the Conservation of the Indonesian Saltwater Crocodile Population. The Indonesian population of *Crocodylus porosus* was transferred from Appendix I to Appendix II at the 1985 CITES conference in Buenos Aires. A copy of an Indonesian government report on the program for conserving the saltwater crocodile in Irian Jaya was received from the CITES Secretariat. There was too little time to translate the report into English before the CSG meeting, so the full content of the report was not available for review and discussion by the Group. A translation is expected to be available during 1987.

#### FARMING AND RANCHING

Interest in farming and ranching crocodilians continues to grow worldwide. The CSG supports the development of these establishments, but captive production of crocodilian hides and meat does not replace the need to conserve the species in the wild. As stated in Article IV(3) of CITES governing trade in Appendix II species, efforts should be made to "... maintain that species throughout its range at a level consistent with its role in the ecosystems in which it occurs ...." In order to accomplish that, wild populations that are subject to harvest must be rigorously managed to avoid over exploitation, and populations throughout the range of the species should be totally protected in national parks and wildlife sanctuaries in order to preserve genetic diversity.

Cameroon. Richard Luxmoore reported on a preliminary proposal to ranch crocodiles in Cameroon and indicated that he would keep the CSG informed as the project developed.

Philippines. Unconfirmed reports concerning attempts by the Republic of the Philippines-Japan Crocodile Farming Institute to obtain *Crocodylus novaeguineae* for stocking its farm in Puerto Princessa, Palawan Island, were reviewed. It was decided that letters would be sent to appropriate authorities in the Philippines expressing the CSG's concern over the possibility of escaped farm stock resulting in the establishment of an exotic species of crocodile into the Philippines. In addition, Victor Onions will visit the Palawan farm within the next two months and will report back to the CSG.

Honduras. The chairman reported on *Crocodylus acutus* farms being established in Honduras. The main farm is being developed by a cattle rancher and slaughter house operator, but a study commissioned by World Bank is expected to advocate additional farms.

Bolivia. The chairman reported on efforts to develop *Caiman yacare* farms in Bolivia. Bolivian law requires all caiman hide tanners to operate farms to lessen the pressure on the wild population from the export of 50,000 or more hides. None of the tanner's farms were anything more than natural ponds and lakes with no supplemental feeding or other intensive management. However, one of the tanners is planning to establish a caiman farm that would utilize the offal from a nearby slaughter house. In addition, one true farm operated by a heavy equipment importer apparently already exists.

Colombia. A farm for *Caiman crocodilus* has been developed by Monterrey Forestal in Sambrano, Colombia. Reportedly additional farms have been established in other parts of the country, but details are lacking.

**CESSATION OF BARRAMUNDI NETTING IN THE RIVERS OF KAKADU NATIONAL PARK.** The CSG received a letter from the head of the Australia's federal national park service reporting that the decision had been made to close all the rivers in Kakadu National Park to barramundi netting. The closure will be phased in over a period of months. The Group decided that in the light of IUCN General Assembly Resolution 16/26 Conservation of the Australian population of the saltwater crocodile (*Crocodylus porosus*), the chairman should write to appropriate government officials in Australia to congratulate them on the closure.

**TAGGING OF HIDES IN INTERNATIONAL TRADE.** Greg Mitchell indicated that all hides moving in international commerce should be tagged with locking, tamper-proof tags, like the ones used by Papua New Guinea, the U.S.A., and Zimbabwe to identify legal hide exports. The universal use of tags on legal hides would be an immense aid in regulating international trade. Following the discussion, the CSG approved a resolution on tagging:

WHEREAS, the importance of affixing tamper-proof tags to legal commercial crocodilian hides to distinguish them from illegal hides is widely recognized, and

WHEREAS, several countries have successfully implemented hide tagging programs; and

WHEREAS, data (such as number of crocodilians harvested annually, skin size, trade routes, and countries of origin) generated by a hide tagging program are of great utility to proper management of wild crocodilian populations.

NOW THEREFORE BE IT RESOLVED, that the Crocodile Specialist Group assembled on the occasion of its 8th Working Meeting in Quito, Ecuador, 13-18 October 1986, recommends that a universal tagging system, involving tamper-proof, serially numbered tags inscribed with country of origin, be implemented worldwide, and

BE IT FURTHER RESOLVED that countries of origin establish a monitoring program in order to maintain permanent records of all tags issued, especially with respect to size class of crocodilians harvested.

**CSG ACTION PROGRAM FOR CROCODILIANS.** Professor Messel reported on the need to produce an action program for crocodilian conservation in which the projects are priority ranked. At the last meeting the Group agreed to produce such a program for the SSC, but most members had not submitted regional or national projects to the chairman for inclusion in the overall program. Following further discussion, the CSG members renewed their commitment to produce an action program.

**INTERNATIONAL ALLIGATOR AND CROCODILE TRADE STUDY (IACS).** Ted Joanen asked the Group to endorse a continuation of the IACS study. During the sessions on the second day of the meeting in Quito, Don Ashley had introduced the people who compiled the three parts of the study of international trade in classic alligator and crocodile belly hides; Ginette Hemley of TRAFFIC U.S.A., and Richard Luxmoore of the IUCN Conservation Monitoring Centre, Cambridge, U.K., and Tom Milliken of TRAFFIC Japan. Each of these individuals presented their portion of the study, but the papers were not submitted for publication in this volume. The CSG gave a vote of confidence to the authors of the three studies and agreed by resolution that the IACS survey should be continued.

WHEREAS, the International Alligator and Crocodile Trade Study (IACS) has produced valuable data on international trade in classic alligator and crocodile belly hides; and

WHEREAS, the data produced by IACS is useful for management of crocodilian populations; and

WHEREAS, the U.S. Fish and Wildlife Service, the Louisiana Department of Wildlife and Fisheries, the Florida Game and Fresh Water Fish Commission, and the Texas Parks and Wildlife Department provided financial support of the IACS.

NOW THEREFORE BE IT RESOLVED, that the Crocodile Specialist Group on the occasion of its 8th Working Meeting in Quito, Ecuador, 13-18 October 1986, recommends a



continuation of the study and of its support by the various alligator producing states and the U.S. Fish and Wildlife Service.

**INTERNATIONAL CONGRESS OF HERPETOLOGY.** Rene Honegger described plans for the 1st International Congress of Herpetology in 1989, and indicated that CSG members should participate. He and Romulus Whitaker are on the organizing committee. Topics relevant to the CSG are on the agenda of the congress.

The first part of the paper discusses the importance of the research and the objectives of the study. It highlights the need for a comprehensive understanding of the subject matter and the role of the researcher in this process. The second part of the paper presents the methodology used in the study, including the data collection methods and the analysis techniques. The third part of the paper discusses the results of the study and the conclusions drawn from the findings. The final part of the paper provides a summary of the key points and offers suggestions for future research.

The research was conducted in a systematic and rigorous manner, following the principles of scientific inquiry. The data was collected from a variety of sources, including interviews, surveys, and archival records. The analysis was carried out using both qualitative and quantitative methods, allowing for a thorough examination of the data. The results of the study are presented in a clear and concise manner, with the conclusions drawn from the findings being well-supported by the evidence.

The findings of the study have important implications for the field of research. They provide a new perspective on the subject matter and highlight the need for further research in this area. The study also demonstrates the value of a multidisciplinary approach to research, as it allows for a more complete understanding of the subject matter.

In conclusion, the study has provided a comprehensive and detailed examination of the subject matter. The findings are well-supported by the evidence and have important implications for the field of research. The study also demonstrates the value of a multidisciplinary approach to research, as it allows for a more complete understanding of the subject matter.

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Names of CSG members (at the time of the meeting) are capitalized.



# PRODUCTION EFFICIENCY AT CROCODILE REARING STATIONS IN ZIMBABWE

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## INTRODUCTION

Zimbabwe recognizes wildlife as a renewable resource and believes that conservation is encouraged when the resource is used for the benefit of the people who live with it (Child 1977, 1987). This philosophy is illustrated by the sustained-yield utilization of the Nile crocodile (*Crocodylus niloticus*) in which, for 20 years, crocodile eggs have been collected from the wild and hatched, and the hatchlings raised for their skins on licensed rearing stations (Blake 1974, 1982; Blake and Loveridge 1975, Shwedick 1979, Child 1987).

This exploitation is controlled by the Department of National Parks and Wild Life Management (the Department) to which stations are obliged to submit monthly stock returns plus cards and maps which record egg collection data.

Similar captive propagation, based on the exploitation of wild eggs or hatchlings, is being or has been tried elsewhere and is commonly recommended as a conservation strategy for developing countries (e.g., Medem 1981, Hollands 1987, Whitaker et al. 1985). However, Magnusson (1984) made a number of observations pertinent to the farming and ranching of crocodilians and concluded that, particularly for species with poorly valued hide, captive propagation is unlikely to be as economically viable as controlled hunting.

A strong argument can be made to the effect that rearing is usually preferable to hunting where a species has a classic hide (Hutton and Child submitted ms.), but this largely depends on estimates of the efficiency that can be achieved in captive propagation. Figures commonly quoted for the success of hatching and rearing of crocodiles in Zimbabwe are drawn from a preliminary analysis, made in 1975, of each rearing station's returns (Blake and Loveridge 1975). This paper updates Blake and Loveridge (1975) and reports on the production and efficiency (percentage of fertile eggs resulting in saleable hides) of Zimbabwe's crocodile rearing stations from the inception of return forms until August 1986.

## METHODS

Zimbabwe has five well established crocodile rearing stations: Kariba Crocodile Farm (Kariba) established 1965, Binga Crocodile Farm (Binga) established 1967, Spencer's Creek Crocodile Ranch (Spencer's Creek) established 1971, Sengwa Crocodile Ranch (Senga Mouth) established 1977 and Rokari Crocodile Ranch (Rokari) established 1981. Each of these is currently producing hides from a mixture of farming and ranching. Stations are allocated permits to collect eggs from crocodiles which are otherwise fully protected throughout Zimbabwe (Hutton 1986). Permits carry a number of standard conditions including the requirement that stations keep a stock register and from this make a monthly return to the Department. After egg collection and hatching, they also submit egg record cards and maps showing the locality of each nest. Stock returns are available, in one form or another, since 1965; records of egg collection since 1971 (Appendix 1).

The data in these records were extracted to give information on hatching and subsequent rearing success. As an index of the care with which each station compiled returns (prior to 1985) a comparison was made of the total number of crocodiles which hatched according to their egg record cards and monthly stock returns.

The Department, in terms of Zimbabwe's commitment to CITES, is required to issue a special permit giving details of the size, value and origin of each export consignment of crocodiles and their products. These permits, together with monthly stock returns, were used to provide information on the number of hides being produced by each station.

## RESULTS

### a. Information from return forms.

Monthly return forms were standardized in 1978 (Appendix 1). Before this they varied greatly in the amount of information they contained. Those from Binga allow accurate assessment of hatchling mortality from 1968, whereas similar information can only be extracted from Kariba after 1978.

Prior to 1985 the difference between the number of hatchlings recorded on egg cards and monthly returns was consistently below 1% at Kariba, Binga and Rokari, but large (up to 15%) and variable at Spencer's Creek and Sengwa Mouth (there should have been no difference). Spencer's Creek and Kariba commonly returned a large percentage of incomplete egg cards (up to 29%) while, by contrast, those from Sengwa Mouth were always complete (Hutton and Brennan 1985).

### b. Number of wild eggs collected and discarded.

At present, only the crocodile population of the Zambezi Valley is exploited. Eggs are collected from three sub-populations, that of the upper Zambezi River and its tributaries west of Lake Kariba, that of Lake Kariba and its inflowing rivers and that of the lower Zambezi River downstream (east) of Kariba dam. Prior to 1985 the quota of wild eggs given to any station never exceeded 2500 and was commonly less (Fig. 1). The total number of eggs removed from the wild rose sharply in 1977 and 1981 when the two most recent stations were opened. In 1985 almost 14000 eggs were collected from approximately 300 nests. The majority of these eggs (82%) were collected from Lake Kariba (Fig. 2).

By tradition, only good eggs have counted against quotas and because eggs which appeared inviable were discarded, the total number of eggs handled was greater than that collected for incubation. Between 1982 and 1985 the percentage of eggs discarded by some stations rose to almost 20% (Fig. 3) while the mean rejection rate was 14.5%. The system has now been changed so that all eggs count against quotas which have been increased by 10% to compensate (10% is the mean inviability rate at Lake Ngezi, Zimbabwe [Hutton 1984]). In 1985, the first year of the new system, the mean rate of rejection fell to 7.4%, but mean incubation success remained high (88.8% in 1984 and 90.5% in 1985).

### c. Eggs from captive stock.

Kariba has been collecting eggs from captive breeding stock since 1974, Spencer's Creek since 1976 and in 1985 all five stations obtained eggs in this way (Table 1). It is notable that in 1984 Spencer's Creek obtained 2185 eggs from captive breeding stock and only 711 from the wild population.



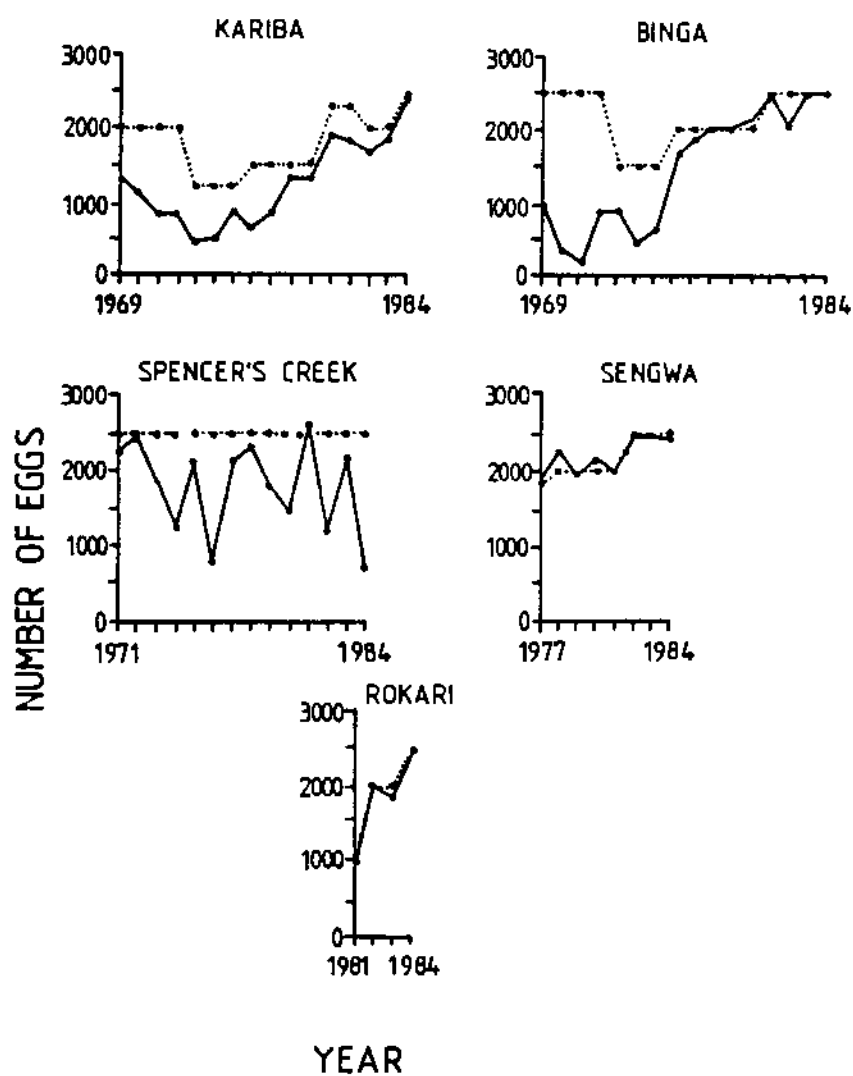


Figure 1. The quota of wild eggs allocated to each station (●-●-●-●-●) and the number of viable eggs collected (●-●-●-●-●), 1969-1984.

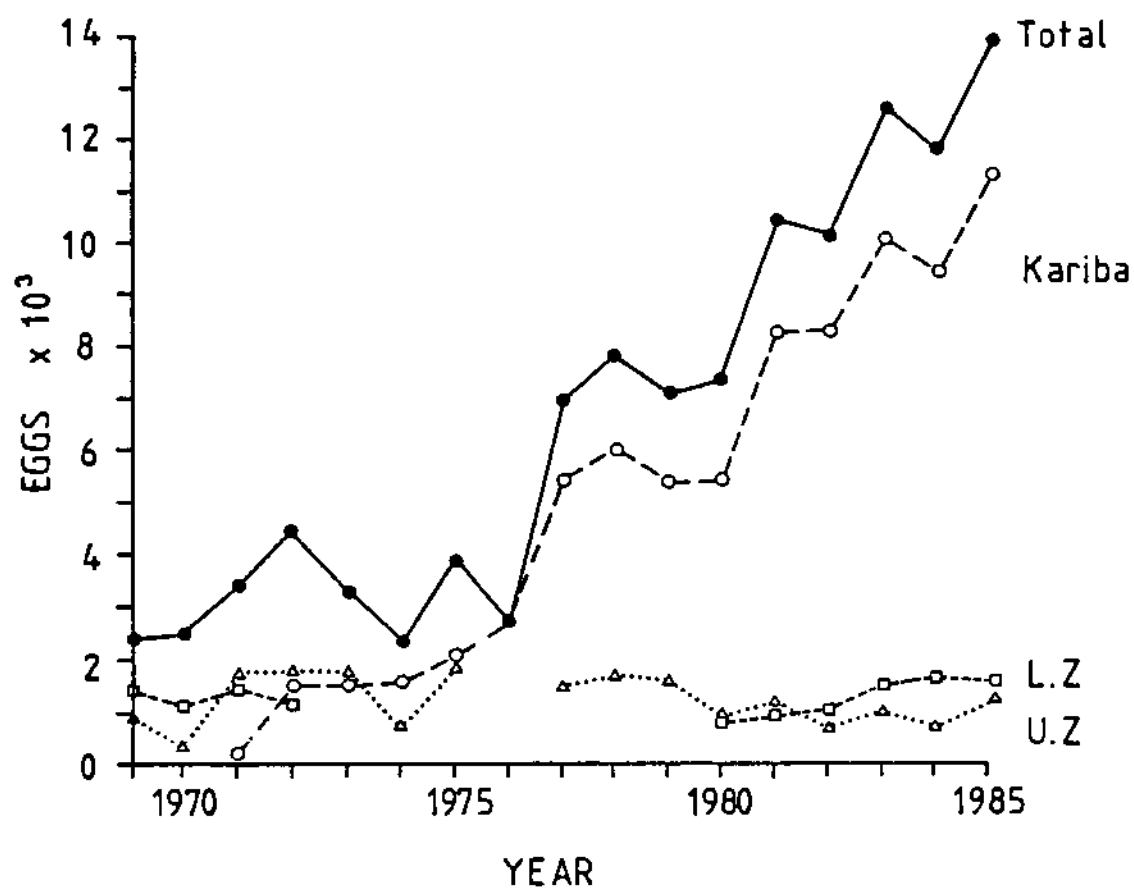


Figure 2. The total number of eggs removed from nests in each of the three main collecting areas of the Zambezi Valley since the first issue of egg collecting permits. U.Z. = Upper Zambezi River; L.Z. = Lower Zambezi River; Kariba = Lake Kariba.

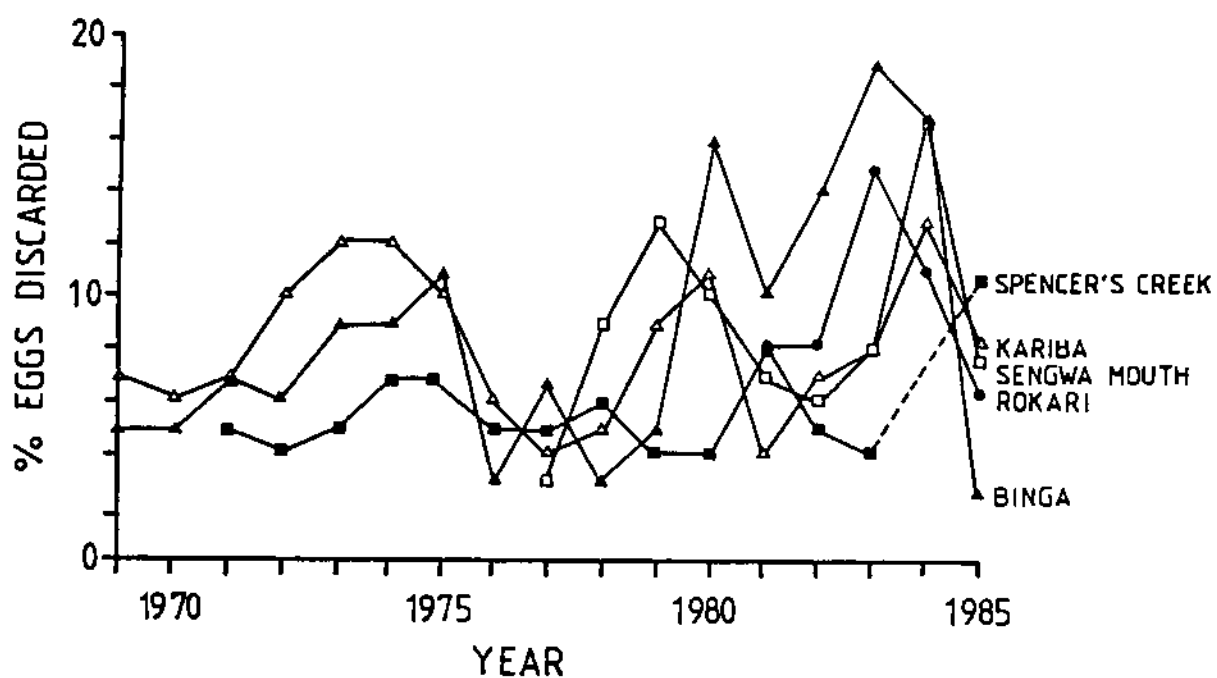


Figure 3. The percentage of eggs discarded by the collectors of each station, 1969-1985.

#### d. Hatching success.

Generally, since 1979, rearing stations have achieved 80-90% success when hatching wild eggs (Fig. 4). The average over the period 1981-1985 was 89%. At Kariba (where most breeders are  $F_2$ ) the hatching success from captive stock has been significantly lower than that of wild eggs, but this has not been the case at Spencer's Creek where most breeders have been taken from the wild (Wilcoxon matched pairs signed-rank test,  $T = 2.5$ ;  $n = 9$ ;  $p < 0.005$ , and  $T = 15.5$ ;  $n = 9$ ;  $p > 0.005$ , respectively).

#### e. Rearing success.

i. Hatchlings - The quantity and quality of crocodiles surviving to the end of their first year has shown great variation both within and between stations. Mortality on the most successful station (Binga) has ranged from 5-55% in consecutive years while, prior to 1986, Spencer's Creek had losses consistently greater than 30% and even suffered a total die-off in 1983. However, since 1983 four stations have achieved losses below 20%, and three are continually improving (Fig. 5). The average mortality of all stations combined during the period 1981-1985 was 28.2%. In the first 8 months of 1986 hatchling losses have been less than 8% on all stations except Kariba where it has been inordinately high (33%). At Spencer's Creek there has been a spectacular reversal of the trend with only 51 of 3314 hatchlings (1.5%) having died.

It is notable that mortality is seasonally variable. A larger percentage of the remaining hatchlings die in September, at the end of the cool season, then in February prior to the cool season or November when the next hot season is advanced (Fig. 6).

ii. Rearing stock - On four stations mortality of rearing stock (yearlings and older) has been commonly below 5% per annum. At Spencer's Creek, however, it has been as high as amongst hatchlings (Fig. 7). The overall mean mortality in the period 1981- 1985 was 3.3%.

#### f. Hide production

The proportion of viable eggs resulting in saleable hides has varied greatly between stations and on some it has been consistently low. During the two year period 1983-1984 the four established stations exported 6192 hides and a further 696 live animals of cropping size. Binga produced 43% of the total and only Binga and Spencer's Creek managed to harvest 1000 crocodiles each year (Table 2.). As some 8000 fertile eggs were available to stations in each of the years 1978-1982 only about 43% were actually hatched and raised to cropping size. In 1985, 4972 hides were exported. As an average of approximately 9000 viable eggs were collected in each of the years 1980-1983, efficiency had risen to about 54%.

### DISCUSSION

The information submitted by some stations has been considerably better than that from others. Simple tests of "reliability" show that records from Binga and Rokari have always been reliable and those from Kariba were reliable after 1979, while those of Sengwa Mouth and Spencer's Creek were difficult to interpret before 1985. As a result of this analysis, record-keeping is being more strictly controlled. In addition, egg cards have been simplified: they were long and tedious to use in the field and much of their information was of dubious value. The accurate marking of nest sites on maps is important for management and has been introduced. When only viable eggs were counted against quotas there was an

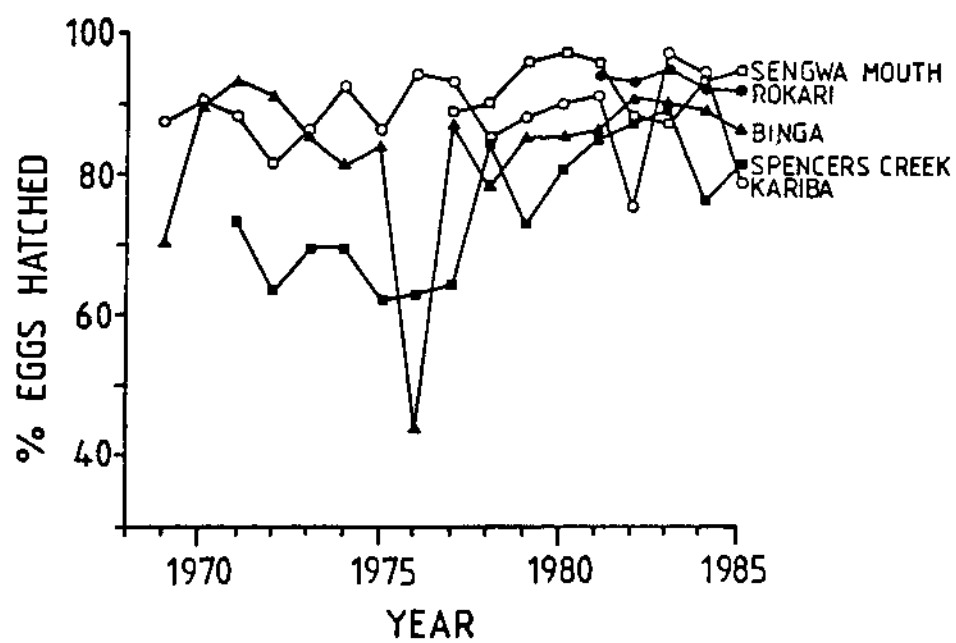


Figure 4. Hatching success of wild eggs on each of the five rearing stations.

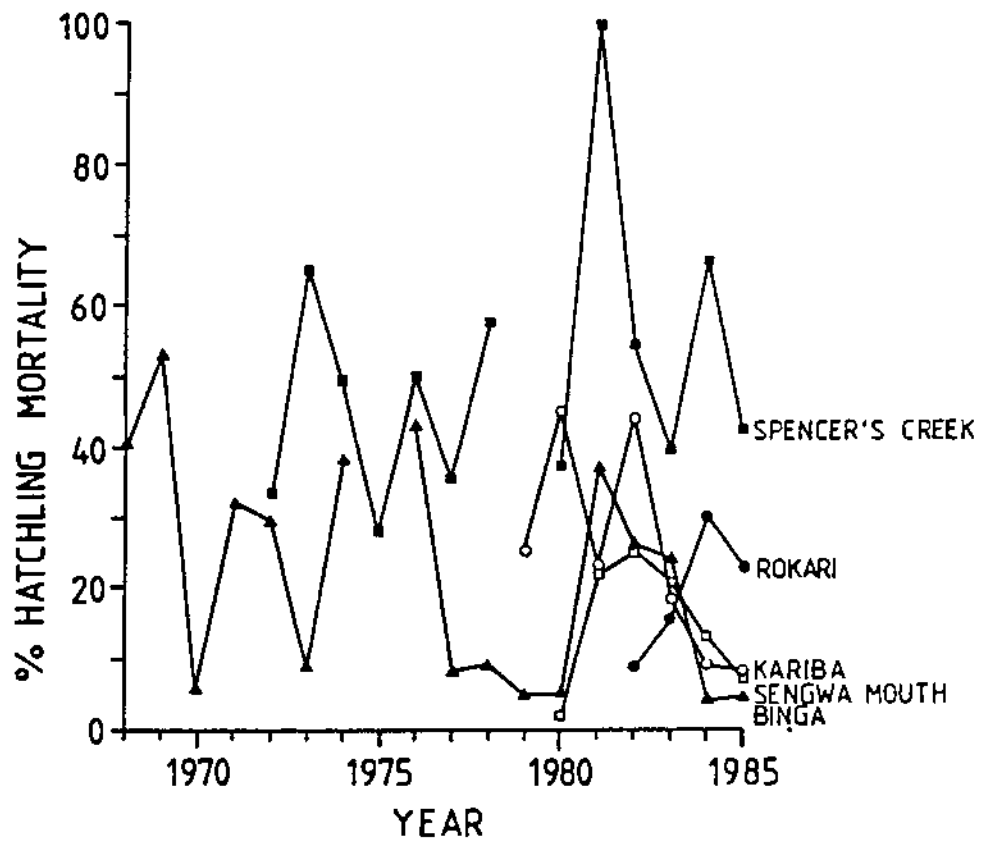


Figure 5. Annual percentage hatchling mortality on each station.

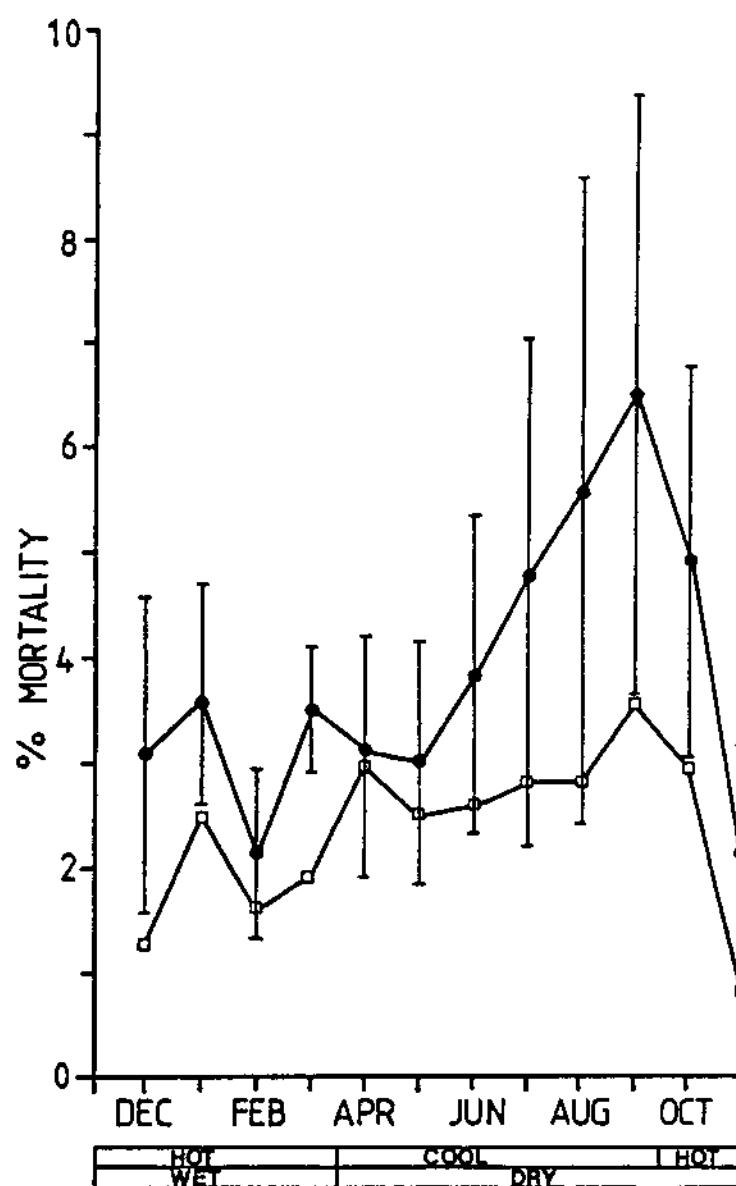


Figure 6. Mean monthly mortality among hatchlings from 1969 to 1984; data from all stations combined (●—●) and with Spencer's Creek omitted (□—□). Vertical bars = 95% confidence interval.

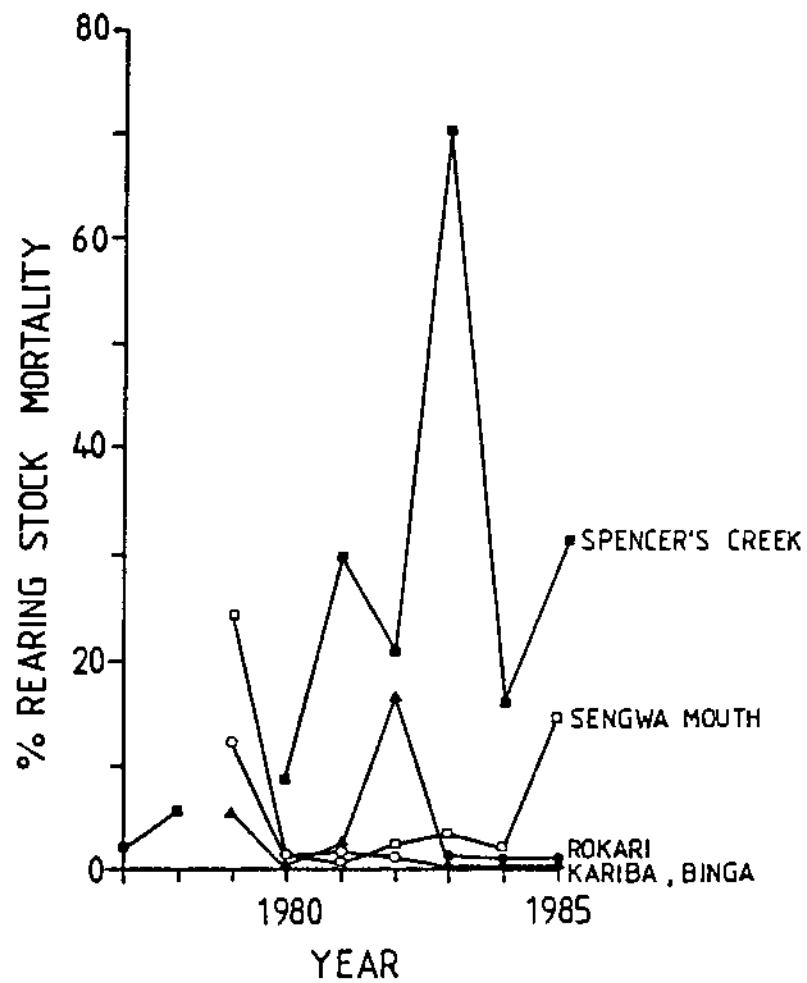


Figure 7. Annual percentage rearing stock mortality on each station.



incentive to discard eggs, the viability of which was uncertain. Inefficiency, therefore, may have been introduced at this earliest stage of the rearing process. As noted, the overall rate of rejection of eggs fell from 14.5% to 7.4% in the first year that the new quota system was introduced, and it is hoped that this improvement will be sustained.

The current overall quota of 14000 wild eggs is likely to continue until there are better data on the size and dynamics of the Zambezi Valley crocodile population. However, the number of captive breeding stock is steadily increasing. Approximately 300 females have been "put aside" and are due to breed in the next five years. Although it is unlikely that all of these will be selected for breeding, Spencer's Creek already produces over 2000 eggs while each of the other stations has the potential to produce 1000 eggs from captive stock. It is therefore not inconceivable that within five years all stations will be producing 2000 of their own eggs.

Blake (1974, 1982) has described egg collection and a similar system continues, though aircraft are increasingly used to find nests. Eggs are usually collected after 50 days because, though never vigorously tested, it appears that collection in the first few weeks after laying causes inordinately high embryonic mortality. However, the time of collection will also affect efficiency if, as suggested, incubation strongly influences the subsequent growth of hatchlings (Hutton 1987; Joanen et al. 1987). Early collection and subsequent controlled incubation is favored, but difficult to achieve in the wild. While eggs are spending 75% of their incubation under natural conditions it is unlikely that hatching success better than 90% can be regularly achieved. The early collection and controlled incubation of eggs from captive stock is being encouraged. It is too early to say if any station has mastered the successful raising of hatchlings, but the low mortality recorded on some stations in recent years is encouraging.

The ultimate cause of death is generally disease (Foggin 1987) and as there is a considerable variation in its occurrence and severity, depending on climate, management, egg incubation, diet and housing, it is clear that these factors play a major role in its development and that severe losses are a manifestation of poor husbandry. As noted, mortality is seasonal, being at its greatest at the end of the cool season (Fig. 6) and the inordinately high loss of animals at Spencer's Creek has generally been attributed to the station's altitude which, at 900 m, is in the frost zone. The exceptional success of Spencer's Creek in 1986 is undoubtedly due to the construction of heated pens for hatchlings and a change in management which resulted in greatly improved husbandry.

Whatever the predetermining factors, disease has seriously affected the viability of crocodile farming in Zimbabwe and largely accounts for the fact that efficiency has been less than 50%. In addition to the economic considerations, there are ethical objections to a system of conservation and management in which large numbers of animals succumb to disease (Foggin 1987).

Cursory examination is enough to show that the variation in success between stations is more related to personality than technology (though there is scope for technical improvement) and that efficiency has been unnecessarily low on some stations. In order to improve the industry's performance, in 1985 the Department and the Crocodile Farmers Association together adopted minimum standards for each stage of the rearing process and any station which does not achieve these may suffer a reduction in its quota of wild eggs. Blake and Loveridge (1975) indicated that the efficiency of the rearing process was inversely proportional to the number of eggs collected and it must be noted that stations encountering serious rearing problems have usually requested reduced quotas for themselves.

According to the minimum standards it is acceptable to have a hatching failure of 15% of fertile eggs, 25% hatchling mortality and 5% mortality of yearlings and older. In fact, with a heightened appreciation of the importance to hatchlings of consistently high temperatures, together with improved technology in this field, it is expected that hatchling losses will fall below 10% while there seems to be no need for rearing stock mortality to exceed 1%.

From losses in the first 8 months of 1986 it is clear that four of the five stations are already set to achieve this expected efficiency. Kariba, which has lost more than 30% of its hatchlings, has experienced atypical conditions and, in any case, has recently been sold to the operator of Rokari.

In conclusion, with recent improvements in management and small changes in technology it is not unreasonable to expect the wild harvest of 14000 eggs to produce an annual crop of 9500 hides at an efficiency of 75%.

#### ACKNOWLEDGEMENTS

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#### LITERATURE CITED

- Blake, D.K. 1974. The rearing of crocodiles for commercial and conservation purposes in Rhodesia. *Rhod. Sci. News* 8:315-324.
- \_\_\_\_\_. 1982. Crocodile ranching in Zimbabwe. *Zimb. Sci. News* 6:208-209.
- \_\_\_\_\_ and J.P. Loveridge. 1975. The role of commercial crocodile farms in crocodile conservation. *Biol. Cons.* 8:261-272.
- Child, G.F.T. 1977. Problems and progress in nature conservation in Rhodesia. *Koedoe* 20 (Supplement):116-137.
- \_\_\_\_\_. 1987. The management of crocodiles in Zimbabwe. Pages 49-62 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- Foggin, C.M. 1987. Diseases and disease control on crocodile farms in Zimbabwe. Pages 351-362 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- Hollands, M. 1987. The management of crocodiles in Papua New Guinea. Pages 73-89 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- Hutton, J.M. 1984. The population ecology of the Nile crocodile, *Crocodylus niloticus* Laurenti, 1768, at Ngezi, Zimbabwe. Ph.D. dissertation. Univ. of Zimbabwe. Harare Zimbabwe.
- \_\_\_\_\_. 1986. Cashing in on crocs. *Zimbabwe Wildl.* March 1986:27-29.
- \_\_\_\_\_. 1987. Incubation temperatures, sex ratios and sex determination in a population of Nile crocodiles (*Crocodylus niloticus*). *Proc. J. Zool. (Lond)* 211:143-155.
- \_\_\_\_\_ and S.L. Brennan. 1985. An analysis of records of the crocodile rearing industry in Zimbabwe. Internal report. Branch of Terrestrial Ecology, Department of National Parks and Wild Life Management, Zimbabwe.

- \_\_\_\_\_ and G.F.T. Child. 1985. Crocodile management in Zimbabwe. Submitted manuscript.
- Joanen, T., L. McNease, and M.J.W. Ferguson. 1987. The effects of incubation temperature on post-hatching growth of American alligator. Pages 533-537 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. Wildlife Management: Crocodiles and Alligators. Surrey Beatty and Sons, Chipping Norton, Australia.
- Magnusson, W.E. 1984. Economics, developing countries and the captive propagation of crocodiles. Wild. Soc. Bull. 12:194-197.
- Medem, F. 1981. Assistance to crocodile management in rural areas of Botswana. FAO consultancy report. 29 pp.
- Shwedick, B.M. 1979. Conservation and utilization of the Nile crocodile (*Crocodylus niloticus*) in Zimbabwe. Proc. 3rd Ann. Reptile Symp. Capt. Husb. pp. 59-68. Knoxville, Tennessee.
- Whitaker, R., P. Sukran, and C. Hartono. 1985. The crocodile resource in Irian Jaya. WWF/IUCN consultants report. 52 pp. and Supplement.

## APPENDIX 1

## Return of Records from Crocodile Rearing Stations

Permits issued to stations between 1965 and 1970 required them to submit monthly returns to the Director of the Department containing: (a) number (with date and place) of eggs taken or crocodiles captured, (b) the number of crocodiles which had died, and (c) number of crocodiles slaughtered, divided into three size classes.

In 1969, "Crocodile Egg Record" cards were introduced to be completed, on a voluntary basis, at the time of collection. These cards record a number of physical characteristics (e.g. the depth of the first egg, distance of the nest from water, the number of fertile and infertile eggs) and also the success of incubation. In 1971, a clause was added to permits requiring that these cards be kept in respect of all nests from which eggs were collected.

After 1969, the collection of live animals was no longer permitted and the permit format was altered. Holders were required to submit, by the 15th of each month, a return in respect of the preceding month giving details of: a) number of eggs collected, b) number of eggs hatched, c) number of crocodiles slaughtered or sold in either age or size classes, d) other adjustments to numbers (escape, etc.).

In June 1978, Form 245 "Return of Reptiles" was introduced and subsequent monthly returns were made on this. These forms recorded the number of hatchlings, rearing and breeding stock, the number which died or were cropped and the number of eggs collected and hatched. Reference to monthly returns was dropped from permits, and from 1978-1984 their conditions read:

- "a) In respect of any nest from which crocodile eggs are collected, a "Crocodile Egg Record" card will be kept.
- b) The holder of this permit shall submit, within 30 days of the expiry of this permit, the following information in respect of eggs removed:
  - (i) the number of eggs removed each month,
  - (ii) number of crocodiles hatched from eggs removed,
  - (iii) completed egg cards."

Crocodiles were divided into age classes, defined as: a) hatchlings: from hatching to one year, b) rearing stock: one year and over, stock being reared for skins, c) breeding stock: animals retained for display and egg production. These definitions have been retained. Hatchlings are transferred to rearing stock in December each year, shortly before new eggs hatch.

In 1982, Form 245 was replaced with the "Form of Register and Return of Amphibia and Reptiles" which must be kept on the rearing station at all times. The top copy is returned to the Department each month.

Table 1. Number of eggs produced by captive breeding stock on Zimbabwe crocodile rearing stations.

	Year											
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Kariba	21	28	416	603	429	581	565	310	602	505	375	534
Binga											249	619
Spencer's Creek			558	535	1199	1341	1499	1895	1790	1729	2185	2123
Sengwa mouth										76	580	611
Rokari												213

Table 2. Number of hides and live crocodiles exported between 1 January 1983 and 31 December 1984.

Station	No. skins exported	No. live rearing stock	Total no. cropped & exported	Yearly mean export
Kariba	1002	200	1202	601
Binga	2781	206	2987	1494
Spencer's Creek	322	270	592	296
Sengwa mouth	2087	20	2107	1054
Grand Total			6888	3445

# CROCODILIAN RESEARCH IN THE NORTHERN TERRITORY, 1984-86

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A significant research effort into crocodilians has been undertaken in the Northern Territory of Australia over the period 1984-1986. It has involved collaboration between the Conservation Commission of the Northern Territory and the staff and students of a number of Universities. Highlights are summarized below:

## 1. EMBRYOLOGY

Research into crocodilian embryology was undertaken in order to improve the success with which crocodilian eggs could be incubated and to increase the "fitness" of hatchlings produced through artificial incubation.

### i. Descriptive Embryology

Mark Ferguson's (1985) comprehensive review of crocodilian embryology combined data on *Crocodylus porosus* and *C. johnstoni* embryology obtained in the Northern Territory with detailed information on *Alligator mississippiensis* obtained in Louisiana (also see Ferguson 1987). Techniques for retrieving crocodilian embryos from eggs have been described by Webb and Manolis (1987). Heap (1986) examined and described the cutaneous papillae and a series of dorsal organs in the skin of *C. johnstoni* and *C. porosus* embryos and hatchlings.

### ii. Egg Function

Yolk rotation, opaque banding and the fluid changes which take place within crocodilian eggs have been linked together in a model of crocodilian egg function (Webb et al. 1987b, c). The effects of rotating crocodilian eggs have also been examined (Webb et al. 1987c). Prior to opaque banding eggs can be rotated without increasing mortality (the yolk will rotate within the egg, bringing the embryo back to the top) and after about 18 days incubation at 30°C they can also be rotated without increasing mortality (the enlarging allantois floats up through the yolk and can still act as a respiratory organ).

### iii. Egg Chemistry

The first detailed analysis of the chemistry of crocodilian eggs was undertaken (Manolis et al. 1987). There now exists a large body of baseline information which can be used to determine whether or not deficiencies in the chemistry of captive laid eggs occur.

#### iv. Embryonic Metabolism

Detailed studies of the metabolic rates and respiratory physiology of *C. johnstoni* eggs and to a lesser extent *C. porosus* eggs have been undertaken by Whitehead (1987a, b). These provide guidelines for the selection of artificial incubation regimes.

#### v. Embryonic Development Rate

The relationship between embryonic development rate, total incubation time and incubation temperature has been quantified for *C. johnstoni* and *C. porosus* (Webb et al. 1987a).

#### vi. Sex Determination

Embryonic development rate has been shown to be more closely associated with sex determination than is incubation temperature per se. With both *C. porosus* and *C. johnstoni*, the relationship between incubation environment and sex determination has been quantified, and a series of switch experiments with both species have quantified the embryonic stages at which sex is influenced by temperature. With *C. johnstoni*, increasing incubation temperature within the first four days is sufficient to effect the sex of offspring (Webb et al. 1987a). Research into the histology of the developing gonad is underway at the University of N.S.W. (Michel Beal), and the histochemistry is now being researched at Macquarie University (Jean Joss, America Cuff). The development of the pituitary, which appears to be involved in sex determination, is being studied at the University of New England (Martin Dillon).

#### vii. Effects of Incubation Environment

The relationship between hatchling size and the amount of residual yolk hatchlings contain is a function of embryonic development rate. Fast development (high incubation temperatures) gives small hatchlings with abundant residual yolk - slow development gives the reverse (Webb et al. 1987a). Preliminary results from studies currently underway indicate that post-hatching survivorship and growth in *C. porosus* and *C. johnstoni* are both partly dependent on incubation conditions, as has been demonstrated for *A. mississippiensis* by Ted Joanen. A method for estimating the amount of residual yolk from the dimensions of a hatchling's abdomen has been described (Smith and Webb 1986).

#### viii. Theoretical Explanation for Temperature

With post-hatching growth and sex each being influenced by incubation temperature (or rate of embryonic development), the sex determining mechanism could function to ensure maleness was only allocated to embryos endowed with the potential for fast growth and large size within the egg. This hypothesis would predict the opposite relationship between incubation temperature and sex in turtles, where females are usually bigger than males, which in fact occurs.

## 2. ECOLOGY AND NATURAL HISTORY

### I. Reviews

Comprehensive reviews of the ecology and population dynamics of *C. porosus* and *C. johnstoni* were prepared as supporting data for the management plans for both species (CCNT 1986a, b).

#### ii. Sex Ratio and Survivorship in *C. johnstoni*

Anthony Smith is currently completing his PhD (Australian National University) on the sex ratios and survival of recruits within the wild population in the McKinlay River area.

#### iii. Population Dynamics of *C. johnstoni* in Katherine Gorge

Harvey Stockwell is into the second year of her study of the *C. johnstoni* population in Katherine Gorge and the results to date indicate greatly reduced growth rates, reduced adult sizes and reduced recruitment in comparison to the *C. johnstoni* population in the McKinlay River area.

#### iv. Population Models

The dynamics of the McKinlay River population of *C. johnstoni* were incorporated into a computer simulation model (Smith and Webb 1985), and sensitivity tests were carried out to identify the priorities that should be given to the measurement of different variables. Survivorship estimates, classically the hardest to measure, are the ones that most effort should be concentrated on.

#### v. A Standardized Approach to Studying Crocodilian Populations

With the benefits of hindsight, Webb and Smith (1987) examined an approach to studying crocodilian natural history and population dynamics that would maximize the management information obtained. They recognised three levels of resolution that should be addressed from the very start of a study: 1. Rate of increase - is the population stable, increasing or decreasing; 2. A concise summary of life history processes which allows estimates of fecundity, survival by age and size, dispersal, sex ratio and at least some of the sources of variation in each; 3. Compensatory population mechanisms such as density-dependence.

## 3. HUSBANDRY AND FARMING

### i. Parasitology

In collaboration with the Northern Territory Department of Primary Production, a major effort has been expended in isolating and identifying parasites in captive and wild *C. johnstoni* and *C. porosus*.



## ii. Husbandry Research

A major husbandry research program is being initiated by the CCNT with intensive raising facilities and a full-time veterinarian to liaise with the crocodile farms. A solar water heating system was tested during 1986 as a means of providing *C. porosus* hatchlings with warm water, but without exorbitant electricity charges. Survivorship among *C. porosus* hatchlings increased as a consequence.

### 4. C. POROSUS EGG HARVEST

As part of the program to ranch *C. porosus* through an egg harvest program, a major study of *C. porosus* nesting was undertaken in both the 1984-85 and 1985-86 seasons. The results of this study, combined with data already in existence, will allow quantification of time of nesting, the extent of mortality in the field, and the economics involved in collecting eggs from the field. Economic assessments to date indicate that the cost of hatchlings produced from wild collected eggs will be about half that of those produced in captivity. The impact of egg harvests to date appears negligible (Webb et al. 1986).

### 5. PHYSIOLOGICAL EFFECTS OF CAPTURE

Some large crocodiles caught in the wild have died immediately after capture, and it was considered possible that such deaths could be the result of extreme exhaustion. A study of the effects of capture on blood chemistry was carried out with the imported expertise of Al Bennett (University of California), Roger Seymour and Dave Bradford (University of Adelaide), and it confirmed that extreme respiratory acidosis arose in large crocodilians that had been struggling (Bennett et al. 1985, Seymour et al. 1985, 1986).

### 6. HABITATS

Floating mats of vegetation, upon which *C. porosus* nest, are beginning to consolidate now that buffalo numbers are being reduced. An additional factor in some areas has been the spread of *Mimosa pigra* (Hill et al. 1987).

### 7. MONITORING RESEARCH

The University of Sydney have carried out spotlight surveys in the southern Gulf of Carpentaria (Messel et al. 1986) and the Victoria River (Messel, unpubl. data). Monitoring research carried out by CCNT is discussed in more depth by Webb et al. (1987a), Bayliss et al. (1986), Bayliss (1987) and Choquenot and Webb (1987). The main areas of study have been:

- i. Quantifying rates of population increase;
- ii. Obtaining habitat specific correction factors for relating relative density indices to absolute densities;
- iii. Developing helicopter surveys as an alternative to spotlight surveys;
- iv. Obtaining a correction for nest counts to total population size;

- v. Developing a more accurate means of estimating crocodilian sizes in spotlight counts;
- vi. Continuation of the long-term monitoring of some Arnhem Land Rivers.
- vii. of the impact of harvesting.

#### LITERATURE CITED

- Bayliss, P.G. 1987. Survey methods and monitoring within crocodile management programmes. Pages 157-175 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- \_\_\_\_\_, G.J.W. Webb, P.J. Whitehead, K. Dempsey, and A.M.A. Smith. 1986. Estimating the abundance of saltwater crocodiles, *Crocodylus porosus* Schneider, in tidal wetlands of the Northern Territory: a mark-recapture experiment to correct spotlight counts to absolute numbers and the calibration of helicopter and spotlight counts. *Aust. Wildl. Res.* 13:309-320.
- Bennett, A.F., R.S. Seymour, D.F. Bradford, and G.J.W. Webb. 1985. Mass-dependence of anaerobic metabolism and acid-base disturbance during activity in the salt-water crocodile, *Crocodylus porosus*. *J. Exp. Biol.* 118:161-171.
- CCNT. 1986a. *Crocodylus porosus* in the Northern Territory: biology and history of management. Conserv. Comm. N.T. Tech. Rep. No. 31.
- \_\_\_\_\_. 1986b. *Crocodylus johnstoni* in the Northern Territory: biology and history of management. Conserv. Comm. N.T. Tech. Rep. No. 32.
- Choquenot, D. and G.J.W. Webb. 1987. A photographic technique for estimating the size of crocodilians seen in spotlight surveys and quantifying observer bias in estimating sizes. Pages 217-224 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- Ferguson, M.W.F. 1985. The reproductive biology and embryology of crocodilians. Pages 329-491 in C. Gans, F. Billett, and P. Maderson, eds. *Biology of the Reptilia*. Vol. 14. John Wiley and Sons, New York.
- \_\_\_\_\_. 1987. Post-laying stages of embryonic development in crocodilians. Pages 427-444 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- Heaphy, L. 1985. An investigation of the cutaneous papillae and dorsal organs of *Crocodylus porosus* and *C. johnstoni*. BSc. (hons.) thesis. School of Zoology, University of N.S.W.
- Hill, R., G.J.W. Webb, and A.M.A. Smith. 1987. Floating vegetation mats on a floodplain billabong in the Northern Territory of Australia. *Hydrobiologia* 150:153-164.
- Manolis, S.C., G.J.W. Webb, and K.E. Dempsey. 1987. Crocodile egg chemistry. Pages 445-472 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.

- Messel, H., G.C. Vorlicek, A.G. Wells, W.J. Green, I.C. Onley, and F.W. King. 1986. Surveys of tidal river systems in the Northern Territory of Australia and their crocodile populations. Monograph 19. Pergamon Press, Sydney.
- Seymour, R.S., A.F. Bennett, and D.F. Bradford. 1985. Blood gas tensions and acid-base regulation in the salt-water crocodile *Crocodylus porosus*, at rest and after exhaustive exercise. *J. Exp. Biol.* 118:143-59.
- \_\_\_\_\_, G.J.W. Webb, A.F. Bennett, and D.F. Bradford. 1986. Effect of capture on the physiology of *Crocodylus porosus*. Pages 253-257 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- Smith, A.M.A. and G.J.W. Webb. 1985. *Crocodylus johnstoni* in the McKinlay River area, N.T. VII. A population simulation model. *Aust. Wildl. Res.* 12:541-554.
- \_\_\_\_\_, and G.J.W. Webb. 1987. A method of estimating residual yolk mass in hatchling crocodilians. *Herp. Rev.* 18:13.
- Webb, G.J.W., P.G. Bayliss, and S.C. Manolis. 1986. Population research on crocodiles in the Northern Territory, 1984-86. Report to the 8th Working Meeting of the IUCN-SSC Crocodile Specialists Group, Ecuador, October 1986.
- \_\_\_\_\_, A.M. Beal, S.C. Manolis, and K.E. Dempsey. 1987a. The effects of incubation temperature on sex determination and embryonic development rate in *Crocodylus johnstoni* and *C. porosus*. Pages 507-531 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- \_\_\_\_\_, and S.C. Manolis. 1987. Methods for retrieving and examining crocodilian embryos. Pages 423-426 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- \_\_\_\_\_, S.C. Manolis, K.E. Dempsey, and P.J. Whitehead. 1987b. Crocodilian eggs: a functional overview. Pages 417-422 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- \_\_\_\_\_, S.C. Manolis, P.J. Whitehead, and K. Dempsey. 1987c. The possible relationship between embryo orientation, opaque banding and the dehydration of albumen in crocodile eggs. *Copeia* 1987:252-257.
- \_\_\_\_\_, and A.M.A. Smith. 1987. Life history parameters, population dynamics and the management of crocodilians. Pages 199-210 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- Whitehead, P.J. 1987a. Respiration of *Crocodylus johnstoni* embryos. Pages 473-497 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- \_\_\_\_\_. 1987b. Respiration and energy utilization in the eggs of the Australian freshwater crocodile, *Crocodylus johnstoni* Krefft 1873. MSc thesis, University of Adelaide.

# POPULATION RESEARCH ON CROCODILES IN THE NORTHERN TERRITORY, 1984-86

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Within the Northern Territory of Australia, *Crocodylus johnstoni* (the Australian freshwater crocodile) and/or *Crocodylus porosus* (the estuarine or saltwater crocodile) occupy most if not all coastal wetlands, regardless of whether they contain fresh or saline water, or are under tidal influence or not (CCNT 1986a, b). The wetland habitats range from open coastline to densely vegetated swamps, from long meandering tidal rivers with exposed mudbanks to perennial streams in rocky escarpments and scattered flood plain billabongs. The extent of all wetlands is strongly influenced by season - particularly by flooding during the wet season.

The diverse habitats occupied by crocodiles in the Northern Territory make quantification of the distribution and abundance of both species difficult. Survey methods need to be habitat specific, and the numbers of animals or nests counted using different methods may need to be standardized against each other, or corrected to real numbers (absolute densities), depending on the management problems being addressed. Where the proportion of large crocodiles in the population is changing as recovery continues, a new set of variables needs to be accounted for; the visibility of large and small crocodiles is not necessarily the same due to size itself and to size-related effects of wariness (Bayliss et al. 1986).

This paper summarizes the results of a series of investigations aimed broadly at refining survey methodology, and clarifying the relationship between relative densities and absolute densities, particularly with *C. porosus*. It addresses Messel's (1986) criticisms of our 1984 estimate of the *C. porosus* population (Webb et al. 1984) and quantifies the rates of population growth that have occurred since the mid-1970's in various habitats. Preliminary data on the impact of harvesting *C. porosus* eggs from the wild are presented.

## HABITATS

Habitats occupied by *C. porosus* and *C. johnstoni* in the Northern Territory are summarized on Fig. 1. The majority of *C. porosus* are either in tidal rivers containing saline water during the dry season (B, C, D), or in coastal flood plain channels, billabongs and swamps (E, F, G, H), most of which contain freshwater throughout the year. Wetlands upstream of these, including river channels in rocky escarpments (I) or on upstream flood plains (J), which often recede to chains of billabongs during the dry season, contain mainly *C. johnstoni*. The two species overlap in many river systems giving recognizable zones of sympatry.

The abundance of *C. porosus* habitats in the Northern Territory was estimated on a regional basis (Fig. 2) from 1:100,000 maps supplemented with aerial photographs and information from helicopter and light aircraft surveys (Webb et al. 1984). A distinction was made between tidal rivers where *C. porosus* were known to breed regularly (major breeding) and those where breeding was unknown or irregular (minor breeding). A distinction was also made between mainstreams, secondary creeks (represented by double lines on the maps and generally less than 100 m wide) and tertiary creeks (represented by single lines on the maps and up to 2 km long).

Notwithstanding the errors involved in any such assessment of habitat availability, the results vary significantly from those used as the basis of a *C. porosus* total population estimate by Messel et al. (1981)

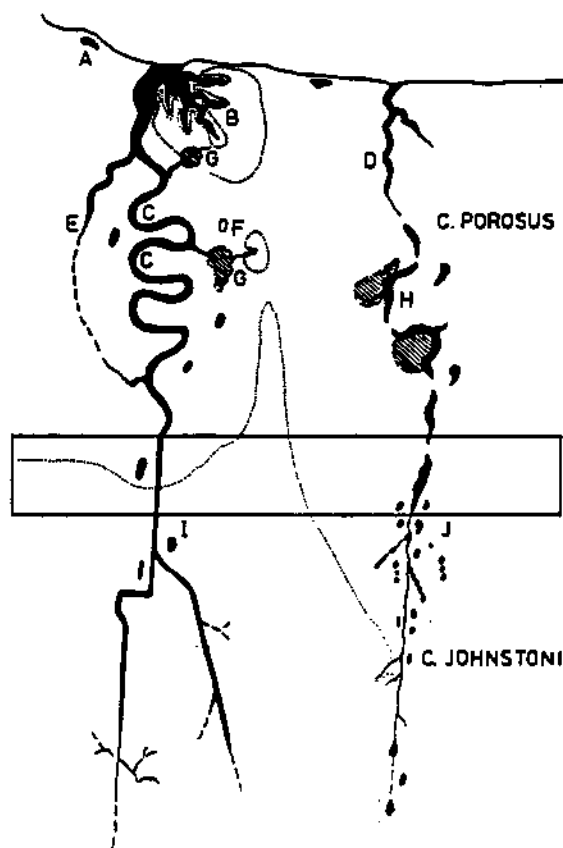


Figure 1. Schematic representation of Northern Territory wetlands occupied by crocodiles. Dotted lines indicate elevated land and cross-hatched lines are freshwater swamps. A, freshwater billabongs behind beach lines; B, a tidal river penetrating into elevated land; C, a tidal river meandering over a flood plain; D, remnant of a meandering tidal river that has become silted; E, tidal flood plain creek with no freshwater input during the dry season; F, isolated flood plain billabongs; G, spring-fed freshwater swamp adjacent to a tidal river; H, isolated sections of an old meandering river no longer open to the sea and containing fresh water and often floating rafts of vegetation; I, non-tidal upper reaches of a river draining rocky escarpment; J, a seasonally flowing mainstream channel that has numerous freshwater billabongs associated with it (after Webb et al. 1987).

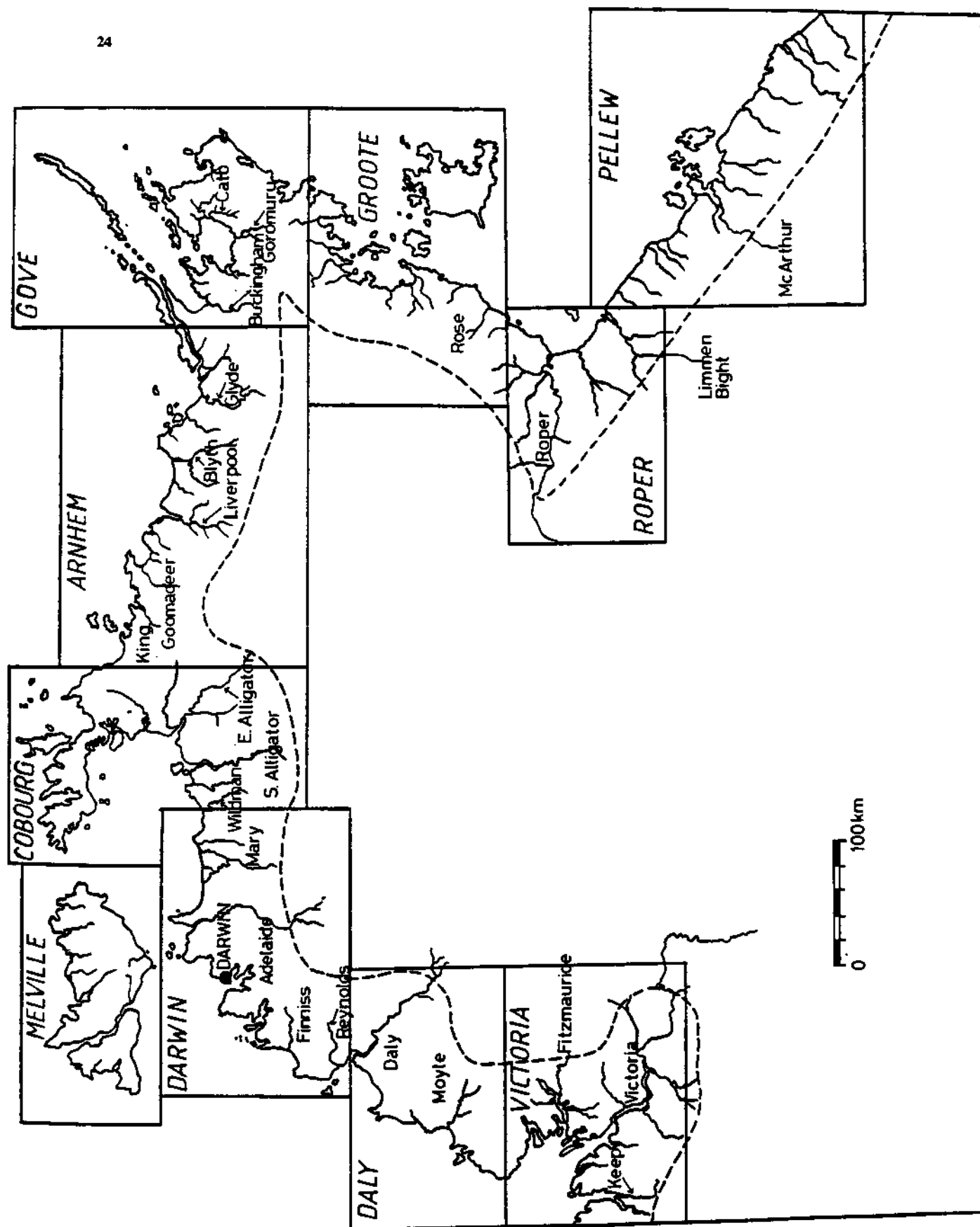


Figure 2. Geographic regions in the Northern Territory in which habitats and population densities have been assessed. The inland limit of *Crocodylus porosus* is indicated by the dashed line.

Table 1. Habitat available for *Crocodylus porosus* in the Northern Territory. C = coastline; C-S = coastal secondary creeks; Mi = minor breeding tiday mainstreams; Mi-S = secondary creeks off minor breeding tidal mainstreams; Ma = major breeding tidal mainstreams; Ma-S = secondary creeks off major breeding tidal mainstreams; TC = tertiary tidal creeks; EC = escarpment channels; FC = flood plain channels; FSW = freshwater swamp.

Region	C km	C-S km	Mi km	Mi-S km	Ma km	Ma-S km	TC No.	EC km	FC km	FSW km <sup>2</sup>
Victoria	435	64	949	205	-	-	1487	169	-	13
Daly	233	28	64	31	110	2	146	51	144	1401
Darwin	722	122	233	110	230	67	1425	20	575	392
Melville	683	228	380	428	14	1	1158	-	46	67
Cobourg	1137	127	224	69	329	38	1213	-	224	826
Arnhem	666	56	233	57	350	64	502	64	247	793
Gove	1933	299	142	109	181	155	1090	12	-	61
Groote	1563	190	13	4	81	25	431	152	45	145
Roper	175	26	242	35	292	53	406	44	10	42
Pelieu	725	98	705	92	-	-	365	22	-	33
Totals	8272	1238	3185	1140	1587	405	8223	534	1291	3773

and Messel (1986; Table 2). They did not specifically estimate the amount of freshwater swamp or flood plain channel, but recognised it as *C. porosus* habitat and guessed that the population there was 20% of the their estimated tidal population.

As can be seen from Table 1, the regions on Figure 2 have vastly different proportions of different habitat types. Some regions have extensive breeding habitat and little non-breeding habitat, whereas others have the reverse. These differences are summarized on Tables 3 and 4.

In the Victoria and Pellew regions, where the mean annual rainfall is the lowest in the coastal fringe (Fig. 3), there is minimal breeding habitat for *C. porosus*. These areas never contained high densities of *C. porosus* in the past (Webb et al. 1984), and cannot be expected to do so in the future. The suggestion that over 100,000 *C. porosus* were taken from the Victoria River alone (Messel et al. 1984) cannot be substantiated - the total harvest of *C. porosus* skins from the Northern Territory, during the period 1945-46 to 1971, was about 113,000, and a relatively small proportion of these came from the Victoria River (Webb et al. 1984).

### "ALL CROCODILES" VERSUS "NON-HATCHLINGS" IN POPULATION ESTIMATES

The extent to which "young-of-the-year" should be included or excluded from survey data pertaining to crocodilian populations depends on the extent to which they can be recognised in surveys, the level of mortality being experienced at the time of survey, and the population statistic being addressed (total population size or rates of recovery).

With *C. johnstoni*, hatching occurs in a six-week pulse at the start of the wet season (November-December), and mortality is approximately 88% during the first year (Smith and Webb 1985). But this occurs almost exclusively during the first wet season, with some 50% mortality within the first two months (Smith, unpubl. data).

By the following dry season, when spotlight surveys are conducted, "young-of-the-year" are an integral part of the population age structure (Fig. 4). Their probability of surviving is the same as that of older sub-adults (Webb and Smith 1984; Smith and Webb 1985), and in spotlight counts (which are often carried out from a vantage point on the edge of a billabong) they cannot be recognised. There is no logical reason to exclude them from estimates of the total population size based on dry season surveys, nor from analyses of rates of recovery.

With *C. porosus*, hatching occurs from March to September, and peaks in April-May. Most spotlight surveys are conducted between June and November of the same year (in the dry season), when hatchlings are mostly 3-4 months of age, but can range from 0 to 9 months of age. In the Blyth-Cadell River System, 81% of the number of "young-of-the-year" estimated from dry season spotlight surveys were represented as 1 year olds the following year. They have higher probabilities of surviving than do older sub-adult year classes (Table 5). Deleting them from estimates of the total population size on the basis of "low survivorship" is simply not supported by the data. They are a significant but highly variable segment of the population and at least the mean number of hatchlings should be included in reports of the total population size.

When assessing rates of population increase with *C. porosus*, greater stability will result if the hatchling size class is deleted, and only non-hatchlings are considered (Fig. 5). This is because the number of hatchlings recruited into the population each year varies with the extent of nesting and embryonic mortality within nests. Within Northern Territory rivers, excluding hatchlings has the effect of increasing the annual rates of recovery by about 1.4% per year, while reducing the standard error of that estimate by about 0.1% (Table 6; see below).



Table 2. A comparison of two estimates of *Crocodylus porosus* habitat availability in the Northern Territory of Australia. MS = mainstream; SC = secondary creeks. \*\*\* the 1000 km of upstream freshwater channel estimated by Messel et al. (1981) equates approximately to the escarpment channel of Webb et al. (1984).

Category	Webb et al. (1984)		Messel et al. (1981, 1986)
Coastline	8272	km	3200 km
Coastal secondary creeks	1238	km	-
Tidal river major breeding (MS+SC)	1992	km	2175.5 km
Tidal river minor breeding (MS+SC)	4325	km	2482.1 km
Flood plain channel	1291	km	-
Escarpment channel	534	km	1000* km
Freshwater swamp	3773	km <sup>2</sup>	-
Tertiary creeks	8223	ck's	-

Table 3. Regions of the Northern Territory (Fig. 1) ranked according to the amounts of breeding and non-breeding habitat for *Crocodylus porosus* within them. Rank 1 = lowest and 10 = highest.

Area	Breeding			Non-breeding	
	Swamp	F/Channel	Tidal	Coast	Tidal
Victoria	1	2	1.5	3	10
Daly	10	7	5	2	1
Darwin	7	10	6	6	7
Melville	5	3	3	5	9
Cobourg	9	8	9	8	6
Arnhem	8	9	10	4	5
Gove	4	6	7	10	3
Groote	6	4	4	9	2
Roper	3	7	8	1	4
Pellw	2	1.5	1.5	7	8

Table 4. Areas of the Northern Territory (Fig. 1) ranked according to the abundance of all breeding habitat (rank 1 = highest). When hunters were questioned about the densities of *Crocodylus porosus* that existed in the late 1940s, at the start of commercial hunting, they identified 15 high density (6-12/km), 10 medium density (1-5/km), and 17 low density areas (<1/km) (Webb et al. 1984).

Area	Breeding	Non-breeding	Historical Densities		
			High	Medium	Low
Arnhem	10	3	2	4	6
Cobourg	9	9	3	2	
Darwin	8	6	5		
Daly	7	1	2		
Roper	6	2		1	2
Gove	5	6	1	1	2
Groote	4	4	2	1	2
Melville	3	9		1	
Pellew	2	9			3
Victoria	1	6			2

Table 5. The relationship between age and the probability of being represented in the river the following year for *Crocodylus porosus* in the Blyth-Cadell River system between 1974 and 1984 (data from Messel et al. [1981, 1984] and CCNT as analyzed by Webb et al. [1984]).

Interval (years)	Mean	Maximum	Minimum
0.3-1.3	0.81	1.31	0.56
1.3-2.3	0.69	1.03	0.30
2.3-3.3	0.79	1.03	0.60
3.3-4.3	0.56	0.79	0.36
4.3-5.3	0.56	0.80	0.27

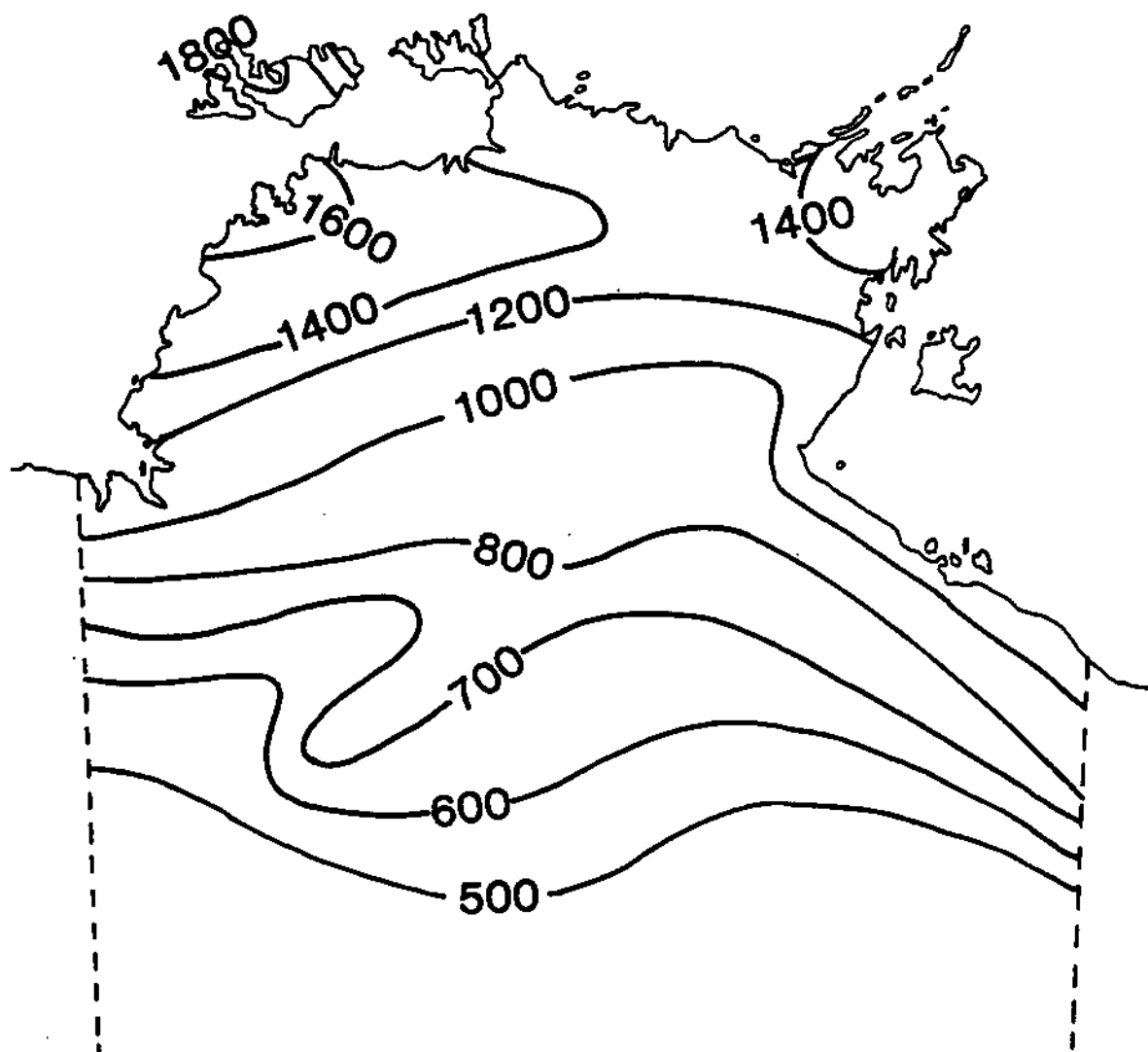


Figure 3. Mean annual rainfall (mm) in the Northern Territory (1873-1984).

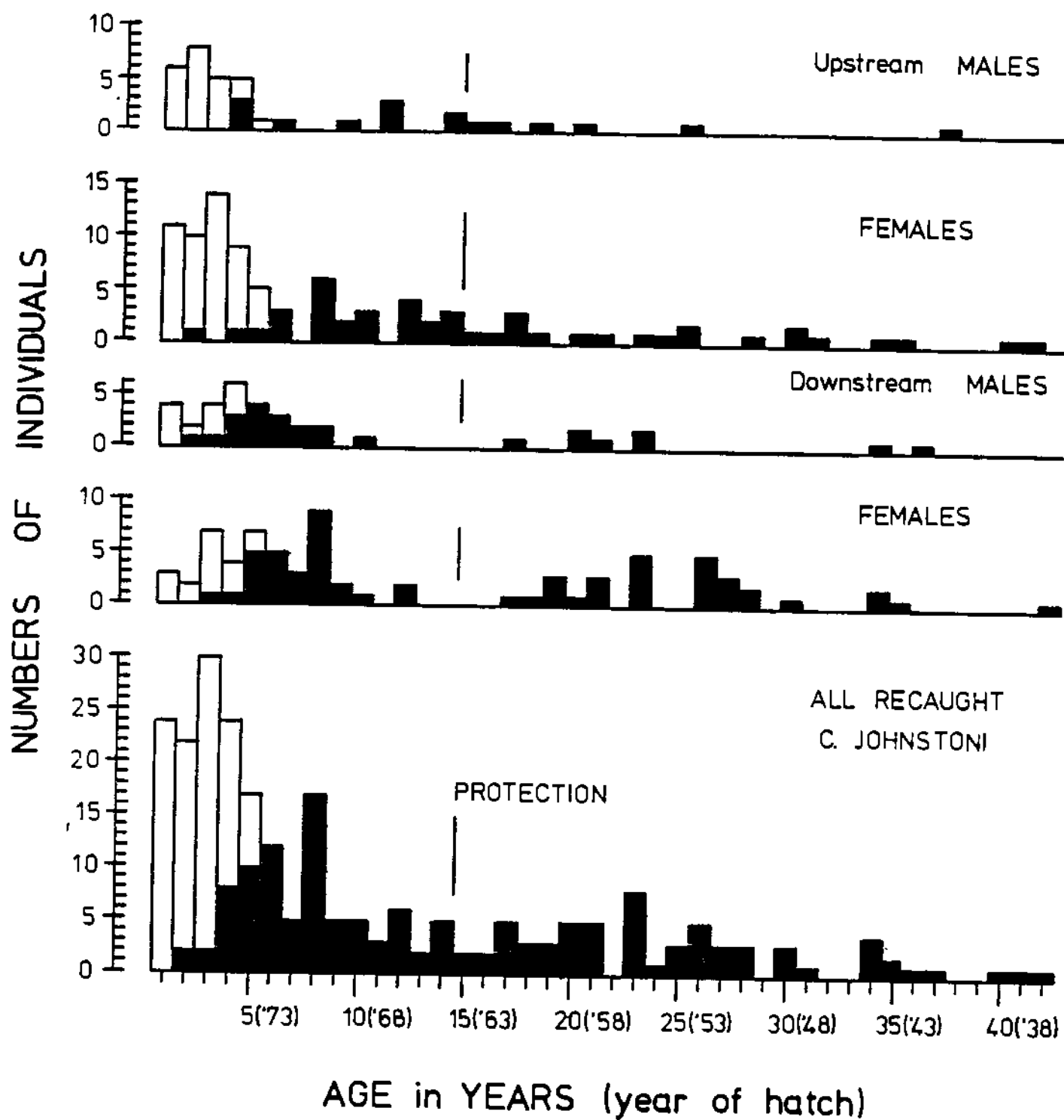


Figure 4. The age structure of a population of *Crocodylus johnstoni* within the Northern Territory (after Webb et al. 1983a).

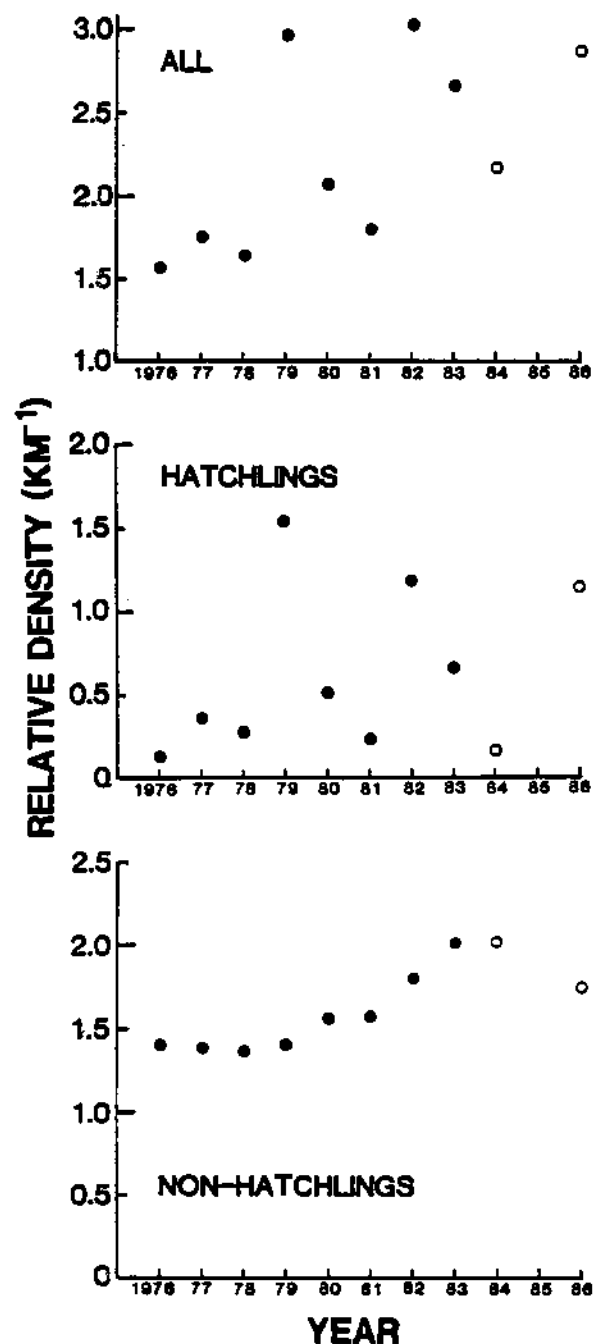


Figure 5. Relative densities of *Crocodylus porosus* in the Liverpool-Tomkinson River system. Closed circles indicate data from Messel et al. (1981) and open circles data from CCNT surveys.

## RATES OF *C. POROSUS* RECOVERY

When the Northern Territory introduced protective legislation for *C. porosus* in 1971, the populations had been intensively hunted since 1945-46, and the adult population was reduced to a wary remnant. Within the first 2-5 years after protection, numbers increased rapidly in breeding areas (because recruits were not being harvested), although the average size of individuals was small. In some remote breeding areas this initial increase occurred prior to protection (Fig. 6).

Spotlight surveys carried out by the University of Sydney, the Conservation Commission of the Northern Territory (CCNT) and other organizations were initiated after this initial increase, and thus the analyses in Table 6 refer to rates of recovery from the mid-1970's to the mid-1980's - they underestimate the recovery of numbers that occurred between protection and the mid-1970's (Fig. 6).

These rates of recovery are based on spotlight counts alone and are not corrected for the changing size structure of the *C. porosus* population (see below). All regions from which there are survey data, indicate a positive rate of population increase among non-hatchlings - even low density areas such as Pellew (see Fig. 2). When all crocodiles were considered, the Roper region was the only one which did not have a similar positive rate of increase. It showed a 2.1% annual decrease between 1979 and 1985 [two spotlight surveys only; an additional survey in 1986 was by helicopter, and hatchlings are not detected], which was attributable to the lack of hatchlings counted in 1985 in one side creek of the Towns River (28 in 1979; 0 in 1985).

The exponential rates of increase are generally higher in the "non-hatchlings" than in "all crocodiles", and the mean rates for all areas combined are 8.3% p.a. (all crocodiles) and 9.7% p.a. (non-hatchlings). This is unequivocal evidence of an expanding population.

## THE IMPACT OF HARVESTING *C. POROSUS* EGGS

During the 1983-84 season a preliminary one-day harvest of *C. porosus* eggs (994 eggs) was undertaken in the Adelaide River. However during the 1984-85 and 1985-86 *C. porosus* nesting seasons, experimental harvests (3517 and 3470 eggs respectively) were undertaken within parts of three river systems close to Darwin (Finniss, Reynolds, Adelaide; Fig. 2). Eggs from all nests were individually numbered and incubated under controlled conditions, and the post-hatching growth and survivorship of all resulting hatchlings (individually numbered by mutilating a known sequence of tail scutes), is now being monitored within the crocodile farms. The post-hatching performance of these individuals can be correlated with details of individual eggs, nests, habitats and incubation conditions.

All dead eggs were opened and the embryos were used to determine whether death had occurred before or after collection. As a consequence, the mortality within each area up until collection could be quantified (Table 7; data from the 1985-86 nesting season are not yet fully analyzed).

Harvesting eggs at an earlier stage of embryonic development was partly responsible for the reduced mortalities compared to wild incubation, but substantial losses in the field still occurred. These were due to flooding, overheating and what appeared to be asphyxia within sodden, muddy nests.

The impact of reducing hatchling recruitment by harvesting eggs could be expected to be detected in the 2-6' size class the following year. Spotlight surveys within the accessible parts of all areas harvested indicated no major decline in numbers, which is consistent with the view that harvests of eggs will result in a minimal impact on the size of wild populations (Webb et al. 1984, 1987). This approach to harvesting a wild population is atypical, as the general aim is usually to reduce densities to extract a sustainable yield

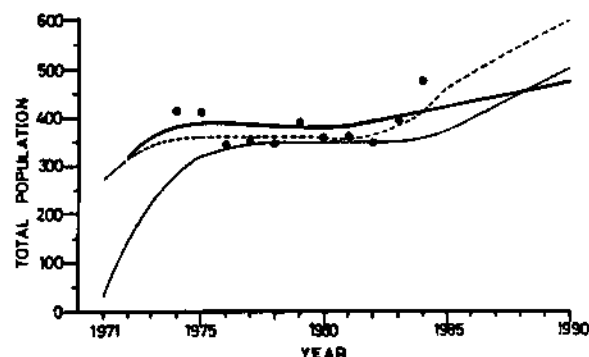


Figure 6. Total population estimates of *Crocodylus porosus* (excluding hatchlings) within the Blyth-Cadell River system as determined from corrected spotlight counts (dots). The dashed line represents the computer simulation of population predicted backwards to 1971 and forwards to 1990. The heavy line applies a density-dependent mortality among juveniles. The thin line does not apply density-dependent mortality, but assumes harvesting had continued up until protection, and that no juveniles were in the population at that time.

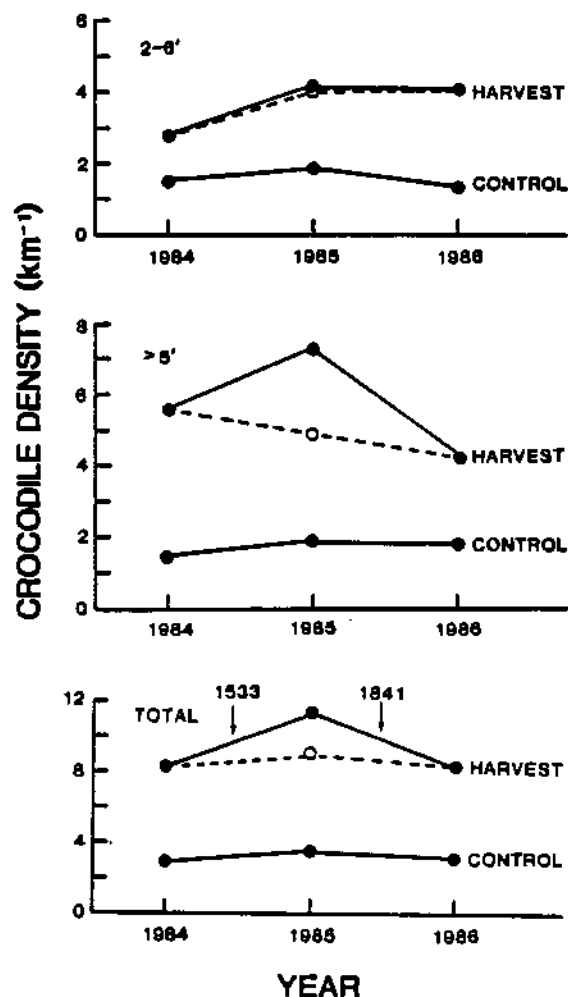


Figure 7. Relative densities of *Crocodylus porosus* in flood plain channels (Finniss-Reynolds River system) in which eggs were harvested and not harvested (1984-86). Numbers refer to the number of eggs harvested during a particular nesting season. Open circles indicate densities with one channel excluded (see text).



Table 6. Exponential annual rates of increase of *Crocodylus porosus* in major river systems within the Northern Territory between the mid-1970s and mid-1980s. Analyses are based on spotlight counts and/or helicopter counts standardized to spotlight counts. Original data from Messel et al. (1981,1986), Webb et al. (1984), and additional unpublished survey results from CCNT and ANPWS (Bayliss 1986). Rates are calculated for all crocodiles (T) and with hatchlings excluded (NH);  $R^2$  is explained variance; "\*" only two surveys, regression analysis impossible.

Area/River	Years	(N)	All Crocodiles			Non-Hatchlings		
			r	$R^2$	p	r	$R^2$	p
<b>DALY</b>								
Daly	1978-86	(4)	+0.104	0.91	0.10	+0.103	0.95	0.05
	MEAN		+0.104			+0.103		
<b>DARWIN</b>								
Finnis	1984-86	(3)	+0.40	0.01	NS	+0.038	0.01	NS
Reynolds	1984-86	(3)	+0.130	0.03	NS	+0.140	0.03	NS
Adelaide	1977-86	(7)	+0.055	0.84	0.01	+0.035	0.74	NS
Mary	1984-86	(3)	+0.276	0.70	NS	+0.276	0.70	NS
	MEAN		+0.125			+0.122		
<b>MELVILLE</b>								
Andranangoo	1975-84	(5)	+0.072	0.96	0.10	+0.089	0.94	0.10
Johnston	1972-84	(4)	+0.113	0.56	NS	+0.110	0.55	NS
Bath	1972-84	(4)	+0.134	0.74	NS	+0.134	0.74	NS
Dongau	1972-84	(6)	+0.016	0.03	NS	+0.039	0.10	NS
Tinganoo	1972-84	(5)	+0.181	0.73	NS	+0.181	0.73	NS
	MEAN		+0.103			+0.111		
<b>COBOURG</b>								
Wildman	1978-84	(3)	+0.098	0.93	NS	+0.153	0.74	ns
W. Alligator	1977-84	(4)	+0.051	0.99	0.05	+0.056	0.79	NS
S. Alligator	1977-84	(10)	+0.225	0.27	NS	+0.213	0.24	NS
E. Alligator	1977-85	(8)	+0.072	0.64	0.01	+0.058	0.64	0.01
Murganella	1977-84	(4)	+0.096	0.57	NS	+0.114	0.91	NS
<b>ARNHEM</b>								
King	1975-79	(4)	+0.240	0.74	NS	+0.278	0.87	NS
All-Night	1975-79	(3)	+0.271	0.39	NS	+0.271	0.39	NS
Goomadeer	1975-84	(8)	+0.016	0.06	NS	+0.002	0.00	NS
Majarie	1975-84	(7)	+0.040	0.18	NS	+0.035	0.14	NS
Wurugooj	1975-84	(7)	+0.139	0.38	NS	+0.135	0.37	NS
Liverpool-								
Tomkinson	1976-86	(10)	+0.054	0.45	0.05	+0.039	0.71	0.01
Nungbulgarri	1975-84	(8)	+0.089	0.48	NS	+0.071	0.36	NS
Blyth-Cadell	1974-86	(13)	+0.002	0.00	NS	-0.004	0.00	NS
Crab	1981-83	(3)	+0.001	0.00	NS	+0.001	0.00	NS
Ngandadauda	1975-83	(3)	+0.029	0.92	NS	+0.05	0.99	0.10
Glyde	1975-84	(4)	+0.143	0.78	NS	+0.153	0.98	0.05
	MEAN		+0.093			+0.094		

**GOVE**

Darwarunga	1975-84	(3)	+0.129	0.89	NS	+0.126	0.90	NS
Habgood	1975-84	(3)	+0.081	0.89	NS	+0.095	0.80	NS
Habgood Ck	1975-84	(3)	+0.001	0.00	NS	+0.001	0.00	NS
Baralminar	1975-84	(3)	+0.096	0.89	NS	+0.096	0.89	NS
Gbolpa	1975-84	(3)	+0.075	0.83	NS	+0.091	0.93	NS
Goromuru	1975-84	(3)	+0.006	0.06	NS	+0.050	0.82	NS
Cato	1975-84	(3)	+0.015	0.25	NS	+0.101	0.92	NS
Peter John	1975-84	(3)	-0.018	0.03	NS	-0.004	0.01	NS
Burungbirinung	1975-84	(3)	+0.096	0.52	NS	+0.222	0.65	NS
MEAN			+0.053			+0.086		

**ROPER\***

Limmen Bight	1979-86	(3)	+0.061	-	-	+0.077	0.94	NS
Towns	1979-86	(3)	-0.110	-	-	+0.006	-	-
Roper	1979-86	(3)	-0.015	-	-	+0.017	-	-
MEAN			+0.021			+0.033		

**PELLEW**

McArthur	1979-86	(3)	+0.055	-	-	+0.054	0.99	0.10
Wearyan-Foelsche	1979-86	(3)	+0.035	-	-	+0.021	0.37	NS
MEAN			+0.045			+0.038		

**MEAN OF ALL AREAS**

(SE)  $\pm 0.013$   $\pm 0.012$

%pa

+8.3

+9.7

(N)

40

40

Table 7. Results of the experimental *Crocodylus porosus* egg harvest in 1984-85 compared to results for wild nests in two of the same areas in the 1980-81 season.

Area:	Melacca	Melacca	Adelaide	Finniss-Reynolds	Finniss-Reynolds
Season	1980-81	1984-85	1984-85	1980-81	1984-85
Wild or harvest	wild	harvest	harvest	wild	harvest
Nests examined	18	19	22	33	26
Eggs examined	917	959	1025	1795	1533
Eggs hatched (%)	35.6	80.3	59.2	29.2	45.7
Eggs infertile (%)	9.4	3.6	7.9	5.0	5.4
Eggs damaged (%)	0.6	0.8	0.4	2.4	2.3
Eggs failed					
1. in field (%)	54.4	9.6	17.9	62.8	26.0
2. in laboratory (%)	-	5.6	14.6	-	20.5

(Caughley 1977). Populations at equilibrium are often reduced by 30-50% (depending on the harvest model used) to achieve maximum sustained-yield.

In the Finnis-Reynolds area (Fig. 7), some channels were harvested and others were not. Analysis of variance of density trends between harvested and unharvested areas (Table 8) showed no significant effect of harvest (the time by experiment interaction was not significant). There was a significant three-fold difference in the densities between the harvested and unharvested areas (Fig. 7), which indicates that harvests were concentrated in the flood plain channels with the highest densities of crocodiles. An increase in the number of >6' animals in 1985 (Fig. 7) was largely due to increased numbers of >6' animals in one harvested channel, but this effect was trivial (time by size class interaction was not significant; Table 8), and unrelated to the harvest of eggs.

In the Adelaide River, no local control was available and so the Liverpool-Tomkinson data were used as a control of sorts. This population is within a tidal breeding system (as is the Adelaide) and had:

1. Similar non-hatchling densities between 1977 and 1979, well before the egg harvests, (Fig. 8); and,
2. A positive rate of increase after 1977-79 (Fig. 8), as did the Adelaide River.

The Blyth-Cadell system, which has been surveyed more regularly, was rejected as a control because its rate of increase was close to zero - lower than that of the harvested population.

Because of the more extensive survey data, analysis of covariance was used to test for differences in density trends over time (Table 9). No significant difference in the average exponential rates of increase (all crocodiles) between the two populations could be demonstrated, regardless of size class (Table 10), indicating no major effect of the harvest (as is obvious from Fig. 9).

Taken together, the survey results from the Adelaide and Finnis-Reynolds areas indicate that some 7,981 eggs were collected from 162 wild nests within 140 km of Darwin, with no significant impact on the wild populations. More data are needed to quantify subtle or longer-term effects, and the study is continuing, but results to date are consistent with predictions of a minor impact.

#### FLOOD-PRONENESS OF *C. POROSUS* NESTS

A detailed analysis of flood mortality among eggs collected to date is currently being undertaken. Melacca Swamp (our main monitoring area for *C. porosus* nesting), is the least "flood-prone" of the areas currently under study, and mortality due to flooding was modelled over the period 1960-61 to 1980-81 (Webb et al. 1983c). The results indicate flood losses ranging from 0% to 50% per annum, depending on the pattern of annual rainfall (mean = 26%); this indicates a total mortality of between about 20% and 70% of eggs per year (mean = 46%). The degree to which individual nests are prone to mortality due to flooding is largely unpredictable, due to the equally unpredictable timing and extent of wet season rains.

Our random egg harvest (see above) did not appear to have any major impact on the populations, and for economic and safety reasons, the main criteria for an efficient harvest in the future will be the accessibility of nests to collectors, and the number of nests available at the time of collection. By leaving a random sample of nests (those that are inaccessible for a variety of reasons), and by concentrating the harvest at the peak of nesting, the impact should be less than that currently experienced. Attempts to incorporate a predicted probability of embryo mortality (due to flooding, overheating, predation etc.) into the current harvest strategy, may well prove to be costly and cosmetic.

Table 8. Analysis of variance of small (2-6') and large >6') *Crocodylus porosus* density trends between flood plain channels that are harvested for eggs (treatment) and those that are unharvested (control) in the Finniss-Reynolds Rivers system, 1984-86. Relative densities are transformed to natural logarithms. '\*' this interaction tests the egg-harvest response. NS = not significant; E = experiment (treatment and control); T = time in years. Flood plain channels are treated as replicates (N=4).

Source	SS	d.f.	MS	F	Significance
Harvest-unharvest (E)	5.49	1	5.49	16.64	$p < 0.001$
Time (T)	0.58	2	0.29	0.88	NS
Size-class (S)	0.45	1	0.45	1.36	NS
E.T*	0.02	2	0.01	0.03	NS
T.S	0.03	2	0.01	0.03	NS
E.S	0.17	1	0.17	0.51	NS
E.T.S	0.31	2	0.15	0.45	NS
Residual	11.75	36	0.33		
Total	18.79	47			

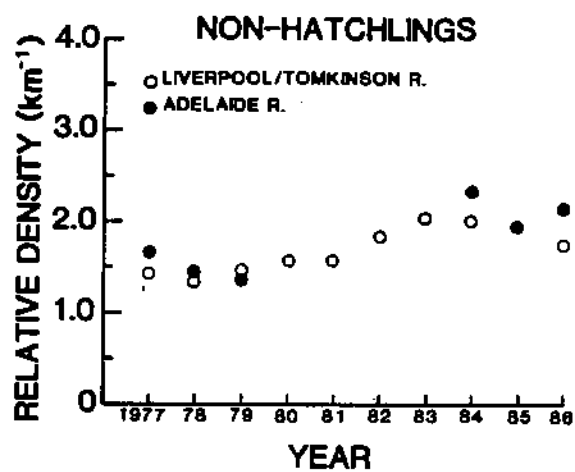


Figure 8. Relative densities of non-hatchling *Crocodylus porosus* in the Adelaide and Liverpool-Tomkinson Rivers, 1976-1986. Closed circles indicate data from Messel et al. (1981, 1986) and open circles indicate data from Webb et al. (1984, unpubl. data).

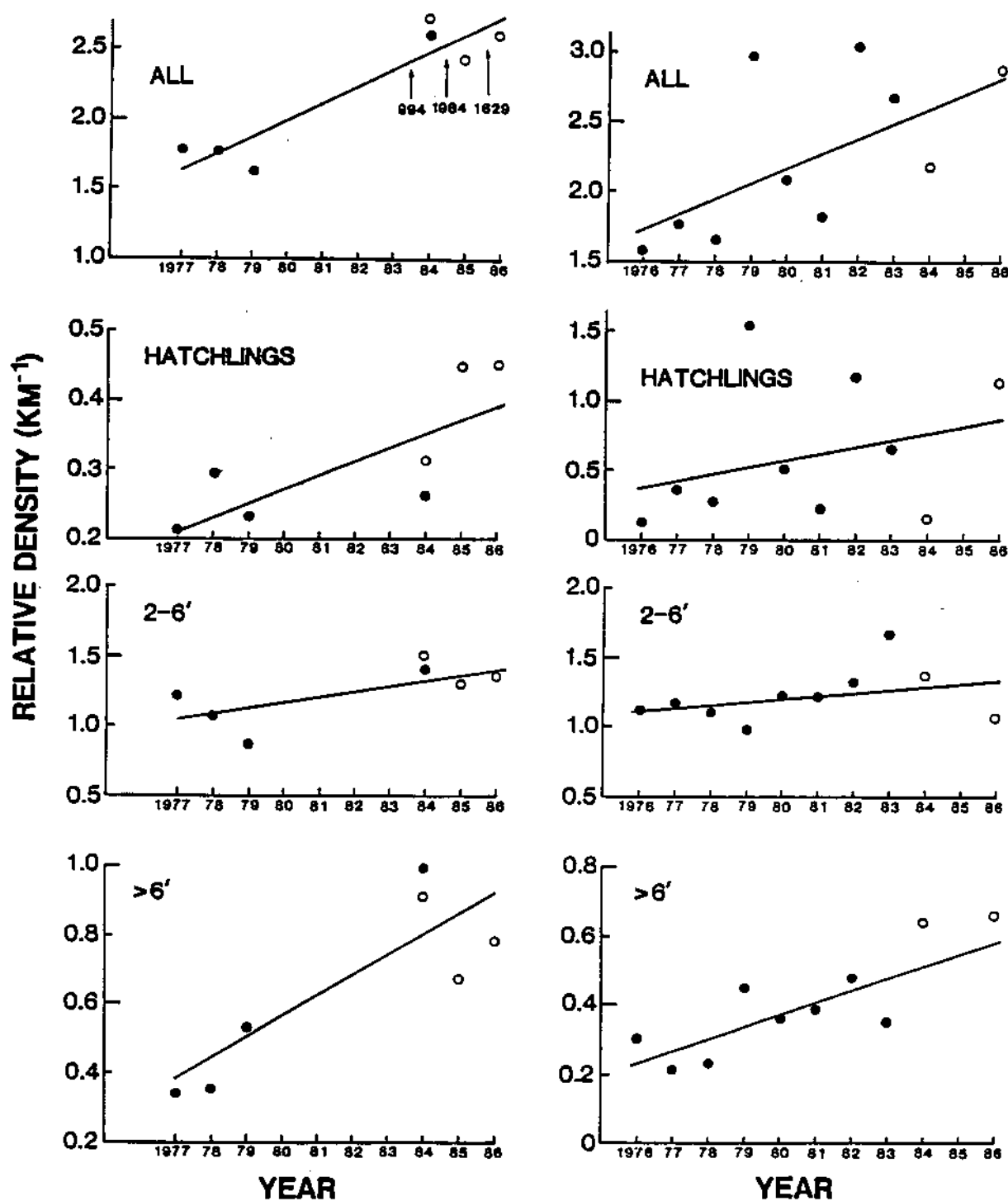


Figure 9. Relative densities of *Crocodylus porosus* in the Adelaide (harvested) and Liverpool-Tomkinson River (unharvested) systems. Numbers refer to the numbers of eggs harvested in a particular nesting season. Closed circles indicate surveys by Messel et al. (1979b, 1981, 1986), and open circles are surveys by the CCNT. Lines indicate the average exponential rates of increase derived by linear regression analysis.

Table 9. A summary of an analysis of covariance between *Crocodylus porosus* density trends in the Adelaide River (eggs are harvested) and the Liverpool-Tomkinson Rivers (eggs are unharvested), 1976-1986. Densities are transformed to natural logarithms. 'Slopes' test significant differences between the average annual exponential rates of increase ( $r$ ). NS = not significant.

Source	d.f.	F-ratio	Significance
Slopes	1.11	0.01	NS
Intercepts	1/12	0.90	NS

Table 10. Exponential annual rates of increase of *Crocodylus porosus* populations in the Adelaide and Liverpool-Tomkinson Rivers, with standard errors (SE) of the slope and significance of the regression; '\*\*' =  $p < 0.05$ , '\*\*\*' =  $p < 0.01$ , NS = not significant.

River	Size Class	$r$ (p.a.)	SE	Significance
Adelaide	All	0.055	0.011	**
	Hatchling	0.065	0.021	*
	2-6'	0.034	0.017	$p < 0.10$
	> 6'	0.099	0.024	*
	Non-hatchling	0.054	0.014	*
Liverpool-Tomkinson	All	0.054	0.021	*
	Hatchling	0.108	0.094	NS
	2-6'	0.020	0.015	NS
	> 6'	0.090	0.020	*
	Non-hatchling	0.039	0.009	**



## ESTIMATING CROCODILE TOTAL LENGTHS

Estimating the total lengths of crocodiles sighted during spotlight and helicopter counts expands the information contained in survey results. However, many factors affect the ability of an observer to estimate the size of a crocodile accurately (Magnusson 1983), and the precision of such estimates has rarely been quantified. Choquenot and Webb (1987) used a calibrated camera to examine the accuracy of two experienced observers (Fig. 10), and found that one (Observer A) was erratic over all size classes when compared to the other (Observer B).

Observers also vary in the consistency with which they estimate the lengths of the same crocodiles, in the same areas, as found by Messel et al. (1981). For example, when we examined data from re-surveys of the same flood plain channel with the same observer, on six separate occasions, during the same night, a significant relationship was found between the numbers of 2-6' and >6' crocodiles sighted (Fig. 11). These data suggest that, animals in the 2-6' category on one survey were placed within the >6' category in another, because of random error in estimating lengths.

The same type of variation occurs in data collected by different survey teams. Approximately the same number of crocodiles are sighted at the same time (Table 11), but the size estimates and proportions of "eyes only" can vary significantly (Table 12). In the Adelaide River (1984), the CCNT survey teams were apparently more cautious in allocating lengths to crocodiles sighted - they were more likely to place an animal within the "eyes only" category (Table 12).

There appears to be no simple solution to the problem of standardizing observer length estimates, because in addition to variable precision and accuracy, there may be drift with observers who are not regularly sighting and catching crocodiles. A calibrated camera technique (Choquenot and Webb 1987) could overcome some of these problems, and merits further investigation.

In the interim, caution needs to be exercised in the extent to which length estimates are incorporated into bold conclusions about short-term changes in the size and age structure of populations. The size estimating procedure is inherently inaccurate, and long-term data are needed to separate variability due to observers from that due to real changes in the structure of the population.

## CORRECTION FACTORS FOR SPOTLIGHT COUNTS

Spotlight counts provide precise relative density indices which can be used to monitor population rates of increase, but they are inherently inaccurate (Bayliss 1987). Animals are usually missed on surveys and deviations from absolute density is termed visibility bias. Correction factors which can be applied to relative density indices are needed to:

1. Standardize relative density indices for any size-related bias in sightability, which could affect the stability of the index over time (if the average size or level of wariness is increasing or decreasing) or in different areas (where the size or wariness of individuals varies);
2. Adjust the relative density indices in habitats where there are different probabilities of detection, to afford comparison;
3. Correct relative density indices to absolute densities for estimating the total population size.

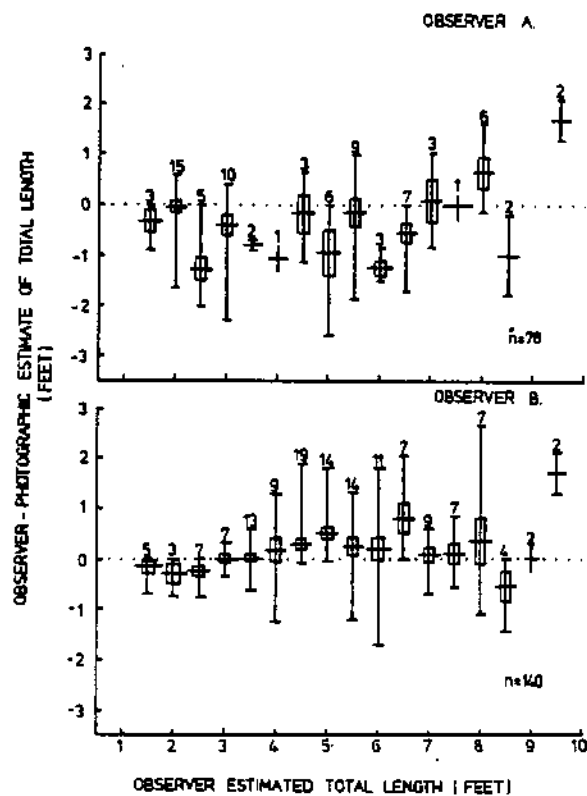


Figure 10. A comparison of spotter estimated sizes (to the nearest half-foot) and those estimated from a photographic method (Choquenot and Webb 1987) for *Crocodylus porosus* sighted during spotlight surveys in the Adelaide River. All photographs were analyzed by the same person. Horizontal lines are the means and ranges; boxes are one standard deviation (SD) on either side of the mean; numbers are the sample sizes for each half-foot category. Values above the broken line indicate an observer is overestimating the size of crocodiles sighted.

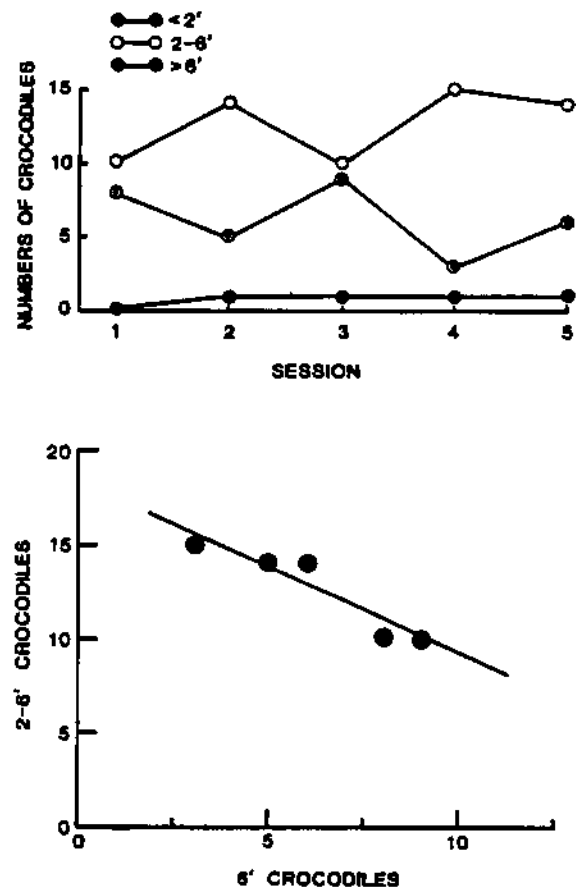


Figure 11. Numbers of different sized *Crocodylus porosus* sighted over five sessions in a flood plain channel of the Finniss River (upper); and the relationship between the number of 1-6' (Y) and >6' (X) crocodiles in the same channel (lower),  $Y = 18.5 - 0.95X$  ( $r^2 = 0.88$ ,  $n = 5$ ,  $p < 0.025$ ).

Table 11. Relative densities of three river systems surveyed independently by the University of Sydney (US; Messel et al. 1986), the Conservation Commission of the Northern Territory (CCNT), and Australian National Parks and Wildlife Service (ANPWS). Also presented is the linear regression equation for these data. "\*" = hatchlings excluded.

Relative Density (km <sup>-1</sup> )			
CCNT-ANPWS	US	Year	River
2.718	2.606	1984	Adelaide
0.207	0.206	1985	McArthur
0.116	0.145	1985	Wearyan-Foelsche
3.229	3.114	1984	East Alligator*
Calibration Equation			
US = 0.021 + 0.955 (CCNT-ANPWS)			
(R <sup>2</sup> = 1.00, n=4, p<0.001)			

Table 12. The size distribution of *Crocodylus porosus* sighted in two independent spotlight surveys of the Adelaide River, at the same time of year, in 1984.

	Messel et al. (1986)		CCNT (unpublished)	
	%	No.	%	No.
Hatchlings	9.6	60	12.7	80
2-3'	5.8	36	8.9	56
3-4'	16.8	105	11.1	70
4-5'	12.6	79	7.6	48
5-6'	10.2	64	9.4	59
6-7'	12.5	78	7.0	44
>7'	19.2	120	15.2	96
"Eyes only"	11.7	73	25.9	163
<i>C. johnstoni</i>	1.8	11	2.2	14
Totals		626		630

### 1. How Precise are Spotlight Counts?

Replicated surveys of *C. porosus* in tidal rivers and flood plain channels show high precision (Table 13), even with a small number of samples. This precision was even maintained during sessions in which tags were harpooned into the crocodiles in flood plain channels (Fig. 12).

### 2. Relating Spotlight Counts to Absolute Numbers in Tidal Rivers and Flood Plain Channels

Bayliss et al. (1986) estimated the total population of *C. porosus* within three sections of the Adelaide River using a mark-recapture technique, and obtained a precise estimate of the total population size. They then quantified mean sighting fractions seen in spotlight surveys in each of the three areas (Table 14).

More recently, the same mark-recapture technique was used to estimate the total population of *C. johnstoni* and *C. porosus* in two isolated sections of flood plain channel which were bordered by floating mats of vegetation; sighting fractions were derived in the same way (Table 14). Additional correction factors for *C. johnstoni* in isolated flood plain billabongs devoid of floating vegetation were derived from data in Webb et al. (1983b).

### 3. Relating Spotlight Counts to Helicopter Counts

Spotlight surveys have other major limitations besides inherent visibility bias. They are time-consuming, expensive, often dangerous, and more importantly, are restricted to habitats that are accessible by boat. There are large areas of crocodile habitat in the Northern Territory that have not been surveyed due to poor or impossible boat access. For *C. porosus*, helicopter surveys are much cheaper and less time-consuming than boat surveys, yet they provide an index of density that relates to that obtained by spotlighting (Bayliss et al. 1986). Helicopter counts are similar to spotlight counts in tidal rivers with large exposed mud-banks, but in tidal sidecreeks they are almost double that of spotlight counts, and hence require a different calibration equation (Table 15). Thus, helicopter surveys can be used to derive different calibration equations for spotlight counts in different habitats. For example, spotlight counts in tidal side creeks record only a small proportion of the total population in such creeks (Bayliss et al. 1986; 35%) due to stream sinuosity (Fig. 13), and these problems are largely overcome by aerial survey.

Helicopter survey techniques are also being developed for *C. johnstoni*, (which is more difficult to see from the air), and the results are also summarized in Table 15. The *C. johnstoni* calibration equation is preliminary and will be refined with additional data from surveys in 1986.

The validity of the equations relating helicopter counts to spotlight counts derived in the Adelaide River were tested in a low density area in 1986. Sections of the McArthur River were surveyed by helicopter in September during high and low bank exposure, and the calibrated helicopter counts were compared to spotlight counts in the same area (Table 16). Even though the relative density was one-twelfth that in the Adelaide River, the calibration equations were applicable. Subsequently, three major river systems (remainder of the McArthur, Limmen Bight, Wearyan-Foelesche) and 25 coastal creeks in the southern Gulf of Carpentaria were surveyed over a two day period, at half the cost of spotlight surveys and taking one-sixth the time. (Surveys in less remote areas can be surveyed at one-quarter the cost of spotlight surveys.)

Table 13. The precision of *Crocodylus porosus* and *C. johnstoni* spotlight counts in different habitats. Data are from: 1 = Messel et al. (1981); 2 = Bayliss et al. (1986); 3 = CCNT (unpubl.). "\*" indicates precision measured on sessions where tags were being harpooned into the crocodiles; DS = downstream, US = upstream.

Area	Habitat	Mean N Sessions		SE (in %)
<i>Crocodylus porosus</i>				
Blyth <sup>1</sup>	Mainstream, tidal, DS	55-66	28-27	1.1-3.7
Blyth <sup>1</sup>	Mainstream, tidal, US	39-42	15	2.0-4.0
Adelaide <sup>2</sup>	Mainstream, tidal, DS	88	2	0.6
Adelaide <sup>2</sup>	Mainstream, tidal, US	32	2	3.1
Adelaide <sup>2</sup>	Sidecreeks, tidal, DS	30	2	1.6
Finniss <sup>3</sup>	Flood plain channel No. 1	47	5	3.1
Finniss <sup>3</sup>	Flood plain channel No. 2*	36	7	9.7
<i>Crocodylus johnstoni</i>				
Finniss <sup>3</sup>	Flood plain channel No. 2*	74	7	7.1

Table 14. The mean probability (p) of sighting crocodiles on spotlight surveys in different habitats, with the correction factors (CF) needed to adjust relative densities to absolute densities. Data are from: 1 = Bayliss et al. (1986); 2 = Webb et al. (1983b); 3 = CCNT (unpubl. data).

River	Habitat	Year	p	CF
<i>Crocodylus porosus</i>				
Adelaide <sup>1</sup>	Tidal; downstream	1984	0.66	1.51
Adelaide <sup>1</sup>	Tidal; upstream	1984	0.59	1.69
Adelaide <sup>1</sup>	Mean mainstream			1.60
Adelaide <sup>1</sup>	Tidal; side creeks	1984	0.35	2.86
Finniss <sup>3</sup>	Non-tidal; flood plain channel No. 1	1986	0.64	1.56
Finniss <sup>3</sup>	Non-tidal; flood plain channel No. 2	1986	0.51	1.96
Finniss	Mean non-tidal; flood plain channel			1.76
<i>Crocodylus johnstoni</i>				
Finniss <sup>3</sup>	Non-tidal; flood plain channel No. 2	1986	0.44	2.27
McKinlay <sup>2</sup>	Non-tidal; billabongs; no floating vegetation	1978	0.66	1.51

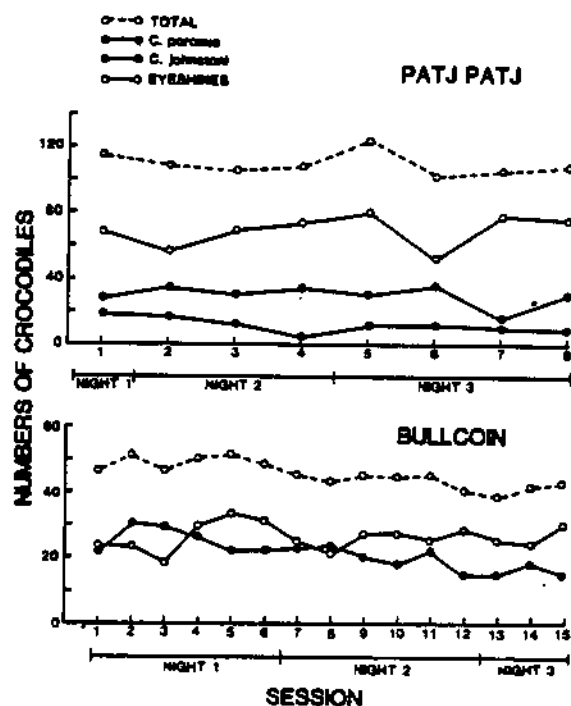


Figure 12. Numbers of crocodiles sighted in two flood plain channels in the Finnis River during a mark-recapture experiment (see text).

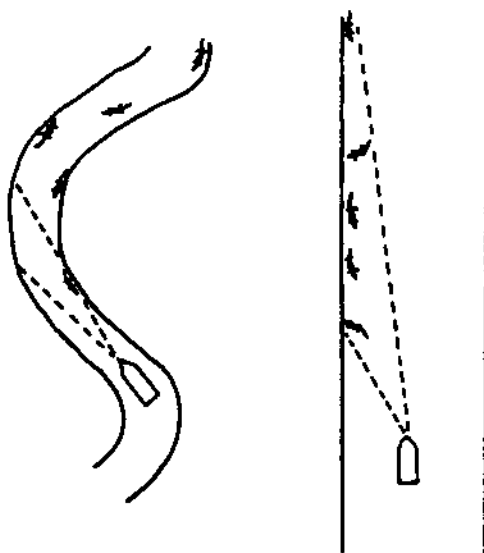


Figure 13. Schematic representation of spotlighting in a mainstream tidal river (left) and a tidal side creek (right). Crocodiles that are a considerable distance from the boat can be counted as eyeshines if they submerge before they have been reached. In side creeks, crocodiles usually submerge close to the survey boat before being detected.

Table 15. Summary of equations used to standardize helicopter counts to spotlight counts. Data are from Bayliss et al. (1986) and unpublished survey results from the CCNT. Equations were derived by linear regression analysis; S = spotlight counts, H = helicopter counts, Banks = number of banks surveyed by helicopter.

Habitat	Banks	Tide	Equation	R <sup>2</sup>	N	Significance
<i>Crocodylus porosus</i>						
Tidal mainstream	1	Spring	$S = 2.07H$	0.98	7	$p < 0.001$
Tidal mainstream	1	Neap	$S = 3.18H$	0.96	8	$p < 0.001$
Tidal side creeks	2	Neap	$S = 0.55H$	0.99	4	$p < 0.001$
<i>Crocodylus johnstoni</i>						
Non-tidal	1		$S = 64.8 + 7.39H$	0.76	37	$p < 0.001$

Table 16. Comparison between helicopter counts converted to spotlight counts and actual spotlight counts of *Crocodylus porosus* and *C. johnstoni* in a section of the McArthur River. Equations used to convert the helicopter counts to spotlight counts for high (spring) and low (neap) tide bank exposures were derived in the Adelaide River (see Table 15). Data refer to non-hatchlings only.

Bank Exposure	Methods	<i>C. porosus</i>	<i>C. johnstoni</i>
Low	Helicopter	28	4
High	Helicopter	28	3
High	Spotlight	28	3



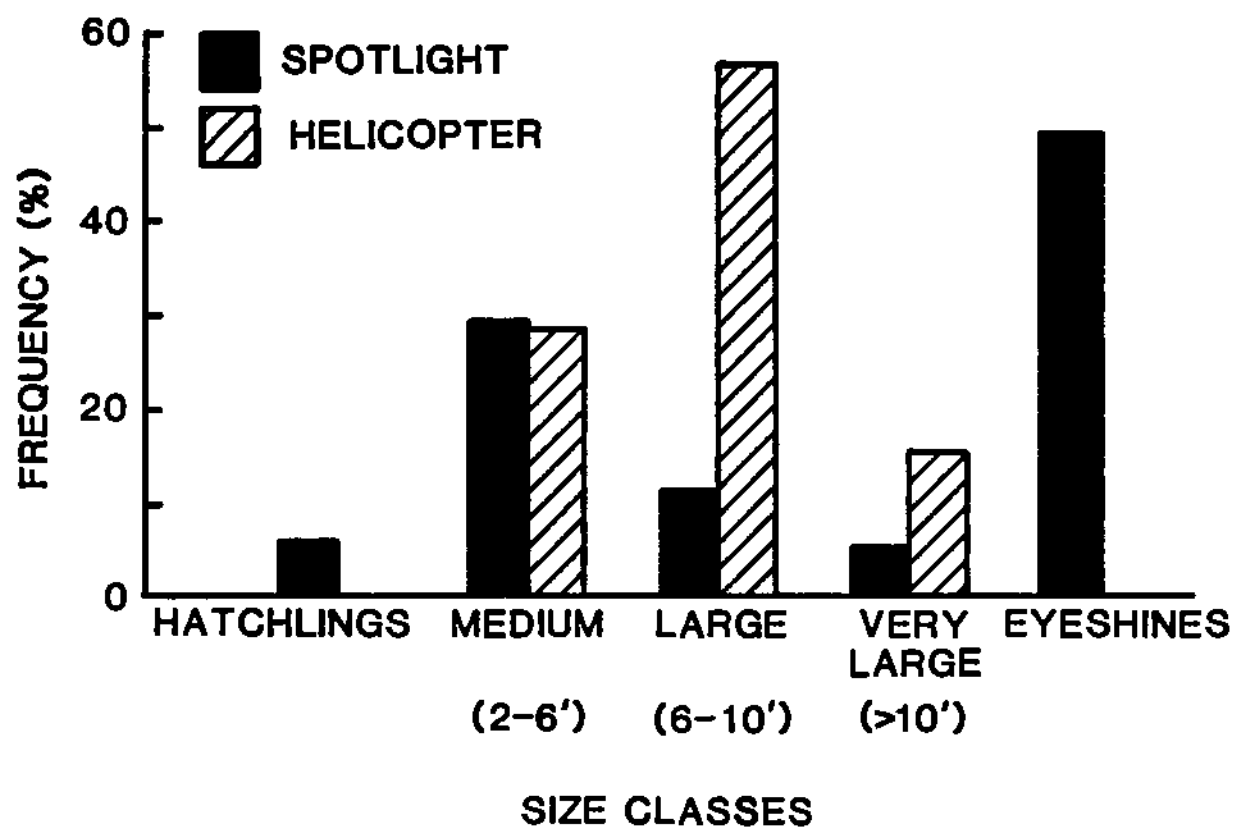


Figure 14. Proportions of hatchlings, 2-6', >6', and eyeshines sighted in spotlight and helicopter surveys in the McArthur River, a low density area.

The size classes of crocodiles seen in helicopter surveys in the McArthur River suggest that the "eyes only" fraction seen in spotlight surveys in this river should be apportioned to the greater than 6' category (Fig. 14), which are presumably more wary of spotlights.

Although there are advantages in spotlight surveys (e.g., a more accurate assessment of the age-size structure of the population, and the proportion of animals that are hatchlings) helicopter surveys are cost-effective and provide most of the information necessary to determine relative distribution and abundance patterns, and to assess long-term trends in the numbers of non-hatchlings. A further advantage is the ability to improve the precision of a population index rapidly by replication at a reasonable cost.

Future research will involve further refinement of the helicopter census technique for both *C. porosus* and *C. johnstoni*, and on calibrating *C. porosus* nest counts by helicopter to estimates of absolute crocodile numbers in habitats that are impossible or difficult to survey by spotlight or helicopter (e.g. densely vegetated freshwater swamps).

#### 4. Relating Absolute Numbers in Flood Plain Channels and Tidal Rivers to Nest Numbers

During the 1984-85 and 1985-86 wet seasons, intensive surveys of *C. porosus* nests were carried out in parts of the Adelaide, Finniss and Reynolds Rivers. These same areas were surveyed by spotlight in 1984, 1985 and 1986, and in three areas the total population of *C. porosus* was estimated using the corrections in Table 14. Accordingly, a relationship was derived between numbers of nests and the total population size (Table 17).

The results indicate that the nesting female portion of the population varies from 4.3% to 13.9% of the total population, with a mean value of 5.7% (6.5% for non-hatchlings). This percentage in turn can be used to estimate the total population of *C. porosus* in breeding areas where nests can be counted. Population monitoring of *Alligator mississippiensis* in Louisiana, where nesting females represent 5% of the population, is based solely on correcting nest counts in this fashion (Joanen and McNease 1986).

Nest counts may also be a more accurate index of the adult crocodile population in areas where females are wary or where they reside outside of the accessible mainstreams. For example, Messel et al. (1979b) counted 3 crocodiles greater than 7' in length in spotlight counts within the Liverpool-Tomkinson River system in 1976, yet there were 38 nests in one season in the same area (Messel et al. 1981). As maturity is reached at 7-8' in females and >11' in males, there were at least some 40-50 crocodiles >7' in the system although only three were sighted (some were no doubt within the "eyes only" category).

#### 5. Standardizing for Size in Spotlight Counts

Large *C. porosus* are more wary than smaller ones (Webb and Messel 1979), and have lower probabilities of being sighted in spotlight surveys (Bayliss et al. 1986). This trend was as apparent 13 years after protection (Bayliss et al. 1986), as it was 4 years after protection (Webb and Messel 1979), and thus it does not appear to be totally explicable on the basis of learned behavior among the older crocodiles which experienced hunting prior to protection (<1971). Increased size appears to be inherently associated with increased wariness in *C. porosus* (Table 18).

Within recovering populations, where the mean size of individuals is increasing with time, size-dependent wariness causes an increasingly pronounced negative bias in density indices. For example, if 105 crocodiles were sighted in a tidal river in 1975, and they were composed of 100 3-4' and 5 7-8' crocodiles, it would indicate a total population of 139 [Table 18;  $(100 \times 1.30) + (5 \times 1.71)$ ]. If in 1984 the same number of individuals (105) was sighted, it may superficially appear that the rate of recovery had been zero. Even if

Table 17. The relationship between numbers of *Crocodylus porosus* nests made during the 1984-85 and 1985-86 nesting seasons and the total population in the same areas. T = total numbers of crocodiles; NH = non-hatchlings; CF = correction factors for adjusting number of nests to population size.

River	Year	Habitat	T	NH	Nests	CF T	CF NH
Adelaide	1984	Mainstream 32.0-82.0 km	518	398	26	17.9	15.3
Adelaide	1985	Mainstream 32.0-82.0 km	504	372	23	21.9	16.2
Finniss	1985	Flood plain channel no. 1	72	70	10	7.2	7.0
Finniss	1985	Flood plain channel no. 2	70	70	3	23.3	23.3
Mean						17.6	15.5

Table 18. The probability (p) of sighting *Crocodylus porosus* of different sizes in spotlight counts, as quantified in the Adelaide River in 1984, 13 years after protection (Bayliss et al. 1986). Sizes refer to total length estimated in feet. The correction factors (CF) are the values needed to correct counts of different sized *C. porosus* to absolute numbers.

Size	p	CF
1-2	0.69	1.44
2-3	0.75	1.34
3-4	0.77	1.30
4-5	0.77	1.31
5-6	0.73	1.36
6-7	0.67	1.49
7-8	0.59	1.71
8-9	0.47	2.13
9-10	0.33	3.08
10 +	0.15	6.54

the numbers sighted were corrected with a single correction factor, the rate of recovery would still appear to be zero. However, if the population structure was now composed of 40 2-3', 30 4-5', 20 6-7', 10 8-9' and 5 10'+ crocodiles, the real population would be 177  $[(40 \times 1.34) + (30 \times 1.31) + (20 \times 1.49) + 10 \times 2.13) + (5 \times 6.54)]$ , and there would be a positive rate of increase (+2.7% p.a.).

Because of the errors involved in estimating sizes (see above), our mean annual rates of population increase (Table 6; +8.3% p.a. for all crocodiles and +9.7% p.a. for non-hatchlings) do not account for the changed size structure. Hence the real rates of increase are higher than those given on Table 6.

## 6. The Adelaide River - A Test Case

Although indices derived from spotlight counts can be used to monitor trends in numbers, they are inherently inaccurate - not all crocodiles are counted. The uncounted population falls into two categories: those within the area surveyed that were not sighted (see above), for whatever reason, and those in areas associated with the mainstream that were not surveyed.

In the Adelaide River system (Fig. 15), 50 km east of Darwin, *C. porosus* occupy a variety of tidal and non-tidal habitats, some of which can be readily surveyed by spotlight and others which cannot. On Fig. 16, the total population size within the Adelaide River is estimated in stages, using appropriate correction factors for different habitats. The stages incorporated into this estimate are:

1. Spotlight counts in 1984 (CCNT, unpublished data) yielded 80 hatchlings and 514 non-hatchlings in the mainstream and its major side creeks; similar results were obtained by Messel et al. (1986, 60 hatchlings and 542 non-hatchlings; a-c on Fig. 16).
2. Using the general mainstream correction factor (1.60) between relative densities and absolute densities (Table 14), these sighted individuals give a total population estimate of 950 animals (128 hatchlings and 822 non-hatchlings). Using correction factors in Messel et al. (1981), similar numbers (95 hatchlings and 889 non-hatchlings; total = 984) are derived (d on Fig. 16).
3. However, separate correction factors are needed for upstream, downstream and side creeks (Table 14), and when these are applied to the spotlight counts, it indicates a population of 1133 individuals (e on Fig. 16).
4. Completely excluded from this estimate is the population which exists year-round in Melacca Swamp (Fig. 15), a heavily vegetated wetland which cannot be surveyed by spotlight. Using nest counts (22 in each of 1984-85 and 1985-86) as the relative density index, and correcting them with the mean correction (17.6) derived in Table 17, an additional 387 animals are indicated; this increases the total population estimate to 1520 (f on Fig. 16).
5. In addition to Melacca Swamp, the flood plains of the Adelaide River contain some 150-200 permanent and semi-permanent billabongs and minor swamps. In 1986, a sample of these was surveyed by both helicopter (106) and spotlight (20). When these indices were corrected to absolute densities, it yielded an additional 80 animals, increasing the total population estimate to 1600 (g on Fig. 16).
6. In addition to these habitats, there are large numbers of small tertiary creeks which are inaccessible to survey boats and which were not surveyed by helicopter, and additional upstream billabongs (that contain *C. porosus* and in at least one case nesting adults) which were not included in our survey. Thus 1600 represents a conservative estimate of the total population of *C. porosus* within the Adelaide River system alone.

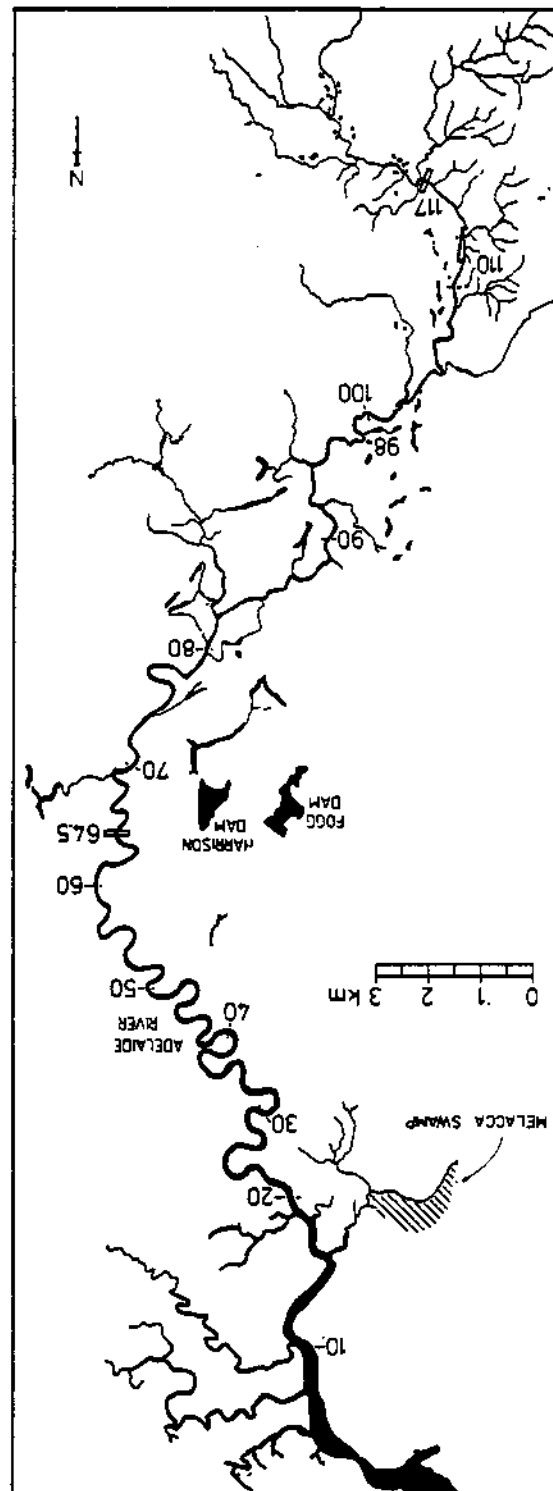


Figure 15. The Adelaide River system. Numbers are river kilometers from the mouth.

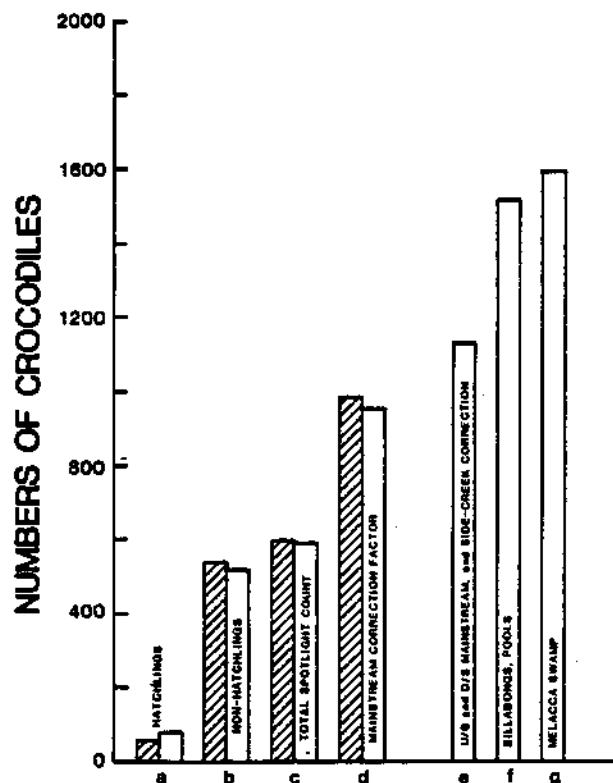


Figure 16. Number of *Crocodylus porosus* in the Adelaide River system: a, hatchlings sighted in spotlight surveys; b, non-hatchlings sighted in spotlight surveys; c, total number of *C. porosus* sighted in spotlight surveys; d, population estimate using mainstream correction factors (see text); e, population estimate using appropriate correction factors for upstream, downstream, and side creek habitats; f, population estimate accounting for *C. porosus* in various billabongs outside of the mainstream; g, total population estimate including *C. porosus* in Melacca swamp. Shaded bars indicate survey data from Messel et al. (1986), and unshaded bars are survey data from the CCNT.

## THE SIZE OF THE NORTHERN TERRITORY POPULATION OF *C. POROSUS*

Webb et al. (1984) derived a conservative estimate of the Northern Territory *C. porosus* population of 30,000 individuals, and guessed that the real population was closer to 40,000 when the full extent of unsurveyed habitats was taken into consideration. This estimate was considered an overestimate by Messel (1986) and Messel et al. (1986), yet we had consistently used conservative correction factors:

1. Coastline. Two estimates of the absolute density of *C. porosus* on the coast were obtained; one between Darwin and the Victoria River (0.09/km) and one around the coast of Melville Island (0.38/km). Neither area includes the best breeding areas for *C. porosus* (Table 4), and thus a mean of the two estimates (0.24) is probably more realistic than the lower value (0.09) used by Webb et al. (1984).
2. Coastal Secondary Creeks. Coastal secondary creeks between Darwin and the Victoria River were surveyed by helicopter and the counts were corrected to absolute densities (2.57/km). The 1238 km of coastal secondary creek in the Northern Territory was composed of 638 separate creeks, with a mean length of 1.9 km, which assumes a mean total population of about 5 crocodiles per creek.
3. Major Breeding Tidal Systems. Mainstreams (1587 km) and sidecreeks (405 km; 207 creeks) were lumped in our previous estimate, and given the mean relative density of 3.16 crocodiles sighted per km derived from surveys. This was then multiplied by a conservative correction factor (1.33). The mean mainstream correction factor is closer to 1.6 (Table 12).
4. Sidecreek Corrections to Breeding Tidal Systems. In reality, the probability of sighting crocodiles in tidal sidecreeks is lower than in wide mainstreams (Table 12), and within the Adelaide River corrections for this underestimating bias increased the population by 19%. A similar correction is applicable to other major breeding systems, yet it was not used in our 1984 estimate.
5. Minor Breeding Tidal Systems. Mainstreams (3185 km) and secondary creeks (1140 km; 717 creeks) were lumped in our previous estimate, and given the mean relative density of 0.71 crocodiles sighted per km derived from surveys. This was then multiplied by a conservative correction factor (1.41). The real correction factor is probably closer to 1.6 (Table 12), plus an additional correction is needed for sidecreeks.
6. Flood Plain Creeks. In the original estimate, 1291 km of flood plain channel was given a relative density derived from spotlight counts in 10.5% of the habitat surveyed (5.60 crocodiles sighted per km). This was multiplied by a correction factor (1.56) based on results from a tidal system. The mean correction factor recently derived is 1.76 (Table 12).
7. Escarpment Channels. In the original estimate, the 534 km of flood plain channel were multiplied by a relative density of 0.60 and a correction factor of 1.53; an absolute density of 0.92 per km. Due to the physical characteristics of these channels, the correction factors applicable are probably between those of the upstream tidal areas (1.69) and those of side creeks (2.86).
8. Freshwater swamps. Although some areas of "swampland" were recognised within the Northern Territory, patches of freshwater swamp with high densities of *C. porosus* nests are more restricted (Magnusson et al. 1978). No estimate for this population was made in our original estimate, but given the numbers now estimated in Melacca Swamp alone (387 *C. porosus*), the total population within such habitats in the Northern Territory must be in the 1000's.
9. Tertiary Creeks. The 8223 tertiary creeks identified are an unknown quantity with regard to *C. porosus*. Some of these creeks are completely dry at low tide and others recede to pools. Within

major breeding tidal rivers such creeks (1256 were recognised) have a high probability of containing crocodiles, but along the coast and in low density areas they do not. No estimate was made for them.

10. The Captive Population. As of June 1986, there were 4232 *C. porosus* in captivity in Australia.

The above estimates do not account for the increase in the wild population that has occurred over the last two years, nor does it account for the many bodies of water not included on 1:100,000 maps - 30,000 to 40,000 was a conservative estimate of the *C. porosus* population in 1984.

#### LITERATURE CITED

- Bayliss, P. 1987. Survey methods and monitoring within crocodile management programmes. Pages 157-175 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- \_\_\_\_\_, G.J.W. Webb, P.J. Whitehead, K. Dempsey, and A.M.A. Smith. 1986. Estimating the abundance of saltwater crocodiles, *Crocodylus porosus* Schneider, in tidal wetlands of the Northern Territory: a mark-recapture experiment to correct spotlight counts to absolute numbers, and a calibration of helicopter and spotlight counts. *Aust. Wildl. Res.* 13:309-320.
- Caughley, G. 1977. *Analysis of Vertebrate Populations*. John Wiley and Sons, Sydney.
- CCNT. 1986a. *Crocodylus porosus* in the Northern Territory: Biology and history of management. *Conserv. Comm. N.T. Tech. Rep. No. 31*.
- \_\_\_\_\_. 1986b. *Crocodylus johnstoni* in the Northern Territory: Biology and history of management. *Conserv. Comm. N.T. Tech. Rep. No. 32*.
- Choquenot, D.P. and G.J.W. Webb. 1987. A photographic technique for estimating the size of crocodilians seen in spotlight surveys and quantifying observer bias in estimating sizes. Pages 217-224 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- Joanen, T. and L. McNease. 1987. The management of alligators in Louisiana, USA. Pages 33-42 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- Magnusson, W.E. 1983. Size estimates of crocodilians. *J. Herpetol.* 17:86-88.
- \_\_\_\_\_, G.C. Grigg, and J.A. Taylor. 1978. An aerial survey of potential nesting areas of the saltwater crocodile, *Crocodylus porosus* Schneider, on the north coast of Arnhem Land, Northern Australia. *Aust. Wildl. Res.* 5:401-415.
- Messel, H. 1986. The non-future of saltwater crocodiles in Australia. *Habitat (Aust.)* 14:4-7.
- \_\_\_\_\_, C. Gans, A.G. Wells, and W.G. Green. 1979a. Surveys of tidal river systems in the Northern Territory of Australia and their crocodile populations. Monograph 3. Pergamon Press, Sydney.
- \_\_\_\_\_, G.C. Vorlicek, A.G. Wells, and W.G. Green. 1981. Surveys of tidal river systems in the Northern Territory of Australia and their crocodile populations. Monograph 1. Pergamon Press, Sydney.



- \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_, I.C. Onley, and F.W. King. 1986. Surveys of tidal river systems in the Northern Territory of Australia and their crocodile populations. Monogr. 19. Pergamon Press, Sydney.
- \_\_\_\_\_, A.G. Wells, and W.G. Green. 1979b. Surveys of tidal river systems in the Northern Territory of Australia and their crocodile populations. Monograph 7. Pergamon Press, Sydney.
- Smith, A.M.A. and G.J.W. Webb. 1985. *Crocodylus johnstoni* in the McKinlay River area, N.T. VII. A population simulation model. Aust. Wildl. Res. 12:541-554.
- Webb, G.J.W., R. Buckworth, and S.C. Manolis. 1983a. *Crocodylus johnstoni* in the McKinlay River area, N.T. III. Growth, movement and the population age structure. Aust. Wildl. Res. 10:383-401.
- \_\_\_\_\_, S. Manolis, P. Whitehead, and G. Letts. 1984. A proposal for the transfer of the Australian population of *Crocodylus porosus* Schneider (1801), from Appendix I to Appendix II of C.I.T.E.S. Cons. Comm. N.T. Tech. Rep. 21.
- \_\_\_\_\_, \_\_\_\_\_, and R. Buckworth. 1983b. *Crocodylus johnstoni* in the McKinlay River area, N.T. II. Dry-season habitat selection and an estimate of the total population size. Aust. Wildl. Res. 10: 373-382.
- \_\_\_\_\_, and H. Messel. 1979. Wariness in *Crocodylus porosus*. Aust. Wildl. Res. 6:227-234.
- \_\_\_\_\_, G.C. Sack, R. Buckworth, and S.C. Manolis. 1983c. An examination of *Crocodylus porosus* nests in two northern Australian freshwater swamps, with an analysis of embryo mortality. Aust. Wildl. Res. 10: 571-605.
- \_\_\_\_\_, and A.M.A. Smith. 1984. Sex ratio and survivorship in the Australian freshwater crocodile *Crocodylus johnstoni*. Symp. Zool. Soc. Lond. No. 52:319-355.
- \_\_\_\_\_, P.J. Whitehead, and S.C. Manolis. 1987. The management of crocodiles in the Northern Territory of Australia. Pages 107-124 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. Wildlife Management: Crocodiles and Alligators. Surrey Beatty and Sons, Chipping Norton, Australia.

# RADIOCESIUM LEVELS IN A POPULATION OF AMERICAN ALLIGATORS: A MODEL FOR THE STUDY OF ENVIRONMENTAL CONTAMINANTS IN FREE-LIVING CROCODILIANS

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**ABSTRACT** - Studies of the distribution, fate and potential impacts of environmental contaminants require a thorough knowledge of the basic ecological relationships, movements and behaviors of the target organisms. Although crocodilians have been little-studied in this regard, the continual release of radionuclides and other contaminants into elements of global circulation, suggest that even populations in remote regions, may now be significantly impacted. An example is given of a study of a population of American alligators inhabiting a reservoir which has received low-levels of radionuclide contamination from an operating nuclear production reactor. The principle radionuclide of concern was the gamma-emitter radiocesium which is known to concentrate primarily in skeletal muscle. By estimating the population number and sizes of individual alligators present in the reservoir and then determining radiocesium concentrations of selected individuals, the resident alligator population ( $n = 12$ ), was calculated to represent an average live-weight biomass of 1.9 kg/ha, which was 3% of the total biomass/ha of all animals studied in the reservoir. When combined with previously published estimates made for other components of this same reservoir, these calculations indicated that 99% of the radiocesium resided in the abiotic components (sediments and water column). Of the radiocesium estimated to reside within the biota, only 0.4% was located within the animals, and of this fraction, only 0.5% was found in the biomass of the alligator population. Trophic-level concentration or biomagnification of radiocesium does not appear to occur in many aquatic vertebrate food webs and the few determinations that were made on alligators suggested that radiocesium concentrations in their biomass (mean = 13 pCi/g live weight) were lower than those of several of their prey species. A number of features combine to make radiocesium an ideal 'tracer' to study the principles and pathways by which many classes of environmental contaminants may cycle and become concentrated within crocodilian populations. However, more information is still needed for age-specific changes in body radiocesium contents and for rates and patterns of contaminant uptake under natural conditions.

## INTRODUCTION

The catastrophic accident at the Chernobyl nuclear power station in the Soviet Union has served to underscore the potential for global environmental contamination to occur following such an event, with significant contaminant accumulation and impact occurring even in regions far removed from the source of contaminant release (Medvedev 1986). Even though many crocodilian populations are located in areas that are far removed from industrial development, they can no longer be assumed to be free of long-term chronic contaminant input from a variety of sources, as a result of global cycling pathways. While global atmospheric fallout of radioactive materials has been of particular concern in this regard (Comar 1965), the same pathways and mechanisms may also be responsible for the distribution of other classes of contaminants such as pesticides or heavy metals (Clay et al. 1974). Because of their tendency to persist in natural food webs and to cause localized cellular/tissue damage in target organisms for many years after release, many radionuclides are of special concern as environmental stressors (Table 1). Radiocesium, including the isotopes of both  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$ , are of particular concern because of (1) its ubiquity in most environmental releases associated with both nuclear weaponry and the nuclear power industry, (2) its

Table 1. Some general properties of radionuclides which have proved important as environmental contaminants of vertebrate wildlife (adapted from Whicker and Shultz, 1982).

Radionuclide	Physical Half-Life	Biological Retention	Principle Form of Emission	Mode of Exposure <sup>a</sup>	Vertebrate Target Organ	Nutrient Analogs
$^3\text{H}$ (tritium)	12 years	Low (days)	Beta	Ing, Abs, Ih	Total body	H
$^{131}\text{I}$	8 days	Moderate (weeks)	Beta	Ing, Abs, Ih	Thyroid	I
$^{137}\text{Cs}$	30 years	Moderate (months)	Gamma	Ing, Abs, Ext	Whole body, muscle	K
$^{45}\text{Ca}$	160 days	Mod.-high (wks-yrs)	Beta	Ing, Abs	Bone	Ca
$^{90}\text{Sr}$	28 years	High (years)	Beta	Ing, Abs	Bone	Ca
$^{60}\text{Co}$	5.2 years	Low (days)	Gamma	Ing, Abs, Ih, Ext	GI, lung, whole body	Co
$^{65}\text{Zn}$	245 days	Mod.-high (mos-yrs)	Gamma	Ing, Abs, Ih, Ext	Liver, lung, whole body	Zn
$^{239}\text{Pu}$	24,000 years	High (years)	Alpha	Ing, Ih, Ads	Bone, lung	None

<sup>a</sup> Ing = ingestion, Abs = absorption, Ads = adsorption, Ih = inhalation, Ext = external gamma exposure.

relatively long half-life and thus tendency to persist in the environment for extended periods of time, (3) its tendency as a gamma-emitter to cause extensive cellular/tissue damage once incorporated into an organism's biomass, and (4) its tendency, as an analog of potassium, to accumulate in highest concentrations in skeletal muscle, which would be the tissue most likely to be consumed by man or other heterotrophic organisms in the food web.

Extensive studies by several authors (e.g., Jenkins and Fendley 1968) have shown that radiocesium and other radionuclides often tend to concentrate at unusually high levels in the bodies of free-living wildlife, following deposition as fallout from the atmospheric testing of nuclear weapons. This has been shown to be particularly true in regions of nutrient poor soils such as the arctic tundra (Hanson 1966) or the southeastern coastal plains of the United States (Jenkins and Fendley 1968). In such areas, fallout-deposited radionuclides form a relatively greater portion of the total soil nutrient pool available to the vegetation of natural communities.

The basic principles for studying the cycling and accumulation of radionuclides in the environment have been developed within the discipline known as radioecology as described by Whicker and Schultz (1982). Much of the work in this field however, has been developed on the basis of laboratory studies and has strongly emphasized homeothermic organisms, such as domestic livestock, which figure prominently in the food web of man. As pointed out by Brisbin et al. (1986), studies of contaminant cycling and radioecology have received practically no attention in the world crocodilian literature.

It is the purpose of this report to describe the basic design and preliminary results of a research program aimed at studying the uptake and cycling of radiocesium in a population of American alligators (*Alligator mississippiensis*) inhabiting a reservoir which received radionuclide releases from an operating nuclear production reactor over an extended period of time. It is also the purpose of this report to use this particular study to evaluate the approaches and methodology which might be used to study other examples of environmental contamination in other crocodilian populations throughout the world.

## MATERIALS AND METHODS

This study was conducted in the Pond B reservoir (Fig. 1) located on the United States Department of Energy's Savannah River Plant (SRP). The SRP is a 750 km<sup>2</sup> nuclear production and research facility of the United States Department of Energy and is located in portions of Aiken, Allendale and Barnwell counties, South Carolina. This area has been closed to public access since 1952, providing the resident population of American alligators with freedom from poaching and many other forms of disturbance. Detailed descriptions of this site and its resident alligator population have been provided elsewhere (Murphy 1981; Brisbin 1982; Brisbin et al. 1982; Seigel et al. 1986). The Pond B reservoir forms part of the SRP's Par Pond reservoir system which has, since the early 1960's, provided a closed-loop system of cooling water for one or more of the SRP's nuclear production reactors. Pond B was formed in 1961 by impounding a natural stream water course, while at the same time diverting water to the impoundment from the site's R-reactor complex. Input from the R-reactor was discontinued in 1964 and since that time hydrologic input to the reservoir has been only from direct rainfall and subsurface groundwater seepage. Although the surface area and other physical characteristics of the reservoir vary slightly in response to balances of precipitation and evaporation, the lake is approximately 87 ha in surface area and has 9.0 km of shoreline. Maximum depth near the dam is 12.2 m. The lake has numerous shallow coves which are heavily vegetated with macrophytes in contrast to the more open deeper waters in the central part of the lake. The majority of the lake's alligators are generally found within 10-20 m of the shore in the shallower more vegetated areas (Fig. 1).

Between 1960-1964, the heated effluents from the R-reactor were contaminated with varying amounts of several radionuclides which resulted from direct inputs from the reactor itself and leakage from a faulty fuel element stored at the reactor site (Alberts et al. 1979). Radionuclide inputs to Pond B

## POND B

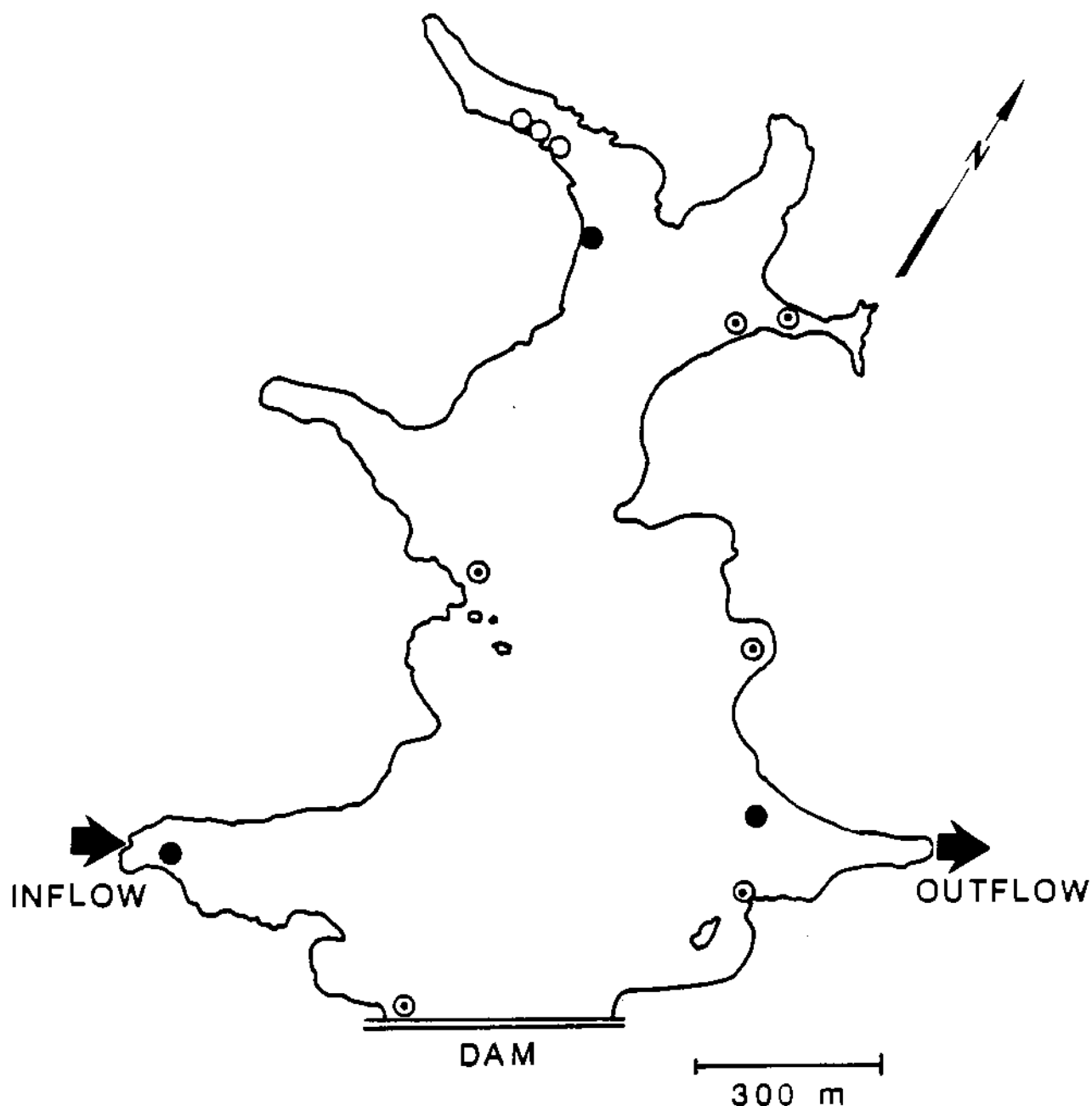


Figure 1. Diagrammatic representation of locations of alligators identified as inhabiting the Pond B reservoir on the U.S. Department of Energy's Savannah River Plant. Symbols are placed at locations approximating the geographic center of all sightings of that individual (total sightings = 46). Further details concerning the alligators indicated here are provided in Table 2. Solid circles = adults ( $> 1.7$  m), open circles with central points = immatures (0.5 - 1.6 m), and open circles = juveniles ( $< 0.5$  m). Solid arrows indicate locations where reactor effluents entered and exited the reservoir between 1961-1964.

during this period totaled about 50,000 Ci of tritium, 150 Ci of  $^{137}\text{Cs}$ , 12 Ci each of  $^{90}\text{Sr}$ , and  $^{103,106}\text{Ru}$  and lesser amounts of  $^{60}\text{Co}$ ,  $^{238,239}\text{Pu}$  and other transuranic elements.

Measurable quantities of most of these radionuclides, particularly radiocesium, can still be found in both abiotic and biotic components of the Pond B reservoir ecosystem. Since the time of reservoir formation, the waters of Pond B have tended to become nutrient-poor and relatively acidic, as is typical for natural freshwater systems of this region. This in turn has tended to produce a situation favoring high concentration factors (concentration in biota/concentration in water) for radiocesium (Whicker et al. 1984). This, in combination with the generally low cation-binding capacity of the soils and sediments of region (Brisbin et al. 1974a; Whicker et al. 1984), has tended to enhance the continued recycling of radiocesium and other radionuclides into the biotic components of the reservoir.

Murphy (1981) described the alligator population resident in Pond B in the late 1970's as including several adults of breeding size. Although no evidence of reproduction was found at that time, Murphy predicted that the subsequent reproduction of these animals together with the likely dispersal of juvenile alligators to Pond B along the canal connecting it to the main portion of Par Pond (Fig. 1) should eventually result in the establishment of a viable breeding population of alligators in this reservoir.

Population numbers of alligators were estimated in the present study by night-time eye-shine census techniques (Wood et al. 1985). Census cruises were made from an airboat with the entire shoreline of the reservoir being covered each night that a census was conducted. Shorelines were censused from a distance of approximately 50 m although the size of the reservoir permitted the identification of even juvenile alligators at a distance greater than the maximum width of the reservoir. Census cruises, which took approximately 1.0 hrs to complete, were conducted on June 16, 17, 18, July 17, 18, 19, August 5 and September 17, 1986. Each alligator that was located was approached as closely as possible in order to allow estimation of body size. Very small animals were captured whenever possible and marked with tail scute clippings in order to prevent duplicate identifications of the same individuals. Following the last census cruise, records from all cruises were combined in order to estimate the maximum number of individuals that were likely to be present in the reservoir. In this procedure, locations of alligators on different cruises were compared with respect to body size and location in the reservoir. A strong tendency was shown for most animals to be associated with specific locations along the shoreline, thus facilitating the differentiation of individuals and preventing duplicate counting. Body size estimates, expressed as total body length to the nearest meter, were converted to body weight estimates using length-weight regression equations presented by Chabreck and Joanen (1979).

Body-burdens of radiocesium were determined by procedures similar to those described by Brisbin et al. (1973). In the present case, body burdens were determined for hatchling alligators in a lead-shielded whole-body counting chamber with a NaI (Th) crystal measuring 10.2 cm in height and 15.2 cm in width. Hatchlings were restrained in plastic tubes and placed so that the center of their body was centered immediately above the crystal detector. Gamma emissions were analyzed on a Canberra 8100 multi-channel pulse-height analyzer, and counts accumulated during a 2000 sec counting period were compared with same-day net counts from an aqueous phantom of similar body size and configuration to the alligator. Body burdens of radiocesium were expressed as pCi/g of whole-body live weight. Although no alligators have yet been captured which could not be counted in the previously described equipment, the determination of radiocesium contents for larger individuals (> 1.5 m) would require either sacrifice and whole-body homogenization techniques (Brisbin and Smith 1975) or, if alligators were to be kept alive after radiocesium determination, alternative counting techniques could be adapted using portable field gamma-counting equipment similar to that described by Rabon and Johnson (1973) and Wright and Splichal (1973) for use with deer and feral swine. In using this field equipment, the thick skin of large alligators would require the use of correction equations described by Stribling et al. (1986).

## RESULTS

The eight census cruises produced a total of 42 sightings of alligators (range = 3-9 sightings/cruise). An additional four sightings were made between census cruises while conducting other research activities at the reservoir. Of the 46 sightings, 34 were able to provide a size estimate for the alligator observed. Eight of the sightings included the hand-capture and positive identification of one of three hatchlings found in a cove at the northern end of the reservoir (Fig. 1). These hatchlings were always found in close proximity to one another and probably represented a cohort which hatched from a nest in that area in 1985.

Taken together, the census cruise data indicated that in addition to the three hatchlings, nine other alligators resided in the Pond B reservoir, including three adults whose sizes suggested that they were potentially reproductive (Table 2, Fig. 1). Application of length-weight regression equations indicated that these alligators represented a total estimated biomass of 161.2 kg, or an average of 1.85 kg/ha for the entire reservoir.

Whole-body burdens of radiocesium for the three hatchling alligators, as determined on June 17 and 18, 1986, were 12.68, 15.33 and 11.61 (mean = 13.21) pCi/g live weight. Applying this value to the total alligator biomass estimated for the reservoir indicated a total inventory of 0.0244 Ci radiocesium/ha for the Pond B alligator population. This value was then combined with previously published radiocesium inventory estimates for other biotic and abiotic compartments of the reservoir, and with preliminary inventory data recently collected for waterfowl (principally American coots (*Fulica americana*) and ring-necked ducks (*Aythya collaris*), and largemouth bass (*Micropterus salmoides*) (Table 3). These comparisons indicated that less than 0.6% of the total inventory of radiocesium present in Pond B was found in the biota. Approximately 99% of the radiocesium was found in the sediments, with most of the remainder being in the water column of the reservoir. Of the radiocesium found in the biota, 99.6% was incorporated into the biomass of the macrophytes (Table 3). Of the total inventory of 3.9 Ci radiocesium/ha found in the animals, only 0.5% was incorporated into alligator biomass. The inventory of radiocesium in the alligators was lower than that of any other biotic component studied, although it was of the same general order of magnitude as estimated for benthic gastropods and waterfowl. The radiocesium inventory in the alligators was nearly two orders of magnitude less than that found in the largemouth bass and benthic invertebrate community of the reservoir.

## DISCUSSION

The present status of the Pond B alligator population, as determined by the census reported here, is a reasonable consequence of the status reported by Murphy (1981) who found 3-11 alligators, including several large adults, in Pond B in the early-mid 1970's. Since these earlier surveys, there have been several known deaths of large adult alligators in Pond B (Murphy 1981; Brisbin et al. 1982; Seigel et al. 1986), possibly as a consequence of *Aeromonas hydrophila* infections and stress (Brisbin 1982). These, together with the probable dispersal of juveniles into Pond B from the adjacent North Arm of Par Pond, as predicted by Murphy (1981), would produce a population age structure similar to that found in this study (Table 2).

As illustrated by the study reported here, there are a number of quantities which are difficult to estimate accurately in the process of calculating the total standing crop of a contaminant such as radiocesium in a population of wild crocodilians. Errors in estimating these quantities will undoubtedly introduce errors of varying magnitude into the final inventory calculations and hence may influence the final conclusions which are drawn. Chief among these factors is the difficulty involved in capturing and accurately estimating the average radiocesium body burdens of large adult crocodilians. In fact, no such estimates have yet been obtained for the Pond B alligator population, and all estimates of biomass radiocesium concentrations thus

Table 2. American alligators censused during the summer of 1986 on the Pond B reservoir of the U.S. Department of Energy's Savannah River Plant.

Alligator No. <sup>a</sup>	Estimated Total Length (m)	Estimated Live Body Weight (kg) <sup>b</sup>
1	2.40	55.90
2	1.45	9.90
3	1.70	17.50
4	0.36	0.10
5	0.37	0.11
6	0.24	0.08
7	1.12	3.60
8	1.00	1.30
9	1.25	5.60
10	2.40	55.90
11	1.25	5.60
12	1.25	5.60
		Total = 161.20

<sup>a</sup> Alligators are numbered in sequence, according to their location along the reservoir shoreline, proceeding clockwise from the point of reactor effluent inflow, as indicated in Fig. 1.

<sup>b</sup> Calculated from the length/weight regression equation for wild alligators (Chabreck and Joanen 1979).



had to be based on the average of those values obtained for the more easily captured and handled hatchlings. Since alligators shift their diet from a largely insect/invertebrate to a vertebrate prey base as they grow larger, there is the possibility that weight-specific radiocesium body burdens may change with age. However, as will be discussed later, data from other species such as fish-eating birds (Brisbin et al. 1973; Dombay and McFarlane 1978) and snakes feeding on aquatic vertebrates (Brisbin et al. 1974b) from this same reservoir system, indicate that predators in the higher trophic levels of vertebrate food webs do not tend to show high levels of radiocesium biomagnification. Thus, radiocesium concentration levels in the biomass of the larger adult alligators is probably not significantly greater and possibly could even be lower than those reported here for the hatchlings.

Another possible source of inaccuracy in the calculation of contaminant standing crop is the field estimation of the sizes of individual animals, and the use of correct regression coefficients to predict body weights from field estimates of length. Murphy (1981) has shown significant differences between the growth patterns of alligators inhabiting different regions of the Par Pond reservoir system, and if these differences produce corresponding differences in length-weight relationships, the validity of using length-weight regression coefficients derived from populations in another part of the species range (e.g., Chabreck and Joanen 1979) must be questioned until verification can be obtained with actual length-weight data from individuals from the Pond B population itself.

While certain quantities in a contaminant inventory calculation may be more difficult to estimate for crocodilians than other species, others may actually be easier. Estimation of alligator numbers, for example, particularly in a situation such as Pond B, can almost certainly be performed more accurately than can the estimation of population numbers for such biota as fish or benthic invertebrates. The population estimate of 5434 for largemouth bass in Pond B, for example, was based on 747 mark-recaptures and had a 95% confidence interval of 3589-7279 individuals. In terms of the average weight/individual bass (mean = 255 g), this represents a deviation of about 470 kg for the total bass population biomass. This is more than twice the total biomass estimate for the entire reservoir population of either alligators or waterfowl (Table 3).

Despite the factors discussed above, it is unlikely that any of the inaccuracies involved in estimating the inventory/distribution of radiocesium in the Pond B alligators would alter the basic conclusion of this study -- namely, that concentration levels of this isotope in alligator biomass are relatively low compared to many other species and/or compartments in the reservoir (Table 3), and that, above all, the total amount of released radiocesium which is now contained in the alligators is infinitesimally small (Table 3). To be sure, population densities of alligators in Pond B (mean = 0.47/mi of shoreline censused) are low compared to some other alligator populations whose densities can range as high as 64 alligators/mi elsewhere in South Carolina (Bara 1974) or 58/mi in Florida (mean for all states = 5.25-5.64/mi in 1978 and 1977, respectively; Chabreck 1979). However, even if the alligator population density, and hence total standing-crop biomass, were increased 100-fold to approximate the highest densities reported in the literature, the alligators would still represent less than 0.3% of the radiocesium inventory in the biota and less than 0.001% of the total inventory in the reservoir. Moreover, the calculations presented here for the percentage contribution of alligators to the Pond B radiocesium inventory (Table 3) are likely to represent an overestimation since no data were available for several biotic components of the reservoir--notably turtles and fish other than largemouth bass. The radiocesium inventory in the reservoir's catfish (*Osteichthyes: Ictaluridae*) may be a particularly important omission in this regard.

These findings emphasize the importance of concomitant ecosystem studies of physical factors such as the chemistry of the sediment/water interface, for understanding of the distribution, fate and effects of such released contaminants. However, while physical forces may indeed be of overwhelming importance in determining the rates and patterns of radiocesium distribution within the reservoir, the importance of that small part of the total inventory which does indeed come to contaminate wildlife such as alligators, should not be underestimated. As an endangered species, many legal issues presently relate to the state of well-being of alligators in the southeastern United States. Thus it is extremely important, and in some cases legally mandated, to evaluate those factors which regulate the fate and effects of such contaminants in these

animals—even though, in terms of the total ecosystem and/or biota, the total amount of contaminant involved may be relatively minor. Indeed, the rise of environmental consciousness in the United States and much of the developed world, was often first focused by concerns over contaminant levels in just such predators at higher trophic levels of the ecosystem. Levels of pesticide residues in birds of prey and fish-eating seabirds, for example, have always been one of the foremost causes of environmental concern since the first publication and societal impact of *Silent Spring* (Carson 1962).

It cannot be emphasized too strongly, however, that any study of the ecological cycling of radionuclides or any other environmental contaminant in a population of alligators or other legally or politically 'visible' species must include consideration of contaminant distribution and movement within all biotic and abiotic compartments of the ecosystem. In the case of the Pond B alligator population, for example, this means that, in addition to studies of sediment and water chemistry, radiocesium cycling must also be studied in the populations of fish, turtles, waterfowl, and other species that may form an important part of the alligators' food base. Previous studies by Brisbin et al. (1973) have shown that American coots contain the highest body burdens of radiocesium of any of the common species of waterfowl found in the Pond B reservoir, and since they are extremely abundant, and relatively slow moving, these coots may form an important item in the diet of resident alligators. Coots arrive in the Par Pond reservoir system in October and depart for northern breeding grounds the following spring. During their winter stay on the reservoir, these birds increase in radiocesium content until December, January and February. Thereafter, a precipitous decline in radiocesium content occurs as the birds which had been resident at the site move northward and are replaced by birds that had wintered further south and thus had not had an opportunity to accumulate elevated body burdens of radiocesium. Thus, the intake of radiocesium by alligators feeding on these waterfowl would be greatest in the mid-winter months—a period of time when most alligators are probably least likely to be feeding actively because of cold temperatures. However, as indicated by Murphy (1981) the input of heated reactor effluents into parts of the Par Pond reservoir system has created a condition in which some resident alligators may indeed remain active and feed, as confirmed by field observations, even during the coldest winter months. This in turn, would expose alligators to the intake of radiocesium from feeding on coots, at the time of year when the radiocesium content of these birds was highest. In the Pond B reservoir, however, the lack of such thermal input would probably prevent such an occurrence since few if any of the alligators remain active and feeding during the colder months (Brisbin et al. 1982).

The inventory approach to contaminant distribution in an ecosystem such as Pond B, is based upon the structure of the ecological pyramid of standing-crop biomass and ultimately the contaminant itself, in various trophic levels. In terms of kg of biomass/ha, the biomass pyramid of Pond B (Table 3) is similar to several of those described by Odum (1971) for a variety of both aquatic and terrestrial ecosystems. As mentioned previously, however, the principle of biomagnification of the contaminant through successively higher trophic levels does not seem to hold for the Pond B ecosystem. The highest weight-specific radiocesium concentrations are shown by macrophytes and several of the potential prey species of alligators (invertebrates, bass and waterfowl; Table 3).

Besides the inventory approach, a complete understanding of contaminant distribution and cycling requires a knowledge of turnover rates within both populations and the bodies of individual organisms. While no such studies have yet been performed with crocodilians, studies of bioelimination rates of radiocesium in captive snakes (Staton and Brisbin 1974) agree well with calculations reported by Reichle et al. (1970) for other poikilothermic vertebrates. Together, these predict that radiocesium half-lives of alligators of larger body size ( $> 2$  m) would probably be extremely long, and complete elimination of the isotope following cessation of contaminant input, might require several years or longer. Such 'physiological' turnover rates as described by these authors and determined under laboratory conditions, may differ significantly from 'ecological' turnover rates which quantify the rates of elimination under free-living field conditions. As shown by Bagshaw and Brisbin (1984) these ecological turnover rates may be as much as 6-8 times longer than laboratory-determined physiological turnover rates for the same species. Studies of contaminant turnover rates under field conditions, however, are often difficult to undertake since they require the multiple recapture, whole-body counting and release of given individuals (Fendley et al. 1977).

Table 3. Standing crop inventories of biomass and radiocesium contents of American alligators and other components of the Pond B reservoir of the U.S. Department of Energy's Savannah River Plant<sup>a</sup>.

Components	kg/ha <sup>b</sup>	Average pCi Radiocesium/g <sup>b</sup>	Ci Radiocesium/ ha	References
<u>Abiotic Components:</u>				
Sediments <sup>c</sup>	---	1,450 <sup>d</sup>	199,000	Whicker et al. (1986), J. E. Pinder (pers. com.)
Filtered Water	37,000,000	0.020	$\frac{740}{199,740}$	Whicker et al. (1984)
		Total =		
Seston:	799 <sup>e</sup>	46.1 <sup>e</sup>	36.8	Whicker et al. (1984), and J. Bowling (pers. com.)
<u>Flora:</u>				
Aquatic Macrophytes	6,568 <sup>e</sup>	144 <sup>e</sup>	945	Whicker et al. (1986) J. E. Pinder (pers. com.)
<u>Fauna:</u>				
Benthic Invertebrates <sup>f</sup>	26.2 <sup>e</sup>	47.5 <sup>e</sup>	1.24	Whicker et al. (1984)
Benthic Gastropods <sup>g</sup>	9.64	5.00	0.0482	Whicker et al. (1984)
Largemouth Bass <sup>h</sup>	15.9 <sup>i</sup>	161.0 <sup>j</sup>	2.56	i, j (see below)
Waterfowl	1.24 <sup>k,l</sup>	39.8 <sup>m</sup>	0.0494	k, l, m (see below)
Alligators	1.85	13.2	<u>0.0244</u>	This Study (Table 2)
Totals =	54.8		3.92	

- a Calculated on the basis of radiocesium estimated to be present in 1983-85 (Whicker et al. 1986).
- b Expressed as live (wet) weight.
- c Cores taken to a depth at which radiocesium levels were no longer detectable.
- d  $\text{pCi/cm}^2$  of bottom surface area.
- e Assuming a ratio of 0.25 g dry weight/g live (wet) weight for all biomass.
- f Excluding gastropods.
- g Soft tissue plus shell.
- h Fish  $\geq 150$  mm standard length.
- i Assuming a population size of 5434 fish as estimated in the summer of 1986 (G. C. White, pers. com.) and an average live weight of 255.1 g/fish ( $n = 747$ , R. Buchner, pers. com.).
- j Average for 28 fish sampled from Pond B in 1983 (F. W. Whicker, pers. com.).
- k Based on population estimates by Mayer et al. (1986) and assuming a ratio of coots to other waterfowl species of 0.71, as estimated by Brisbin (1974) for the North Arm of the adjacent Par Pond reservoir.
- l Based on a weighted average, combining average live body weights for coots (mean = 535.7 g,  $n = 10$ ) and Ring-necked Ducks (mean = 681.5 g,  $n = 10$ ) collected from the Par Pond reservoir (R. A. Kennamer, pers. com.).
- m Based on a weighted average, combining average radiocesium body burdens determined for coots (mean = 54.1 pCi/g live weight,  $n = 6$ ) and Ring-necked Ducks (mean = 12.8 pCi/g live weight,  $n = 5$ ) collected from Pond B in 1984 (F. W. Whicker, pers. com.).

The ease with which individual hatchling alligators could be repeatedly located, recaptured and whole-body counted without apparent undue stress or harm suggests that these may be among the most appropriate of all organisms in Pond B for studies of radiocesium turnover rates under field conditions.

The general principles established by the Pond B alligator study have application for studies of many forms of environmental contaminants besides radionuclides. Studies by Clay et al. (1974), have indicated, for example, how studies of radiocesium in waterfowl can provide a better understanding of the contamination of the same birds with heavy metals. However, only gamma-emitting radioisotopes such as radiocesium can be easily quantified in whole-body biomass without sacrificing and/or tissue biopsy procedures. Such gamma-emitters are thus ideal for testing hypotheses concerning cycling and uptake rates in individual organisms as described above.

Finally, regardless of whatever contaminant may be involved, the ultimate interest of contaminant-cycling studies to those charged with the conservation and well-being of wildlife, involves the possibility of direct harm or damage to those organisms in whose bodies the contaminant may come to reside. To date, there has been no evidence of either somatic or genetic damage to any of the alligators or other organisms studied in Pond B. However, the potential for increased levels of environmental contamination as the result of possible future accidents and/or other inadvertent releases of radionuclides on either a local or global scale, suggests strongly that even though contamination levels may presently be low and apparently inconsequential to the organisms involved, studies of the patterns of ecological distribution and cycling dynamics of contaminants in such ecosystems can be important to the future well-being of many forms of wildlife in general and crocodilians in particular.

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#### LITERATURE CITED

- Alberts, J.J., L.J. Tilly, and T.J. Vigerstad. 1979. Seasonal cycling of cesium-137 in a reservoir. *Science* 203:649-651.
- Bagshaw, C., and I.L. Brisbin, Jr. 1984. Long-term declines in radiocesium of two sympatric snake populations. *Jour. Appl. Ecol.* 21:407-413.
- Bara, M.O. 1974. American alligator investigations, final study report August 1970-December 1975. Publ. So. Car. Wildl. Mar. Res. Dept.
- Brisbin, I.L., Jr. 1974. Abundance and diversity of waterfowl inhabiting heated and unheated portions of a reactor cooling reservoir. In J. W. Gibbons and R.R. Sharitz, eds. *Thermal Ecology*. AEC Symposium Series, CONF-730505.

- \_\_\_\_\_. 1982. Applied ecological studies of the American alligator at the Savannah River Ecology Laboratory: An overview of program goals and design. *In* F. W. King, ed. *Crocodiles - Proc. 5th Working Meeting of the IUCN/SSC Crocodile Specialist Group*. IUCN, Gland, Switzerland.
- \_\_\_\_\_. 1986. The compilation of a cross-indexed bibliography for the American alligator: A study of trends in the literature concerning an endangered species. *In* S. Gorzula, ed. *Crocodiles - Proc. 7th Working Meeting of the IUCN/SSC Crocodile Specialist Group*. IUCN-Fudena, Gland, Switzerland.
- \_\_\_\_\_, R.J. Beyers, R.W. Dapson, R.A. Geiger, J.B. Gentry, J.W. Gibbons, M.H. Smith, and S.K. Woods. 1974a. Patterns of radiocesium in the sediments of a stream channel contaminated by production reactor effluents. *Health Phys.* 27:19-27.
- \_\_\_\_\_, R.A. Geiger, and M.H. Smith. 1973. Accumulation and redistribution of radiocesium by migratory waterfowl inhabiting a reactor cooling reservoir. *In* Proc. Intl. Symp. Env. Behav. of Radionuclides Released in the Nuclear Industry. Publ. Intl. Atomic Energy Agency, Vienna, Austria.
- \_\_\_\_\_, and M.H. Smith. 1975. Radiocesium concentrations in whole-body homogenates and several body compartments of naturally contaminated white-tailed deer. *In* F.G. Howell, J.B. Gentry, and M.H. Smith, eds. *Mineral Cycling in Southeastern Ecosystems*. ERDA Symposium Series (CONF-740513).
- \_\_\_\_\_, E.A. Standora, and M.J. Vargo. 1982. Body temperatures and behavior of American alligators during cold winter weather. *Amer. Midl. Naturalist* 107:209-218.
- \_\_\_\_\_, M.A. Staton, J.E. Pinder III, and R.A. Geiger. 1974b. Radiocesium concentrations of snakes from contaminated and non-contaminated habitats of the AEC Savannah River Plant. *Copeia* 1974:501-506.
- Carson, R. 1962. *Silent Spring*. Houghton-Mifflin Co. Boston, Massachusetts.
- Chabreck, R.H. 1979. Cooperative surveys of the American alligator in the southeastern United States during 1978. Mimeo. Report. School of For. and Wildl. Mgt., Louisiana State Univ. Baton Rouge, Louisiana.
- \_\_\_\_\_, and T. Joanen. 1979. Growth rates of American alligators in Louisiana. *Herpetologica* 35:51- 57.
- Clay, D.L., I.L. Brisbin, Jr., P.B. Bush, and E.E. Provost. 1974. Patterns of mercury contamination in a wintering waterfowl community. *Proc. Ann. Conf. S.E. Assoc. Fish and Wildl. Agencies* 32:309-317.
- Comar, C.L. 1965. Movement of fallout radionuclides through the biosphere and man. *Ann. Rev. Nuclear Sci.* 15:175-206.
- Domby, A.H., and R.W. McFarlane. 1978. Feeding ecology of little blue herons at a radionuclide-contaminated reservoir. *In* *Wading Birds*, Res. Rept. No. 7, Natl. Audubon Soc.
- Fendley, T.T., M.N. Manlove, and I.L. Brisbin, Jr. 1977. The accumulation and elimination of radiocesium by naturally contaminated wood ducks. *Health Phys.* 32:415- 422.
- Hanson, W.C. 1966. Radioecological concentration processes characterizing arctic ecosystems. *In* B. Aberg and F. P. Hungate, eds. *Radioecological Concentration Processes*, Proc. Intern. Symp. Radioecol. Pergamon Press. New York.
- Jenkins, J.H., and T.T. Fendley. 1968. The extent of contamination, detection and health significance of high accumulations of radioactivity in southeastern game populations. *Proc. 22nd Ann. Conf. S.E. Game and Fish Comm.* 22:89-95.

- Mayer, J.J., R.A. Kennamer, and R.T. Hoppe. 1986. Waterfowl of the Savannah River Plant. Publ. (SREL-22) of the Savannah River Ecology Laboratory. Aiken, South Carolina.
- Medvedev, Z. A. 1986. Ecological aspects of the Chernobyl nuclear plant disaster. Trends in Ecol. and Evol. 1:23-25.
- Murphy, T.M. 1981. The Population Status of the American Alligator on the Savannah River Plant, South Carolina. Publ. (SRO-NERP-4) of the Savannah River Plant, National Environmental Research Park Program. Aiken, South Carolina.
- Odum, E.P. 1971. Fundamentals of Ecology. W. B. Saunders Co. Philadelphia, Pennsylvania.
- Rabon, E.W., and J.E. Johnson. 1973. Rapid field-monitoring of cesium-137 in white-tailed deer. Health Phys. 25:515-516.
- Reichle, D.E., P.B. Dunaway, and D.J. Nelson. 1970. Turnover and concentrations of radionuclides in food chains. Nuclear Safety 11:43-55.
- Seigel, R.A., L.A. Brandt, J.L. Knight, and S.S. Novak. 1986. Ecological Studies on the American alligator (*Alligator mississippiensis*) on the Savannah River Plant. Publ. (SREL-26) of the Savannah River Ecology Laboratory. Aiken, South Carolina.
- Staton, M.A., and I.L. Brisbin, Jr. 1974. Some aspects of radiocesium retention in naturally contaminated captive snakes. Herpetologica 30:204-211.
- Stribling, H.L., I.L. Brisbin, Jr., and J.R. Sweeney. 1986. Portable counter calibration adjustments required to monitor feral swine radiocesium levels. Health Phys. 50:663-665.
- Whicker, F.W., J.J. Alberts, J.W. Bowling, and J.E. Pinder III. 1984. Radionuclide concentrations and inventories are being estimated for major components of the Pond B ecosystem. In: 1984 Annual Report of the Savannah River Ecology Laboratory. Aiken, South Carolina.
- , J.W. Bowling, M.S. Kelly, J.E. Pinder III, K.A. Orlandini, and J.J. Alberts. 1986. Inventories of  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$ , and  $^{239,240}\text{Pu}$  in Pond B: Implications for the relative importances of radionuclide cycling processes in lake ecosystems. In: 1986 Annual Report of the Savannah River Ecology Laboratory. Aiken, South Carolina.
- , and V. Schultz. 1982. Radioecology: Nuclear Energy and the Environment. (2 Vols.) CRC Press. Boca Raton, Florida.
- Wood, J.M., A.R. Woodward, S.R. Humphrey, and T.C. Hines. 1985. Night counts as an index of American alligator population trends. Wildl. Soc. Bull. 13:262-273.
- Wright, C.N., and W.F. Splichal, Jr. 1973. A portable cesium counter for field use. Health Phys. 25:516-517.

# PREDATION OF ALLIGATOR NESTS IN OKEFENOKEE SWAMP NATIONAL WILDLIFE REFUGE, GEORGIA, U.S.A.

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**ABSTRACT** - Predation of 70 alligator nests in Chesser and Grand Prairies of the Okefenokee Swamp is discussed. In 11 nesting seasons 16% of monitored nests survived predation. Black bears (*Ursus americanus*) and raccoons (*Procyon lotor*) were the major consumers of alligator eggs. Thirty-nine percent of female alligators guarded their nests from human intrusion and 58% of these nests survived predation.

## INTRODUCTION

Across its range the American alligator (*Alligator mississippiensis*) exhibits some degree of nest tending behavior but predators of alligator eggs still manage to significantly affect nesting success. In coastal South Carolina raccoons destroyed 11.1% of 117 clutches late in the incubation period (Wilkinson 1983). On Rockefeller Refuge, Louisiana, Joanen (1969) reported a 16.5% (N = 44) loss of nests to raccoons and found that predation occurred usually at the end of the seventh week of incubation with raccoons making multiple visits to the nest mound until all eggs were consumed. In a North Florida study 43% of 35 nests were preyed upon primarily by raccoons (Deitz and Hines 1980). The highest recorded predation rate was in the Okefenokee Swamp National Wildlife Refuge, Georgia, where predators destroyed 86% of nests (Metzen 1977). Here I report on nest predation and identify predators in the Okefenokee Swamp.

## METHODS

The study area of Chesser and Grand Prairies is an aquatic macrophyte marsh containing thousands of tree islands. A boat trail connects the prairies with several fishing lakes and in normal rainfall years is navigable by motor-boat traffic. Twelve km of this boat trail and its intersecting alligator trails were explored for nests. Searches for nests were conducted on foot or from paddle craft.

To identify predators of eggs, some nests were monitored with set cameras; Kodak Instamatic X-15 cameras with mouse-trap shutter releases were mounted on stakes and connected to the nest mound with thread. Disturbance to the mound tripped the camera and a single photograph recorded each incident. Unless the integrity of the mound was disturbed by predators, eggs and egg chambers were not examined.

When possible, nesting females were identified by atypical scutes. The nest guarding behavior of females was determined by approaching their nests; those hissing or lunging at the intruder were considered to be guarding nests; those present but not displaying defensive behavior toward humans, were considered not to be guarding nests. "Guarding" as defined here does not necessarily mean that females avoiding humans will not guard nests from other predators.



## RESULTS

Eighty-eight percent of nesting starts occurred from 20 June to 30 June. In 11 nesting seasons (1976-1986) 83 nests were located within 200 m of the 12 km trail through Chesser and Grand Prairie; predators destroyed 70 nests (Fig. 1). Fifty-nine percent of all nests and 42% of nests monitored with cameras were preyed upon before 10 July. Because of this early predator activity 45% of nests in Grand Prairie and 39% in Chesser Prairie were first discovered after predation.

**Nest sites** - Typically, nests were constructed in the interior of small (< 100 sq m) tree islands or at the periphery of large (> 100 sq m) tree islands. On large tree islands, nests were often at the base of a tree. Two or more alligator trails connected nests with holes, ponds or boat trails. Twenty-one nests in Chesser Prairie were located within 3 m of boat trails or ponds more than 1 m in depth and these deep-water nests had a predation rate of 67%.

**Guarding Behavior** - Nests of alligators not guarding from humans had higher predation rates than nests of guarding alligators. In Grand Prairie only one nest was guarded and predators destroyed all except one nest. In Chesser Prairie 44% of nests were unguarded with a predation rate of 86%; guarded nests had a predation rate of 39%. Although male alligators (> 3 m in total length) were frequently observed near females nesting in deep water, only two were observed in possible guarding postures: one hissed at me near a nest which had been preyed on and the other lunged and hissed at me near a pod of two day old neonates.

**Nest repair** - After predations some damaged nests still contained viable eggs; often a small excavation exposed the upper eggs with the mound retaining most of its mass and shape. In 17% (N = 12) of nests preyed on before 10 July, females made effective repairs. During this early incubation period all nesting females crawled over their nests and used their feet to scoop more plant material over nest mounds. Thus, the same activity that added mass to undamaged nests also repaired nests damaged by predators. Repeated or major structural damage to nests was not usually repaired but on 6 July, 1978 a female in Grand Prairie scooped a small amount of nest material over two whole eggs after her other eggs had been consumed in repeated predations. During nest repair she used her mouth to remove whole egg shells from the mound; set cameras photographed two other females engaged in similar behavior. Nests which had been emptied of viable eggs by predators usually contained a few scattered egg shells but some apparently intact nest mounds contained whole egg shells in the egg chamber.

**Predators of eggs** - Set camera photographs identified predators in 16 incidents of nest predation. One nest was destroyed by rice rats (*Oryzomys palustris*), two by raccoons, four by raccoons and bears, and nine by bears.

Early in the nesting season bears, including sows with cubs, were commonly seen wading in shallow water near nests. Although alligators were not observed defending nests from bears, one set camera photographed an egg consuming bear with extensive neck wounds. Bears usually consumed all eggs during a single visit but sometimes they made repeated visits to mounds.

In Grand Prairie a nest damaged in daylight hours by a bear, was repaired by the alligator then further damaged by raccoons and bears on three successive nights until all eggs were consumed. Bears sometimes left whole egg shells at the nest site but usually only small fragments of shell remained. Typically, nest mounds damaged by bear were massively excavated and leveled to the depth of the egg chamber.

Before the beginning of the nesting season, raccoons excavated holes in old nest debris and they preyed on nests throughout the incubation period. Set camera photographs identified raccoons excavating nests and consuming eggs during both night and daylight hours. Typically they excavated holes into the egg chamber and drained eggs by removing one end of the egg. Usually eggs were not consumed in one visit

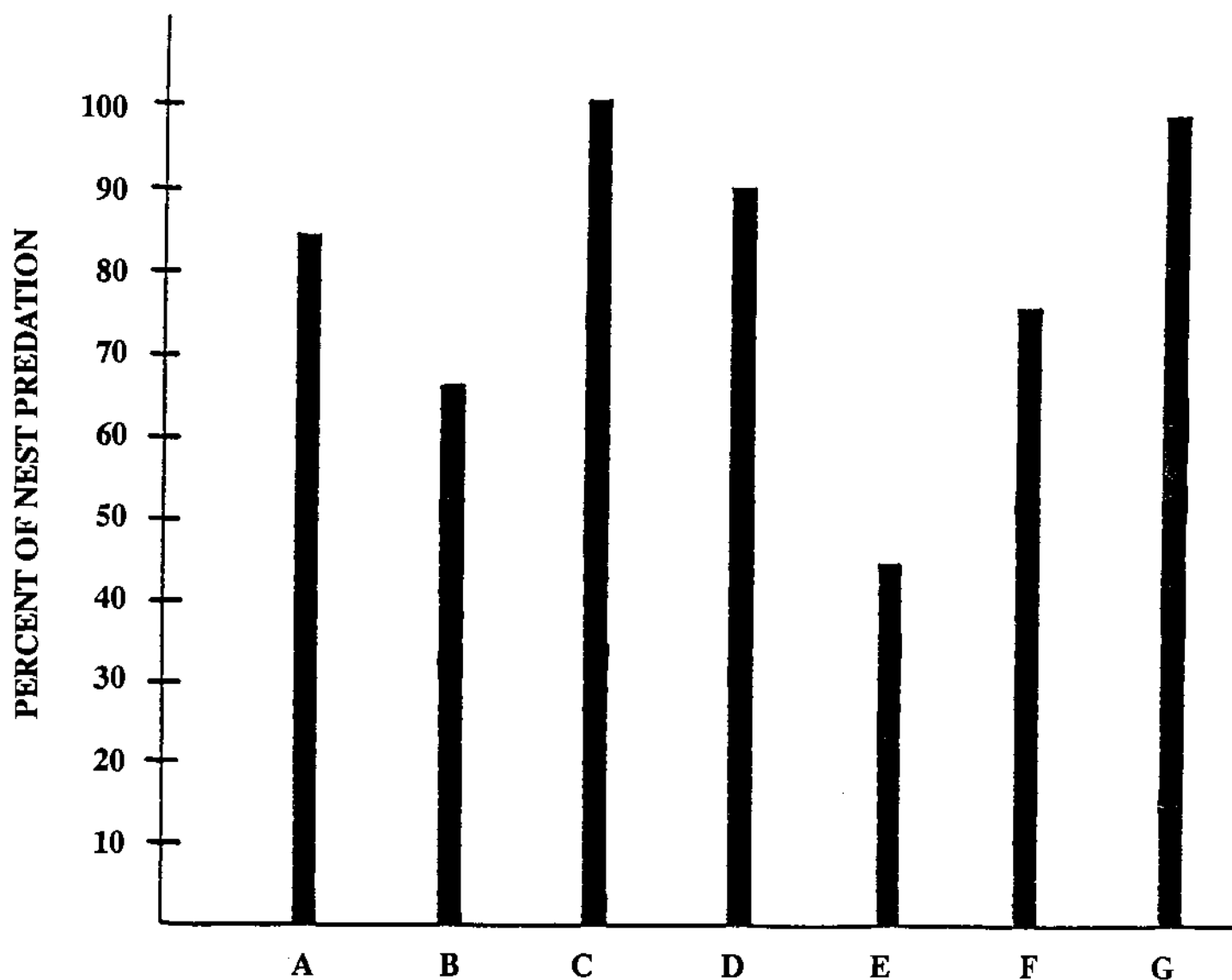


Figure 1. Predation rates of nests in Okefenokee Swamp, Georgia. A = nests with turtle eggs; B = nests near deep water; C = repaired nests; D = unguarded nests; E = guarded nests; F = Chesser Prairie; G = Grand Prairie. Total predation rate of 70 nests = 84%.

and raccoons returned over a period of several days to consume the remainder of the alligator eggs. Raccoons also consumed turtle eggs in the mound.

Turtles often laid eggs in alligator nests and in the process they eroded the mound, cracked alligator eggs and exposed alligator eggs to sunlight and opportunistic predators. Seventeen percent of alligator nests contained one or more clutches of turtle eggs and had a predation rate of 83%. Set camera photographs taken before 10 July identified Florida red-belly turtles (*Chrysemys nelsoni*) on alligator nests during night and daylight hours. One alligator nest was damaged by *C. nelsoni* laying eggs on 26 and 27 June and 3 July, 1986; the turtles deposited eggs inside the egg cavity exposing several alligator eggs and on 4 and 6 July, rice rats bit through the shells of the exposed eggs. By 29 July all alligator and turtle eggs in this nest were destroyed.

Nesting alligators, including those not guarding nests from humans, attacked turtles crawling on their mounds. On one occasion an alligator lunged with open mouth at the gravid turtle; another nesting alligator bit an escaping *C. nelsoni* but did not crush the turtle's shell.

### DISCUSSION

Black bears were responsible for the massive and early nest predation in the Okefenokee Swamp. At the shallow-water nesting sites they could easily evade female alligators defending their nests. Although only two male alligators were observed in defensive postures near nest sites, it is possible that the movement of large territorial males in the vicinity of deep-water nests inhibited bear activity. Deep water might also be an advantage for females defending nests from bears. It has been suggested that alligators see humans as facsimiles of bears (Deitz and Hines 1980) and that an alligator guarding a nest from humans will also guard from bears. Guarding alligators were more successful in hatching nests and presumably more successful in thwarting predators of eggs, but some non-guarding alligators evidently defended nests from bears; because bears usually consumed all eggs in one visit it was assumed that an alligator was defending her nest from bears when the bear made several visits to consume all eggs. A Florida study showed that guarding alligators immediately attacked small predator models but delayed serious attack on large predator models (Kushlan and Kushlan 1980). Humans and bears are the only predators able to seriously threaten the nesting alligator. For a female alligator an adult black bear is a formidable opponent and if her nest defense requires contact with the bear she could be injured. Such aggressive contact could also alter her behavior in successive encounters with bears and perhaps with humans. Guarding alligators that are attacked or stressed by humans learn not to guard (Kushlan and Kushlan 1980) and sometimes a single incident can produce this behavior (Joanen and McNease 1970). Nesting alligators encounters with aggressive bears could have the same effect. It is also possible that the bears which massively prey on nests in Grand Prairie have had such extensive nest raiding experience that few alligators can thwart their egg consuming habit.

In defense of nests from raccoons, alligators seem to differ in behavior. In Louisiana an alligator was present at her nest but did not defend it from a raccoon (Joanen 1969). In Florida an alligator not defending her nest from humans did defend from a raccoon (Deitz and Hines 1980).

Raccoons are not a lethal threat to an adult alligator and can not usually consume all eggs in one visit, but they are successful in preying on nests. In the Okefenokee some raccoons learn to raid nests from their mothers - set cameras identified females with young preying on alligator eggs. Other raccoons probably follow familiar scents to nest mounds. Raccoons inexperienced in locating alligator eggs but experienced in locating turtle eggs by scent could be expected to occasionally cross an alligator mound and find both the familiar turtle eggs and the unfamiliar alligator eggs.

Turtles laying eggs in nest mounds can affect predation of alligator eggs. In Florida, turtles have damaged alligator nests, excavating the mound, crushing eggs and depositing a powerful scent package for predators to locate (Deitz and Jackson 1979, Kushlan and Kushlan 1980). Certainly, exposure of alligator eggs by turtles makes the eggs vulnerable to opportunistic predation. In a South Carolina study, 4.2% of alligator nests were used by rodents with no impact on eggs (Wilkinson 1983). In my study, however, after *C. nelsoni* damaged one nest the exposed eggs were destroyed by rice rats.

Turtles crawling on a nest mound might be easily thwarted by the guarding alligator. Dietz and Jackson (1979) reported two gravid, dead *C. nelsoni* near nest mounds but the heavy shell of *C. nelsoni* in Okefenokee has an excellent chance of withstanding the pressure of a female alligator's jaws and turtles can employ other escape strategies, such as burrowing into the mound or assuming a stationary posture when confronted by the guarding alligator.

Nests with minor damage were effectively repaired by some Okefenokee alligators; mounds were restored and exposed eggs were reburied. Repair behavior should be an advantage to alligators nesting in areas of intense predator activity but because nests can be targeted again by the same predator and because other predators can be attracted to the scent of broken eggs these nests remain extremely vulnerable to predation. In this study, predators eventually destroyed all repaired nests.

#### ACKNOWLEDGEMENTS

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#### LITERATURE CITED

- Deitz, D.C. and T.C. Hines. 1980. Alligator nesting in North-central Florida. *Copeia* 1980:249-258.
- \_\_\_\_ and D.R. Jackson. 1979. Use of American alligator nests by nesting turtles. *J. Herpetol.* 13:510-512.
- Joanen, T. 1969. Nesting ecology of alligators in Louisiana. *Proc. S.E. Assoc. Game and Fish Comm.* 23:141-151.
- \_\_\_\_ and L. McNease. 1970. A telemetric study of nesting female alligators on Rockefeller Refuge, Louisiana. *Ann. Conf. Southeast Assoc. Game and Fish Comm.* 24:175-193.
- Kushlan, J.A. and M.S. Kushlan. 1980. Everglades alligator nests: nesting sites for marsh reptiles. *Copeia* 1980:930-932.
- \_\_\_\_ and \_\_\_\_\_. 1980. Function of nest attendance in the American alligator. *Herpetologica* 36:27-32.
- Metzen, W.D. 1977. Nesting ecology of alligators on the Okefenokee National Wildlife Refuge. *Proc. Ann. Conf. Assoc. Game and Fish Comm.* 31:29-32.
- Wilkinson, P.M. 1983. Nesting ecology of the American alligator in coastal South Carolina. S.C. Wildlife Marine Resources Dept. 113 pp.

# CLASSIFICATION AND POPULATION STATUS OF THE AMERICAN ALLIGATOR

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The Endangered Species Act of 1973 required that the U.S. Fish and Wildlife Service categorize the American alligator (*Alligator mississippiensis*) into three basic classifications throughout its range in the southeastern United States: endangered, threatened, or threatened due to similarity of appearance [T (S/A)]. These categories simply designate the general population status of the animal in relation to its rate of recovery. Generally, the endangered status indicates a low population within a geographic area; whereas, the threatened status indicates an increasing population well on its way toward recovery. Threatened due to similarity of appearance indicates a recovered population. Important factors which are considered in making a status determination include: habitat evaluations; government research, management, and enforcement programs; natural mortality factors; utilization; the adequacy of regulatory mechanisms; and miscellaneous other factors.

Alligators are currently classified as threatened in 5.8 percent of their range, as endangered in 48.9 percent of their range, and as recovered in 45.3 percent of their range (Table 1). The historic stronghold of the alligator is for practical purposes the 51.1 percent of the range presently classified as threatened S/A (recovered) or threatened. Classification status reviews are periodically conducted by the U. S. Fish and Wildlife Service, usually as a result of state petitions to change the legal status of the alligator. The collection of biological information pertaining to status reviews has greatly enhanced management capability for the alligator.

Since the IUCN/CSG meeting in Caracas, Venezuela in 1984, the U. S. Fish and Wildlife Service reclassified the biological status of the alligator in only one state. The entire State of Florida was reclassified to threatened S/A, effectively returning management authority back to the State (Federal Register Vol. 50, No. 119, 20 June 1985).

Most recently, a rangewide delisting for the American alligator has been proposed (Federal Register Vol. 51, No. 105, 2 June 1986). A final rule, if approved, will consolidate the classification status of all American alligators, throughout the range, to the special category of threatened due to similarity of appearance. This historic action formally recognizes that the population status of the alligator is indeed in great shape.

## POPULATION STATUS BY STATE

Ten states contain alligators in all or parts of the state. In general, alligator populations are increasing throughout the range. Areas on the fringes of the range generally have stable populations and cannot biologically harbor high densities, characteristic of states bordering the Gulf of Mexico.

Louisiana - The 1985 coastal marsh population, where nest count indices were used to calculate population levels, was projected to be 468,000, a 14.1% increase over the estimate for 1984. Water levels affect the degree of nesting, a factor which must be considered when making annual population estimates based on nest transects (McNease and Joanen 1978). Nest count estimates have shown an annual increment of approximately 10.1 percent since initiation of the survey in 1970 (Joanen et al. 1984). In areas of the state where the nest count method is not feasible, standardized night counts were conducted along established

transect lines. Night count data were then applied to population modeling. Louisiana personnel surveyed 23 different areas of the state in 1985; transects covered a total distance of 127 miles. Alligators per mile averaged 6.4, slightly below the range-wide average of 7.06 for the same year (Chabreck 1986). McNease and Joanen (1978) reported available alligator habitat within Louisiana coastal marshes comprise 2.9 million acres; Taylor (1980) reported statewide alligator habitat for non-marsh as 1.1 million acres.

**Florida** - Florida population trend monitoring is limited to annual night-light surveys run on selected areas scattered throughout the state. Seventeen areas were surveyed in both 1984 and 1985; 8 showed increases and 9 decreases. Mean alligators per mile counted along all survey routes was 16.3 in 1984 and 16.5 in 1985. However, water levels were lower in most parts of the state in 1985 (A. Woodward, pers. comm. 1986). Alligator night count data collected prior to 1977 and compared to night count information collected between 1977-81 show increases in numbers of alligators observed per mile. Florida lakes averaged 11.9 alligators per mile prior to 1977 and 13.8 per mile from 1977-81. In comparison, Florida marshes averaged 11.3 per mile prior to 1977 and 13.3 per mile from 1977-81 (Federal Register Vol. 49, No. 120, 20 June 1984).

**Georgia** - A 1986 alligator population survey indicated population increases are occurring in most of Georgia. An analysis of population trends by counties showed that 64 were increasing, 39 were stable, and none were decreasing. The 1986 estimates increased from 1% to as high as 5% when compared to the 1984 survey. A total of 2,117,701 acres of alligator habitat was reported in a 103 county area (S. Ruckel, pers. comm. 1986). Georgia personnel surveyed 12 different areas of the state in 1986, transecting a total distance of 77.8 miles. Alligators per mile averaged 13.25, well above the range-wide average of 7.06 in 1985 (Chabreck 1986).

**Texas** - Texas alligator population trends, in general, remain stable to increasing. Aerial nest counts in coastal counties indicate an estimated population of over 150,000 alligators occurring on the middle and upper coast. Additionally, sizable populations exist in the extensive inland alligator habitat; however, the relative magnitude of this inland population remains to be determined. Night count surveys in 1986, covering 196 miles, indicated an average of 4.08 alligators per mile. The coastal marsh of Jefferson County exhibited the highest population trend data with a high of 70 alligators per mile. Average density in the 220,000 acres of upper coastal marsh as measured by 1985 and 1986 aerial nest counts was 61 alligators per 100 acres.

Relative abundance of alligators as measured by frequency of sightings in 80 Texas counties within the historic alligator range in Texas varies from regular sightings in 46% of the counties to occasional sightings in 25% of the counties to rare sightings in 23% of the counties. In those same counties over the past five years, biologists estimate that alligator populations are increasing in 33% of the counties, decreasing in 16%, and unchanged in 37%. Population trends were unknown in 14% of the counties. Changes in Texas alligator habitat since 1984 are not measurable. Some coastal marsh continues to be lost to subsidence, draining, and spoil activity, while reservoir construction has created additional inland habitat (B. Thompson, pers. comm. 1986).

**South Carolina** - Eight South Carolina counties (29%) were reported to have increasing populations out of 28 counties containing alligators. Increases were estimated to be 2-5 percent. Nineteen counties (68%) reported stable populations (T. Murphy, pers. comm. 1986). The best habitat is associated with coastal impoundments and marshes, comprising approximately 100,000 acres in Georgetown, Charleston, Colleton, and Beaufort Counties. The next tier of counties inland represent moderate to high alligator densities and a significant amount of habitat, particularly in Berkeley and Jasper Counties. The amount of suitable alligator habitat diminishes rapidly from these counties to the fall line, with generally isolated ponds supporting limited numbers of alligators. South Carolina reports approximately 250,000 acres of alligator habitat statewide (T. Murphy, pers. comm. 1982). Most nesting (84%) occurred in seven river drainages. The drainages in order of highest nest counts were: Santee, Cooper, Combahee, Savannah, Ashepoo, Pee Dee, and South Edisto Rivers (Wilkinson 1983).

Arkansas - The alligator's range is limited in Arkansas. The trend for Arkansas alligators is a stable to slightly increasing population. Since 1972, the state restocked 2,700 alligators from Louisiana in 40 of 45 counties lying within the historic range of the species. Because of the restocking effort, successful reproduction has been documented in 6 counties that were previously void of alligators (S. Barkley, pers. comm. 1986). Night count data for 13 miles of survey lines searched in 1986 indicate 0.08 alligators per mile (Chabreck 1986).

Mississippi - No current population estimates are available for this state. Mississippi night count data for 54.0 miles of survey lines indicate an average of 1.46 alligators per mile, well below the range-wide 1986 average of 7.06 alligators per mile (Chabreck 1986). However, this data compares closely with its neighboring state of Alabama which recorded 1.76 alligators per mile.

Alabama - No current population estimates are available for Alabama. Seven night count routes, covering 134.5 miles in length, were run which averaged 3.49 alligators per mile (Chabreck 1986). However, of the 7 surveys conducted, 4 were run in the coastal county of Baldwin which is known for its high alligator population. Excluding this one county, alligators per mile of survey averaged 1.76; comparable with Mississippi findings.

North Carolina - Alligators occurred in low densities on night count survey routes in coastal North Carolina. Highest densities occurred in estuaries of the Cape Fear #3 Watershed and in lakes of the Neuse Watershed. Alligators were found to be concentrated on military bases, national forests, and private property. Alligator densities decreased by watershed from south to north. No alligators were found north of Albemarle Sound, supporting the belief that this is the northern limit of the alligator's range. There are no recent night count data from survey routes in North Carolina. However, the sampling design which was established in 1979-80, is for the express purpose of providing baseline data with which to compare the results of future surveys. Now that North Carolina has a non-game and endangered wildlife program, it is hoped that their surveys can be repeated at 3-5 year intervals, so as to monitor population trends (P. Doerr, pers. comm. 1984).

#### PROPOSED STATUS CHANGE

The U. S. Fish and Wildlife Service proposed to classify the American alligator throughout its range to the status of threatened due to similarity of appearance, under provisions of the Endangered Species Act. The proposal as advertised in the Federal Register (Vol. 51, No. 105, 2 June 1986) deals with alligator populations in Alabama, Arkansas, Georgia, Mississippi, North Carolina, Oklahoma, and South Carolina. Alligator populations in these seven states are relatively stable and contain approximately 17 percent of the species' total habitat. This action formally recognizes that the alligator is no longer biologically threatened or endangered but supports a need for continued federal control on taking and commerce to insure against excessive taking and to continue necessary protections for the crocodile (*Crocodylus acutus*) in the United States (Federal Register Vol. 51, No. 105, 2 June 1986).

#### AVAILABLE ALLIGATOR HABITAT

Noticeable increases in alligator populations range-wide have stimulated state conservation departments to evaluate these populations and also to classify alligator habitat (McNease and Joanen 1978, Joanen and McNease 1981, Taylor 1980, Thompson et al. 1983, Wilkinson 1983, Federal Register Vol. 49, No. 120, 20 June 1984). Obvious differences exist in the quality of habitat for alligators and in most cases habitat has been classified into 3 distinct habitat types: coastal marshes, inland freshwater rivers, swamps and marshes, and natural and man-made lakes. Surveys have shown that alligator populations vary according to habitat type and also that within a single habitat type obvious differences may exist in population levels. McNease and

Joanen (1978) found that certain ecological features may exist in one type that may not exist in the same habitat type just a few miles away. In the coastal marshes of Louisiana, interspersions of land/water ratios and also water levels were two important factors that must be taken into consideration when evaluating alligator habitat. Probably the best example of this in Louisiana are some dense solid stands of *Panicum hemitomon* which provide little or no open water, no habitat diversity, and very poor alligator nesting habitat. However, other *Panicum* marshes interspersed with ponds, potholes, and open lakes provide some of the finest nesting habitat to be found on the Louisiana coast.

Inland lakes, both man-made and natural, possess varying degrees of alligator populations. Important factors that must be considered when evaluating these areas as alligator habitat are vegetative cover and water depth. Lakes which seem to provide the best alligator habitat are those which have some open freshwater marshes attached, or those which have vegetative cover extending from the shoreline out into the open water areas.

Freshwater swamps attached to large river systems or lakes probably provide the largest single habitat type within the range of the alligator; however, they possess the lowest alligator concentrations when compared to the other habitat types. The exception to this would be swamps which possess imbedded open freshwater marshes of sizeable acreage. Generally, riverine swamps lack the proper interspersions of vegetative cover and land/water ratio of the coastal marsh zone or inland lakes. Riverine systems are also known for their extremes in seasonal water level fluctuations along with extreme currents.

The amount of alligator habitat (wetlands) reported by 5 states are presented in Table 2. Although any wetland habitat has the potential of being used by alligators, the frequency of use varies considerably. Salt water marshes, large deep open water lakes, and large rivers in Louisiana have been found to be used only occasionally and only by the adult segment of the population. A careful review of the different habitat types along with a better understanding of their value to alligators is of the utmost importance in the management of a resource. Wetlands in themselves do not qualify as alligator habitat, but rather the true estimate of habitat suitability must be measured by studying wetlands which possess distinctive ecological features and comparing these characteristic ecological features to existing alligator populations.

#### LITERATURE CITED

- Chabreck, R.H. 1986. Cooperative surveys of the American alligator in southeastern United States during 1985, Louisiana State Univ., Baton Rouge, 3 pp, Mimeograph.
- Joanen, T., and L. McNease. 1981. Management of the alligator as a renewable resource in Louisiana. Ga. Dept. of Nat. Res. Tech. Bull. WL 5:62-72.
- \_\_\_\_\_, \_\_\_\_\_, G. Perry, D. Richard, and D. Taylor. 1984. Louisiana's alligator management program. Proc. Southeastern Assoc. Fish and Wildlife Agencies 38:201-211.
- McNease, L., and T. Joanen. 1978. Distribution and relative abundance of the alligator in Louisiana coastal marshes. Proc. Southeastern Assoc. Fish and Wildlife Agencies 32:182-186.
- Taylor, D. 1980. An alligator population model and associated minimum population estimate for non-marsh alligator habitat in Louisiana. La. Dept. of Wildlife and Fisheries. 32 pp. Mimeograph.
- Thompson, B.C., F.E. Potter, Jr., and W.C. Brownlee. 1983. Management plan for the American alligator in Texas. Texas Parks and Wildlife Dept. 41 pp.
- Wilkinson, P.M. 1983. Nesting ecology of the American alligator in coastal South Carolina. S. C. Wildlife and Marine Res. Dept. 113 pp, Mimeograph.



TABLE 1. Alligator Classification Status by State - September 1986

State	Number of Counties			Total
	Threatened S/A	Endangered	Threatened	
Mississippi		55		55
Alabama		33		33
North Carolina		21		21
Texas	74			74
Arkansas		3		3
Oklahoma		1		1
Georgia		81	21	102
Louisiana	63			63
Florida	64			64
South Carolina		23	5	28
Total	201	217	26	444
Percent	45.3	48.9	5.8	

TABLE 2. Available Alligator Habitat Reported for Five States

State	Habitat Type	Acreage
Louisiana	Coastal marsh	2,900,000
	Inland wetland*	1,100,000
Florida	Fresh marsh	3,600,000
	Permanently flooded wooded swamp	1,200,000
	Lakes	1,700,000
	Rivers and streams	200,000
South Carolina	Coastal marshes and impoundments	100,000
	Inland wetland*	150,000
Texas	Coastal marsh	293,000
	Inland wetland*	3,328,000
Georgia	Unclassified wetland	5,824,000

\* Swamps, lakes, ponds, rivers and streams, marshes, reservoirs.

# FEED FORMULATION FOR ALLIGATORS: AN OVERVIEW AND INITIAL STUDIES

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The feeding of alligators (*Alligator mississippiensis*) by means of a nutritionally balanced pelletized feed, produced with conventional feed ingredients and feed mill technology, would offer many advantages to the alligator farming industry. Such a product could be prepared in numerous locations and at any time of the year, thus improving upon the current practice of relying on locally and/or seasonally available feed such as animal carcasses, fish, and/or meat scraps. Expenses and operating problems associated with freezer storage could be avoided. The mixing of vitamins, trace minerals, and feed additives could be done more accurately and thoroughly through the use of modern feed mill technology than is currently practiced. Most importantly, the nutrient content of the food and the nutrition of the alligators, could be more effectively controlled.

Managing the nutrition of any animal requires a fair understanding of the nutritional needs and versatility of the species in question. Unfortunately, information on the nutrient requirements of alligators is scanty at best, and the ability of alligators to utilize nutrients in practical feedstuffs has received practically no attention. Pilot studies have indicated that alligators can grow on rations composed of practical feed ingredients (T. Joanen, L. McNease, M. Staton, unpubl.). Growth, however, was slower and with poorer feed conversion than for alligators fed a diet of nutria (*Myocastor coypu*) carcass, a conventional feed source for alligator farming in the United States. Further studies aimed at making practical feed formulation a reality in the alligator industry have now been initiated. The objectives are: (1) to formulate a practical, cost-effective ration for the feeding of alligators in farming operations, (2) to determine the most effective and practical physical form in which to use such a ration, and (3) to develop a feeding program making optimal use of the ration. In order to meet these goals, a number of basic issues must be considered, as discussed below.

## THE NUTRIENT REQUIREMENTS OF ALLIGATORS

The basic nutrient groups in the diet of any species are proteins, carbohydrates, lipids, vitamins, and minerals. These nutrients must provide the energy and raw material required by the organism for maintenance, growth, and/or reproduction. Energy is mainly derived from carbohydrates, protein, and lipids, whereas the nutrient classes which contribute to the structural needs of the organism are mainly proteins, minerals, and lipids. It is important to note that the composition of these nutrient classes (e.g., amino acids in proteins, fatty acids in lipids, specific vitamins or minerals, etc.) may be just as important as

the total amount of each of the nutrient classes in the total ration. Furthermore, the ratio of the nutrient classes or nutrients to each other is a major consideration. For example, the protein:energy ratio and the calcium:phosphorus ratio are known to be key nutritional characteristics of the diets of those species that have been sufficiently studied. Required nutrients must be identified and the minimum, optimum, and maximum amount of each required nutrient must be established. Possible interactions between nutrients must also be considered.

It is possible that some nutrient requirements and interactions among nutrients can be reasonably anticipated for alligators from data on other species. Of special interest are the carnivorous fishes because of their similar dietary habits and poikilothermic nature.

Finally, it should be noted that, as for other species, the nutrient requirements of alligators will change with age and season. For example, using data from Coulson and Hernandez (1983), it can be estimated that the weight-specific metabolic rate of alligators decreases approximately tenfold from the time of hatching until reaching harvest age. These same authors demonstrated that blood glucose levels of alligators change seasonally, even when the animals were maintained at a constant temperature. Such variations in blood glucose may affect appetite and food consumption, and it may be necessary to vary the nutrient content of the food during periods differing in consumption patterns.

The following discussion describes the major dietary components in relation to what is known concerning the nutrient requirements of alligators.

**1. Carbohydrates** - Coulson and Hernandez (1983) correctly point out that alligators, like all other extant crocodilians, are carnivores and that ingestion of plant carbohydrates in the natural environment is minimal for this species. This may occur, for example, while consuming prey to which plants have adhered or in which undigested plants remain in the gastrointestinal tract. Coulson and Hernandez (1983) also point out that of a number of carbohydrates fed experimentally to caimans (*Caiman crocodilus crocodilus*), only glucose was absorbed with other monosaccharides, disaccharides and polysaccharides being unassimilated. (Furthermore, as will be discussed later, Coulson and Hernandez (1983) reported that alligators were unable to utilize protein of plant origin). These conclusions appear logical because of the carnivorous habits of crocodilians.

The apparent inability of crocodilians to utilize carbohydrates and proteins of plant origin led to the general avoidance of grains and other feedstuffs of plant origin in attempts at feed formulation for alligators. Obviously, it would be wasteful to include ingredients which could not be utilized in a diet. Nevertheless, from a practical standpoint, it would be highly desirable to include some carbohydrate in crocodilian rations. Carbohydrates are considered to be the least expensive energy source in practical livestock rations, and they possess binding properties which make them highly desirable in manufacturing various forms of pelletized rations, such as semi-moist petfoods (e.g., Drochner and Muller-Schlosser 1980). This is especially important to alligators since their jaw structure makes it unlikely that they can efficiently use a meal form of diet. Furthermore, when feeding alligators, it is likely that some of the feed would be dragged into water or perhaps even be fed to the animals in water as a routine practice. The presence of a good binder would prevent the feed from readily dissolving and thus enhance its utility. It would be most desirable to use a binder which could also serve as a nutrient source.

It is noteworthy that other carnivorous species, such as salmonid fish and cats, are able to utilize dietary plant carbohydrate in formulated feeds (e.g., NRC 1978; Spannhoff and Plantikow 1983). For example, although there is no known dietary carbohydrate requirement for the domestic cat, commercial cat foods containing 40% or more are well utilized (NRC 1978). Carbohydrate utilization may not be as efficient in carnivores as in omnivores. However, it is sufficient to allow inclusion of carbohydrates in amounts which contribute significantly to energy content and binding characteristics of such feeds.

It is known that the utilization of carbohydrate by normally-carnivorous species is enhanced by heat-treatment, a common process in feed-manufacturing. Such heat treatment may enhance the nutrient value

of ingredients containing carbohydrate for alligator feed formulation as well. It is also known that increasing the complexity of dietary carbohydrates has a negative effect on its availability to carnivorous species (Spannhof and Plantikow 1983). Hence, if alligator feeds are to include carbohydrate, care will necessarily need to be taken in including them.

**2. Protein** - As carnivores, alligators undoubtedly have the ability to metabolize large quantities of dietary animal protein. Beyond the basic requirement of dietary protein for maintenance, growth, and (as adults) for reproduction, protein is either excreted or broken down to carbon skeletons and converted to glucose/glycogen or lipid for storage. Feeding protein above the maintenance, growth, and reproductive requirements is wasteful. This is of particular practical interest since protein is the most expensive component of formulated rations, and therefore, calories supplied by protein are more expensive than those from carbohydrates or fat. It is thus essential in cost-effective feed formulation for alligators to determine the amount and amino acid composition of dietary protein which will optimally meet requirements, and meet the requirements for energy and glucose with feed-grade fats and carbohydrates when ever possible.

A major question to be answered in alligator protein nutrition is the feeding value of proteins of plant origin. It has been reported that alligators are unable to digest proteins of vegetable origin (Coulson and Hernandez 1983). As with carbohydrates, this seems plausible due to the carnivorous feeding habits of this species. However, other carnivorous species such as cats, dogs, and salmonid fish are readily able to utilize plant protein. Because protein sources of vegetable origin are frequently less expensive than animal by-products, because there are many more feed ingredients of plant origin, and because plant-based proteins may contain amino acids in abundance which are lacking in protein sources of animal origin, it would be highly desirable to add feedstuffs of vegetable origins to the list of ingredients available to the alligator feed formulator. This topic deserves further research.

**3. Lipids** - Coulson and Hernandez (1983) point out that dietary fat is readily digested by alligators. It is probable that alligators have a basic dietary requirement for lipid, at least for a source of glycerol and essential fatty acids. In fact, alligators grow well on rations low in fat, and those grown on some high fat diets may develop a "fatty liver" condition (Coulson, pers. comm.). From a management standpoint, it is also important to keep fat at low levels in the diet, since fat from food dragged into water may make cleaning and sanitation of tanks in which alligators are grown more difficult (T. Joanen, pers. comm.).

From the standpoint of cost, it would be desirable to include as much fat in the diet as possible, within the constraints listed above and assuming that it is efficiently used by the animal and that it does not present a problem in manufacturing the food. A less expensive energy source such as fat should be used, whenever possible, to spare the use of more expensive protein. It is interesting to note that another carnivorous species, the domestic cat, has been known to utilize over 60% dietary fat under experimental conditions (NRC 1978). Such levels could not be considered in practical diets for a number of reasons, but it does suggest that the metabolism of at least some carnivorous species are well adapted to high levels of dietary fat.

Perhaps even more important than the amount of fat is the composition of fat fed to animals, particularly carnivorous species. Carnivores frequently receive adequate essential fatty acid levels in their natural diet, and some species lose the ability to synthesize the essential metabolites (e.g., for cats, see Rivers et al. 1975; Rivers and Frankel 1980). Essential fatty acid deficiencies are most likely to occur in animals maintained over long periods of time. Since alligators are routinely farmed for up to three years, essential fatty acid nutrition must be addressed. Very importantly, Garnett (1985) has recently suggested that *Crocodylus porosus* requires a dietary source of long chain polyunsaturated  $\omega$ 3 fatty acids. Garnett (1985) cites reports that crocodiles fed over extended periods of time on pork meat develop a dermatitis of unknown etiology, which could result from an essential fatty acid deficiency. Thus addition of some long-chain polyunsaturated  $\omega$ 3 and/or  $\omega$ 6 fatty acids to alligator rations at some level may be vital. It is interesting to note that Halver (1976) considers the fatty acid composition of dietary fat to rank second only to amino acid composition in terms of importance in formulating diets for cultivated warmwater and coldwater fish species.

**4. Vitamins** - The vitamin needs of alligators have been the subject of some concern and research. Lance (1982) and Lance et al. (1983) have discussed the importance of Vitamin E in alligator reproductive performance. Coulson and Hernandez (1983) point out that a dietary source of vitamin D or exposure to sunlight for several hours a day is needed to allow for normal bone formation.

A vitamin premix currently available to alligator farmers (McNease and Joanen 1981) has been used successfully for a number of years. The recommended usage level of this premix is 0.5 to 1% by weight, when added to meat rations such as nutria, chicken, or fish. It is important to point out that such meat rations consist of as much as 50 to 75% water. Thus, the premix is actually being fed at levels of 1 to 4% on a dry matter basis. This represents an excessive range in utilization which is probably counter-productive from a cost standpoint. Other questions also arise concerning the differences between using this premix in a dry ration rather than with a meat. For example, what is the difference between the endogenous vitamin content of the meats being fed and that of rations composed of practical feedstuffs? What contribution do gut microflora make to the overall vitamin requirement of the animal? Are vitamins from the premix utilized equally when fed with a "wet feed" (i.e., meat) as with a formulated feed?

Pilot studies and experimental work reported here have used the vitamin premix at 1% of diet, but this diet, as formulated, consisted primarily of dry matter (less than 10% water by analysis). This is a considerably lower rate of vitamin supplementation than is currently used with fresh meat. It is not known to what extent these differences may have influenced results to date.

**5. Minerals** - Lance (1982) and Lance et al. (1983) have studied the role of some trace minerals in alligator reproduction. However, the trace mineral nutrition of growing alligators has received little attention in the literature. The minimum and maximum levels of minerals of both micro- and macronutrient status must be considered. Until specific studies are available, reasonable guidelines can be drawn from two sources: (1) the mineral content of common prey items in the natural environment, and (2) the mineral requirements of other animals, particularly carnivores. Neither of these approaches is without problems however. As will be discussed subsequently, for example, the amounts of calcium and phosphorus in the diet, even at levels substantially below those present in nutria carcass, significantly affect consumption and growth performance of alligators offered diets containing differing amounts of these minerals.

Use of a trace mineral premix, as currently added to rations for other domestic species, may be advisable until the mineral requirements of alligators have been further studied. We have included a trace mineral premix in diets of the second experiment reported here, and it is possible that its use resulted in the improved food conversion ratios, as will be discussed later.

#### FEEDSTUFFS AVAILABLE FOR PRACTICAL FEED FORMULATION

The availability of a long and diverse list of ingredients is desirable for feed formulation purposes. Currently, the list of ingredients available to the alligator feed formulator must be restricted to feedstuffs of animal origin (e.g., Table 1). Grains and other ingredients of plant origin are not included because it is presumed that they would not be effectively utilized by alligators, as discussed previously.

Expansion of this list would be an important contribution to the practice of alligator feed formulation. Casein, an animal-based ingredient is excluded from Table 1 because of its relatively high cost. However, it may be useful in small quantities, since it is an excellent protein source and offers some binding characteristics. Casein has been used in experiments described herein, and apparently is well utilized.

It should be noted that the availability of nutrients in any feed is not equal to the gross levels present. Such availability varies according to species, ingredient, nutrient, and the presence of other ingredients in

the diet. Nutrient availability is a subject which should receive considerable attention as the practice of alligator feed formulation becomes widespread.

### PRACTICAL RATIONS AND THEIR USE IN THE ALLIGATOR INDUSTRY

Alligators are apparently able to utilize diets with high levels of dietary protein (e.g., nutria meat contains approximately 70% protein). However their ability to use dietary carbohydrate and fat, as noted above, is in question. The percentage of protein could perhaps be lowered by increasing fat and carbohydrate levels, as allowable by nutritional, managerial, and manufacturing constraints. Nevertheless, a high protein diet of at least 50-60% appears probable. The dietary protein requirement of the young of many fish species, for example, exceeds 50% (NRC 1983). Such high protein diets are amenable to pelletizing by the extrusion process, which is currently used in manufacturing feed for crayfish, fish, and other aquatic species. Once the amount and composition of fat and carbohydrate, if any, that can be added to the diet and efficiently used by alligators have been resolved, the overall level of the major nutrient classes in the diet can be fixed. With regard to the specific composition of nutrient classes, the mineral content of the diet and the fatty acid composition of dietary lipid appear to be the issues still most in question. Past experience, the results of studies to date, and experiments planned for the near future would appear to be sufficient to suggest working vitamin and amino acid compositions for a commercially viable product which would be useful to the alligator industry.

### FACILITIES FOR THE STUDY OF ALLIGATOR NUTRITION

Special facilities were constructed to allow controlled, captive studies of alligators through their first 12 months of life. Housed in an insulated building, sixteen tanks, constructed of plywood and lined with fiberglass, were laid out in four rows of four tanks each. The tanks were raised on supports such that they were approximately thirty inches from floor level.

Each row consists of four rectangular tanks providing a total living area of 10 to 12 square feet (0.9 to 1.1 square meters) per tank. This living area was apportioned into a dry area (1.3 of area) and a wet area (2.3 of area), with water levels ranging from 4 to 8 cm.

Beneath each row was a reservoir for water which was recirculated through the four tanks. Water in the reservoirs was heated with a 1500 watt heating element to a temperature which was controlled by a thermostat with a remote sensor submerged in the water. A pump, placed in the reservoir, was operated by a clock-controlled switch. Warm water was pumped to the alligator tanks on a regular basis. A return line carried overflow water back to the heating reservoir. The temperature of the water in which the alligators were located was set and maintained relatively constant by adjusting the thermostat. The frequency of pump operation varied according to the room temperature, ranging from 10 to 18 intervals (20 minutes each per 24 hours) including periods when room air temperature fell as low as 3.9°C. This arrangement was successful in maintaining temperatures generally between 26° and 32°C a great percentage of the time, and averaging approximately 29.5°C (see experimental section for data). Water temperature was monitored by a thermometer submerged in the water of each tank.

## PRELIMINARY STUDIES

The following two experiments have used the facilities described above to provide preliminary data relevant to the development of a feed for alligator farming.

### I. FEEDING TRIALS TO EVALUATE THE EFFECTS OF SUPPLEMENTING A DRY FORMULATED FEED WITH VARIOUS ADDITIVES.

#### Introduction

Since the natural diet of alligators consists of a relatively large proportion of protein, we initially focused on this aspect of the diet. Preliminary analyses (Table 2) indicated that nutria meat was approximately 70% protein, on a dry matter basis. Just as important, however, was the amino acid composition of the protein to be fed. The amino acid composition of diets used in this study were arrived at by targeting the amino acid balance of: (1) nutria, (2) alligator eggs, (3) fish muscle (following the "balanced amino acid mixture" of Coulson and Hernandez (1983)), since alligators are known to grow well on diets of fish (McNease and Joanen 1981), and (4) chicken egg, which is considered to be a protein of high nutritional value for a wide variety of vertebrates. An attempt was made to formulate the feed such that the amino acid composition, as a percentage of protein, matched at the least the minimum for the same amino acid in one of these four proteins. The calculated amino acid composition of this diet (designated as "basal") is compared with that of these reference protein sources in Table 3. In most cases, the targeted minimum amino acid level was exceeded, and only in the case of tryptophan was the level less.

The basal diet (Diet 1-1), was then modified by the addition of a number of nutrients in order to assess the effects of their supplementation (Table 4). Lysine and methionine were selected because they are generally considered to be the first and second limiting amino acids in the rations of traditional livestock species, and because synthetic forms of these amino acids are commercially available at prices and in quantities which make their inclusion in livestock rations routine practice. Lysine (80%) was added at 2% of diet (Diet 1-2), and DL-methionine at 1% (Diet 1-3). Diet 1-4 consisted of both 2% additional lysine and 1% additional methionine above their respective levels in the basal ration.

Calcium and phosphorus are generally maintained proportional to each other in formulated rations and hence are discussed together here. The levels of these minerals in the basal diet exceeded the requirements for all other species during their pre-adult growth period, and in fact, exceeded the amounts normally found in commercial rations, raising the possibility that high levels of these minerals might be having deleterious effects on food utilization and growth performance. For example, it is well known that high calcium levels lead to decreased food consumption and growth in broiler chickens (Scott et al. 1982). Furthermore, high levels of calcium may have an inhibitory effect on energy utilization (e.g., Cheng et al. 1949). For this reason, three additional diets were formulated. These three diets started with Diet 1-4 as the control, and contained added Ca/P (Diet 1-5), added fat (poultry oil) (Diet 1-6), or both (Diet 1-7).

#### Methods and Materials

Hatchling alligators were obtained from Rockefeller Wildlife Refuge in Louisiana 2 to 4 weeks after being hatched by artificial incubation. Body weight variation was considerable, varying from 49 to 117 g at the time the experiments were begun, approximately 4 to 6 weeks after hatching. Therefore, the animals were separated according to size rank, into two blocks of "small" (avg. = 76.6 g) and "large" (avg. = 95.2 g) animals. Thirteen small animals and 10 large animals were then assigned to each of two tanks (see

description of facilities, above). The two tanks were then randomly assigned to 8 treatments representing experimental and control diets.

Water temperatures ranged between 25.1° and 31.9°C, averaging 28.4°-30.0°C for all tanks. Room air temperatures varied from 8.9° to 28.8°C, while air temperatures within the tank were much more constant, ranging from 25.0° to 30.0°C (mean = 27.4°C,  $n = 16$ ). Tanks were cleaned twice per week, after feedings. Water in the heating reservoirs was changed and the reservoirs cleaned approximately every two weeks. During the brief period when the tanks were being cleaned, alligators were exposed to room air temperatures.

Alligators were fed 3 times per week. Food offered, on a wet-weight basis, represented 25% of the average body weight on a weekly basis, i.e., 8.33% per feeding. For formulated diets, "wet weight basis" meant a 50:50 mix of the formulated diet and water. Since nutria meat contained significantly more than 50% water (62.6 to 76.0%,  $x = 70.6\%$ ,  $n = 48$ ), alligators fed on experimental rations actually received more dry matter of food per feeding than did the controls. It is important to point out, however, that nutria fed in excess of the amount used here has been reported to result in gout (McNease and Joanen 1981; Coulson and Hernandez 1983); this condition was not a problem in the current study, despite the higher dry matter consumption by experimental diet treatment groups.

The amount fed was adjusted approximately every 2 to 3 weeks after body weights were taken, in order to maintain this feeding rate. For purposes of calculating the amount to be fed, the average weight of all "small" animals and of all "large" animals was used, across treatments. This undoubtedly slowed the growth of the faster growing treatment groups, somewhat, and therefore narrowed the differences in treatment effects. The weight of food offered and of food not consumed was also recorded at each feeding.

At the beginning of the experiment, alligators were fed mixtures of first 1:2 and then 2:1 of the moistened experimental diet:nutria, respectively for 4 feedings and 5 feedings, respectively. After these 17 days of feeding, alligators in the experimental treatment groups were completely weaned off of any nutria and were being fed solely the experimental diets.

Individual weights of each alligators were recorded at the beginning and end of the experiment. Weights of 6 selected individuals from each tank were recorded, as well as the total weight of all the animals in the tanks. The six largest alligators from each tank, among the largest in that tank, were chosen on the basis of their apparently successful acceptance of their experimental quarters and diet. The feeding trial lasted a total of 79 days. Weight data recorded over the period of the feeding trial was used to assess growth performance.

### Results and Discussion

Weight-gain data for alligators maintained on the experimental diets and nutria are shown in Table 5. Analyses of variance indicated that growth responses differed significantly between diets ( $F = 32.86$ ,  $df = 15$ ,  $p < 0.0001$ , and  $F = 2.87$ ,  $df = 95$ ,  $p < 0.001$ , for tank average and individual weights, respectively. Results are generally similar, whether comparisons are made on the basis of the average weight for each tank or the average of all 6 individually recorded weights per tank. The basal diet was the most successful in that it produced growth not significantly different from that of the nutria-fed alligators for the six selected individuals in each tank. Diet 1-2 best approached that of the basal diet, but since it was not superior, there appeared to have been no advantage in adding lysine to the diet. Adding methionine depressed growth significantly in most cases, as did the additions of calcium and phosphorus (Diets 1-5 and 1-7). Addition of fat (poultry oil) to raise the energy levels similarly did not result in significantly improved growth.



Table 6 summarizes food consumption and conversion. On a wet weight basis, alligators ate a greater percentage of the nutria diet than the formulated rations. This may have resulted from difficulty in ingesting the formulated food, which was frequently walked-over and packed-down by the alligators which ate first. The next best-consumed diet (basal) was the experimental diet which supported best growth. Feed conversions for nutria meat were significantly better than those of the formulated rations. The latter were all similar in value, with the exception of those containing added calcium and phosphorus.

If we accept that equal growth can be maintained on either nutria or the basal diet, at the dry matter feeding levels used in this experiment, it would take approximately 2.7 (1.80/.66) times as much dry matter of formulated ration as that of nutria to achieve that equal growth. Since nutria carcasses, on a dry matter basis, are substantially more expensive than many commonly used animal by-product feedstuffs (Table 7), this 2.7:1 margin may not be a barrier to the farmer, who would benefit from the many advantages associated with a dry formulated feed. Nevertheless, to suggest that the basal diet be used as a basis to formulate a commercially viable feed for the alligator industry is highly premature. Many questions must be answered in order to "refine" formulated feeds for alligators and achieve satisfactory feed consumption, conversion, and growth responses. One such question is addressed in the next experiment.

## II. THE EFFECTS OF DIETARY CALCIUM AND PHOSPHORUS ON THE GROWTH OF ALLIGATORS

### Introduction

Results from Experiment I, as reported above, showed a growth depression resulting from the addition of calcium (Ca) and phosphorus (P) to the diets of alligators. However, the levels of these minerals in diets of that experiment were much higher than those used in feeds for other livestock species. Since many of the animal by-product feed ingredients considered to be of potential use in alligator feed formulation contain relatively large amounts of these minerals, it is essential to determine the response of alligators to a range of dietary calcium and phosphorus. The present experiment was initiated to (1) determine to what extent alligator growth, feed consumption, and/or feed utilization are affected by dietary calcium and phosphorus, (2) to indicate what levels of Ca and P are appropriate for alligator diets, and (3) to determine whether the optimal Ca:P ratio for alligators is 2:1, as for most animals.

### Materials and Methods

Procedures used in this experiment were similar to those followed in Experiment I, with the following exceptions. Nine or ten animals were kept in each tank, and animals were no longer classified as large or small. Body weight variation was considerable (94 to 321g), but an attempt was made to ensure that the range of variation and the average body weight of alligators in each tank was similar (average = 193.0 g, ranging from 190.4-199.2 g). Animals from Experiment I were used. Each treatment group contained approximately the same number of animals from each of the treatment groups of Experiment I in order to equally distribute any residual effects from those previous treatments. During the course of the twelve week experiment, body weights of each animal were recorded at 4 week intervals. Average tank water temperatures ranged from 29.0° to 30.3°C, while minimum and maximum recorded temperatures were 25.4° and 33.2°C, respectively.

In this experiment, diets were mixed with water such that the dry feed comprised 50 to 58% of the food offered. Prior to initiating the experiment, all alligators were fed for approximately 6 weeks on a diet consisting of approximately 75% nutria meat and 25% extra lean beef fortified with vitamins. Most alligators used in the current experiment had eaten a moistened meal (in Experiment I) and it was possible to "wean" the alligators from the meat onto experimental diets after only four feedings. Alligators were

fed three times per week, and tanks were cleaned after each feeding. Water and air temperatures were similar to those in Experiment I.

Diets with a protein content and amino acid balance similar to that of the basal diet of Experiment I were formulated using ingredients with low levels of Ca and P (Table 8). Gelatin and carboxymethyl cellulose were each added at 2% of diet as a binder. A source of potassium (potassium carbonate) was added to raise the calculated level of potassium in the diet to 1%, since this was approximately the level found in nutria carcass (Table 2). A trace mineral premix, formulated for use in poultry rations, was also added to diets in this experiment, as opposed to Experiment I.

Rations were formulated so that Ca and P levels varied, as shown in Table 8. This was accomplished by adding different amounts of feed grade dicalcium phosphate (21% Ca, 18.5% P), deflourinated phosphate (32% Ca, 18% P), sodium phosphate (22% P), and limestone (38% Ca). Sand was used as a filler to maintain the isocaloric and isonitrogenous status of the diets. An alligator vitamin premix was again added at 1% of diet on a dry matter basis. Poultry oil was added to raise the ether extract to approximately 5%.

### Results and Discussion

Data on food consumption, food conversion, mortality and growth are summarized in Tables 9 and 10. During the final four week period of the 12 week study, food consumption and growth decreased dramatically in all treatment groups. The causes for this are uncertain, but we believe they are not due to nutritional insufficiency, and that the general results described here are valid and useful in feed formulation. We believe data for the second month of the study to be most representative, as the animals' condition had not worsened by this time, and raw meat had been completely removed from the diet several weeks before.

Analyses of variance indicated differences among treatment mean weight gains for the total 12 week study ( $F = 6.40$ ,  $df = 11$ ,  $p < 0.02$ ) as well as weeks 5-8 ( $F = 8.01$ ,  $df = 11$ ,  $p < 0.01$ ). Alligators receiving Diet 2-1 (1% Ca, 0.5%P) grew significantly better than did those receiving other diets during weeks 5-8. Generally, growth decreased as the percentage of these minerals increased or as the ratio of Ca/P departed from 2:1.

During the first two months of the study, alligators ate between 64.9 and 92% of the food offered to them during any one month. There is no apparent relationship between diet and food conversion. Instead, diets which were consumed most tended to result in increased growth performance.

It is noteworthy that the feed conversion experienced during the initial two periods of this study was substantially better than that in the previous feeding trial (Experiment I). The reason for this improvement could have been the decreased Ca/P levels used in this diet, but the enhanced feed efficiency may also have been a result of the mineral modifications described above. The exact reason or reasons may be left for later research, but the results of this experiment have important implications for the development of a commercially viable formulated feed for the alligator industry. As noted previously, the basal diet of Experiment I, on a basis of feed cost/unit of body weight gain, bordered on economic viability. The feed efficiencies reported here represent an improvement of approximately 33% over those in Experiment I. Likewise, growth on Diet 2-1 was approximately 33% better than that of Diet 2-6, which is the diet of this experiment which most resembles that of the basal diet of Experiment I.

Hence, the nutrient profile of Diet 2-1 of this experiment is closer to that which might serve as a guide for an attempt at a commercially feasible ration. Nevertheless, it should be pointed out that nutria meat was converted to alligator body mass (in Experiment I) more efficiently than were diets in this experiment, again by a factor of about one-third.

## Summary

This report discusses and researches some of the basic needs for making conventional feed formulation and manufacture a reality in the alligator industry. Although information about the nutrition of and manufacture of feed for other species may be useful, the unique nature of crocodilians creates a need for carefully planned research. Of primary importance is knowledge of the nutrient requirements of alligators as well as the ability of these reptiles to utilize nutrients in commercial feedstuffs. It would also be of great value to the alligator feed formulator, for a variety of reasons, to expand the list of feedstuffs now available for alligator rations.

An initial attempt was made at characterizing the nutrient profile of nutria meat and alligator eggs. This information provided guidelines for formulating a basal diet subsequently used in experiments to investigate the effects of various forms of nutrient supplementation.

In these feeding trials, a total of 13 formulated rations were used. Diets were formulated in order to allow comparison between treatments which would answer specific nutritional questions. It was found that these questions could be answered by examining growth data after about three months, and feeding trials were restricted to approximately that time period.

In the first feeding trial (Experiment I), a high protein diet was formulated with an amino acid balance derived from the amino acid composition of nutria, fish, alligator egg, and chicken egg protein. It was determined that adding lysine (2% of diet), methionine (1%), or both resulted in poorer growth performance. Adding calcium and phosphorus to a diet already high in these minerals resulted in poorer growth as well. Adding a source of fat (poultry oil) to diets did not result in significantly improved growth.

In the second feeding trial (Experiment 6), the effect of calcium and phosphorus on growth performance and feed conversion was studied further. A basal diet with an amino acid composition similar to the best-performing diet in Experiment I was formulated with feed ingredients low in calcium and phosphorus. Dietary levels of calcium and phosphorus were increased by adding various sources of these minerals. A total of six diets were formulated in this manner and were maintained isocaloric and isonitrogenous. Preliminary results indicate that the amounts of calcium and phosphorus in the diet did affect growth performance. Alligators fed a diet containing 1% calcium and 0.5% phosphorus grew best. Results also suggested that the ratio of Ca:P should be maintained at 2:1.

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## LITERATURE CITED

- Cheng, L.S., M.G. Morehouse, and H.J. Deuel, Jr. 1949. The effects of the level of dietary calcium and magnesium on the digestibility of fatty acids, simple triglycerides, and some natural and hydrogenated fats. *J. Nutr.* 37:237.
- Coulson, R.A., and T. Hernandez. 1983. Alligator metabolism, studies of chemical reactions *in vivo*. Pergamon Press, New York.
- Drochner, W., and S. Muller-Schlosser. 1980. Digestibility and tolerance of various sugars in cats. In: R.S. Anderson (ed.) *Nutrition of the dog and cat*. Pergamon Press, London.
- Feedstuffs. 1983. Feedstuffs ingredients analysis table: 1983 edition. *Feedstuffs* (1983 Reference Issue) 21:25.
- \_\_\_\_\_. 1986. Ingredient market, June 9, 1986. *Feedstuffs* 16:30.
- Garnett, S. 1985. Fatty acid nutrition of the estuarine crocodile *Crocodylus porosus*. *Comp. Biochem. Physiol.* 81B:1033.
- Halver, J.E. 1976. Formulating practical diets for fish. *J. Fish. Res. Board Can.* 33:1032.
- Lance, V. 1982. Trace elements, vitamin E and glutathione peroxidase in the American alligator, *Alligator mississippiensis*. *Proc. Ann. Alligator Prod. Conf., College Vet. Med. Univ. Fla., Gainesville* 2:17.
- \_\_\_\_\_, T. Joanen, and L. McNease. 1983. Selenium, vitamin E, and trace elements in the plasma of wild and farm-reared alligators during the reproductive cycle. *Can. J. Zool.* 61:1744.
- McNease, L., and T. Joanen. 1981. Nutrition of alligators. In: T. Cardeilhac and R. Larsen (eds.). *Proc. First Ann. Alligator Production Conference*. College Vet. Med. Univ. Fla., Gainesville.
- National Research Council. 1978. Nutrient requirements of cats. *Nutrient requirements of domestic animals series*. Washington, D.C.
- \_\_\_\_\_. 1983. Nutrient requirements of warmwater fishes and shellfishes. *Nutrient requirements of domestic animals series*. Washington, D.C.
- \_\_\_\_\_. 1984. Nutrient requirements of poultry, 8th edition. *Nutrient requirements of domestic animals series*. Washington, D.C.
- Nesbein, M.C., R.E. Austic, and L.E. Card. 1979. *Poultry production*, 12th ed. Lea & Febiger, Philadelphia, Pennsylvania.
- Rivers, J.P.W., A.J. Sinclair, and M.A. Crawford. 1975. Inability of the cat to desaturate essential fatty acids. *Nature* 258:171.
- \_\_\_\_\_, and T.L. Frankel. 1980. Fat in the diet of cats and dogs. In: R.S. Anderson (ed.). *Nutrition of the dog and cat*. Pergamon Press, London.
- Scott, M.L., M.C. Nesheim and R.J. Young. 1982. *Nutrition of the chicken*. M.L. Scott Associates, Ithaca, New York.
- Spannhoff, L., and H. Plantikow. 1983. Studies on carbohydrate digestion in rainbow trout. *Aquaculture* 30:95.

Table 1. Nutrient profiles of some feedstuffs of potential use in feed formulation for alligators. Information summarized from Feedstuffs (1983, 1986) and NRC (1984).

	Unit	Blood	Meal	Animal Fat	Fish Meal (Menhaden)	Fish Meal (AAJPCO)	Meat Meal (Rendered)	Meat & Bone Meal (50%)	Crab Meal	Poultry By- Products Meal	Feather Meal
<b>General</b>											
Price	\$/lb	0.165		0.10	0.148	-	-	0.92	-	0.11	0.58
Dry Matter	%	89.3-93.0		99.5	92	88.4	92-92.8	92.6-93	95.0	93-94	93
Crude protein	%	80.0-88.9		0.0	60.5-62.0	59.0	54.4-55	50-50.4	30.0	58	86.4
Crude fiber	%	0.6-1.0		-	0.7-1.0	1.0	2.5-8.7	2.8	10.5	2-2.5	1
Crude fat	%	1.0		99.4	9.4-10.2	5.6	7.1-7.2	8.5-8.6	2.2	13-14	3.3
Ash	%	4.4		-	20.0	20.2	33.0	33.0	31.0	16.0	-
Linoleic Acid	%	0.1		-	0.12	-	0.28	0.036	-	2.54	-
<b>Minerals</b>											
Calcium	%	0.06-0.28		-	5.0-5.11	5.5	7.6-8.27	9.2-10.3	18.0	3-4.0	0.33
Phosphorus	%	0.09-0.42		-	2.88-3.0	3.3	4.0-4.1	4.7-5.1	1.5	1.7-2.4	0.55
Potassium	%	0.41-0.90		-	0.72-0.77	0.39	0.55-0.60	1.02-1.4	0.45	0.3-0.6	0.31
Sodium	%	0.31-0.33		-	0.34-0.41	1.07	1.15-1.6	0.72-0.73	0.85	0.40-0.28	0.71
Magnesium	%	0.22-0.40		-	0.14-0.16	0.21	0.27-0.58	1.12-1.13	0.88	0.22-0.15	0.20
Sulfur	%	0.32		-	0.45	0.24	0.49-0.5	0.26-0.5	0.04	0.51	1.50
Manganese	mg/kg	5.3-6.0		-	33-35.6	22.8	9.5-10	12.3-14	133.0	11	21
Iron	mg/kg	380-3000		-	438-440	360	440	490-500	440	440	76
Copper	mg/kg	3-9.9		-	11-11.4	14.6	9.7-10	1.5-2	32.8	14	7
Zinc	mg/kg	306		-	147-151	n.a.	103	93	102	120	54
Selenium	mg/kg	-		-	2.10-2.2	1.5-2.0	0.4-0.42	0.25	3.8	0.5-1.0	0.84
<b>Vitamins</b>											
Carotene	mg/kg	-		-	-	-	-	-	-	-	-
Vitamin A	10 <sup>6</sup> /g	-		-	-	-	-	-	-	-	-
Vitamin E	mg/kg	-		7.9	5.7-7	18.5	1	0.8-1.0	-	2-2.2	-
Thiamin (B <sub>1</sub> )	mg/kg	0.44-0.5		-	0.2-0.5	1.3	0.2	0.2-0.8	-	1	0.1
Riboflavin (B <sub>2</sub> )	mg/kg	1.3-1.5		-	4.8-4.9	6.5	5.2-5.5	4.4-5.2	7.5	10.0-11	2.1
Pantothenic Acid	mg/kg	1.1-5.0		-	8.8-9	8.7	5-5.8	4.1-4.4	6.6	8.8-12.3	10
Biotin	mg/kg	0.08-0.2		-	0.15-0.20	n.a.	0.14-0.17	0.14-0.64	n.a.	0.30	0.44
Folic Acid	mg/kg	0.08-0.4		-	0.6-1	n.a.	0.3-0.6	0.3-0.6	n.a.	1	0.2
Choline	mg/kg	280-990		-	3056-3080	3510	2007-2200	1996-2000	2024	5952-5980	891
Vitamin B <sub>12</sub>	mg/kg	44		-	104-150	250	68-90	70-100	448	310	78
Niacin	mg/kg	13-31.0		-	55	60.8	57-59.4	46-59.4	44.0	39.6-40	27
Pyridoxine (B <sub>6</sub> )	4.4	-		4	-	3	12.8	-	414	3.0	-
<b>Amino Acids</b>											
Arginine	%	2.35-3.81		-	3.23-3.79	3.73	3.7-3.73	3.35-3.62	1.7	3.84-4	5.42
Glycine	%	4.0-4.4		-	3.88-4.19	3.93	6.30	6.79-6.9	1.8	2.93-5.90	6.31
Serine	%	3.86		-	2.25	-	1.60	1.88	-	3.68	9.26
Histidine	%	3.05-5.26		-	1.44-1.46	1.53	1.1-1.30	0.90-0.96	0.5	1.50-1.61	0.34
Isoleucine	%	0.8-0.88		-	2.83-2.85	3.64	1.60-1.9	1.40-1.7	1.2	2-2.33	3.26
Leucine	%	10.3-11.82		-	4.5-5.0	4.69	3.32-3.5	2.80-3.2	1.6	3.70-4.4	6.72
Lysine	%	5.3-8.85		-	4.7-4.83	5.17	3.00	2.60	1.4	2.57-2.70	1.67
Methionine	%	0.75-1.0		-	1.78-1.8	1.72	0.75	0.65-0.67	0.5	1-1.04	0.42
Oxystine	%	0.86-1.4		-	0.56-0.6	0.57	0.66-0.68	0.25-0.33	0.2	0.69-1.0	4
Phenylalanine	%	5.1-6.55		-	2.28-2.48	0.67	1.70-1.9	1.50-1.7	1.2	1.79-2.10	3.26
Tryptophan	%	1.0-1.34		-	0.72-0.68	2.68	0.35-0.36	0.26-0.28	0.3	0.53-0.55	0.50
Threonine	%	3.8-3.94		-	2.34-2.50	2.49	1.74-1.8	1.50-1.63	1.2	2-2.03	3.43
Valine	%	5.2-8.60		-	3.23-3.43	3.26	2.30-2.6	2-2.25	1.5	2.60-2.65	5.57

Table 2. Analyses of nutria carcass (excluding pelt and viscera) and homogenates of whole alligator eggs, excluding shells. Samples of nutria (n=20) and alligator egg (n=4) homogenates were pooled and analyzed in duplicate.

Nutrient	Nutria	Alligator Egg
General		
Ash (5)	19.03	5.44
Ether Extract (%)	8.46	40.80
Total Lipids (%)	10.44	49.14
Crude Protein (%)	70.57	42.51
Crude Fiber (%)	0.18	0.063
Minerals		
Calcium (%)	6.03	NA <sup>1</sup>
Phosphorus (%)	3.40	NA
Sodium (%)	0.33	NA
Potassium (%)	1.03	NA
Chlorine (%)	0.32	NA

<sup>1</sup> Analysis not available.

Table 3. Partial amino acid analyses of protein in nutria, fish, alligator egg, chicken egg, and the basal diet of Experiment (I).

Amino Acid	% of Protein in:				
	Nutria <sup>1</sup>	Fish <sup>2</sup>	Alligator Egg <sup>1</sup>	Chicken Egg <sup>3</sup>	Basal Diet <sup>4</sup>
Arginine	5.74	3.42	5.91	6.40	5.3
Glycine	17.44	7.08	9.92	3.24	6.1
Serine	5.10	5.70	9.62	7.60	5.7
Histidine	3.53	2.61	4.48	2.32	3.4
Isoleucine	3.06	5.18	5.14	4.98	3.3
Leucine	8.53	7.13	9.27	8.30	9.7
Lysine	9.42	8.32	11.00	7.07	7.5
Methionine	NA <sup>5</sup>	0.38	NA	3.24	1.7
Cystine	NA	0.38	NA	2.20	1.2
Phenylalanine	3.41	4.18	2.93	4.70	5.3
Tyrosine	2.00	6.51	1.75	4.40	3.9
Threonine	4.60	3.75	7.11	4.98	4.2
Tryptophan	NA	1.81	NA	1.44	1.1
Valine	3.74	5.13	4.43	6.47	7.1

<sup>1</sup> By analysis (hydrolysis in 6N HCl 22 hrs 100° in vacuo).

<sup>2</sup> From Coulson and Hernandez (1983).

<sup>3</sup> From Nesheim, Austic, and Card (1979).

<sup>4</sup> By calculation.

<sup>5</sup> Analyses not available.

Table 4. Experiment I: Experimental and control diets--% composition and calculated analysis.

Ingredients	Diet							
	1-1 (Basal)	1-2	1-3	1-4	1-5	1-6	1-7	1-8 <sup>1</sup>
Casein	20.0	19.6	19.8	19.4	18.6	18.8	18.1	-
Blood meal	25.0	24.5	24.8	24.3	23.3	23.5	22.6	-
Fish meal	15.0	14.7	14.9	14.6	14.0	14.1	13.5	-
Feather meal	10.0	9.8	9.9	9.7	9.3	9.4	9.0	-
Meat & Bone meal	17.0	16.7	16.8	16.5	15.8	16.0	15.3	-
Poultry BP meal	10.0	9.8	9.9	9.7	9.3	9.4	9.0	-
Carboxymethyl Cellulose	1.5	1.5	1.5	1.5	1.5	1.5	1.5	-
Vitamin	1.0	1.0	1.0	1.0	0.9	0.9	0.9	1.0
NaCl	0.5	0.5	0.5	0.5	0.5	0.5	0.5	-
Lysine, 80%	-	2.0	-	2.0	1.9	1.9	1.8	-
DL Methionine	-	-	1.0	1.0	0.9	0.9	0.9	-
Ground Limestone	-	-	-	-	1.4	-	1.4	-
Phosphate, DiCal	-	-	-	-	2.8	-	2.8	-
Poultry Oil	-	-	-	-	-	3.0	3.0	-
<b>Calculated Analysis</b>								
Moisture (%) <sup>2</sup>	6.9	6.8	6.9	6.8	6.6	6.6	6.4	74.0
Protein (%)	71.8	71.9	72.0	72.1	69.1	70.0	67.1	69.9
Ether Extract (%)	4.9	4.8	4.9	4.8	4.6	7.6	7.4	8.5
Crude Fiber (%)	1.1	1.1	1.1	1.0	1.0	1.0	1.0	0.2
Calcium (%)	3.0	2.9	3.0	2.9	3.9	2.8	3.8	6.0
Available Phosphorus (%)	1.8	1.7	1.7	1.7	2.1	1.6	2.1	3.4
Potassium (%)	0.5	0.5	0.5	0.4	0.4	0.4	0.4	1.0
Chloride (%)	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.3
Lysine (%)	5.4	6.9	5.4	6.8	6.5	6.6	6.3	6.6
Methionine (%)	1.2	1.2	2.2	2.2	2.1	2.1	2.0	n/a
Cystine (%)	0.9	0.8	0.8	0.8	0.8	0.8	0.8	n/a

<sup>1</sup> Nutritional content by analysis; Control Diet (Ground Nutria Meat + Vitamins).

<sup>2</sup> Fed on a wet weight basis as a 50:50 mix with water; % moisture for diets 1-7 on a wet weight, as fed, was approximately 53.4%.



Table 5. Growth responses (g) to dietary treatment as compared by Duncan's multiple range test. Means with the same superscript are not significantly different.

Diet	Treatment	Tank Average	Average of 6 Individuals
1-8	Nutria	105.5 <sup>1</sup>	128.5 <sup>1,2</sup>
1-1	Basal	96.2 <sup>2</sup>	131.9 <sup>1</sup>
1-2	Basal + Lysine (Lys)	94.1 <sup>2,3</sup>	124.2 <sup>1,2</sup>
1-3	Basal + Methionine (Met)	83.6 <sup>4</sup>	98.3 <sup>3,4</sup>
1-4	Basal + Lys, Met	85.5 <sup>3,4</sup>	99.7 <sup>3,4</sup>
1-5	Diet 1-4 + Ca, P	69.6 <sup>5</sup>	88.4 <sup>4</sup>
1-6	Diet 1-4 + Fat	83.0 <sup>4</sup>	104.6 <sup>2,3,4</sup>
1-7	Diet 1-4 + Ca, P, Fat	60.7 <sup>5</sup>	79.1 <sup>4</sup>

Table 6. Consumption and food conversion (tank totals) for the "post-weaning" period (days 17-79).

Diet	Treatment	Consumption (g/wk/animal)		Food Conversion <sup>1</sup>	
		Wet Wt	Dry Wt	Wet Wt	Dry Wt
1-1	Basal	28.2	13.1	3.17	1.82
1-2	Basal + Lysine (Lys)	25.3	11.8	3.00	1.72
1-3	Basal + Methionine (Met)	24.0	11.1	3.17	1.82
1-4	Basal + Lys, Met	24.2	11.3	3.24	1.86
1-5	Diet 1-4 + Ca, P	25.1	11.7	4.40	2.52
1-6	Diet 1-4 + Fat	25.3	11.8	3.62	2.07
1-7	Diet 1-4 + Ca, P, Fat	23.2	10.8	5.23	3.00
1-8	Nutria	29.1	7.6	2.75	0.66

<sup>1</sup> g food intake/g body weight gain on wet weight and dry weight basis of feed; body weight in wet weight only.

Table 7. Prices of commonly used animal by-product feed ingredients and commercially available ground nutria meat.

Ingredient	\$ / pound	
	Wet Weight	Dry Weight
Nutria -- High <sup>1</sup>	0.16	0.53
Nutria -- Low <sup>1</sup>	0.10	0.33
Blood Meal <sup>2</sup>	0.162	0.185
Feather Meal <sup>2</sup>	0.063	0.067
Fish Meal <sup>2</sup>	0.153	0.166
Meat and Bone Meal <sup>2</sup>	0.090	0.097
Poultry BP Meal <sup>2</sup>	0.100	0.108

<sup>1</sup> Assumes 30% dry matter.

<sup>2</sup> Atlanta prices, Feedstuffs, January 27, 1986.

Table 8. Experiment II: Composition of experimental diets.

	Diet					
	2-1	2-2	2-3	2-4	2-5	2-6
<b>Ingredients (% of Diet)</b>						
Casein	36.6	36.6	36.6	36.6	36.6	36.6
Blood meal	27.7	27.7	27.7	27.7	27.7	27.7
Feather meal	17.8	17.8	17.8	17.8	17.8	17.8
Poultry oil	4.0	4.0	4.0	4.0	4.0	4.0
Gelatin	2.0	2.0	2.0	2.0	2.0	2.0
Vitamin premix	1.0	1.0	1.0	1.0	1.0	1.0
Salt	0.5	0.5	0.5	0.5	0.5	0.5
Chromic Oxide	0.5	0.5	0.5	0.5	0.5	0.5
Potassium carbonate	0.1	0.1	0.1	0.1	0.1	0.1
Trace mineral premix <sup>1</sup>	0.1	0.1	0.1	0.1	0.1	0.1
L-Arginine	0.2	0.2	0.2	0.2	0.1	0.1
dL-Methionine	0.1	0.1	0.1	0.1	0.1	0.1
Dicalcium phosphate	-	-	-	3.8	-	-
Sodium phosphate	-	-	0.5	-	-	-
Defluorinated phosphate	-	2.0	5.3	-	-	7.8
Limestone	2.6	2.8	-	4.2	10.0	3.4
Sand	8.8	6.6	5.5	3.3	1.3	0.1
<b>Nutrients</b>						
Calcium (% of diet)	1.00	1.50	1.50	2.00	3.00	3.00
Phosphorus (% of diet)	0.50	0.75	1.25	1.00	0.50	1.50
Calcium : Phosphorus ratio	2:1	2:1	1.2:1	2:1	6:1	2:1

<sup>1</sup> Trace mineral premix provides (in mg/kg diet): MnO<sub>2</sub>, 222; ZnO, 150; FeSO<sub>4</sub>·7H<sub>2</sub>O, 200; FeCO<sub>3</sub>, 83; CuSO<sub>4</sub>, 29; Ca (IO<sub>3</sub>)<sub>2</sub>, 15.

Table 9. Percent food consumption, food conversion and mortality in alligators offered different dietary treatments over a 12-week period.

Diet	Treatment		% Food Consumed			g Dry Matter Consumed g Body Wt Gained			Mortality
	% CA	% P	Weeks	Weeks	Weeks	Weeks	Weeks	Weeks	
			1-4	5-8	9-12	1-4	5-8	9-12	
2-1	1.0	0.50	92.0	83.1	48.5	0.74	0.92	2.03	0
2-2	1.5	0.75	88.0	77.4	51.2	0.72	1.10	1.59	0
2-3	1.5	1.25	69.8	71.1	50.1	0.72	1.01	2.54	1
2-4	2.0	1.0	86.1	77.2	52.5	0.70	1.00	1.86	1
2-5	3.0	0.5	73.5	67.9	44.6	0.76	0.96	2.86	1
2-6	3.0	1.5	69.0	72.3	47.0	0.70	1.08	1.75	0

Table 10. Average body weight changes in alligators offered dietary levels of calcium and phosphorus over a 12-week period, as compared by Duncan's multiple range test. Values sharing the same superscript are not significantly different.

Diet	Treatment		Average Body Weight Gain (g)	
	% Ca	% P	Weeks 1-12	Weeks 5-8
2-1	1.0	0.50	221.3 <sup>1</sup>	100.0 <sup>1</sup>
2-2	1.5	0.75	210.9 <sup>1,2</sup>	77.6 <sup>2</sup>
2-3	1.5	1.25	183.1 <sup>2,3</sup>	80.9 <sup>2</sup>
2-4	2.0	1.0	214.1 <sup>1,2</sup>	86.6 <sup>2</sup>
2-5	3.0	0.5	163.3 <sup>3</sup>	74.4 <sup>2</sup>
2-6	3.0	1.5	182.2 <sup>2,3</sup>	76.1 <sup>2</sup>

# GEORGIA'S COASTAL ISLAND ALLIGATORS, VARIATIONS IN HABITAT AND PREY AVAILABILITY

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**ABSTRACT** - A protected coastal alligator population on a Georgia barrier island was studied by capture, tagging and recapture methods to determine the movement patterns of different size alligators. Prey availability was determined to be a criteria for movement to and from fresh, brackish and salt water habitats. Water level fluctuations were evident in all habitats. Alligator density was highest in freshwater ponds during winter denning and basking seasons. Brackish areas were exploited by alligators 1 to 2 m in total body length and tidal salt marshes were used by alligators more than 1.5 m total body length.

## INTRODUCTION

The Georgia coastal zone has seen a dramatic human population increase in the last fifteen years. Understanding the habitat uses and environmental pressures placed on existing American alligator (*Alligator mississippiensis*) populations could help government planners and private developers from destroying the animals natural habitat and rangewide corridors. In coastal areas of Louisiana, Joanen and McNease (1972a) reported that 40.3% of the estimated alligator population could be found in fresh marsh habitat, 30.2% in intermediate marsh habitat, and 28.5% in brackish marsh habitat. American alligator movements have been described through tagging and radio telemetric studies in Florida (Goodwin and Marion 1979), Louisiana (Joanen and McNease 1970, 1972b), and Texas (Smith 1980). However, little was known of alligator movements and habitat preference within the coastal zone areas of Georgia. From 1975 the American alligator of Georgia's Atlantic coastal area has been the focus of studies sponsored in part by the Atlanta Zoological Society and the Department of Herpetology, Zoo Atlanta. This long term study concentrated on the subadult alligator population endemic to Wassaw Island. Additional observations and data were collected from Savannah River National Wildlife Refuge; Oatland, Skidaway, Ossabaw, Blackbeard, Little St. Simon's and Cumberland Islands. I here report data related to Georgia's coastal island American alligator population dynamics, rangewide movements, prey availability and environmental pressures.

## STUDY AREA

The principle data collected during the study period from 1 June 1975 to 1 October 1986 came from Wassaw Island National Wildlife Refuge's American alligator population endemic to the 1,012 high ground ha of Great Wassaw Island (Fig. 1) and its surrounding estuary bordered by Odingsell River, Wassaw Creek, New Cut to Salt Pond Shoals, and Wassaw Sound. Wassaw Island was formed from a typical sand sharing development of dune ridges beginning during the Holocene Period. Still under the same wind and wave action today, the island is slowly changing as the beachfront erodes from the north end and exposes the forests in that area to a pounding surf whose powerful currents shift and deposits sands on the south end of the island where emergent plants and forests rebuild the ecosystem. Great Wassaw Island consists mainly of a virgin forest of live oak, slash pine, mixed hardwoods and beach dune communities in

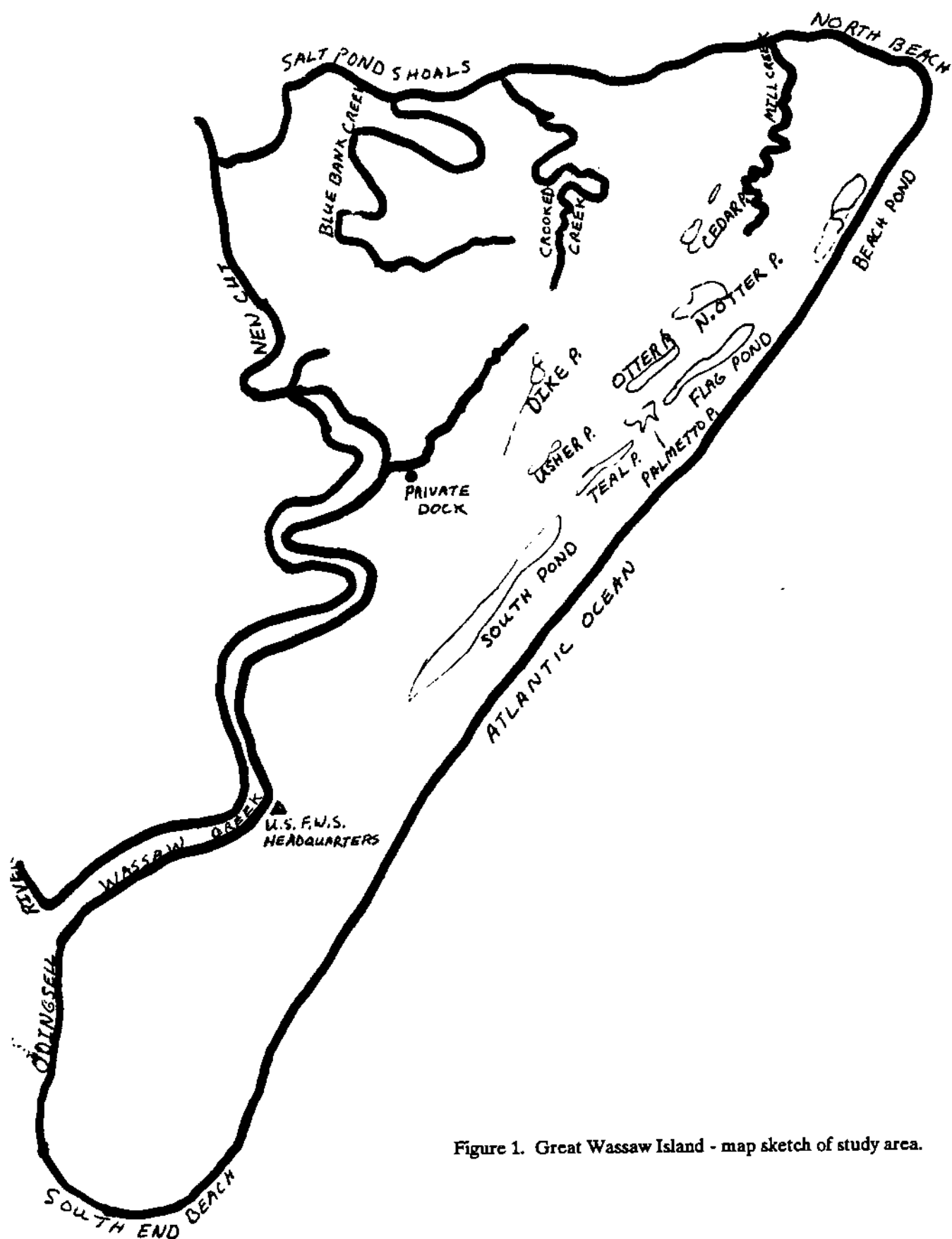


Figure 1. Great Wassaw Island - map sketch of study area.



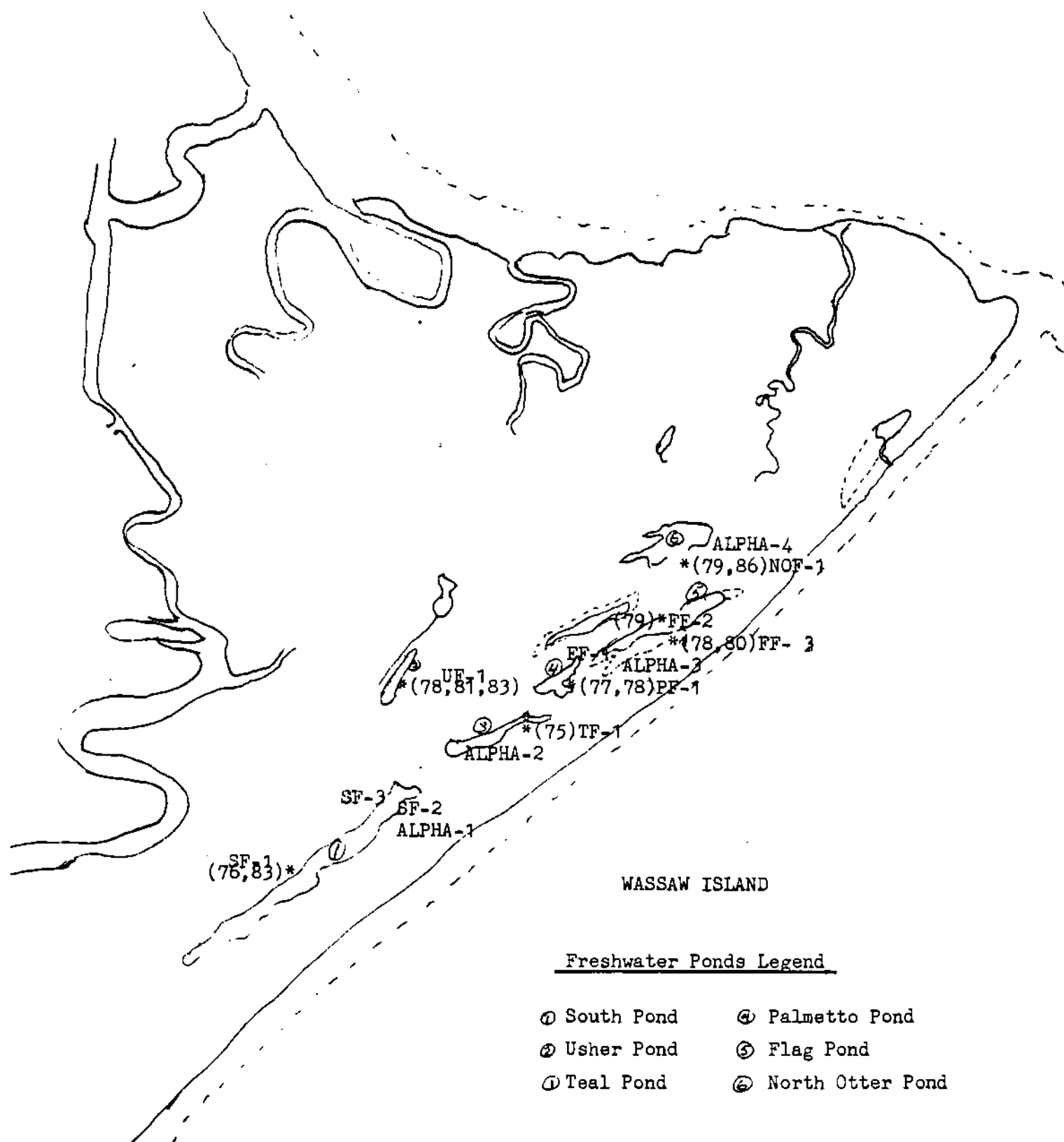


Figure 2. Distribution of known adult breeding American alligators on Wassaw Island.

various stages of development. Interior ponds were formed as swales and sloughs were isolated by new beach front dune ridges. Some ponds retain feeder creeks to the tidal marshes allowing for excess drainage of rainwater and incoming salt water on spring tides associated with full and new moons. These shallow brackish ponds remain relatively clear of vegetation and do not fluctuate as rapidly as the freshwater ponds or tidal creeks and serve as a seasonal nursery area for striped mullet, tarpon, shrimp and blue crabs. The brackish ponds are Cedar Pond, fed and drained by the Cedar Creek branch of Mill Creek; Otter Pond, fed and drained by Mill Creek; Dike Pond, fed and drained by Crooked Creek; and Beach Pond, which has undergone several changes since 1970. Beach Pond was an isolated interior freshwater pond fed by rainfall, but during a storm in the winter of 1970, the beach dune was eroded and salt water intrusion began forming a channel for daily tidal influx. This condition remained until 1982 when another dune ridge formed and isolated the twelve year old estuary forming a brackish pond with intermittent levels of rainwater and occasional spring tides cresting the dune ridge.

Beach Pond is basically a shallow pan and susceptible to drought conditions, mud cracking, and browning of vegetation. The rainfed freshwater ponds are the nesting and nursery areas of the adult females and their hatchlings (Fig. 2). The largest, the 18.2 ha Flag Pond, is vegetatively choked with < 3.5 m high cattails, wild hibiscus and needle grass. Guarded from the sea by a 10 m high dune ridge, Flag Pond is tunneled with gator trails and dotted with dens. Bordering meadows and willow trees are used by deer and by herons and egrets as nesting areas. North Otter Pond, Teal, Palmetto, Usher and South Ponds are the remaining freshwater habitats. Because freshwater ponds are subject to occasional drought conditions, no large freshwater fish species exist on Wassaw Island. The salt marsh estuary surrounding Great Wassaw Island is nearly 75% of the total refuge system. Flooded and drained twice daily, the marshes are subject to mean tidal change of 2.3 m and spring tides range > 3 m several times a year.

For the purposes of this study, alligators were located primarily at night using 12 volt head and hand held lamps and captured by hand or with wire-noose poles. Once captured, each alligator was tagged in the webbing between digits with a Number 1 size National Band and Tag Co. 1005 monel steel stamped tag (Fig. 3) and a numerical code was punched through the last four rows of double dorsal caudal scutes and the first eight single dorsal caudal scutes (Fig. 4) using a coding method described by Bustard and Choudhury (1981). Larger alligators had Hasco Company metal tags affixed to the first single caudal scute. For identification by observation, three or more colored rings were placed through the punched holes and when read from anterior to posterior the colored rings indicated the ranking capture of a certain alligator in a designated habitat of a particular year.

The following data were recorded from each capture:

- Head Length (HL) - straight line distance between premaxilla and supraoccipital points
- Head Width (HW) - straight line distance between quadratojugal points
- Total Body Length (TBL) - straight line distance - premaxilla to tail tip
- Body Girth (BG) - circumference of body posterior to front limbs
- Tail Length (TL) - straight line distance from vent posterior to tip of tail
- Body Temperature (BT) - cloaca reading
- Air Temperature (AT) - ambient
- Water Temperature (WT) - pond, pool, creek, etc.
- Ground Temperature (GT) - surface temperature
- Habitat Locality (HL) - e.g. ponds site
- Time of Capture (time) - 24 hour system

A printed data sheet was developed for field use (Fig. 5).

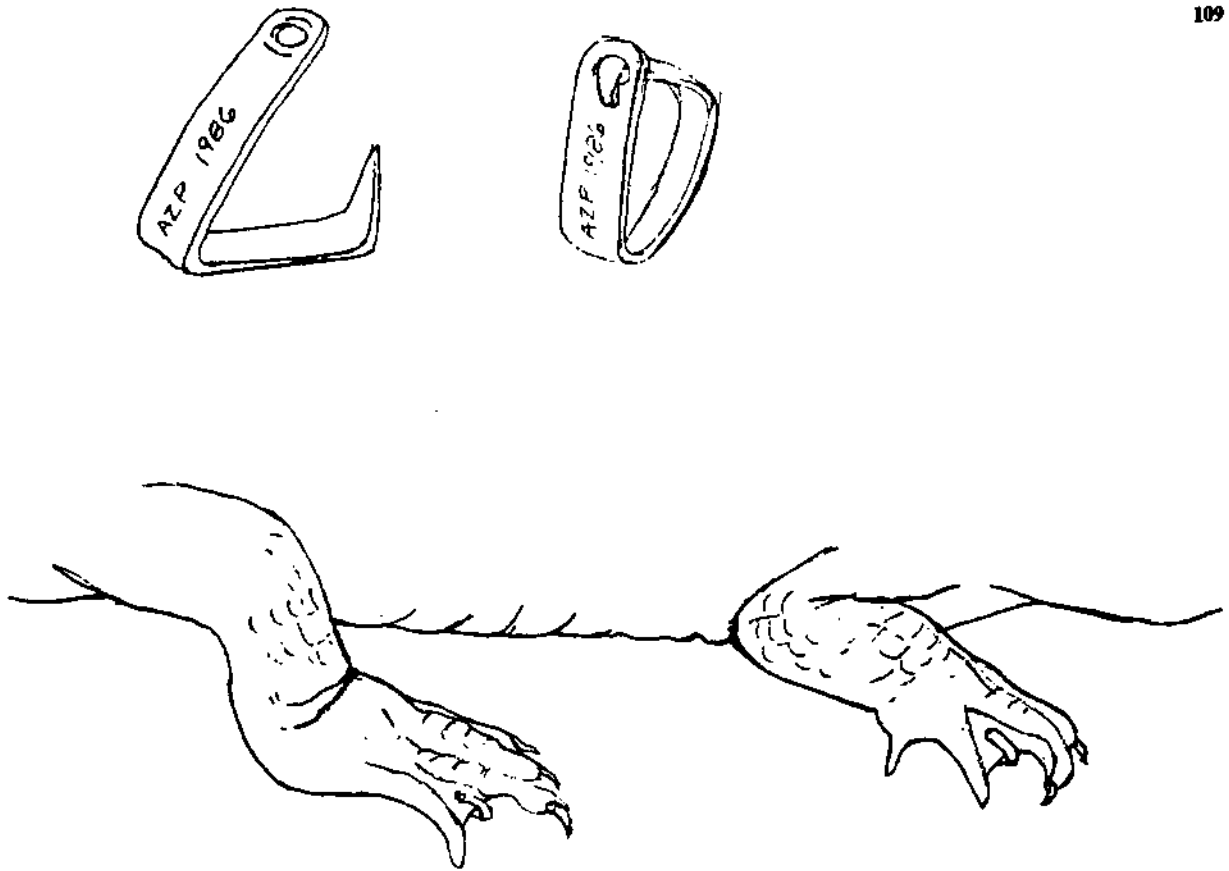


Figure 3. Example of metal tags applied to webbing between digits.

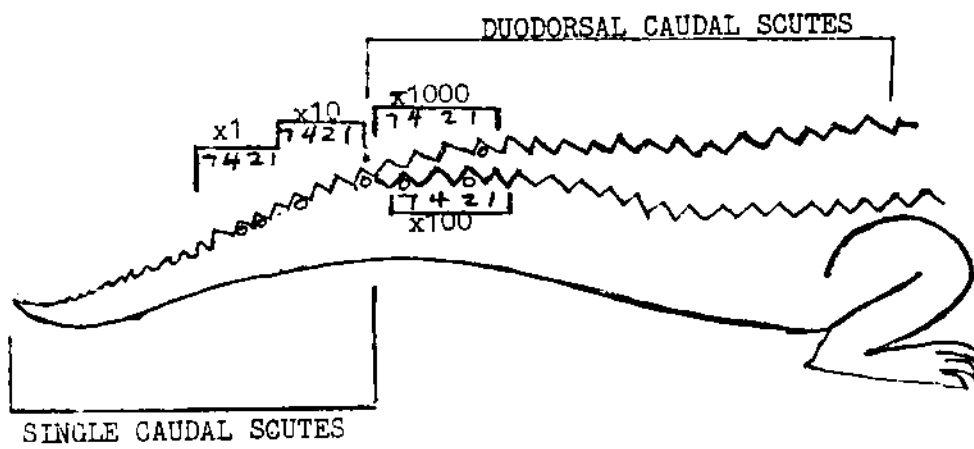


Figure 4. Punch coding and marking technique using the posterior four duodorsal caudal scutes and the anterior eight single caudal scutes (e.g. the scutes with punched holes indicate the number 1986).

D 82-1

American Alligator  
Field Data Sheet

Date June 18, 1982 Time 1:30  
 Capture Site Dike Pond - Brickish  
 Quadrant \_\_\_\_\_  
 Captured by Tamarack, Florida, Howard  
 Assistant(s) Boam; Howard  
 Method of Capture \_\_\_\_\_  
 Hand(s) \_\_\_\_\_ Pole ☒  
 Net \_\_\_\_\_ Other \_\_\_\_\_  
 Remarks \_\_\_\_\_

Temperatures

Body(internal) 29°C Air 32°C  
 Water 29°C Ground \_\_\_\_\_

Measurements 127.8 cm.

Total Body Length 49.2 inches  
 Body Girth 39.9 cm  
 Tail Length 25 inches 64.2 cm.  
 Tail Girth 27.5 cm  
 Head Length 17.5 cm  
 Head Width 8.75 cm  
 Body condition and abnormalities  
none

Identification Record

Sex M

Tagging Information

	old tags	new tags
Toe Tag	<u>443 RF</u>	<u>-445 RR</u>
Caudal tag	_____	_____
Caudal Punch	<u>345</u>	_____
Ring Color Code	<u>White-Black-Blue</u>	

Additional information

Signed and Recorded by :  
BERRY SEAN

Figure 5. Copy of field data sheet.

Each alligator captured was given a file code identification and plotted on an aerial photo map to monitor and chart movement patterns. The file code was identical to the ring color code system used in the caudal scutes. The habitat (Designated Letter Abbreviation), year of capture, ranking order of capture, for example:

F80-3 - 3rd individual captured in Flag Pond in 1980  
 MC78-1 - 1st individual captured in Mill Creek in 1978  
 NO86-10 - 10th individual captured in North Otter Pond in 1986.

Alligators were classified by size using the following formula:

<u>Size TBL</u>	<u>Classification</u>
Hatchlings	Neonate
.5 m - 1 m	Juvenile
1 m - 2.5 m	Subadult
Adult breeding size female (> 2 m)	Alpha female
Subdominate male (2.5 - 3 m)	Beta Male
Dominate male breeder (> 3 m)	Alpha Male

## RESULTS

**Population Dynamics** - From observations made in 1975 and 1976, a population estimate (including neonates) of 250 plus or minus 50 individual *A. mississippiensis* was made. The breeder adults were not deliberately disturbed by attempted capture and only two Alpha females were captured when they had vacated their territorial limits. Four Alpha males are credited with the courtship and mating of the ten known breeding and nesting Alpha female adults. Three Beta males, sexually mature but physically undersized, were captured and often showed wounds which could have been the results of fighting and territorial aggression. Beta males were not observed in the fresh water ponds after mid May, the courtship time table, and remained in the tidal marshes until the fall denning season.

The largest segment of the population consisted of subadult females and males, juveniles and neonates. Nests and neonates were never guarded from humans by the females on Wassaw Island. However, known nesting was successful 70% of the time and hatching rates were average or above other study areas. Predation and loss of hatchlings because of winter kill and drought were the greatest influences in population dynamics. As would be expected, years of high nesting density and successful hatching pushed the estimated island alligator population to 300+ individuals, and when nesting and successful hatchling survival were low the population estimate was dropped to 200 individuals (Fig. 6).

**Population Dispersion** - The 1976 and 1977 observation surveys of the early spring emerging Wassaw Island alligators from their winter dens established that the resident population (over winters) in the six freshwater ponds often denned communally with breeder females and their offspring including neonates, juveniles, and small subadults up to 1.3 m in length. Other group basking areas showed concentrations of subadult alligators capable of digging their own dens, but den sharing should not be ruled out. These large groups, ranging in size from 1.25 to 2 m of basking subadults were located around small gator pools in Flag Pond. Groups of 20, 22, 29, and 31 alligators were observed on several occasions when suitable conditions prevailed. Alpha and Beta males and breeding size females with no apparent offspring often basked singly on matted grass, floating logs, and living tree trunks.

As spring temperatures rose and pond waters increased the prey resources consisting of insect larvae and adults, mosquito fish, amphibians, and small lizards, the pod of neonates would return to the nursery areas chosen by the female the previous fall after the hatching. Most nursery areas were shallow meadows with varied vegetation for camouflage. Juveniles with sibling neonates were usually guarded as part of the pod as was evident in 1979 when the Palmetto resident female PF-1's 1977 and 1978 hatchlings formed one

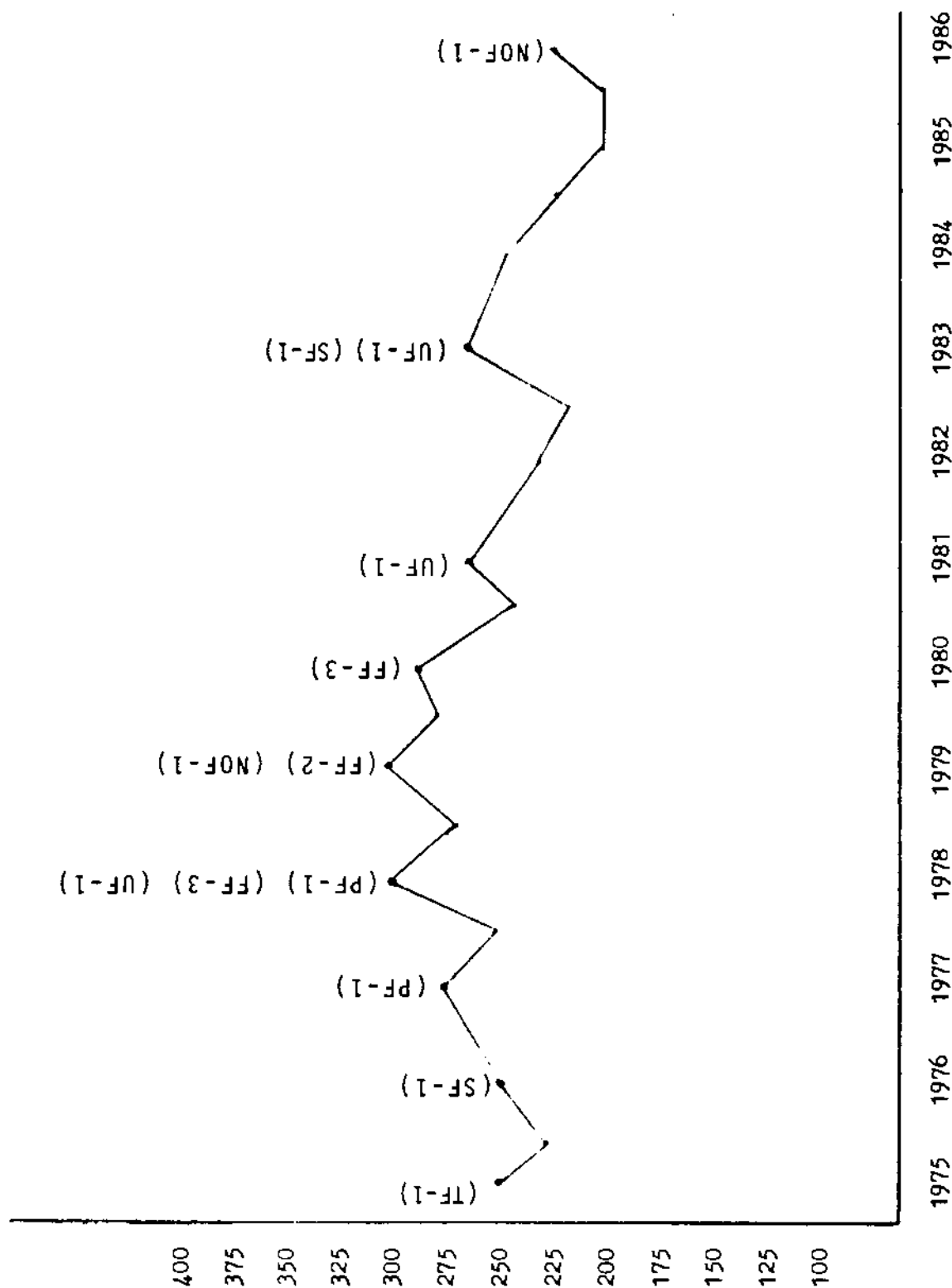


Figure 6. Population estimates of resident Wassaw Island alligators. ( ) indicates the female that nested successfully that year.

pod. Other pods separated or were kept apart by the guarding female. Usher's resident female UF-1's 1978 juveniles relocated to other ponds when the 1981 neonate pod took over the nursery area. The same type of pod separations occurred in 1984 when the 1983 neonate pod took over the nursery area as 1981 juveniles were recovered in Otter Pond. Flag Pond female FF-3 nested successfully in 1978 and in 1980 and the dispersal of the 1978 pod was evident from the nursery area.

**Environmental and Territorial Pressures on Juveniles and Subadult Alligators** - Juveniles and subadults made up the peripheral residents of all fresh-water ponds as long as adequate water levels and prey were available. The 'peripheral' areas of the freshwater ponds were generally flooded, low-forested areas commonly referred to as overflow areas of ponds. These flooded swamp-like areas had no gator holes or large dens. Some small dens excavated by subadults were probably used by nomadic individuals more than as permanent type dens. The capture records indicate a large turnover in peripheral inhabitants and is most likely attributable to the trial and error period experienced by ranging subadults. As confirmed by the tagging project, subadults range from the winter den and spring basking areas into peripheral habitats of freshwater subadult population would relocate into the brackish ponds.

**Prey Availability** - Brackish ponds lack available prey until the high spring tides of late April or early May when thousands of finger size mullet, small shrimp, blue crabs and even tarpon enter through tidal creeks and become stranded until the following fall spring tide. Growing rapidly on the nutrient rich bottom of the brackish ponds, these prey resources provide the proper size food source and quantity for juvenile and subadult coastal alligators where no freshwater fish source is available. The importance of the brackish ponds as the ecological niche exploited by subadult alligators was confirmed by the 91 captures of 65 different alligators in the four brackish pond habitats.

Further subadult alligator captures confirmed their occasional exploitation of tidal pools, sloughs, and surf edge for crabs, schooling fish and dead, deposited bottom species that were washed ashore from commercial fishing trawlers. During one ten-day period in 1977, twenty individual alligators from 1 m to 1.8 m in size were located feeding in pools along a one mile stretch of the boneyard beach. Overall, 32 alligator captures took place on the Barrier Beach habitat of Wassaw Island. Numerous other track sightings on the beach were reported during the study period.

**Tidal Marsh Exploitation** - Marsh sightings of alligators began each spring with the arrival of Beta males in mid-May. Beta male #1 was captured heading toward the marsh near the south landing on 22 May 1977. Presumably too large at 2.3 m (TBL) to benefit from the finger size prey available in the brackish ponds, this and other large subadults and Beta males remain in the tidal marshes until fall cooling temperatures dictate their return to winter dens in freshwater pond embankments. Beta male #2 was captured in Teal Pond on 5 September 1979, four days after a hurricane had passed through plummeting temperatures and refilling the ponds. Beta male #3 was captured in Otter Pond Creek after returning from the tidal marshes on 10 November 1979.

Further information and observation of alligators in the tidal zone began with the captures of subadults feeding on striped mullet (*Mugil cephalus*) which school by the thousands out of the mouth of Mill Creek during outgoing low tides. On 30 June and 2 July 1978, two subadult males, MC78-1 and MC78-2, were captured while feeding in the shallow shoals formed by tidal deposits. Six to eight subadult and adult size alligators were seen by their red eyes which reflected off of hand held lights several times during the summer when below average tides occurred. Extremely low tides can occur due to westerly winds, moon and sun alignment, or as a combination. These lower tides nearly seal off the drainage from Mill Creek. Alligators were observed at night and early morning positioning themselves in shallow passages towards the oncoming current with their mouths 2 to 5 cm agape. As a school of mullet would swim through the small channel, alligators would jerk their heads rapidly sideways in an attempt to catch the fish. Mullet could be seen jumping frantically and turning around in the ambush area. Very few catches were observed, suggesting a low percentage success rate even within a confined area. MC78-1 continued trying to capture oncoming mullet as I approached wading with my headlamp and pole. The violent head jerking motions of

the alligator made noosing extremely difficult and several attempts were required before success was achieved.

During 1980 and 1981 it became more and more apparent that the five previous years of night-time searches and capture successes of the Wassaw Island alligator population had sensitized the freshwater inhabiting alligators. They began reacting to lights by quickly sinking and/or returning to dens. At the end of the 1980 research period, 170 different alligators had been identified on Great Wassaw Island.

Thirteen nights during June, July, and August, 1981, were spent observing alligators in the saltwater creeks and the adjacent marshes. Eighty-seven sightings of alligators were recorded. The smallest was estimated at 1.3 m, the largest 3 m. Patrolling the marshes during spring tides at night with a 100,000 candle power hand-held lamp, I observed only scattered individuals in the main boating channel of Odingsell, Wassaw and Romerly Creeks. As noted previously, six to eight subadult alligators had been observed at the mouth of Mill Creek during separate low and high water observations and eight to 13 large subadult alligators in the winding three km of navigable Mill Creek.

Another observation attempt revealed the most significant feeding behavior to date. To prove the ease of access to and from Mill Creek, my assistant and I canoed out of Otter Pond Creek on an incoming spring tide into the tidal marshes. From the end of Otter Pond, a narrow but distinguishable 40 m trail connected to a small finger channel of Mill Creek. The tide began receding as I reached deeper and wider channels. Mullet were observed pushing and plowing through the *Spartina* marsh grass towards deeper water from the surfacing mud flats. Mullet were seen and could be heard jumping from the shallow marsh beds towards the river channel. Striped mullet, a herbivorous and detritivorous feeding fish, penetrate high mud flats for nutritious deposits of decaying vegetation, and graze on epiphytes and epifauna from marsh grasses and other substrates (Collins 1985). As we approached the first subadult alligator, we found that it had positioned itself perpendicular to the marsh edge with its snout slightly penetrating the first grass stalks. Its mouth agape, body and tail angled down and out in deeper water, the alligator balanced itself against the outgoing current. Mullet were observed pushing, plowing, and jumping out of the higher grass covered mud flats past the alligator's position. The alligator showed no head side-jerking motion before submerging at our approach. Six more alligators from 1.5 m to 3 m (TBL) were observed, all in the same marsh edge position. The largest, an Alpha size male, had positioned himself at the mouth of a small draining tributary across from Mullet Creek intersection with Mill Creek. As his wide head bridged the narrow channel, mullet pushed through the grass edge of the channel, some jumping clear of the water directly over the head of the alligator. With only a slight head-jerk, an Alpha size male caught a 30 cm mullet at midbody. Lifting his head clear of the water, he tossed and rolled the mullet into position for a head-first swallow. The alligator, which hardly moved except in head position, resumed its original position and was not observed capturing another fish for the next hour, as mullet continued jumping and escaping from the small channel by the alligator at a diminishing rate. No other head jerks were observed at the time. An hour after the capture and feeding sequence, the tide had dropped below the surrounding high marsh and no mullet were seen moving toward the deep water channel for 25 minutes. The alligator submerged and did not reappear. No more alligators were seen in the short distance we travelled to the mouth of Mill Creek where it connects with Wassaw Sound. Three hours later, nearing low tide, four large subadults approached the shallow shoals of Mill Creek. Each positioned itself against the current in a shallow passage. Mullet, schooling toward the sound, could be seen and heard by the hundreds as they jumped and swam through the outflowing narrow passages. Soon rapid head-jerking was observed with two animals each successfully catching a mullet.

Beginning in 1981 and continuing through the 1986 research period, marsh boat trips were attempted during the nights of full and new moons. Particular effort was made to capture subadult alligators in Mill Creek in anticipation of recovering previously tagged individuals from interior habitats. During the numerous marsh excursions taken from 1981 to 1986, the receding spring tide feeding behavior was regularly observed.



**Rangewide Movement** - The main advantage of permanent tagging and dorsal caudal scute punch codes is the ability to recapture the marked alligators at any time in the future and have positive identification for comparing data. The projected hypothesis from early observations of the Wassaw Island alligator population was that possible migratory patterns might exist for coastal island alligator populations and that in search of prey, subadult alligators would conditionally leave the freshwater ponds of their winter dens and move into brackish ponds and eventually into the salt marshes and return again to the freshwater winter den site in a cyclic type pattern. Early evidence of rangewide movements came from the 91 captures of juvenile and subadult alligators in the brackish pond habitats. Barrier beach use by alligators searching for crabs, school fish, and washed-ashore, trawler-killed marine animals also was evident by the 32 beach capture records, and finally the additional capture information revealed from the tidal marsh exploiters.

The presence of Beta males in the tidal marshes is most likely attributed to two factors: one, territoriality of Alpha males forcing them from suitable habitat in freshwater ponds; and secondly, the unsuitable prey in the shallow brackish ponds. The smaller, 1.5 to 2.5 m subadults that make up the majority of marsh sightings benefit from the prey resources available in an otherwise marginal or unpreferred habitat. During 1984, S77-5 (1.5 m), F84-2 (1.86 m), F77-1 (1.75 m), and O79-6 (1.44 m) were all captured in Mill Creek. F77-1 had been captured in four different habitat locales since its initial capture in Flag Pond in 1977. S77-5, F77-1 and F84-2 were all initially captured in freshwater ponds. O79-6 was captured in the brackish Otter Pond in 1979. Here was increasing evidence of the use of the salt tidal zone as an ecological niche important to the growth and survivability of a coastal island American alligator population. During 1985, D85-1 (1.62 m) was captured in Mill Creek, further suggesting a preference for a larger prey source over the smaller source provided in the brackish environment of Dike Pond. This past season (1986), MC78-1 (2.07m) was recaptured in the Mill Creek tributary of Mullet Creek. Because eight years had passed since MC78-1's initial capture, it is possible that the tidal marshes provided an available food source necessary to bridge the gap for large subadults and Beta males until a suitable freshwater habitat could be found.

**Long Distance Recoveries** - Female S77-2 (1 m TBL) was first captured in the peripheral southern end of South Pond and was captured again 13 days later on the South End Beach (straight line distance 6.5 km) with jumping cactus spines impaled in her skin from crossing the transitional dune ridge habitat. The greatest distance covered by a recaptured Wassaw alligator was recorded in the 1980 study season. B80-1 female (1.5 m TBL) was captured and tagged on the central barrier beach of Wassaw Island. Fifteen days later an employee with the South Carolina Wildlife Services captured the same tagged alligator as it crossed a dirt road 1.6 km west of the beach on Hilton Head Island, South Carolina (straight line distance between capture sites was over 50 km). In 1982, O82-1 (1.25 m TBL), originally caught in Otter Pond, was recaptured three months later by the Georgia Department of Resources on Wilmington Island (total straight line distance travelled was 12 km). Another alligator captured in Otter Pond in 1982, O82-9 (0.91 m TBL), was recaptured in 1984 using a flap gate trap developed by A.C. Pooley in Natal, South Africa. The colored plastic rings in the dorsal caudal punched scutes alerted a Talahi Island resident to his new guest in his private catfish pond. This alligator (O82-9) had moved 13.5 straight line km from its original capture sight two years earlier.

The recapture record for many individual Wassaw alligators shows a limited distance covered when recaptured. However, the island's complex and varied habitat zones are compact and close. There is strong evidence of ranging behavior in search of adequate habitat and proper size prey availability. Table 1 lists recaptures with habitat changes and the covered distances.

## DISCUSSION

The barrier islands of Georgia's Atlantic coast offer a variety of habitats that are exploited by different size alligators. On Wassaw Island neonates, juveniles, and even subadults were observed emerging from the communal winter dens of adult nesting females. The adult males and the remaining subadults

hibernated from December to March in separate dens. All winter dens were in the freshwater habitats. By establishing the location of the Wassaw Island alligator population in the freshwater habitats when they emerge from the winter dens for basking, their movements were determined from the capture data. Neonates preyed on amphibians, mosquito fish, insects and other arthropods that were abundant in the flooded marshes of spring and fall. Gator holes as reported previously (Meyer 1975) serve as the last freshwater sources on the barrier islands. Dominate males and females capture prey that comes to drink at these water holes (four deer carcasses and one skull with alligator teeth marks were found during this study).

The movements of alligators of Wassaw Island were attributed to several factors. Fluctuating water levels in freshwater ponds have prevented the successful establishment of freshwater fish that are available throughout a majority of the alligators range (Neill 1971). The seasonally abundant fish and crustaceans in brackish habitats on coastal barrier islands were used as the primary food sources for juvenile and < 1.5 m (TBL) subadult alligators. Subadult alligators observed on the barrier beach in tidal pools left by the receding tide demonstrated a feeding method of raking with open jaws through the loose sand at the bottom of the pools for locating and capturing blue crabs. Carrion feeding, on fish and crustaceans deposited by wave action after being thrown overboard from commercial trawlers, was also observed among the barrier beach alligators. Subadult alligators > 1.5 m (TBL) and Beta males exploited the tidal marshes for larger prey such as striped mullet. By blocking or constricting the exit areas of feeding and schooling mullet, alligators were able to snap at the concentrated fish, increasing the possibilities of capture. The Nile crocodile also exhibits a feeding behavior for mullet species at Lake St. Lucia in Natal, South Africa. Pooley and Gans (1976) reported that crocodiles cooperate by forming a semi-circle where a channel empties and the crocodiles catch the incoming fish as they pass through the ranks.

The capture and tagging of the subadult alligator population established over the ten year study period that the coastal alligators were forced to adapt to new habitats and that some food sources required increasingly more sophisticated capture techniques as the alligators matured. The demand by the increasing human population for more waterfront and coastal island properties will inevitably cause additional strain on the resident alligators. Emigrating individual alligators from the Wassaw population have already been recaptured in human residential areas where new deep water habitat was developed.

Human population pressures on the coastal islands are expected to continue into the next century. Government planners and private developers should set aside adequately protected nesting and nursery areas so that the increasing alligator population won't become a dangerous conflict to the new human residents. However, care must also be taken not to destroy the corridors and brackish systems necessary for the movement and survivability of the subadult alligator population of Georgia's Atlantic coastal zone.

#### ACKNOWLEDGEMENTS

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## LITERATURE CITED

- Bustard, H.R., and B.C. Choudhury. 1981. Marking crocodiles for release back into the wild for subsequent identification. *Indian Forester* 102:477-485.
- Collins, M.R. 1985. Species Profiles: Life histories and environmental requirements of coastal fishes and invertebrates (South Florida): Striped mullet. Biological Report 82(11.34) TR EL-82-4.
- Goodwin, T.M., and W.R. Marion. 1979. Seasonal activity ranges and habitat preferences of adult alligators in a north-central Florida lake. *J. Herpetol.* 13:157-164.
- Joanen, T., and L. McNease. 1970. A telemetric study of nesting female alligators on Rockefeller Refuge, Louisiana. *Proc. Ann. Conf. Southeast Assoc. Game and Fish Comm.* 24:175-193.
- \_\_\_\_\_, and \_\_\_\_\_. 1972a. Population distribution of alligators with special reference to the Louisiana coastal marsh zones. Mimeo. *Proc. Symp. Am. Alligator Council.* Lake Charles, Louisiana.
- \_\_\_\_\_, and \_\_\_\_\_. 1972b. A telemetric study of adult male alligators on Rockefeller Refuge, Louisiana. *Proc. Ann. Conf. Southeast Assoc. Game and Fish Comm.* 26:252-275.
- Meyer, G.R. 1975. Alligator ecology and population structure on Georgia Sea Islands. Abstract. *Am. Soc. Ichthy. Herp. Program, 1975 Annual Meeting.*
- Neill, W.T. 1971. The last of the ruling reptiles: Alligators, crocodiles, and their kin. Columbia Univ. Press, New York.
- Pooley, A.C., and C. Gans. 1976. The Nile crocodile. *Sci. Am.* 4:114-124.
- Smith, E.N. 1980. Growth and movement of the American alligator in south Texas: A preliminary report. Report Welder Wildlife Refuge, Sinton, Texas. Mimeographed.

Table 1. Recorded Habitat Changes of Wassaw Island Subadult Alligators.

Identity Code	Original Capture/Date	New Habitat/ Recapture Date	Distance Covered
I76-2	Island Interior 25-5-76	South Pond 28-4-77	1.8 km
		Barrier Beach 18-7-77	4.8 km
		Otter Pond 23-8-84	1.1 km
S77-2	South Pond 28-4-77	Barrier Beach 11-5-77	6.5 km
Beta Male #1	Island Interior 22-5-77	Wassaw Creek 28-7-84	0.7 km
S77-5	South Pond 25-5-77	Mill Creek 30-6-84	5.5 km
F77-1	Flag Pond 7-6-77	Cedar Pond 06-9-78	1.2 km
		N. Otter Pond 11-9-78	0.6 km
		Mill Creek 27-8-84	1.5 km
B77-2	Barrier Beach 16-7-77	Otter Pond 13-9-86	0.8 km
B77-4	Barrier Beach 17-7-77	Cedar Pond 02-6-79	1.6 km
B77-16	Barrier Beach 24-7-77	South Pond 26-4-80	6.3 km
P78-2	Palmetto Pond 25-5-78	Barrier Beach 15-6-82	3.4 km
I79-1	Island Interior 11-5-79	Wassaw Creek 20-7-83	3.7 km
I79-2	Island Interior 04-7-79	South Pond 11-8-79	0.2 km
O79-6	Otter Pond 02-8-79	Mill Creek 10-10-84	1.4 km
U79-10	Usher Pond 06-8-79	Otter Pond 29-8-83	1.6 km
U79-11	Usher Pond 14-8-79	South Pond 06-7-84	1.0 km
NO80-7	N. Otter Pond 28-8-80	Otter Pond 29-6-82	0.1 km
NO80-11	N. Otter Pond 28-8-80	South Pond 28-8-80	3.2 km
NO80-14	N. Otter Pond 28-8-80	Otter Pond 26-7-85	0.1 km
U81-1	Usher Pond 15-9-81	Otter Pond 29-8-83	1.6 km
F84-1	Flag Pond 21-5-84	South Pond 21-7-84	2.4 km
F84-2	Flag Pond 30-5-84	Mill Creek 27-8-84	1.4 km
D85-1	Dike Pond 26-7-85	Mill Creek 14-10-85	2.6 km

# THE CAIMAN OF THE PANTANAL: PAST, PRESENT, AND FUTURE

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The Pantanal is a complex region which lies in the basin of the Rio Paraguai, in the Brazilian states of Mato Grosso and Mato Grosso Du Sul. The region is approximately 100,000 km<sup>2</sup>, and is largely composed of permanent swamp, seasonal swamp, gallery forest, marginal scrub, savannah, and semi-deciduous forest. The Pantanal, for the most part, is less than 100 m above sea level. The climate ranges from extreme drought to rainfall in excess of 1200 mm, which falls between December and February. Temperatures may range from nearly 0° C in the dry season to over 40° C during the rainy season. While endemic species are widespread, they are few in number. The Pantanal caiman or Jacare, better known as the Yacare caiman, *Caiman crocodilus yacare*, is the only crocodilian which inhabits the Pantanal proper (Medem 1983, Prance and Schaller 1982, Schaller and Crawshaw 1982; Fig. 1).

Because the hide of the Yacare caiman bears wider flank regions (Fig. 2a, 2b; the portions most often used in the manufacture of products) than the other races of caiman, it has been the more desirable species and the mainstay of the commercial caiman leather trade. In the United States alone, the caiman hide and product trade, which includes the Yacare, amounted to over ten million dollars in declared value for the first nine months of 1986 and included 355,560 items. Caiman skins, including Yacare, make up at least three-quarters of the estimated 1.5 to 2 million crocodilian skins in annual world trade. However, Yacare only occur in southern Brazil, eastern Bolivia, northeastern Argentina, Uruguay and Paraguay (King and Brazaitis 1971, Brazaitis 1973, Medem 1983). Paraguay and Bolivia are the major exporters of Yacare hides (Hemley 1979).

Yacare caiman are listed under Appendix II under CITES and as an endangered species under the U.S. Endangered Species Act, and are banned from the U.S. trade since June, 1970. In 1971 and in 1974, Karlheinz Fuchs, in non-scientific industry trade journals (Fuchs 1971, 1974), described several races of Yacare caiman (*C. c. paraguayensis*, *C. c. matogrossoensis*) as *nomen nudum*. They were added to the checklist of crocodilians by Wermuth and Mertens (1977), and were subsequently repudiated by Medem (1983), Frair and Behler (1983), and Mayer and Ross (in prep.). Although these *C. c. yacare* synonyms were not adopted as valid subspecies, exempt from the endangered classification of the USA, the names were incorporated into the 1983 official CITES Identification Manual. Today, prompted by industry pressure and the taxonomic confusion which has been raised, and which could have serious ramifications on the management and conservation of the species, the Yacare caiman, particularly populations from Brazil, Paraguay, and Bolivia, are the subject of intensive taxonomic and populational investigation. At this time, the species continues to be banned from U.S. trade. Anticipating the possible availability of large numbers of Bolivian and Brazilian Yacare skins in a climate of relaxed controls, and fueled by the recent infusion of Venezuelan "baba" (*C. c. crocodilus*) skins into the market, the crocodilian skin leather trade launched a major fashion campaign to promote crocodilian skin products in 1986-1987.

The Yacare of the Pantanal is highly subject to any increased demands for Yacare hides. Yacare populations in Brazil, which are totally protected under Law 5197 since 1967 (Fuller and Swift 1984) largely inhabit the Pantanal, a region bordered by Bolivia and Paraguay. Despite complete protection, Brazilian Yacare have historically been taken illegally in large numbers by Bolivian and Paraguayan traders. Unfortunately, illegal hunting practices often take place during periods when the animals are most susceptible to drastic depletion. Animals congregate in numbers in small shallow cattle watering ponds during the dry season. Although areas may be remote and inaccessible during the wet season, such ponds



Figure 1. Bold dark blotches on the sides of the jaws and an overall dark body coloration are typical of adult *Caiman crocodilus yacare* in the Pantanal.



Figure 2a. The region of the body between the fore and hind limbs of *Caiman crocodilus yacare* is particularly wide and bears aesthetically pleasing round scales. These "flanks" are often the only portion of the animal which is utilized, while the remainder of the wild killed animal is discarded.



Figure 2b. The tanned "flank" may include the side of the body, short portions of the legs, the throat, and the base of the tail. Flank skins make up the bulk of the caiman leather trade, and are used to make belts, watchbands, shoes and wallets. In 1986 and 1987, whole belly skins of caiman from the Pantanal began to appear in great numbers as imports into the United States. All are seized by the U.S. Fish and Wildlife Service. Caiman belly skins most often were used in the manufacture of luxury handbags and are often labeled as ALLIGATOR.



are easily accessible by truck during the dry season. Light aircraft can also land virtually anywhere in the Pantanal to pick up illegally taken skins, and fly directly out of the country to ports in Bolivia and Paraguay. Females with young are particularly susceptible, in that lone females are attending young in small easily accessible nursery ponds during the heavily hunted dry season (Cintra 1985, Crawshaw and Schaller 1980). The effect of these illegal hunting practices on the Pantanal caiman is evident.

In cooperation with the Instituto Brasileiro de Desenvolvimento Florestal (IBDF) and Long Island University, New York, and with the support of WWF-U.S.A. and the New York Zoological Society, I visited the Pantanal in October/November 1985 on a cursory preliminary survey of Yacare populations. Areas previously surveyed by Schaller and Crawshaw in October 1978 were re-assessed. Populations were sampled in a transect of the Pantanal from north to south, and west to the Bolivian border. Although the results are not conclusive, based on the very short survey period, they are indicative of the current situation. Few animals found were larger than 1.2 to 1.8 m in length, considerably smaller than the 2.5 m to 2.8 m size potential for the species. In most populations of adults sampled, and observed by Brazilian biologists, males often outnumber females 4:1. In one pond, one female dominated a pond containing over 30 males. In contrast, a sex ratio of 1:1 was not uncommon in populations of sub-adult animals less than one meter in length. Along one 14 km stretch of road bordered by several cattle ponds, Schaller and Crawshaw (1982) estimated a Yacare population of 2000 to 3000 animals. In October 1985, we found the ponds to contain between 25 to 50 animals, and the entire stretch to contain fewer than 500 to 600 animals, mainly in locally protected isolated pools.

Although poachers also take anaconda, spotted cats including jaguar, plus otters and tapirs, they frequently operate unchallenged. Poachers are well equipped and well organized. Even when apprehended, they often escape imprisonment and have fines and the value of confiscated skins reimbursed by the hide buyers. New roads for a developing tourist trade are opening otherwise inaccessible regions. Brazilian wildlife authorities are doing an exemplary job in attempting to stem the flow of illegal skins, but they are working under difficult conditions with little money, poor judicial support, and little equipment. One officer confided that he had called off an attack on a known poaching operation when he realized his men had an average of three bullets per person. Landowners, except for a brave few, do not interfere with poaching unless the poachers take cattle or salt stores.

The future of the Yacare in the Pantanal, as well as the economy of this unique region, could be permanently enhanced by the sound management and conservation of this important wildlife natural resource. Landowners as well as several government agencies have begun to develop pilot projects which would utilize the protected wild populations as a basis for caiman ranching operations. The local fishing industry, and the developing tourist trade may become positive complementary industries. Effective conservation may lie not only in law enforcement, but in an awareness by local peoples in the Pantanal that the protection of the wild population, particularly nesting females, can result in a renewable "cash crop" of young animals for Brazilian caiman ranches. Such an industry has a long way to go. To be economically feasible, a ranched caiman must produce a total estimated return of about \$200 in hide, meat, bone, and tourist revenues. Hide dealers pay only U.S. \$5 to \$10 per skin. Thus, the illegal trade must be stopped if a new ranching industry is to prosper. At the present time, ranching efforts are in their infancy (Luxmoore et al. 1985) and range from serious business investments and the development of state of the art husbandry techniques, to operations such as were seen in Miranda in Mato Grosso do Sul. There, when it was learned that Brazilian authorities may open a hunting season, a new sign was erected in anticipation, naming the ranch "caiman ranch." When I asked where the rearing areas were, the reply was, "The whole ranch. When the time comes, we will kill all of the wild ones."

The long term future of the Pantanal Yacare, and perhaps the economy of local peoples, may best be served not simply in estimating the extent of the endemic Yacare population and harvesting it to its maximum, but in making provision for and supporting the growth of a new Brazilian industry which encompasses the management and conservation of the wild population, ranching, tanning, fishing, marketing and tourism. Such an industry might well be of infinitely greater long range benefit to many more of the Brazilian people and may better preserve the Pantanal caiman.

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I would like to express my thanks to Dr. David Challinor, Smithsonian Institution; World Wildlife Fund - U.S.A.; The New York Zoological Society, particularly John Behler; Dr. Dennis Curley and Long Island University; Jordan Wallauer, Peter Crawshaw and IBDF, Brazil, for help, support, and hospitality during the course of this work. I would also particularly like to express my thanks to my Brazilian colleagues in IBDF, Carlos Yamashita and Renato Cintra who provided me with field assistance, friendship, and an "orthopedic road." There were many others in Brazil, too numerous to mention. Lastly, to my wife Dr. Myrna Watanabe, for her extreme patience and counsel -- my most valued colleague.

## LITERATURE CITED

- Brazaitis, P. 1973. The identification of living crocodilians. *Zoologica* 58:59-101.
- Cintra, R. 1985. Nascimento de filhotes de *Caiman yacare* (Daudin, 1802) (Crocodylia: Alligatoridae) em condicoes semi-naturais no Pantanal Matogrossense. *Papeis Avulsos de Zool., S. Paulo* 36:91-101.
- Crawshaw, P.G., Jr., and G.B. Schaller. 1980. Nesting of Paraguayan caiman (*Caiman yacare*) in Brazil. *Papeis Avulsos Zool.* 33:283-292.
- Frair, W., and J.L. Behler. 1983. Review of Liste der Rezenten Amphibien und Reptilien. Testudines, Crocodylia, Rhynchocephalia. *Herp Rev.* 14:23-25.
- Fuchs, K. 1971. Die sudamerikanischen Reptilhaute. *Das Leder* 22:3-19.
- \_\_\_\_\_. 1974. Die Krokodilhaute. *Eduard Rother Verlag, Darmstadt.* 183 pp.
- Fuller, K.S., and B. Swift. 1984. Latin American Wildlife Trade Laws. *World Wildlife Fund-U.S.A., Washington, D.C.* 354 pp.
- Hemley, G., and J. Caldwell. 1986. The crocodile skin trade since 1979. Pp. 398-412 in Anon., ed. *Crocodiles. Proc. 7th Working Meeting Crocodile Specialist Group SSC/IUCN. Gland, Switzerland.*
- King, F.W., and P. Brazaitis. 1971. Species identification of commercial crocodilian skins. *Zoologica* 56:15-70.
- Luxmoore, R., J.G. Barzdo, S.R. Broad, and D.A. Jones. 1985. A Directory of crocodilian farming operations. *IUCN, Cambridge, U.K.* 204 pp.
- Medem, F. 1983. Los Crocodylia de Sur America. Volumen II. *Colciencias, Bogota, Colombia.* 270 pp.
- Prance, G.T., and G.B. Schaller. 1982. Preliminary study of some vegetation types of the Pantanal, Mato Grosso, Brazil. *Brittonia* 34:228-251.
- Schaller, G.B. 1983. Mammals and their biomass on a Brazilian ranch. *Arq. Zool., Sao Paulo* 31:1-36.
- \_\_\_\_\_, and P.G. Crawshaw, Jr. 1982. Fishing behavior of Paraguayan caiman. *Copeia* 1982:66-72.
- Wermuth, H., and R. Mertens. 1977. Liste der Rezenten Amphibien und Reptilien. Testudines, Crocodylia, Rhynchocephalia. *Das Tierreich* 100:1-174.

# A COMPARISON OF SIZES OF CAIMAN IN HUNTED AND NON HUNTED AREAS IN THE BRASILIAN PANTANAL

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**ABSTRACT** - Sizes of hunted caiman (based on snout-vent length of confiscated skins) in the Brazilian Pantanal were compared with sizes of animals in an unhunted population. There is a significant difference between the size distribution of skins of hunted animals and sizes of animals available in the unhunted population. The hunters show a clear preference for caimans larger than 80 cm snout-vent length.

## INTRODUCTION

The Paraguayan caiman (*Caiman yacare*) may be the most heavily exploited crocodilian in the world, but we know almost nothing about the effect of hunting on populations of this species. We can however, get an idea of the sizes being hunted from the sizes of confiscated skins.

The aim of this paper is to present data on the size of caiman being hunted in the Brazilian Pantanal and compare these with data of sizes of animals in an unhunted population.

## METHODS

I studied the caimans along the transpantanal road in the Municipality of Poconé (56° 59' West, 17° 16' South). The Pantanal is a large area (100,000 km<sup>2</sup>) of seasonal swampland in southwestern Brazil.

During the dry season the caiman form large concentrations in natural and artificial pools along the road. Individuals (200) of different sizes and both sexes were randomly captured and measured.

To get an idea of the size of caiman being hunted, I measured a random sample of skins confiscated by IBDF (the Brazilian wildlife agency), near the Bolivian border. I measured 95 of the approximately 600 skins that they had confiscated.

Because the hunters cut around the neck and in front of the vent it was impossible to measure snout-vent (SV) length directly. I estimated the snout-vent length and the distance between the front and back legs in entire skins. Unfortunately, I had no entire skins of *Caiman yacare* and so I estimated the relationship based on 61 entire skins of the closely related species, *Caiman crocodilus*, which were confiscated by IBDF of Manaus. I used the following equation:

$$SV = \frac{DBL + 1.75}{0.49}$$

Where DBL = Distance between front and back legs; ( $1.75 = a$  and  $0.49 = b$  values of the linear regression of DBL on SV) made for *Caiman crocodilus* skins ( $r = 0.94$ ).

## RESULTS

There is a significant difference between the size distribution of skins of hunted animals and sizes of animals available in the unhunted population. (Fig. 1).

It is unlikely that the sizes of animals in the hunted population are larger than animals in the unhunted population. Therefore the hunters are showing a clear preference for caimans larger than 80 cm snout-vent length.

This small sample suggests that the populations are not being reduced by the hunting. However, the only valid way to determine the effects of hunting is to directly survey the hunted population. This is not being done in Brazil. In a postal survey of the 14 IBDF agencies, Rêbello and Duarte (1984) recorded 8,622 crocodilians among 31,165 reptile skins. And Duarte and Rêbello (1985) recorded 26,880 carnivore skins just in the IBDF office in Rio de Janeiro, but they were not sure if these skins come from the rest of country or due to more efficient confiscation in that state. Even the indirect method of assessing the sizes of hunted skins has not been used in Brazil, since the study by Rêbello and Magnusson (1983). Most skins of crocodilian and other wild life confiscated are destroyed with minimal or no documentation. Just the IBDF office in Manaus will burn about 3000 *Caiman crocodilus* skins. Although there are IBDF Projects to register the confiscated skins of endangered species, it is not well controlled and organized by each regional agency, and the data is not available to the Scientific Community.

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## LITERATURE CITED

- Duarte, J. C. S., and C. H. Rêbello. 1985. Carnivore skins held in Brazil. Traffic Bulletin Vol. VII no. 1: 16-17.
- Rêbello, G. H., and J. C. S. Duarte. 1984. Crocodile specialist group Newsletter, 3 (1). Fev./84.
- \_\_\_\_\_, and W. E. Magnusson. 1983. An analysis of the effect of hunting on *Caiman crocodilus* and *Melanosuchus niger* based on the sizes of confiscated skins. Biological Conservation 26: 95-104.

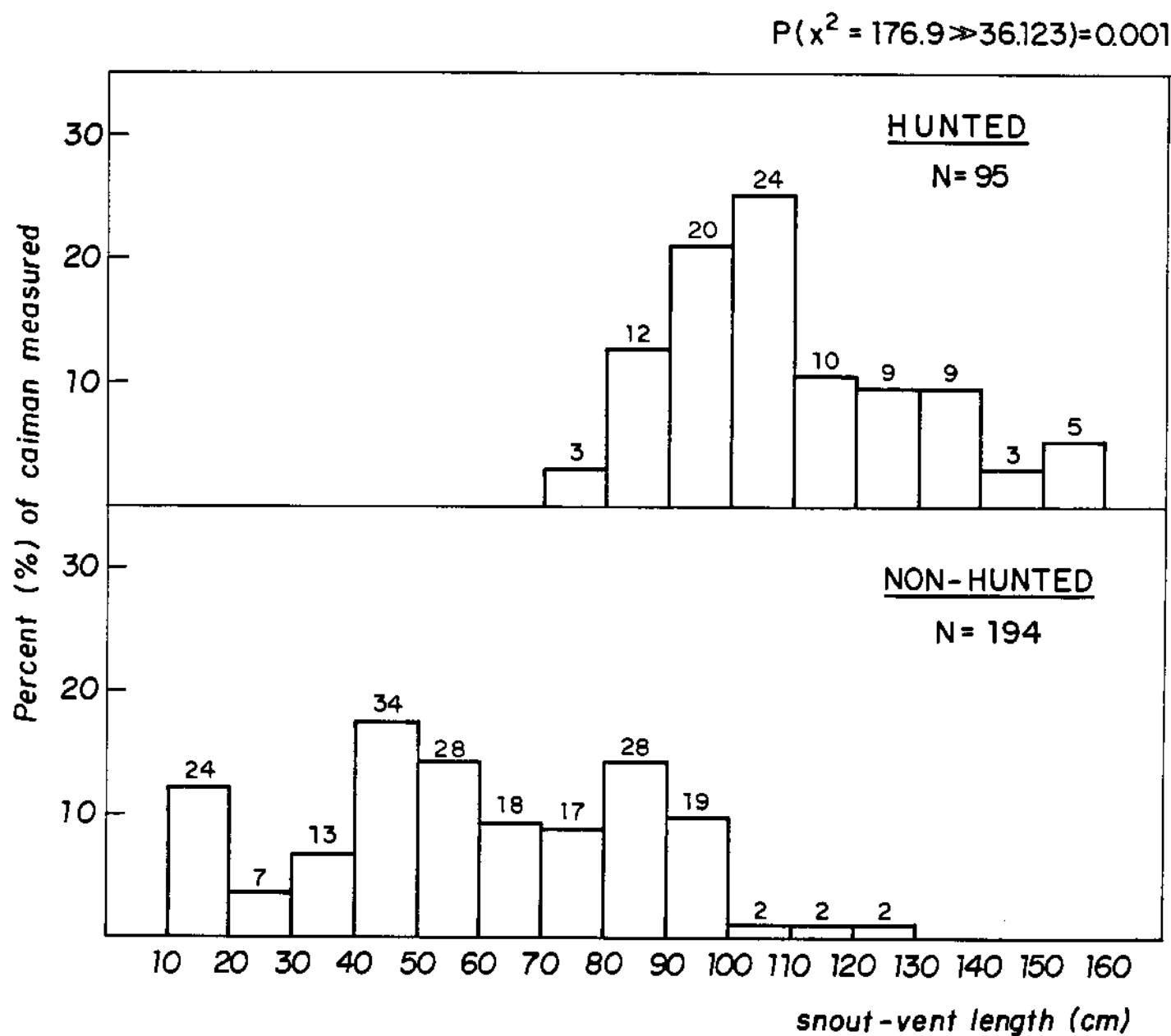


Figure 1. Comparison of size (by snout-vent length) between hunted and non-hunted caiman from two different areas in the pantanal.

**THE CAIMANS OF BOLIVIA:  
A PRELIMINARY REPORT ON A CITES  
AND CENTRO DE DESARROLLO FORESTAL  
SPONSORED SURVEY OF SPECIES DISTRIBUTION AND STATUS**

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**ABSTRACT** - Between June 1986 and May 1987, a survey of the species and distribution of Bolivia's caimans was conducted, including rough estimates of relative abundance of both species and habitat, species utilization and status. Preliminary results suggest that as a consequence of commercial hunting for their hides, *Caiman latirostris* is in immediate danger of extinction; *Melanosuchus niger* is more widely distributed but also is in danger of extinction; and *Caiman yacare* remains widely distributed despite being badly mismanaged. *Paleosuchus palpebrosus* and *Paleosuchus trigonatus* are not commercially hunted and remain locally abundant. Utilization of the caiman resource and the status of wildlife conservation in Bolivia is reviewed. To address regional conservation problems, two resolutions are offered for consideration at the 6th Meeting of the Conference of the Parties to the CITES in Ottawa, Canada, 12-24 July 1987.

## **INTRODUCTION**

This survey of Bolivia's caimans was undertaken at the request of the CITES Secretariat, and conducted under the terms of a formal Convenio (= Memorandum of Understanding) between the Secretariat, on behalf of CITES, and the Centro de Desarrollo Forestal (CDF), on behalf of the government of Bolivia. Vida Silvestre, Parques Nacionales, Caza y Pesca (= Wildlife, National Parks, Hunting, and Fishing) is a department of CDF. The Bolivian survey is part of a larger, tripartite, regional effort, aimed at developing and implementing a comprehensive program for conserving the caimans of Bolivia, southwestern Brazil, and Paraguay. The immediate purpose of the survey was to verify what species of caiman occur in Bolivia and to determine the exact distribution of each. This information will enable the government of Bolivia to assure that its management authority issues CITES country of origin export permits solely for species of caiman that are found in Bolivia.

In addition, the survey is the first phase of an effort to develop a program that monitors the impact of hide exports on the wild populations as required under Document 6.2 of the Buenos Aires Conference of the CITES Parties. During the survey, populations of caimans were identified which could be studied in a second phase of the project to document the ecology and natural history of each species. Data from those studies will provide the scientific base upon which a program for the conservation management and sustained utilization of the caiman resource can be built, thereby satisfying Doc. 6.2.

## METHODS

The species and subspecies of caimans differ in color, morphology of the skull, the numbers of scales on different parts of the bodies, and in various biochemical attributes. In order to verify the specific characteristics of Bolivia's caimans, it was necessary to collect and preserve voucher specimens, which could be used not only by the present research team, but which also would be available to other researchers, who might wish to verify our findings. All the specimens from the tripartite study in Bolivia, southwestern Brazil, and Paraguay, are being shipped to the Florida State Museum (FSM)\*, Gainesville, Florida, U.S.A. In the FSM, the morphology and biochemical characteristics of the voucher specimens will be studied by a single team of researchers, thereby minimizing differences that might inadvertently be introduced if specimens from each of the three countries of origin were studied by separate teams of researchers. When the study is complete, all the specimens will be deposited in the systematics research collections of natural history museums, where they will be available to future researchers. At least 50% of the specimens will be returned to natural history museums in the countries of origin.

The extent and suitability of potential habitat at most collecting sites were explored during the day, but collecting was done at night when caimans are more easily located by their eyeshine reflected in the beam of a spotlight. Every effort was made to collect specimens as humanely as possible; smaller specimens were captured alive by hand and larger specimens were killed instantly by shooting them in the brain. Specimens captured alive were euthanized by lethal injection. Specimens smaller than 1.5 m total length usually were preserved whole, while larger specimens usually were flayed (with attached skulls) after being measured, weighed, and sexed. All specimens were individually tagged and preserved in 10% formalin. After shipment to the FSM, all the specimens were transferred to 60% isopropyl alcohol. In the field, data were recorded on the exact locality where each specimen was collected, as were data on habitat. Blood, liver, heart, muscle, and skin tissue samples were collected from approximately 20% of the specimens after they were euthanized but before preservation. The tissues were dried for later biochemical analysis. Data from these analyses will characterize the various taxa and populations and complement the data from the morphological studies. A total of 3 voucher specimens, hides with regional locality data, were contributed by hide buyers, and 2 additional specimens came from illegal hides, from known localities, seized by CDF forest guards.

Attempts were made to estimate the size and/or density of selected wild populations by counting the number of caimans, e.g., the animals seen or reflected eyeshine, seen per km of river or lagoon shoreline. Some rivers and lagoons were sufficiently small to allow both shores to be scanned from a boat in midstream. Other rivers and lagoons had mudbanks or rockbars that prevented close approach to one shore or were so wide that only one shore could be scanned. For this reason, population densities were estimated on the basis of km of shoreline rather than km of river. By virtue of their narrowness, roadside borrow pits and ditches are an exception; their populations are estimated on the basis of km of length. Having no large scale maps or aerial photographs of the particular waterways, we lacked accurate means of measuring the distances covered. As a consequence, these findings are presented solely as a crude index of abundance and not as incontestable census figures.

Habitat types were quantified by means of aerial transects, i.e., recording how long it took each major habitat type to pass the wing strut of a Cessna 185 flying approximately 140 m above the ground, and then using those data to estimate total available habitat.

Bolivia is so large and has so much potential habitat that it would be impossible to sample every population of caimans with 5 years of effort, much less with only 6 months in the field. Faced with that reality and the concurrent need to uncover every species of caiman that occurs in Bolivia, the survey team made an effort to collect specimens from upstream, downstream, and in between, in every major river system, and from every lake region, network of marshes, and principal wetlands complex. If unexpected

\* In 1988, the name was changed to the Florida Museum of Natural History.

taxa or unusual populations were uncovered in these samples, additional collections were made in the particular region and in surrounding drainage systems.

Illegal cocaine operations made collecting impossible in some regions and difficult in others -- in September 1986, Noel Kempff Mercado, Director of the Santa Cruz de la Sierra Zoo, and two companions were killed when they stumbled onto a cocaine extraction operation in the Serrania Huanchaca of eastern Santa Cruz. Because of these illegal operations, it was not possible to collect extensively in the Chapare region (the lowland portion of the Department of Cochabamba, and adjacent portions of the Department of Beni), involving the upstream sections of the Mamore drainage. Collections also were not as extensive as desirable in the upper Beni river drainage (in southwestern Beni).

Interviews with caiman hunters, hide buyers, ranchers, and knowledgeable local residents provided much valuable data on the distribution and natural history of various caimans.

F. Wayne King and Fred G. Thompson (Florida State Museum, Gainesville, Florida, U.S.A.) and Carlos Alvarez and Dante H. Videz Roca (CDF, Santa Cruz, Bolivia), began the survey on 14 June 1986 in the central and eastern regions of the Department of Santa Cruz, and continued fieldwork in the northern and southern regions until late July. Thompson and Videz surveyed south through the Departments of Chuquisaca and Tarija during the last week in July. King, Thompson, and Videz, surveyed north into the Departments of Beni and Pando in August, ending there on 28 September. Jose Labao Tello (Maputo, Mozambique), who was conducting a survey of the felids of Bolivia on behalf of CITES and CDF, assisted the caiman survey team in Beni and Pando in August and September. From 7 to 21 January 1987, King and Videz resumed the survey in the Departments of Beni and La Paz, and were assisted briefly by Mario Challapa Zapata (CDF, Beni, Trinidad).

Finally, from 18 to 26 May 1987, the fully tanned and finished caiman hides in the warehouses of the six licensed members of the Asociación de Industriales de Cueros de Saurios (ASICUSA) were inventoried by King, Videz, Peter Brazaitis (New York Zoological Society, Bronx, New York 10460, U.S.A.), Juan Villalba-Macias (TRAFFIC/SudAmerica, Montevideo, Uruguay), Candido Pastor (CDF, Cochabamba), and Heriberto Cardozo (CDF, Santa Cruz).

## RESULTS

Since morphological and biochemical analyses of all the specimens collected in Bolivia and Paraguay have not been completed, and the Brazilian specimens are only now being collected, the results reported here are to be considered preliminary. Identifications might change when the analyses are completed. In addition, apart from using the specific name *Caiman crocodilus* rather than the synonym *Caiman sclerops*, the nomenclature used in this report follows that used by the last revisor of South American caimans, Professor Federico Medem (1981, 1983) in recognizing:

- Caiman crocodilus* (Linnaeus 1758).
- Caiman crocodilus apaporiensis* Medem 1955
- Caiman crocodilus chiapasius* (Bocourt 1876)
- Caiman crocodilus crocodilus* (Linnaeus 1758)
- Caiman crocodilus fuscus* (Cope 1868)
- Caiman latirostris* (Daudin 1802).
- Caiman latirostris chacoensis* Freiberg and Leitao de Carvalho 1965.
- Caiman latirostris latirostris* (Daudin 1802)
- Caiman yacare* (Daudin 1802).
- Melanosuchus niger* (Spix 1825).
- Paleosuchus palpebrosus* (Cuvier 1807).
- Paleosuchus trigonatus* (Schneider 1801).



Wermuth and Mertens (1961, 1977), King and Brazaitis (1970), Groombridge 1982), and Wermuth and Fuchs (1983) treat *C. yacare* as a subspecies of *C. crocodilus*, but virtually no justification is given. Schmidt (1928), Donoso-Barros (1974), and the last revisor of the caimans, Medem (1960, 1981, 1983), recognized it as a full species and described its distinctive morphology. While he did not propose separating it as a full species, Densmore (1983), showed that there was more evolutionary distance between *yacare* and the other subspecies of *C. crocodilus* than there was among those other subspecies, evidence which tends to support separation as a species.

Medem (1983), did not consider *Caiman crocodilus matogrossiensi* and *Caiman crocodilus paraguayensis* to be recognizable subspecies. Morphological and biochemical analyses of the specimens collected by the Bolivia, southwestern Brazil, and Paraguay surveys may prove *matogrossiensi* and *paraguayensis* to be good subspecies, but we are following Medem until the analyses have been completed.

**Species:** In his 1973 survey of the caimans of Bolivia, Medem (1983), confirmed the presence of *C. latirostris latirostris*, *C. yacare*, *M. niger*, *P. palpebrosus*, and *P. trigonatus* (Figs. 1-5). Though Bolivian officials have issued CITES country of origin permits for the export of *C. c. crocodilus* hides, Professor Medem did not find this taxon in Bolivia. He did report it (Medem 1983), from upstream tributaries of the Rio Madre de Dios in Peru, and suggested hybridization between *yacare* and *crocodilus* should occur on the upper and middle reaches of the Rio de Madre de Dios upstream of the northwestern border of Bolivia. The present survey largely confirms Professor Medem's findings.

*Caiman latirostris* = Overo and Caiman del Chaco. The Overo is the most critically endangered species of caiman in Bolivia. Although Medem (1983) reported this species from localities in both the Paraguay drainage (in the Paraguai and Pilcomayo rivers), and in the Amazon drainage (in the Itenez, San Miguel, Mamore, Beni, Orthon, and Piray rivers), he found it so endangered that it was poorly known even to the professional caiman hunters. Thirteen years later, the species has been pushed so much closer to extinction that, despite our visiting most of the localities reported by Medem, the Bolivian survey teams only found the Overo in the Pilcomayo river (Fig. 1)<sup>1</sup>. However, the teams did encounter a few caiman hunters and hide buyers, who knew the Overo and reported its presence in the Itenez, Mamore, and Beni rivers. Every one stated it was extremely rare. One buyer reported that the Overo used to be abundant in the Paraguai river, and occurred, but was never numerous, in the Itenez. To illustrate his statement, he reported that 20 years ago, a shipment of hides from the Itenez would include approximately one Overo, *C. latirostris*, hide for every 5,000 Lagarto, *C. yacare*, hides. In recent years, he has not seen even one Overo hide from the Itenez. By 1979, the species had become endangered in Argentina as well. Fitch and Nadeau (1979) surveyed the Argentine Departments of Mburucuya, San Miguel, and Concepción of Corrientes found 1,200 *C. yacare*, but only 2 *C. latirostris* (0.16%). They report that Overo hides accounted for 2.5% of the commercial hides sold because the hunters sought out the species for its more valuable hide.

In Bolivia, the habitat of the Overo consists of rivers, oxbow lakes, and lagoons with abundant emergent or floating vegetation along the banks. It occurs together with *C. yacare*. It seems to prefer quiet water habitats. The species is too endangered to determine whether or not there was any habitat partitioning between it and *C. yacare* as has been observed in Argentina (Nadeau and Fitch 1980).

The species already is commercially extinct in Bolivia; hunters and buyers almost never see it and the species cannot support any further hunting pressure. Clearly, it deserves the protection afforded by its placement on CITES Appendix I. If efforts are not made soon to conserve it, in few years it will become

<sup>1</sup> In his 1987 report to CITES on THE SITUATION OF THE WILD CATS (FELIDAE) IN BOLIVIA, J. Lobao Tello mistakenly reports *Caiman latirostris* as being common in the Itonamos, San Pablo, and Manuripi rivers and in the lake at Puerto Suarez. We have examined the specimens he collected from these localities and there are no *C. latirostris* among them. His records apparently are based on misidentified *Paleosuchus*.

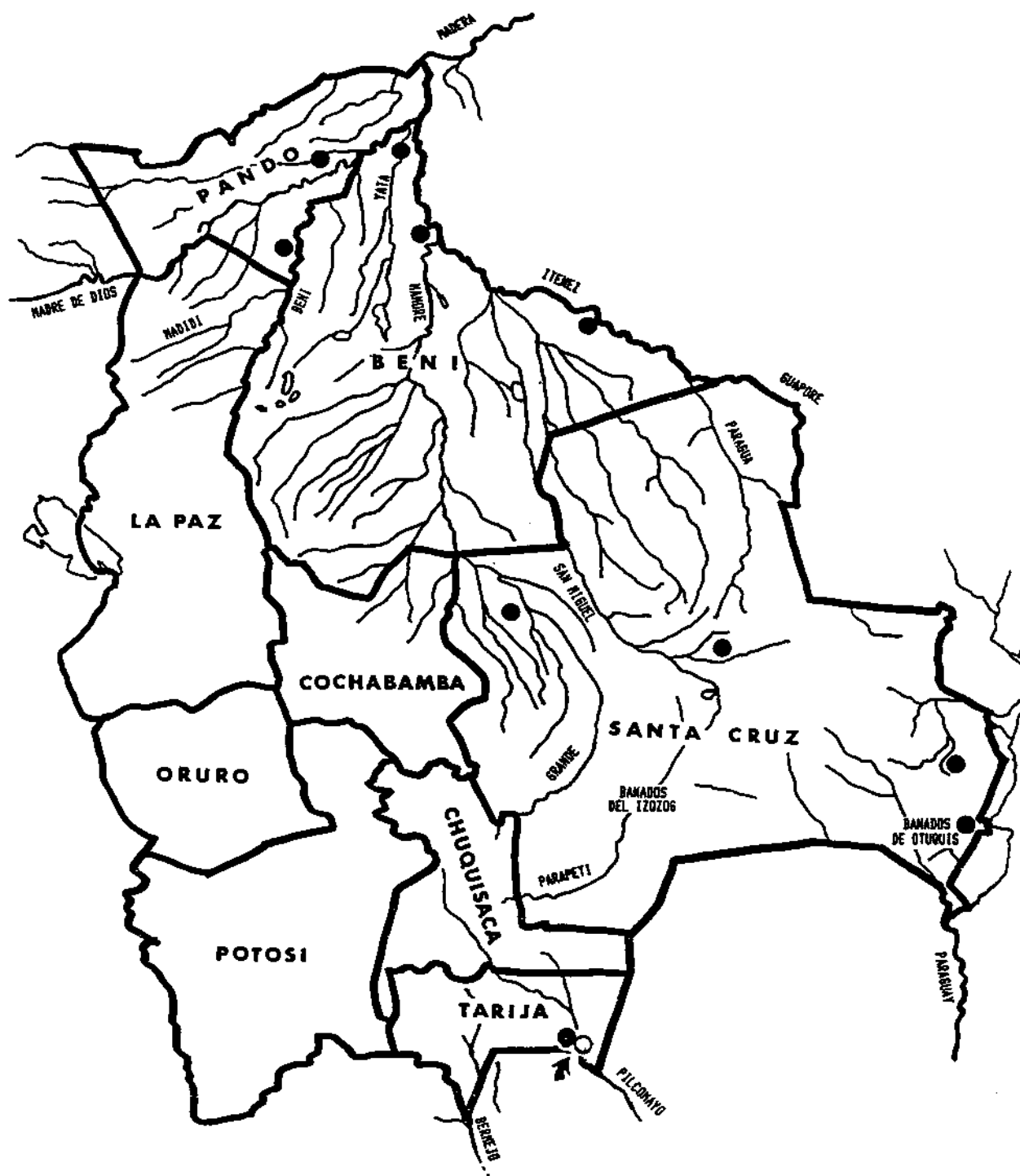


Figure 1. *Caiman latirostris* distribution in Bolivia. The open dot ( ○ ) indicated by arrow at bottom of map is the single locality where the species was found in the present survey. Solid dots ( ● ) are localities from Medem's 1973 survey (1983:Map 8).

truly extinct in Bolivia. If that is allowed to happen, Bolivia will have lost a valuable economic resource, its caiman species with the second most valuable hide.

*Caiman yacare* = Lagarto. This species is found throughout the Bolivian Departments of Beni, Pando, and Santa Cruz, and the lowland portions of Chuquisaca, Cochabamba, La Paz, and Tarija (Fig. 2). It occurs in virtually all permanent water habitats in both the Amazon and Paraguay river drainage basins; rivers, streams, lagoons, oxbow lakes, ponds, swamps, marshes, and even some roadside ditches. It is most plentiful where quiet open waters provide the mature Lagartos with space for courtship and territorial displays, and an abundance of emergent and floating vegetation along the shore provides protective cover for adults and young. The vegetation also provides habitat for insects, snails, frogs, and small fishes which are the prey of young Lagartos, while the open water provides habitat for larger fishes. Medem (1960, 1971) reported similar habitat preferences in Paraguay and Colombia. The species is not abundant in fast water or water that lacks the vegetative cover. This is particularly evident in the large rivers where it is possible to travel for km without seeing the eyeshine of a single Lagarto.

At the present time, the Lagarto is the Bolivian species most heavily hunted for its hide. Over the last decade, it has supported an annual legal export trade of hides from 50,000 to 200,000 Lagartos, and an added illegal trade that brings the total exports to an estimated 400,000 Lagartos a year. As a consequence, though males of the species reach a total length of at least 2.5 m, and females reach 1.8 m, the vast majority of Lagartos encountered are small, usually less than 1.25 m total length.

The breeding season of Lagarto varies from region to region. Information gathered on this survey, indicates that in the region of the upper Itenez river in eastern Santa Cruz, Lagarto court and mate from September to November, build nests and lay eggs in November and December, though occasionally some lay as late as February. However, the survey data also suggest that in the lower reaches of the Beni river in northern Bolivia, Lagarto nest earlier, from August to November. Without fixing any particular region, Medem (1983) states information he received suggests Lagartos nest from the end of August to November, while in the upper Mamore river of central Bolivia, Lovisek (1980) reports Lagarto nest from November to December.

*Melanosuchus niger* = Caiman. Medem (1983) reports hunting of the Caiman in Bolivia began in 1942. Tens of thousands of hides were exported between then and 1961 when Supreme Decree (= Presidential Decree) No. 05912 established a minimum legal size of 2.1 m in length for Caiman hides and prohibited all hunting of the species from 31 July to 1 January. Despite this Presidential regulation, tens of thousands of additional hides of all sizes, taken throughout the year, have been exported, both legally and illegally. As a consequence of this uncontrolled exploitation, the Caiman is in danger of extinction in Bolivia. The species occurs throughout the lowlands of Bolivia (Fig. 3), but in most localities its numbers have been decimated or it has totally disappeared. While it remains as widely distributed as it was during Medem's 1973 survey, the present survey teams did not encounter *Melanosuchus* nearly as often as Medem did. Only in a very few localities, mostly quiet water habitats, is it sufficiently abundant to enable the survey teams to encounter more than one or two specimens, usually juveniles or subadults, in a night. Hunters are still finding a few relatively untouched populations in remote areas -- in August 1986, 927 salted and dried Caiman hides were seized by CDF guards on the Rio Apere northwest of Trinidad, Beni, after the single-engine airplane carrying the contraband hides crashed and was abandoned by its operators; and in May 1987, one dealer in Beni was alleged to have 8,400 Caiman hides ready for shipment to illegal buyers in Paraguay. Such occurrences are becoming less frequent as the species continues to slip toward extinction. The Caiman is the second most endangered crocodilian in Bolivia, and will follow the Overo, *C. latirostris*, to commercial extinction and then to actual extinction if existing conservation laws and regulations are not enforced soon.

Hunters and tanners were questioned to determine what size Caimans attained in the past. The largest hide measured by a tanner in Trinidad was 5.25 m, while one in Cochabamba reported years ago having received one hide in excess of 7 m long. Most agreed that any Caiman over 4 m total length was



Figure 2. *Caiman yacare* distribution in Bolivia. Enclosed stars (★) are localities where the species was found during the present survey. Solid dots (●) are localities from Medem's 1973 survey (1983:Map 8).

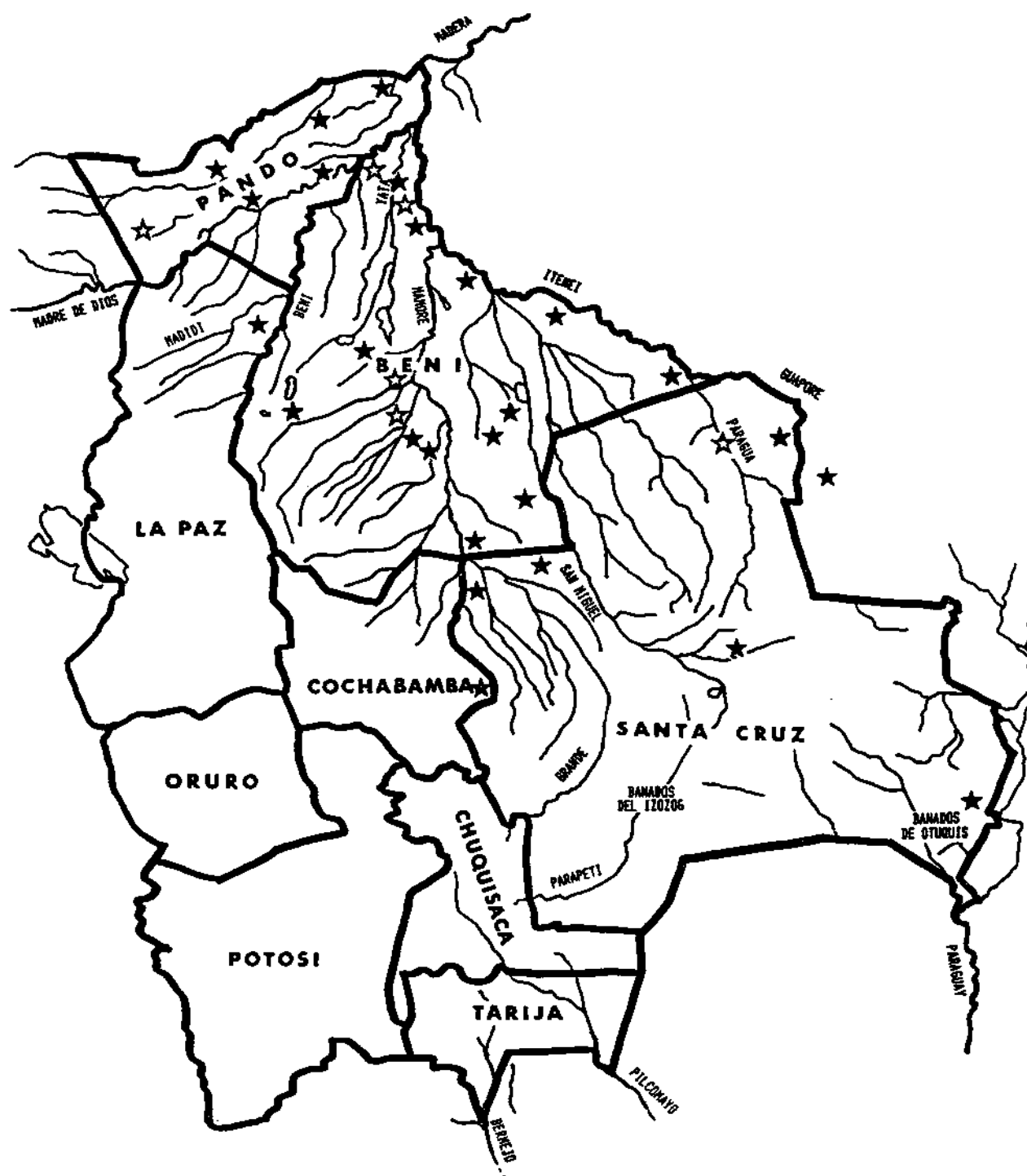


Figure 3. *Melanosuchus niger* distribution in Bolivia. Open stars (☆) are localities where the species was found during the present survey. Solid stars (★) are localities from Medem's 1973 survey (1983:Map 8).

unusually large. Today, any Caiman over 2 m total length is "big," and ones approaching 3 m are virtually non-existent.

Today, the Caiman occupies much the same habitat as the Lagarto, *C. yacare*, rivers, streams, lagoons, and oxbow lakes, that have a well-vegetated shoreline. They tend to be most frequent in situations which provide an expanse of quiet, open water in addition to the vegetative cover. Data produced by the survey do not clarify whether or not Caiman and Lagarto occupied somewhat different habitats prior to their decimation by hide-hunters.

Caimans call year-round, but are more vocal during mating season. In eastern Santa Cruz, mating takes place from September to November. Nesting occurs shortly after mating, and nests can be found from December through January.

*Paleosuchus palpebrosus* = Cocodrilo, and *Paleosuchus trigonatus* = Cocodrilo and Caiman negro. These two species are discussed together, because the two are confused by hunters and laymen alike, because their habitats and other aspects of their ecology in Bolivia are similar, and because neither is heavily hunted.

Both species of Cocodrilo occur widely through northern Bolivia, but only *P. palpebrosus* is found in central and southeastern Bolivia (Figs. 4 and 5). However, their distributions are disjunct and not continuous. They are found in large rivers and small streams (see Vanzolini and Gomes 1979:206-208). They are found at night along the stretches of shore that are devoid of floating and emergent vegetation. They sit exposed on bare sand, gravel, or mud banks, or shelter themselves behind piles of dead tree trunks and limbs. Not one was found among the living plant cover. So consistent was this choice of microhabitat, that as soon as it was possible to determine if a particular eyeshine emanated from a patch of green vegetation or from a bare bank, we could predict whether or not it was *Paleosuchus* or *Caiman*.

Both species of Cocodrilo possess large osteoderms in their belly scales. This heavy dermal armour makes the hides essentially worthless as leather. Hide dealers in Bolivia do not buy the hides, so normally hunters do not kill them. A very few are killed by mistake, but there is no concerted hunting pressure on these species. As a consequence, all available data suggest their populations and distributions are undiminished, except near cities where they have lost habitat to urban sprawl.

**Habitat Distribution:** Nearly two-thirds of Bolivia lies in lowlands occupied by tropical, subtropical, and temperate forests and savannas (Fig. 6). While the present survey, and the 1973 survey by Medem (1983), demonstrated that caimans occur throughout the lowlands, the greatest numbers occur in the habitats of the Beni Plain that stretches from Puerto Heath and the Madre de Dios river of northern La Paz Department to the Huanchaca and Negro highlands of eastern Santa Cruz Department (Fig. 7). The Beni Plain's 100,000 km<sup>2</sup> of savannas and 171,131 km<sup>2</sup> of forests make up 25% of Bolivia's area.

Prior to being hunted for their hides, Bolivia's caimans probably lived in every permanent watersource in the lowlands, and temporarily occupied other habitats during the wet season. Eliana Flores (1986) conservatively estimates that permanent water habitats, lakes, rivers, and streams, occupy 5,812 km<sup>2</sup> of the Bolivian lowlands, but provides no estimate of seasonally flooded habitats. During the present survey, more than 700 km of aerial transects were flown in the Department of Beni, in an attempt to provide an independent estimate of wetland habitats. For purposes of the transects, all habitats were grouped into:

- C = curichi (a small, permanent water lagoon, with extensive vegetation, usually an oxbow lake formed when the river changed channels)
- F = hardwood forest (other than gallery forest), usually rain forest
- G = gallery forest bordering a river or stream
- L = lagoon or lake with a large expanse of open water (permanent water)
- P = palm savanna

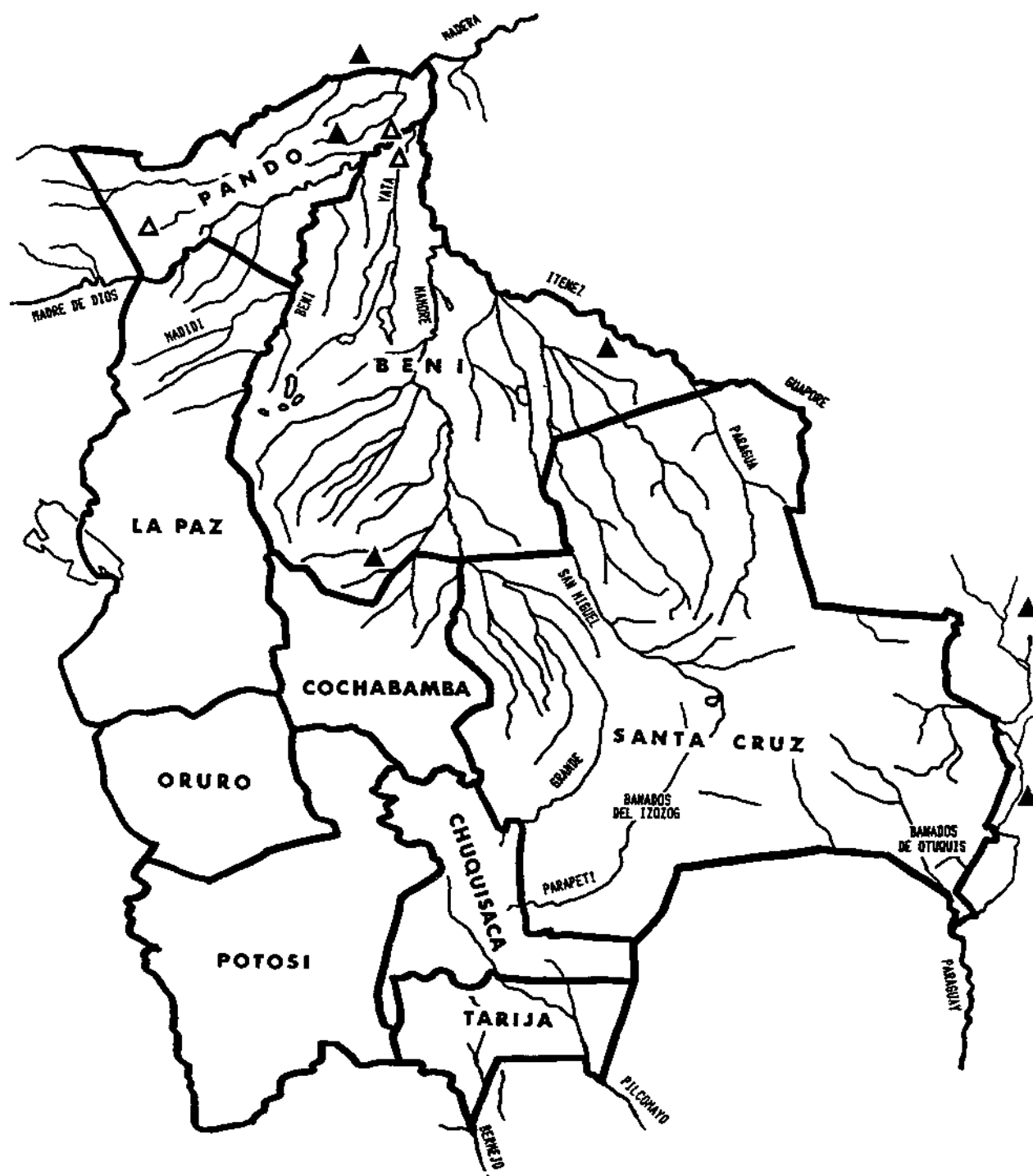


Figure 4. *Paleosuchus palpebrosus* distribution in Bolivia. Open triangles (  $\triangle$  ) are localities where the species was found during the present survey. Solid triangles (  $\blacktriangle$  ) are localities from Medem's 1973 survey (1983:Map 8).

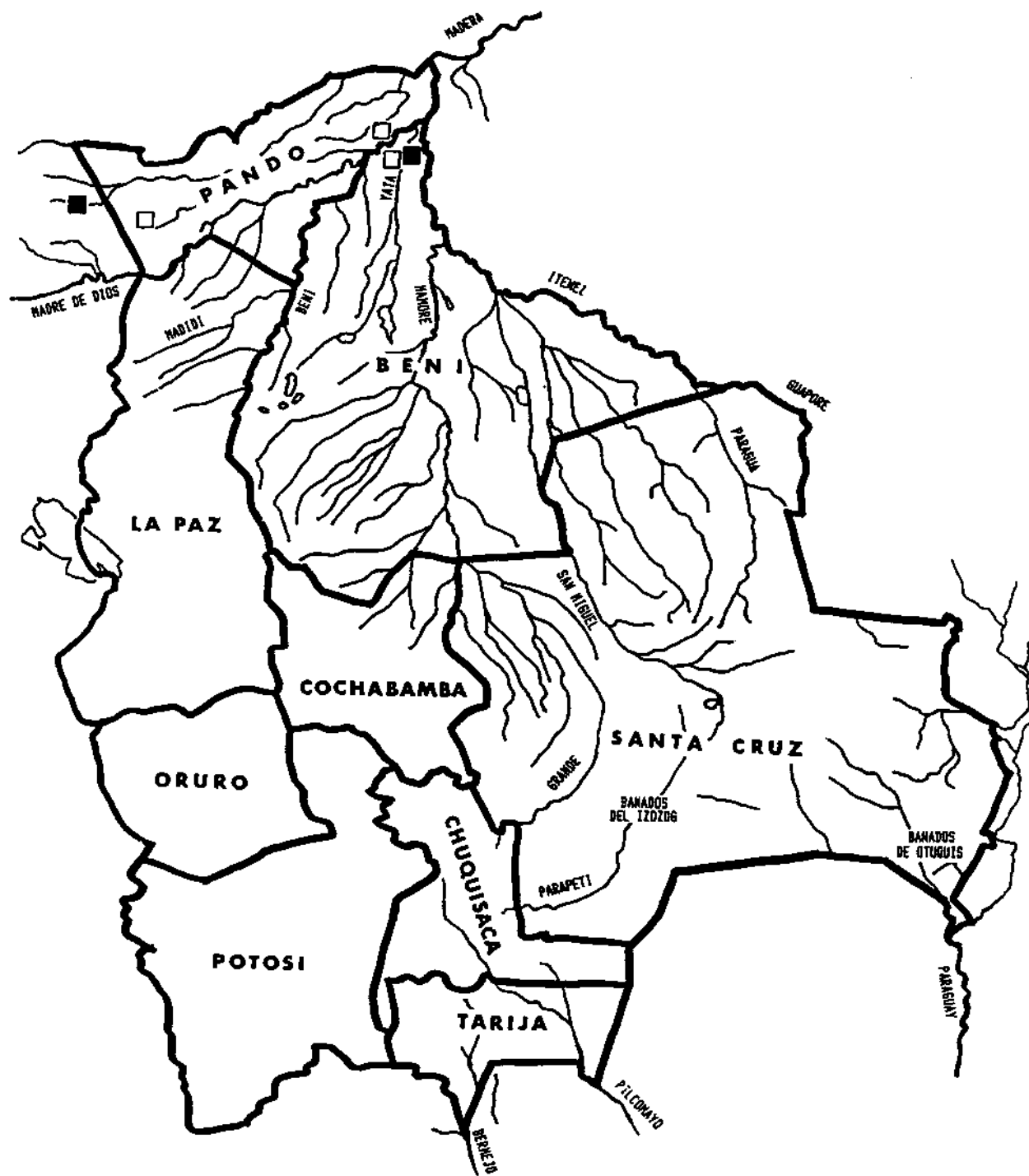


Figure 5. *Paleosuchus trigonatus* distribution in Bolivia. Open squares ( □ ) are localities where the species was found during the present survey. Solid squares ( ■ ) are localities from Medem's 1973 survey (1983:Map 8).



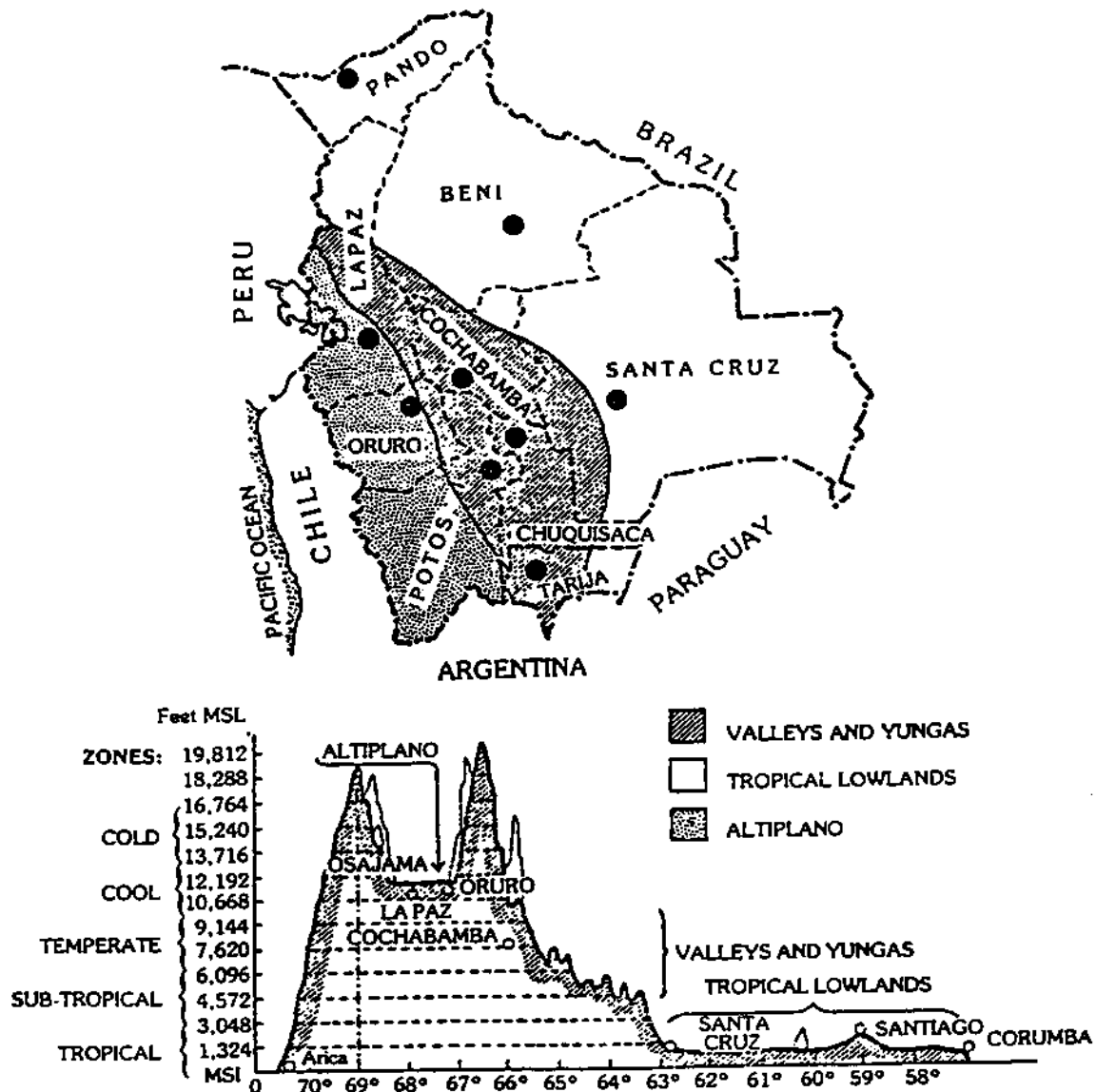
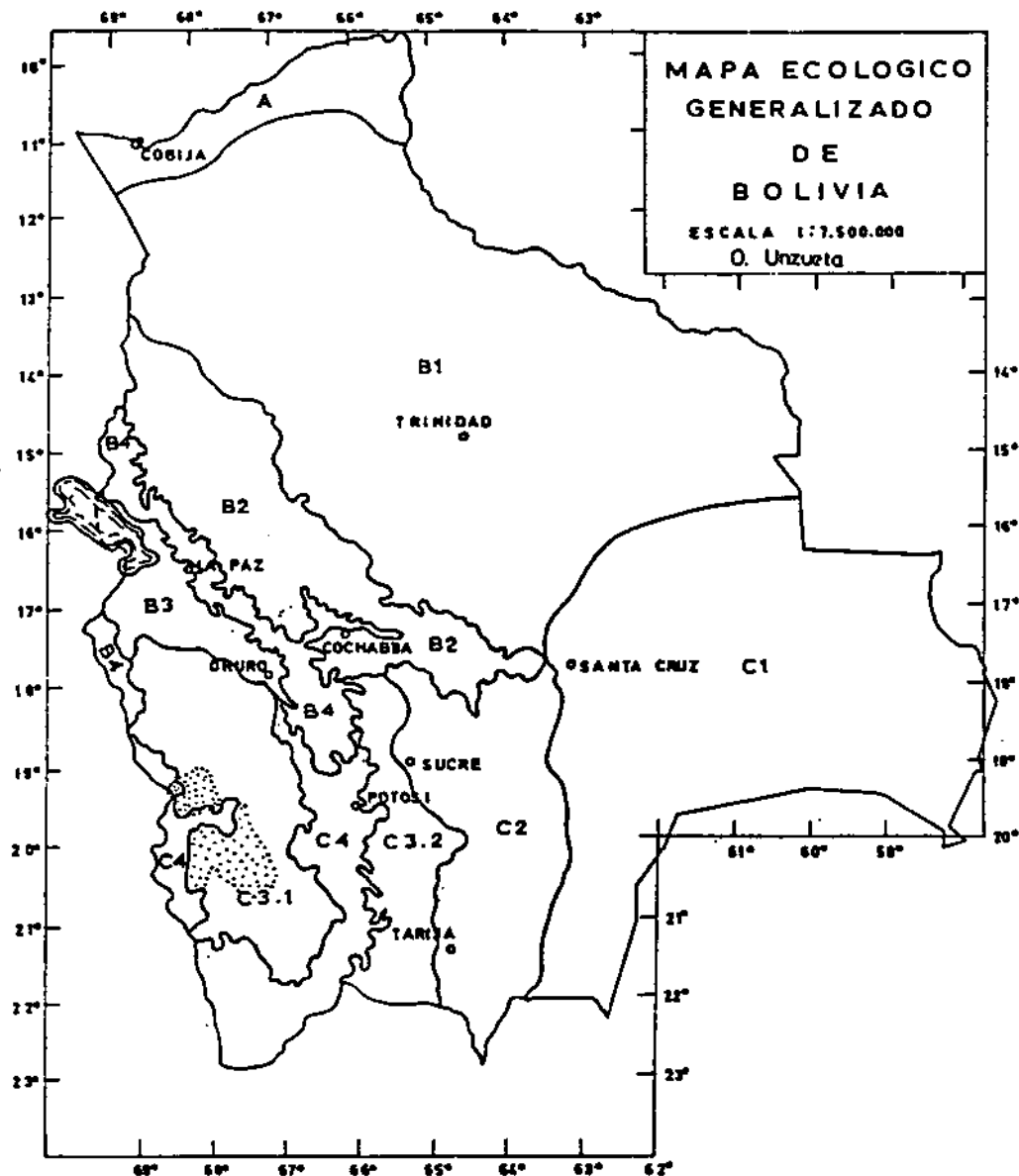


Figure 6. Geographic profile of Bolivia (from Freeman, Cross, Flannery, Harcharik, Hartshorn, Simmonds, and Williams 1980:1-3). Caimans are confined to Bolivia's tropical and subtropical lowlands.



#### REFERENCE KEY

- |                              |                            |
|------------------------------|----------------------------|
| A. Tropical Region           | B4. Subtropical Andes      |
| A. Tropical lowlands         | C. Temperate Region        |
| B. Subtropical Region        | C1. Temperate lowlands     |
| B1. Subtropical lowlands     | C2. Temperate valley lands |
| B2. Subtropical valley lands | C3. Temperate highlands    |
| B3. Subtropical highlands    | C4. Temperate Andes        |

Figure 7. Generalized ecological zones of Bolivia (adapted from Unzueta 1975). In Bolivia, the greatest numbers of caimans are found in the wetlands of the Beni Plain, B1.

- Pt = pantano or marsh, usually *Cyperus* marsh (permanent water)  
 R = river (permanent water)  
 Sw = wet savanna, seasonally flooded (seasonal habitat)  
 Sd = dry savanna  
 Strm = streams (usually permanent water)

These transects were not randomly selected, but rather were flown between Trinidad, Santa Ana, Reyes, and Versalles (Fig. 8) in route to collecting localities. None of the transects crossed the lake region of northcentral Beni. In addition, unless sunlight reflecting off the water could be seen through the leafcover, closed canopy forest obscured the presence of small streams. As a consequence, while the transects are broadly reflective of the relative abundance of habitat types, they undoubtedly under estimate year-round wetland habitats in the Beni and should not be treated as a statistically rigorous sample.

The transects suggest that permanent wetland habitats, year-round habitat for caimans, occupies approximately 23%, or 62,360 km<sup>2</sup>, of the area of the Beni Plain (Fig. 9). Seasonally wet habitat occupies an additional 27%, or 73,205 km<sup>2</sup>. These proportions are not typical of the drier areas of the Bolivian lowlands in Pando, Santa Cruz, Chuquisaca, and Tarija. If it were, the entire 659,149 km<sup>2</sup> of Beni, Pando, northern La Paz, and Santa Cruz, the 60% of Bolivia occupied by the Amazon basin (Flores 1986), could provide a total of 151,604 km<sup>2</sup> of year-round habitat for Bolivia's five species of caiman.

Not all the permanent wetlands are utilized equally by the caimans. As indicated above, *C. latirostris*, *C. yacare*, and *Melanosuchus* are most frequently encountered in habitats that provide both open expanses of quiet water and vegetative cover near shore; the two species of *Paleosuchus* are most frequent in rivers and streams where the banks are bare and cover is provided by dead logs and brush piles. Much of the flat Beni Plain fills with water during the November to May rainy season; savannas flood and rivers rise 3 or 4 m. The elevation at Trinidad is approximately 160 m, and at Riberalta, 440 km further north (downstream in the Amazon Basin), the elevation is still about 145 m. The falling river levels expose great expanses of mud and sand, leaving the Overos, Lagartos, and Caiman with little or no cover in which to hide. This has to be one of the reasons that all species of caimans are scarce in the large rivers. A second reason is the rivers are easily hunted. Hunters told the survey teams that the major rivers essentially have been hunted out for more than a decade.

The extent of available permanent habitat, coupled with a small breeding size and rapid attainment of sexual maturity, is undoubtedly what has allowed Bolivia's Lagarto population to sustain the level of exploitation to which it has been subjected. That same intensive level of exploitation, directed at the larger and more slowly maturing Caiman and Overo, has resulted in their endangerment.

The seasonally flooded habitats allow caimans, particularly the Lagarto, to move from one drainage system to another and to colonize all suitable permanent water habitats. The headwaters of many of Bolivia's rivers are only separated from other rivers or from lakes by short distances of seasonally flooded habitat. For example, the headwaters of the Ipurupuru river, a tributary of the Machupo river flowing into the Itenez, is separated from the middle Mamore river by about 2 km of seasonally wet savanna and scattered curichis (vegetated oxbow lakes).

Similarly the Negro river, a tributary of the Beni river, is separated from the Benicito, a tributary of the Yata river, by seasonally flooded habitat. The same is true of the San Martin river and the Paragua river; and even the Guapore river, a tributary of the Amazon, and several tributaries of the Paraguay river. Numerous other examples could be cited.

**Population Densities:** Of the three commercially exploited species, *Melanosuchus*, *C. latirostris*, and *C. yacare*, only the latter species, the Lagarto, was encountered sufficiently often to allow any estimate of population densities.

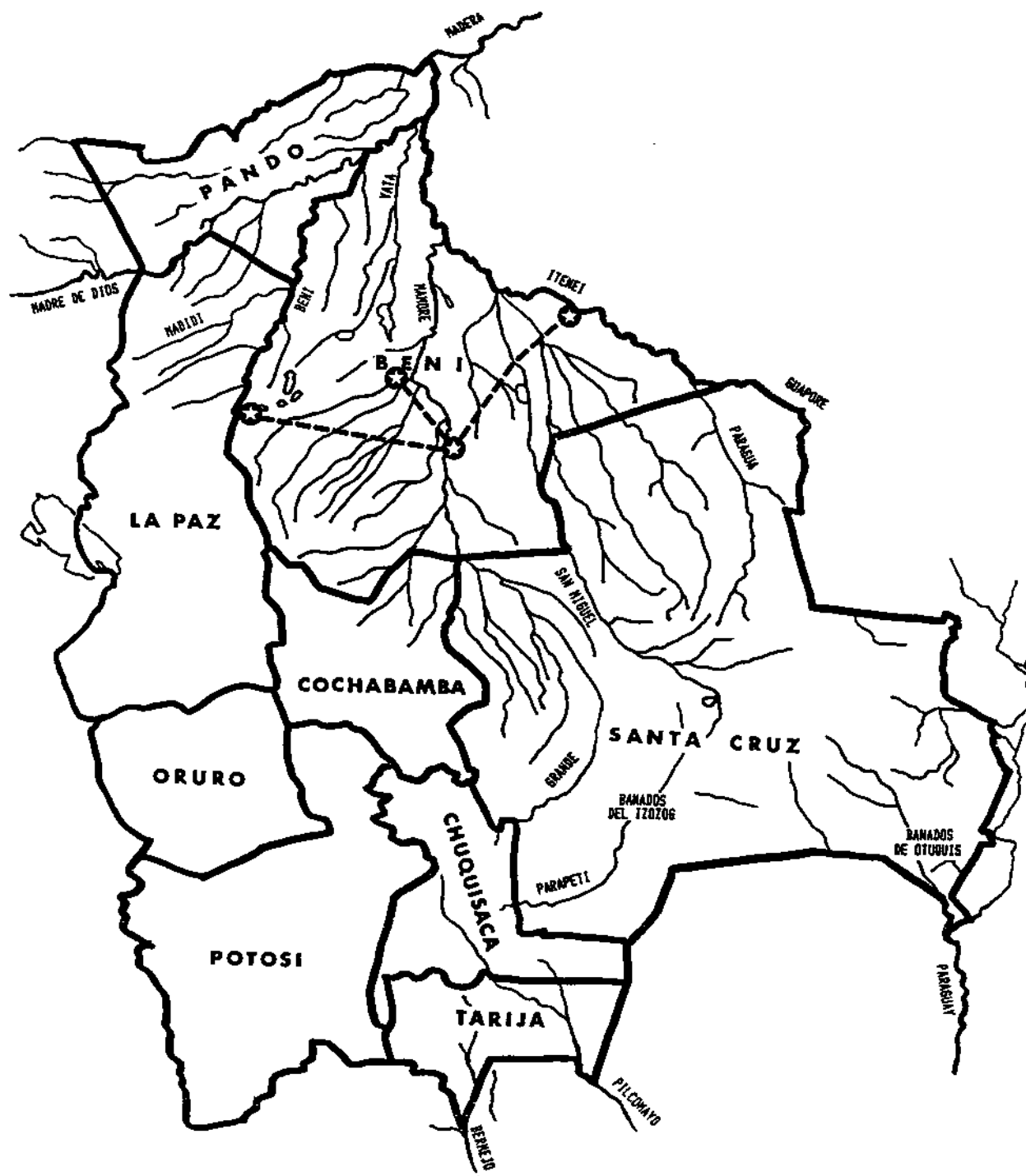


Figure 8. Aerial transects of habitats in the Beni. The transect routes radiate out from Trinidad; northeast to Versalles on the Itenez River; northwest to Santa Ana on the Yacuma River, near its confluence with the Mamore River; and west to Reyes, near the Beni River.

The following estimated densities of Lagartos, *C. yacare*, were encountered during the present survey.

Lagarto, *C. yacare*, are not endangered in Bolivia, but there is ample evidence that the resource is suffering severely from lack of conservation management.

The Lagarto were more abundant in quiet water embayments and lakes (lagos, lagunas, curichis, and arroyos) with vegetative cover, and were relatively scarce in moving water situations that lack cover. However, nowhere in Bolivia, in any type of habitat, did the survey teams encounter populations of Lagartos as dense as they are in parts of the Brazilian pantanal, or as dense as *C. crocodilus* populations are in Venezuela.

Coastal Venezuelan populations of *C. c. crocodilus* reach densities of 0.2-196.6 per km of shore (Seijas 1986). In inland riverine habitats in Venezuela, densities of 2.52 per km are found, with a range of 0.7 to 150.0 per km, and in quiet lagoons an average density of 23.4 per km occurs, with a range of 8.0 to 45.5 per km (Gorzula and Paolillo 1986). In addition, large adults over 1.5 m total length account for between 14% and 29% of the Venezuelan populations (Staton and Dixon 1975, Ayarzagüena 1983, Seijas 1984, Woodward and David 1985), while large adults comprise no more than about 3% or 4% of the populations seen by the Bolivian survey teams. *C. yacare* reach similar densities in protected habitats in the Brazilian pantanal (pers. comm. from P. Brazaitis, NYZS, and P. Crawshaw, IBDF), but where they are intensively hunted in Brazil, *C. c. crocodilus* populations consist largely of animals less than breeding size (Magnusson 1980, 1982).

In the rivers of Peru, *C. crocodilus* populations have densities of from 0.68 to 9.0 per km, and adults over 1.25 m account for 3% of the total (Moya et al. 1980; Vasquez 1981).

The difference between Bolivia and Venezuela and Brazil is not in the biology of the animals. It reflects the total lack of conservation management of the caiman resource in Bolivia (see Resource Utilization, and Wildlife Laws below) -- not a single species of wildlife is professionally managed in Bolivia.

Everywhere the survey teams went in Bolivia, wildlife officials, caiman hunters, ranchers, and local citizens told them about some lagoon, curichi, or river which reputedly was swarming with Lagarto. The teams visited a number of these celebrated localities, either alone or in the company of the person who originally claimed there was a glut of Lagarto at that site. Not one of these localities contained a large, dense population, and not one supported a high percentage of large adult animals. The discovery that the population was not as large as believed always surprised the person who originally told us about it, and it inevitably prompted him to regale us with a story about yet another location with a mythical horde of Lagartos. This was not a deliberate effort to mislead the team members. Rather it resulted from the widespread public misconception that Bolivia's wildlife is endlessly abundant. That city dwellers might believe this is not surprising, but it is distressing to find hunters, ranchers, and especially wildlife officials who are so naive.

**Resource Utilization:** While large caimans of all five species were encountered during the present survey, the vast majority of populations consisted of juveniles and subadults. This is the direct result of Bolivia's poor management of the caiman resource and lack of enforcement of existing wildlife laws. As noted seven years ago by Freeman et al. (1980), illegal hunting for animal skins and the ease of circumventing laws are threatening the future existence of Bolivia's wildlife and parks and is a direct result of the failure of the Centro de Desarrollo Forestal (CDF) to implement conservation legislation and programs. Wildlife, both plant and animal, is viewed solely in terms of how much money it will yield through short-term exploitation (Freeman et al. 1980) and not through management for a sustained utilization. These problems cannot be overcome until a professional cadre of wildlife and park planners, managers, and administrators is created within CDF (Freeman et al. 1980).

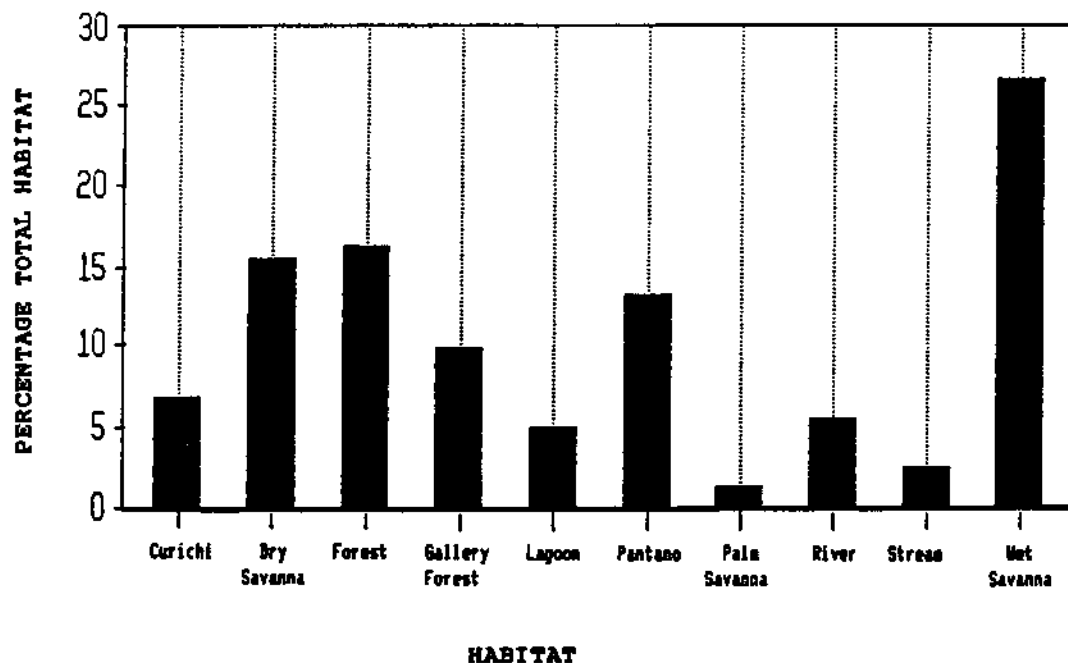


Figure 9. Habitat frequency expressed as a percentage of total time flown in aerial transects. Curichi, lagoon, pantano, river, and streams are permanent water habitats. Wet savanna, and some forest, gallery forest, and palm savanna are seasonally flooded.

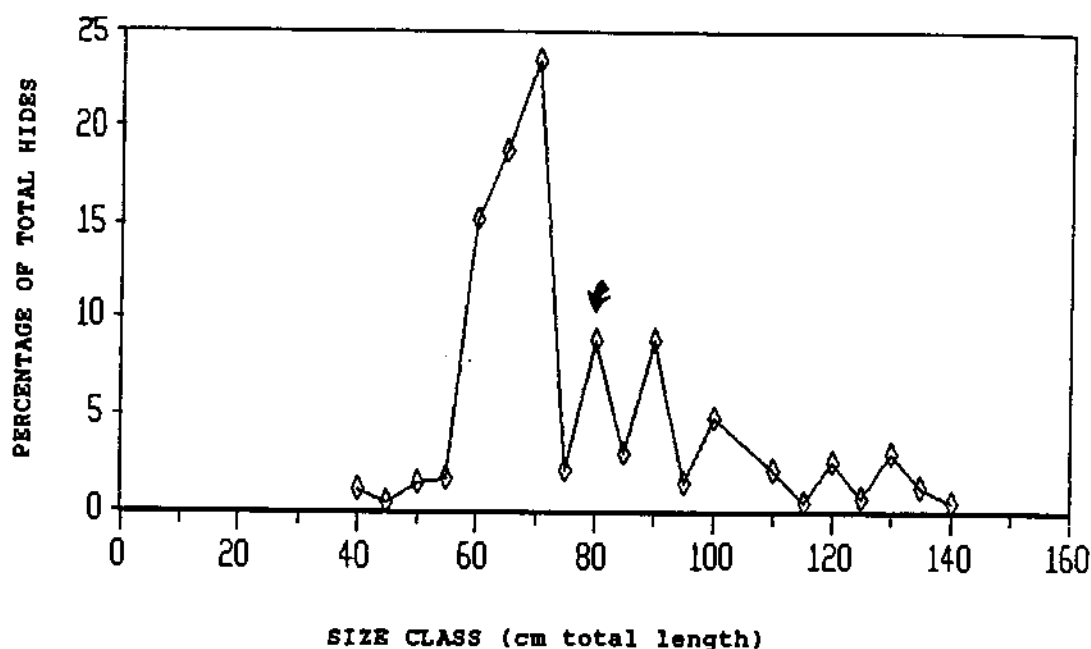


Figure 10. Size classes of Lagarto, *Caiman yacare*, flanks harvested legally in 1985 and 1986 as represented by a sample of 16,000 fully tanned, dyed, and glazed hides in the warehouses of the six tanneries of the Asociación de Industriales de Cueros de Saurios. A flank consists of the soft strip of hide starting immediately under the chin and extending along the neck, over the front leg, alongside the trunk between the bony dorsal (back) and ventral (belly) scales, under the hindleg, and ending just behind the cloacal vent. It is the hide most frequently flayed from the Lagarto, accounting for more than two-thirds of all crocodilian hides entering international trade each year. The arrow indicates the size flank produced by a 1.5 m Lagarto, the minimum size allowed under Bolivian law.

Hard biological data on Bolivian *C. yacare* are not available, but data on *C. crocodilus* suggest that female Lagarto should reach sexual maturity at about 1.3 m total length and an age of 4 years (Staton and Dixon 1977, Magnusson 1982). Most adult female Lagartos are around 1.4 to 1.5 m, and a maximum total length is about 1.77 m (Medem 1983). Males, if not killed, will grow to more than 2.0 m total length, and some will exceed more than 2.5 m. Lagarto can be managed for a sustained harvest, by protecting the breeding females. Without that protection, females will be lost, production of eggs and young will decline, and there will be little recruitment into the adult population to replace the animals killed for their hides. Since there is such a size difference between sexually mature females and males, limiting the hunt solely to Lagartos more than 1.5 m total length results in harvesting mostly males.

In 1961, Supreme Decree No. 05912 prohibited the hunting of Lagartos less than 1.5 m in total length. In 1962, Supreme Decree No. 05987, reaffirmed that minimum size and also closed the hunting season from 1 May to 1 October. Even though similar minimum sizes and closed seasons have been reaffirmed repeatedly by Supreme Decree No. 08063 of 1967 (the closed season was shifted to 1 July-31 December) and numerous Ministerial Resolutions since then, there is virtually no enforcement of the size limit or closed season. Hunting takes place opportunistically throughout the year. As a consequence, the breeding population has been decimated. Most Lagarto have been eliminated from the easily accessible large rivers, and large populations, even of small Lagarto, are found only in the more inaccessible oxbow lakes and marshy lagoons. The species survives because a few females manage to reach sexual maturity, to breed, to produce eggs, and to contribute to the next generation before being killed for their hides. That this has happened is evident not only in the age/size structure and density of the wild populations, but also in the size of animals being killed for their hides.

The inventory of finished Lagarto hides (i.e., hides that have been tanned, dyed, and glazed) in the warehouses of the six tanneries of the Asociación de Industriales de Cueros de Saurios (ASICUSA), provided data on the sizes of Lagarto hides harvested in Bolivia with permission of CDF officials (Fig. 10). Each tannery supplied the inventory team with a detailed list of the sizes and numbers of hides it had in storage. To confirm the accuracy of the list, the team, without prior consultation with the tannery personnel, selected, counted, and measured approximately 16,000 Lagarto flanks, 7% of the total hides. The counts and measurements were then checked against the company's records to uncover any discrepancies.

A 1.5 m Lagarto, the minimum legal size under Bolivian law, yields a flank approximately 80 cm in length. Nearly two-thirds of the Lagarto hides, 65%, are less than legal size (Fig. 10). The smallest flanks measured only 40 cm, the equivalent of 72 cm Lagarto. This is strong evidence that the resource has been grossly mismanaged. Allowing the harvest of such small-sized Lagartos assures that the breeding females are destroyed and that the reproductive potential of the wild populations will continue to decline.

At the present time, *C. yacare* is not an endangered species in Bolivia. The species still occurs throughout the country in every suitable habitat. The killing of under-sized Lagarto has severely damaged the resource by all but eliminating the breeding adults. However, the widespread presence of juveniles indicates successful nesting is occurring. In addition, 35% of the inventoried hides were from Lagartos larger than 1.5 m, and the largest flanks were 140 cm in length, the equivalent of a 2.5 m Lagarto. Clearly, if existing laws governing the killing of Lagarto were enforced, there are sufficient numbers of large animals to rebuild the breeding population within a few years. Conversely, if laws are not enforced and if progressively smaller sizes are killed for their hides, the Lagarto will become endangered.

Lack of active conservation management not only has hurt the Lagarto, *C. yacare*, it has endangered the Caiman, *M. niger*. Supreme Decree No. 05912 of 1961 prohibited the killing of Caiman, *M. niger*, less than 2.1 m in total length and set a closed season between 31 July and 1 January. That size limit and closed season (adjusted to 1 July-31 December) has been reaffirmed in numerous laws and regulations to the present time. Nevertheless, Caiman of all sizes are killed throughout the year. Since the Caiman reaches sexual maturity at between 2.0 m and 2.4 m (Medem 1963, Magnusson 1982) and an age of about 5 years, but they are killed at a much smaller size, the majority of Caiman are killed before they can contribute to

the next generation. With the breeding adults gone, the *M. niger* populations have crashed and the species is in danger of extinction in Bolivia.

*M. niger* is on Appendix I of CITES so international commercial trade is prohibited. Enforcement of this prohibition would alleviate the pressure on this species and allow its populations to recover. In addition, if the harvest of Lagarto, *C. yacare*, were limited to large hides as required by Bolivian law, it would ease enforcement. CDF staff would only have to check the purchases and holdings of a few dozen hide buyers and the six tanneries, not every hunter in the field. Commercial hunters do not hunt for sport. They hunt for money. If they cannot sell the hides they produce, they will not spend the money and time killing Caiman or undersized Lagarto.

**Bolivian Wildlife Law:** In Bolivia, wildlife conservation problems result as much from official non-feasance as it does from non-compliance by the legal hide industry.

Unlike poachers and smugglers, the ASICUSA members operate openly - - their hides are checked by CDF officials between the purchase from the hunter and arrival at the tannery. After tanning, Bolivia law requires that they be checked again in Cochabamba before export. While a majority of ASICUSA's present holdings of Lagarto hides are under the legal size limit, these hides, most of which were acquired in 1985, have been validated by CDF. Nevertheless, the ASICUSA tanners recognize that their future depends on better management of the Lagarto resource. To that end, they have pledged not only to abide by all wildlife laws, but voluntarily to put into practice new procedures that will assist the Parties to CITES, the CITES Secretariat, and CDF in implementing the Convention in Bolivia. To do this, the ASICUSA members must be allowed to operate legally.

The inventory disclosed that ASICUSA has on hand the finished hides of more than 109,000 Lagartos. These hides were purchased and tanned, in part, under the 1985 export quota of 100,000 established by cooperative agreement between CDF and CITES, and in part, under the 1986 export quota of 50,000 established by the President of the Republic of Bolivia under Supreme Decree No. 21312. Yet, in 1986 and 1987, three separate national directors of CDF illegally sold Bolivia/CITES country of origin export permits in the amount of the annual quotas to hide exporters in Paraguay. Since the illegal permits were for the total amounts of the quotas, no additional permits could be issued, thereby denying ASICUSA tanners the opportunity of exporting their legal hides to international markets. Several of the ASICUSA members have more than U.S. \$1,000,000 invested in 1985 and 1986 hides. Unless they are allowed to recoup their investment by selling these legal hides on the international market, they will go out of business. However, the illegal sale of CITES permits to Paraguay companies had an effect far beyond its immediate economic impact on ASICUSA. By providing a ready outlet for poached hides, the illegal sale of the permits more than doubled the number of Lagartos killed, and it sanctioned and encouraged the transnational movement of illegal wildlife products in violation of CITES.

Bolivian Supreme Decree No. 05912 of 27 October 1961, that set minimum size limits and a season on the hunting of Lagarto and Caiman, also prohibited the export of raw hides of these two species, and allowed only the export of crusted (= semi-tanned) and finished (= fully tanned, dyed, and glazed) hides. Secretarial Regulation No. 133225 of 29 March 1966 prohibited the export not only of raw hides but also of crusted hides, thereby only allowing exports of fully tanned hides, and only by licensed tanners. Ministerial Resolution No. 279/72 of 10 May 1972, continued the prohibition of exportation of any but finished Lagarto and Caiman hides, as did Ministerial Resolution No. 14316-74 of 14 May 1974. Other resolutions fixed a tax on every Lagarto and Caiman hide tanned and exported. Still later resolutions allow the finished hides to be exported solely by members of ASICUSA. It should be noted that, with few exceptions, Bolivian general law prohibits monopolies. One of only two or three exceptions involves wildlife, so outlawing all exports of fully tanned, dyed, and glazed caiman hides except by ASICUSA members is entirely legal and is designed to stimulate conservation and development by assuring that legitimate tanners provide the sole market for legal hides and in turn make the only exports. This was most recently reaffirmed in Supreme Decree No. 21312 of 27 June 1987, which prohibited all wildlife exports for a period of three years, except for an annual export of 50,000 Lagarto hides by members of ASICUSA.



When ASICUSA members are not allowed to export their legal hides, it not only violates Bolivian laws, it also puts ASICUSA at an economic disadvantage since the illegal operators do not pay the cost of tanning, dyeing, and glazing their hides, and do not pay taxes on those hides. Faced with this sanctioned illegal trade, it is little wonder that the members of ASICUSA have traded in undersized hides. Any hides not bought by ASICUSA are bought by illegal dealers and shipped to Paraguay.

These problems were recognized in the Resolution contained in Conf. 5.2 from the 5th Meeting of the Conference of the Parties in Buenos Aires, Argentina, 22 April to 3 May 1985, which states that "...other countries are taking advantage of the economic and financial weaknesses of the Bolivian authorities in encouraging... illegal trade..." However correct its intent, Conf. 5.2 did not correct the problem. As mentioned above, ASICUSA members have not been able to export legal hides since 1986, because three former national Directors of CDF sold to illegal dealers in Paraguay sufficient Bolivian/CITES country of origin export permits to cover the entire 1985 and 1986 quotas for the annual export of Lagarto hides. Because of this continued sanctioning of illegal wildlife trade, in October 1986, the Standing Committee of CITES recommended that the Parties to the Convention no longer accept Bolivian export permits.

While this action by the Standing Committee is understandable, its main affect was to penalize ASICUSA, the only legal tanners and exporters of Lagarto hides, and leave the illegal buyers with a corner on the caiman resources. Prior to the October 1986 decision of the Standing Committee, Supreme Decree No. 21312 of 27 June 1987, had prohibited all wildlife exports for three years, except for the export of 50,000 Lagarto hides by the members of ASICUSA. The action of the Standing Committee cut off the only legal method ASICUSA members had to recover their investments in 1985 and 1986 hides and left the trade in the hands of illegal buyers.

The illegal trade in Bolivian Lagarto hides actually increased in volume following the 1985 CITES Conference in Buenos Aires, and seems to have increased yet again after the CITES Standing Committee recommended closing down all Bolivian exports. Today, without export permits of any kind, Bolivian *C. yacare* hides and *M. niger* hides are being flown aboard small airplanes to Paraguay, where they are exported to Europe and Asia, primarily France, Italy, and Japan. Almost any day of the week, radio conversations between hunters on outlying ranches and illegal buyers in Trinidad and other towns in the Beni can be heard discussing the current price of hides being paid in Asuncion. Reports received from the field on 1 July 1987 indicate that poaching of Lagarto and Caiman is at an all time high in southwestern Brazil, despite commercial hunting having been outlawed in Brazil in 1967 when Lei No. 5197 came into force. The rampant illegal hunting is the direct result of illegal hide buyers operating in Bolivia and Paraguay. The need for conserving caimans has reached crisis level in southern South America.

The operating principle behind CITES is international cooperation so that importing nations do not provide markets for wildlife exported illegally from its country of origin. Without that cooperation, no nation can protect and properly manage a wildlife resource as valuable as wild crocodilians. In the case of Bolivia, CITES failed to uphold that principle.

Recognizing the role played by CDF officials in the illegal wildlife trade in southern South America, the Parties to CITES passed Resolution Conf. 5.2 on Implementation of the Convention in Bolivia, which required a 50% reduction in Bolivia's wildlife exports (see also Doc. 6.20.C from the 6th (Ottawa) Meeting of the Conference of the Parties to CITES). When the sale of Bolivia country of origin CITES permits continued to be sold to a company in Paraguay, the Standing Committee recommended closure of all imports from Bolivia, and alerted the Parties by Notification No. 413 of 28 November 1986. However correct that closure might be, it failed to act against the primary source of the illegal trade, Paraguay, the immediate buyer and transshipping nation, and France, Italy, and Japan, the ultimate market and destination. Bolivia played a supportive role in the illegal trade by supplying the CITES permits that allowed companies in Paraguay to ship illegal hides from Paraguay to buyers in Europe and Asia. By failing to implement the Convention, Paraguay played an active role in illegal wildlife trade, not only out of Bolivia, but also out of Brazil and other nations in Latin America. CITES must do more to stop the illegal

trade into and out of Paraguay, than simply urging Bolivia's, "... neighboring countries to co-operate to the maximum of their ability in the control of the illegal trade across their borders . . ." [Resolution Conf. 5.2]

In addition, France, Italy, and Japan must start proper implementation of CITES by no longer allowing importation of illegal wildlife exports from Paraguay and other illicit shipping points. By Decree No. 18.796 of 1975, Paraguay banned all commercial hunting and export of native mammals, birds, reptiles, and amphibians. CITES Notification No. 225 of 13 October 1982 informed all the Parties to CITES that Paraguay Presidential Decree No. 18.796 allows the import of wildlife products for manufacture and re-export, and CITES Notification 388 of 7 May 1986 advised that Decree No. 13806 of 17 February 1986 specifically allows the export of shoes made from *Boa constrictor* and *Eunectes* skins. However, the importation and re-exportation of other CITES listed species, including all crocodilians, would require CITES export permits from the country of origin and CITES re-export permits from Paraguay. CITES Notification No. 225 of 13 October 1982 made it clear that Paraguay officials have not issued CITES export permits or re-export permits for commercial purposes since 29 July 1982. Therefore, CITES officials in France, Italy, and Japan knew that shipments of raw or crusted lagarto hides (not manufactured items) covered by Bolivia country of origin permits and shipped from Paraguay (without CITES re-export permits from Paraguay) were illegal. Yet, each of these nations allowed the importation of such shipments during the past 2 years.

The Parties to CITES need to take sanctions against Paraguay, France, Italy, and Japan until those nations effectively implement the Convention.<sup>2</sup>

In an extraordinary demonstration of his determination to break the pattern of illegal activities that has hindered implementation of CITES in Bolivia, Víctor Paz Estenssoro, the President of the Republic of Bolivia, agreed that the CITES Secretariat could place an expatriate expert in CDF for a period of two years to oversee all CITES operations (see CITES Doc. 6.20). That expatriate specialist will develop and implement new procedures for regulating wildlife exports and will train a cadre of administrative and enforcement personnel to operate the program. Though the present administration of CDF has pledged support for the program, and the entire operation will be under the administrative control of the national Director of CDF, should any problem arise, the specialist will be able to speak directly to the President. This individual is expected to begin work in late 1987. Once this specialist is in place, implementation of the Convention in Bolivia should occur rapidly. Few other sovereign nations have so dramatically demonstrated a willingness to comply with the requirements of the Convention by accepting an expatriate to oversee its CITES operations.

However, Bolivia cannot properly implement the Convention as long as actions by the Parties and the Standing Committee discourage legal trade from Bolivia and favor illegal trade by companies operating in Paraguay. Until the ASICUSA tanners can legally export their hides under CITES, they cannot provide a market in Bolivia for legal hides from professionally managed conservation programs. The Parties to CITES must recognize Bolivia's CITES export permits when, and only when, they cover shipments of fully tanned, dyed, and glazed *C. yacare* hides from ASICUSA tanners.

ASICUSA members have cooperated fully with the CITES survey teams in developing a series of procedures that should assist the Parties to CITES in identifying legal exports from Bolivia and illegal exports from neighboring nations. These procedures are described in the resolution appended to the end of this report, a resolution offered for discussion and possible approval by the Parties at the 6th Meeting of the Conference of the Parties in Ottawa, Canada, 12 to 24 July 1987.<sup>3</sup>

<sup>2</sup> This was debated at length at the 6th Meeting of the Conference of the Parties to CITES in Ottawa, Canada, 12-24 July 1987, and resulted in Resolution Doc. 6.19.1 which urged all Parties to strengthen their efforts to control shipments of CITES-listed species.

<sup>3</sup> Most of the concerns covered by this draft resolution were included in Resolution Doc. 6.20.1, prepared and submitted by the countries of the Latin American and Caribbean region, and approved at the 6th Meeting of the Conference of the Parties to CITES in Ottawa, Canada, 12-24 July 1987.

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Finally, the survey might have been possible, but certainly would have been much more arduous an undertaking, had it not been for the many citizens of Bolivia, who, after a brief explanation of what the survey team was trying to accomplish, accepted the team members into their midst (and occasionally into their homes), proffered logistical support, and supplied much valuable information.

#### LITERATURE CITED

- Ayarzagüena, J. 1983. Ecología del caiman de anteojos o baba (*Caiman crocodilus* L.) en los llanos de Apure (Venezuela). *Doñana Acta Vertebrata* 10:1-136.
- Densmore, L. 1983. Biochemical and immunological systematics of the Order Crocodilia. *Evolutionary Biology* 16:397-465.
- Donoso-Barros, R. 1974. Contribucion al Conocimiento de los Cocodrilos de Bolivia; *Caiman yacare medemi*. *Boletín Soc. Biol. de Concepcion* 47:131-143.
- Fitch, H., and M. Nadeau. 1979. Progress report: An assessment of *Caiman latirostris* and *Caiman crocodilus yacare* in northern Argentina. Report to the New York Zoological Society. Xero-graphed 7 pp.
- Flores, E. 1986. Pages 39-59 in D.A. Scott and M. Carbonell, eds. A Directory of Neotropical Wetlands. IUCN Cambridge and IWRB Slimbridge. xii + 684 pp.
- Freeman, P., B. Cross, R. Flannery, D. Harcharik, G. Hartshorn, G. Simmonds, and J. Williams. 1980. Bolivia: State of the Environment and Natural Resources - A Field Study. xiv + 83 p.
- Gorzula, S., and A. Paolillo. 1986. La ecología y el estado actual de los aligatoridos de la Guayana Venezolana. Pages 37-54 in *Crocodiles: Proceedings of the 7th Working Meeting of the Crocodile Specialist Group of the Species Survival Commission of the International Union for Conservation of Nature and Natural Resources*. IUCN Publ. New Series ISBN2-88032-306-1. xxviii + 446 pp.
- Groombridge, B. 1982. IUCN Amphibia Reptilia Red Data Book, Intl. Union Conserv. Nat. Natural Resources, Gland, Switzerland, Pt. 1:xlili + 426 pp.
- King, W., and P. Brazaitis. 1970. Species identification of commercial crocodilian skins. *Zoologica* 56:15-70.
- Lovisek, J. 1980. The reproduction of *Caiman crocodilus yacare* in Central Bolivia. Society for the Study of Amphibians and Reptiles-Herpetologist League Meetings, Milwaukee, Wisconsin, 6-10 August 1980. Abstracts:30.
- Magnusson, W. 1980. Distribution of caiman within the Parque Nacional da Amazônia (Tapajós). Report to the Instituto Brasileiro de Desenvolvimento Florestal (IBDF), Brasília. 27 pp.
- . 1982. Biological aspects of the conservation of Amazonian crocodilians in Brasil. Pages 108-116 in *Crocodiles: Proceedings of the 5th Working Meeting of the Crocodile Specialist Group*. IUCN Publication New Series ISBN 2-8032-209-X. 409 pp.

- Medem, F. 1960. Notes on the Paraguay caiman, *Caiman yacare* Daudin. Mitteilungen aus dem Zoologischen Museum in Berlin. 36:129-142.
- \_\_\_\_\_. 1963. Osteologia craneal, distribution geographic y ecologia de *Melanosuchus niger* (Spix) (Crocodylia, Alligatoridae). Revista Acad. Colombiana Ciencias Exactas, Físicas y Nat. 12:5-19, 10 pls.
- \_\_\_\_\_. 1971. Biological isolation of sympatric species of South American Crocodylia. Pages 152-158 in Crocodiles: Proceedings of the First Working Meeting of the Crocodile Specialist Group. IUCN Publ. New Series Suppl. Paper 32:1-191.
- \_\_\_\_\_. 1981. Los Crocodylia de Sur America: Los Crocodylia de Colombia. 1:1-354.
- \_\_\_\_\_. 1983. Los Crocodylia de Sur America. 2:1-270.
- Moya Ibañez, L., R. Pezo Díaz, and L. Verdi Olivares. 1980. Observaciones preliminares sobre la Bioecologia del Lagarto Blanco (*Caiman crocodylus* L.) en la Cuenca del Rio Samiria. Pages 107-123 in T. Gutiérrez Gonzales, ed. Seminario sobre Proyectos de Investigacion Ecologia para el Manejo de los Recursos Naturales Renovables del Bosque Tropical Humedo. Direccion General Forestal y de Fauna, Peru. viii + 261 pp.
- Nadeau, M., and H. Fitch. 1980. An assessment of *Caiman latirostris* and *Caiman crocodylus yacare* in northern Argentina: Final report to the New York Zoological Society. Xerographed 17 pp.
- Schmidt, K. 1928. Notes on South American caimans. Field Museum Natural History Zoological Series 12:205-231.
- Seijas, A. 1984. Estimaciones poblacionales de babas (*Caiman crocodylus*) en los Llanos Occidentales de Venezuela. Serie Informes Técnicos DGSIA/IT/165 Ministerio del Ambiente y de los Recursos Naturales Renovables. 23 pp.
- \_\_\_\_\_. 1986. Situacion Actual de las Poblaciones de Babas y Babillas (*Caiman crocodylus*) en la Region Norte-Coastal de Venezuela. Pages 28-33 in Crocodiles: Proceedings of the 7th Working Meeting of the Crocodile Specialist Group of the Species Survival Commission of the International Union for Conservation of Nature and Natural Resources. IUCN Publ. New Series ISBN2-88032-306-1. xxviii + 446 pp.
- Staton, M., and J. Dixon. 1975. Studies on the dry season biology of *Caiman crocodylus crocodylus* from the Venezuelan llanos. Memoria de la Sociedad de Ciencias Naturales La Salle. 35:237-265.
- \_\_\_\_\_, and \_\_\_\_\_. 1977. Breeding biology of the spectacled caiman, *Caiman crocodylus crocodylus*, in the Venezuelan llanos. U.S. Department of the Interior, Fish and Wildlife Service Wildlife Research Report 5:1-21.
- Unzueta, Q. 1975. Memoria Explicativa: Mapa Ecologico de Bolivia. Ministerio de Asuntos Campesinos y Agropecuarios, La Paz. :1-312.
- Vanzolini, P., and N. Gomes. 1979. Notes on the ecology and growth of Amazonian caimans (Crocodylia, Alligatoridae). Papéis Avulsos de Zoologia 32:205-216.
- Vasquez Ruesta, P. 1981. Bases bio-ecológicas para el Manejo de los Alligatoridae en Jenaro Herrera (Requena-Perú). Thesis for the title of Ingeniero Forestal, Universidad Nacional Agraria La Molina, Peru. 205 pp.
- Wermuth, H., and R. Mertens. 1961. Schildkroten, Krokodile, Bruckenechsen. Gustav Fischer Verlag Jena. xxvi + 422 pp.
- \_\_\_\_\_, and \_\_\_\_\_. 1977. Das Tierreich 100:xxvii-174.

- \_\_\_\_\_, and K. Fuchs. 1983. CITES Identification Manual. Secretariat of the Convention on International Trade in Endangered Species of Wild Fauna and Flora, Lausanne, Switzerland. Vol. 3:A-306.001.002.001 and Vol. 5:L-306.001.002.001f.
- Woodward, A., and D. David. 1985. A study of the baba (*Caiman crocodilus crocodilus*) population on the Hato Piñero in Venezuela. Unpublished xeroographed report to Hato Piñero. 12 p., 4 figures, 4 tables.

## DRAFT

## RESOLUTION OF THE CONFERENCE OF THE PARTIES

## Implementation of the Convention in Bolivia

RECOGNIZING the concern for international compliance control expressed in Resolution Conf. 3.0, adopted at the third meeting of the Conference of the Parties (New Delhi 1981);

RESPONDING to the call for Bolivia to implement and effectively comply with the requirements of the Convention as contained in Resolution Conf. 5.2, adopted at the fifth meeting of the Conference of the Parties (Buenos Aires 1985), including a reduction of wildlife exports to 50% until on the population and on the environmental impact studies have been completed, and management programs established;

NOTING that, as indicated in Doc. 6.20 Implementation of the Convention in Certain Countries, prepared by the Secretariat; Bolivia has not been able to effectively implement the Convention, despite support from the highest levels of the its Government;

CONSIDERING that since the fifth meeting of the Conference of the Parties (Buenos Aires 1985), the Government of Bolivia repeatedly has made administrative changes in its wildlife agency in a continuing effort to build a CITES program and enforce its provisions;

ACKNOWLEDGING that, in partial fulfillment of Conf. 5.2, population surveys of caimans and felids have been initiated under a cooperative agreement between Bolivia's Centro de Desarrollo Forestal and the CITES Secretariat;

BELIEVING that agreeing to utilize an expatriate specialist, selected by the CITES Secretariat, to assist in the development of a CITES program is a demonstration of the desire of the Government of Bolivia to comply fully with the provisions of the Convention;

RECOGNIZING that Bolivian law only permits the hunting of Lagarto (*Caiman yacare*) more than 1.5 m in total length, which yields a belly or hornback hide of the same length or two flank hides 80 cm or more in length;

FURTHER RECOGNIZING that Bolivian law prohibits the export of raw or crusted (= semi-tanned) caiman hides, and only permits the export of finished (= fully tanned, dyed, and glazed) caiman hides and hide products by one of the six tanners belonging to the Asociación de Industriales de Cueros de Saurios (ASICUSA);

APPLAUDING the decision by ASICUSA members to assist the Parties to the Convention to identify legal exports of caiman hides from Bolivia by indelibly stamping the reverse side of their hides with the name of the tannery that processed the hides; and by having their CITES permitted export shipments certified and sealed by the Société Générale de Surveillance, a Swiss company specializing in customs control;

AWARE that Bolivia cannot implement CITES unless the Parties to the Convention actively support its efforts by denying entry to shipments of hides exported in contravention of Bolivian law and CITES regulation;

## THE CONFERENCE OF THE PARTIES TO THE CONVENTION

RECOMMENDS that countries receiving wildlife and wildlife products from Bolivia assure that each shipment is accompanied by CITES export permits as required under the provisions of the Convention, and in the case of caiman hides, as an additional guarantee that the shipment was legally exported, the importing nation should:

- 1) allow only the entry of finished (= fully tanned, dyed, and glazed) caiman hides and hide products,
- 2) only if the shipment has been certified and sealed by the Société Générale de Surveillance, and
- 3) only if it was shipped by one of the members of the Asociación de Industriales de Cueros de Saurios (ASICUSA).

EXHORTS neighboring countries not to allow dealers in illegal wildlife to operate openly within their jurisdictions; and

URGES the Parties to the Convention not to encourage illegal trade by allowing imports from dealers in illegal wildlife from nations neighboring Bolivia.

Table 1.

Wetland	Bank or Shoreline	Estimated density /km of shore	Size Range (in m)
A. Beni river, above Cachuela Esperanza	Mud banks with some overhanging vegetation	0.0	---
B. Beni river, downstream from Riberalta	Bare mud and logs	0.1	---
C. Yata river, a tributary of the Beni	Bare mud & well vegetated banks & floating mats	0.25	0.5-1.1
D. Itenez river, near Versalles	Well vegetated	0.75	0.3-0.5
E. San Pablo river, upstream portion of the San Miguel/Itonamas river	Bare mud & well vegetated banks	0.0	---
F. Ipurupuru river, a tributary of the Machupo river flowing into the Itenez	Overhanging vegetation	1.5	1.0-1.5
G. Ibare river, in vicinity of Trinidad	Bare mud	<0.5	0.3-0.5
H. Yapacani river, a tributary of the Mamore	Bare mud & sand	1.5	0.3-1.0
I. Embayment off the Itenez river, upstream from Versalles	Well vegetated & floating plants	2.65	0.6-1.0
J. Embayment off the Paragua river, a tributary of the Itenez	Well vegetated & floating plants	1.25	0.6-2.0
K. Laguna Concepción, west of San Jose de Chiquitos	Well vegetated & floating plants	4.0	0.6-1.0
L. Lago San Jose, near Riberalta	Well vegetated	70.0	0.3-2.0
M. Unnamed lagoon, off the Mamore, upstream from Santa Ana	Well vegetated & floating plants	1.0	1.2
N. Arroyo Biajo, a curichi off the Mamore	Well vegetated	1.25	1.0-1.2



Table 1 Continued.

Wetland	Bank or Shoreline	Estimated density /km of shore	Size Range (in m)
O. Yagaru, north of Ascension de Guayaros	Well vegetated & floating plants	0.4	1.0-1.5
P. San Miguel reservoir, near San Ignacio de Velasco	Well vegetated & floating plants	0.2	2.0
Q. Roadside borrow pits near Reyes	Well vegetated	1.5	1.0
R. Roadside ditches with permanent water near Trinidad	Well vegetated	3.3	0.8-1.5

A. through H. are riverine localities with flowing water; I. through K. are shallow, quiet water embayments off the main channel of the river; L. through O. are oxbow lakes and lagoons formerly broadly connected to the river, but now slightly separated; and P. through R. are man-made wetlands. Within each of these categories, the localities are listed roughly from the north to the south.

# GENETIC PATTERNS AND THE CONSERVATION OF CROCODILIANS: A REVIEW OF STRATEGIES AND OPTIONS

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**ABSTRACT** - Recent developments in the field of ecological genetics are described and the literature is reviewed with respect to studies of crocodilians. The development of starch gel electrophoretic techniques has provided a relatively simple means of surveying levels of genetic variability in both captive and wild populations and also for determining the degree of genetic relatedness between populations. Applications of these techniques to programs of captive propagation and the management of wild crocodilians are discussed. Of particular interest are techniques for determining paternity in mixed captive breeding groups and identification of racial or geographic origins of individual animals. Positive correlations between levels of genetic variability and the general vigor and reproductive output of individual animals of several species suggest that electrophoretic genetic surveys could help to suggest ways in which these traits could be optimized in both captive and wild populations of crocodilians.

## INTRODUCTION

Recent advances in the field of population genetics have provided a number of useful techniques for the management and conservation of both captive and wild populations of various species (Manlove et al. 1975, 1976; Selander 1983; Smith et al. 1976; Johns et al. 1977; Smith et al. 1978; Chessier et al. 1980; Chambers and Bayless 1983; Harris et al. 1984; Vrijenhoek et al. 1985; Meffe 1986). The use of horizontal starch gel electrophoresis, in particular, has provided a means for rapid and inexpensive assessment of the degree of genetic relatedness between populations. It has also provided a means to assess both temporal and spatial patterns of genetic variability (Chessier et al. 1982). This information can then, in turn, be used to determine the extent to which programs of captive propagation may have altered the naturally-occurring patterns and levels of genetic variability of wild populations.

The purpose of this report is to briefly summarize the genetic information currently available for crocodilians and then to examine the implications of these studies for both captive propagation and management of wild populations. First, however, it will be useful to review the basic principles behind the multi-locus approach to biochemical analyses of population genetic parameters.

## BACKGROUND GENETIC INFORMATION

Crocodilians, like most sexually-reproducing organisms, receive two copies of each chromosome and therefore two alleles at each gene locus, one from each parent. If the alleles received from each parent are

identical, the individual is said to be homozygous for that particular gene locus. If different alleles are received from each parent, the individual is said to be heterozygous, and the locus is described as being polymorphic. It should be remembered, however, that in the case of allelic dominance, it is possible for both a homozygous dominant and a heterozygous individual to be phenotypically identical from the point of view of external physical appearance. Under such conditions, it would not be possible to directly determine the frequency of the various alleles in the population on the basis of external phenotypes alone, since the expressions of recessive alleles could be "masked" by the dominant phenotypes of heterozygous individuals.

In such situations, techniques such as starch gel electrophoresis are of key importance; by demonstrating the presence of the gene products of otherwise phenotypically recessive alleles as codominants, in heterozygous individuals, such procedures provide a means of directly quantifying the frequency of alternative alleles within population samples. The determination of such gene frequencies thus provides the means by which hypotheses concerning genetic relatedness between populations may be tested statistically (Chesser 1980).

## LITERATURE REVIEW

Only three current publications provide information concerning levels and patterns of genetic variability in crocodilians and all of these papers deal with the American alligator (*Alligator mississippiensis*). Gartside et al. (1977) report from southwestern Louisiana, while Menzies et al. (1979) provide similar information for alligators from the Everglades National Park in Florida. Adams et al. (1980) provide the only direct comparisons of alligator populations from three different parts of the species range, providing genetic data from alligators in South Carolina, Loxahatchee National Wildlife Refuge in Florida and from the same general region in southwestern Louisiana as that studied by Gartside et al. (1977). A comparison of gene frequencies calculated for the Louisiana alligators indicates close agreement between the results from these two studies which were conducted independently at different laboratories. Adams et al. (1980), for example, report a frequency of 0.77 for the common allele of lactate dehydrogenase-2 while Gartside et al. (1977) report a comparable value of 0.81 for this same allele from Louisiana alligators. This suggests that the use of electrophoresis can produce results which are comparable and independently replicable between laboratories.

In every case where gene frequencies have been compared between alligator populations, the populations in question have been found not to share a common gene pool. Thus, Menzies et al. (1979), in comparing their results with those published earlier by Gartside et al. (1977), found that the Everglades alligator population was genetically different from those of southwestern Louisiana, as described by the latter authors. Similarly, Adams et al. (1980) report that every gene locus examined in their study that had a frequency of 0.15 or greater for the alternate rare allele, showed a statistically significant spatial heterogeneity. For example, Chi-square testing of count data for the allele frequencies of lactate dehydrogenase-2 showed that differences in gene frequencies between the three alligator populations could not be accounted for by chance variation alone, thereby inferring that the three populations in question did not share a common gene pool (Fig. 1).

Even though all wild alligator populations that have been studied so far have been found to be genetically different, the overall degree of genetic divergence between populations is relatively small (Adams et al. 1980). Multi-locus electrophoretic data can be used to quantify the degree of genetic divergence between populations through the calculation of one or more indices of genetic separation. The calculation of Rogers' index of genetic distance (Rogers 1972) by Adams et al. (1980), for example, revealed that values quantifying the degree of genetic separation between alligator populations (range: 0.018 - 0.081; Fig. 2) were all relatively low in comparison to similar values for conspecific populations which may range as high as 0.15 (Selander and Johnson 1973; Avise 1974, 1976).

Lactate Dehydrogenase -2  
( $\chi^2 = 16.61$  ;  $P \leq 0.001$ )

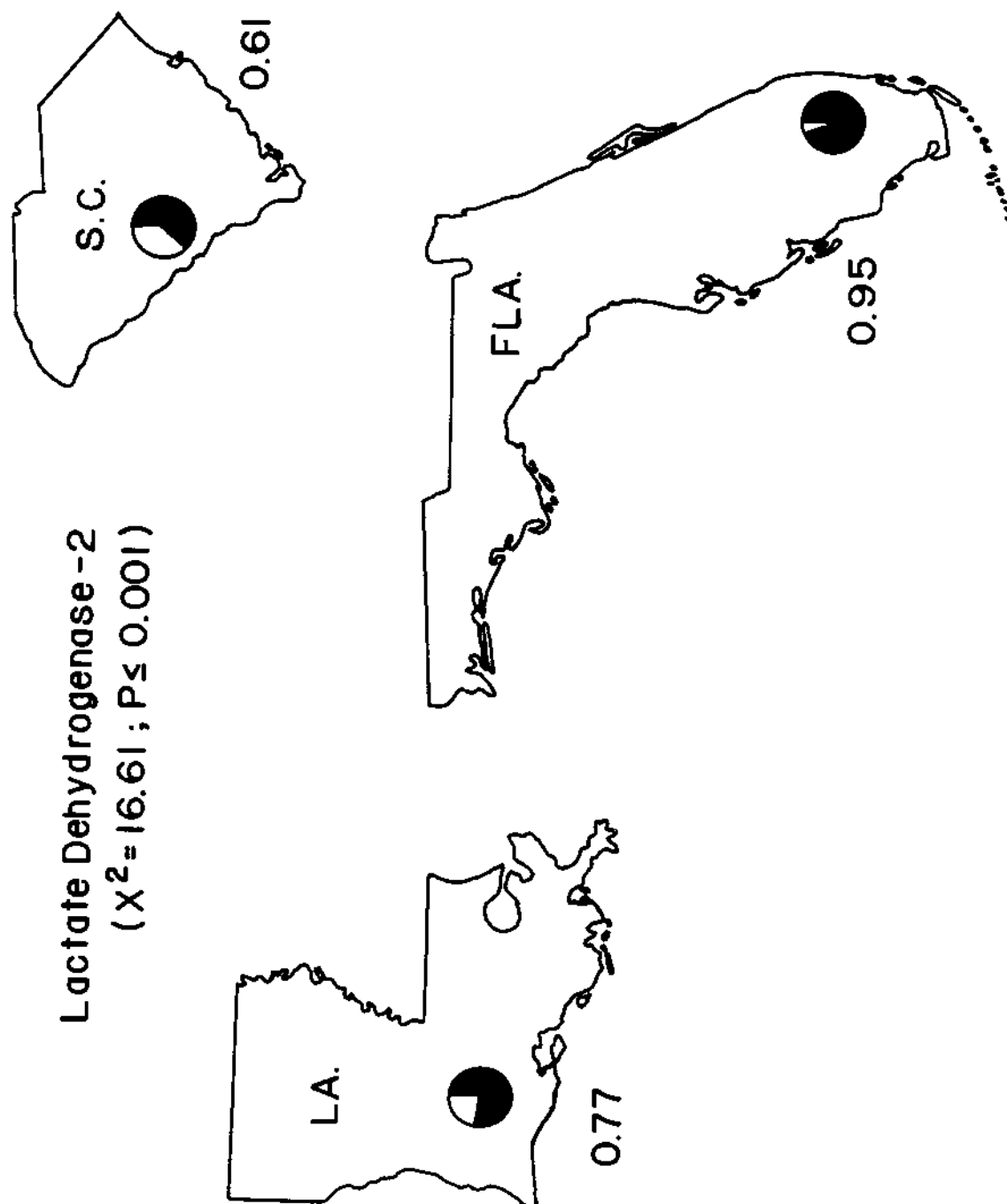


Figure 1. Frequencies of two alternate alleles of the gene encoding lactate dehydrogenase-2, as determined by electrophoretic analyses of tissue samples from American alligator populations in three southeastern states. Blackened portions of each pie diagram represent the frequency of the common allele in each population. Chi-square analyses indicate that the three populations in question do not share a common gene pool. (Drawn from data presented by Adams et al. 1980).

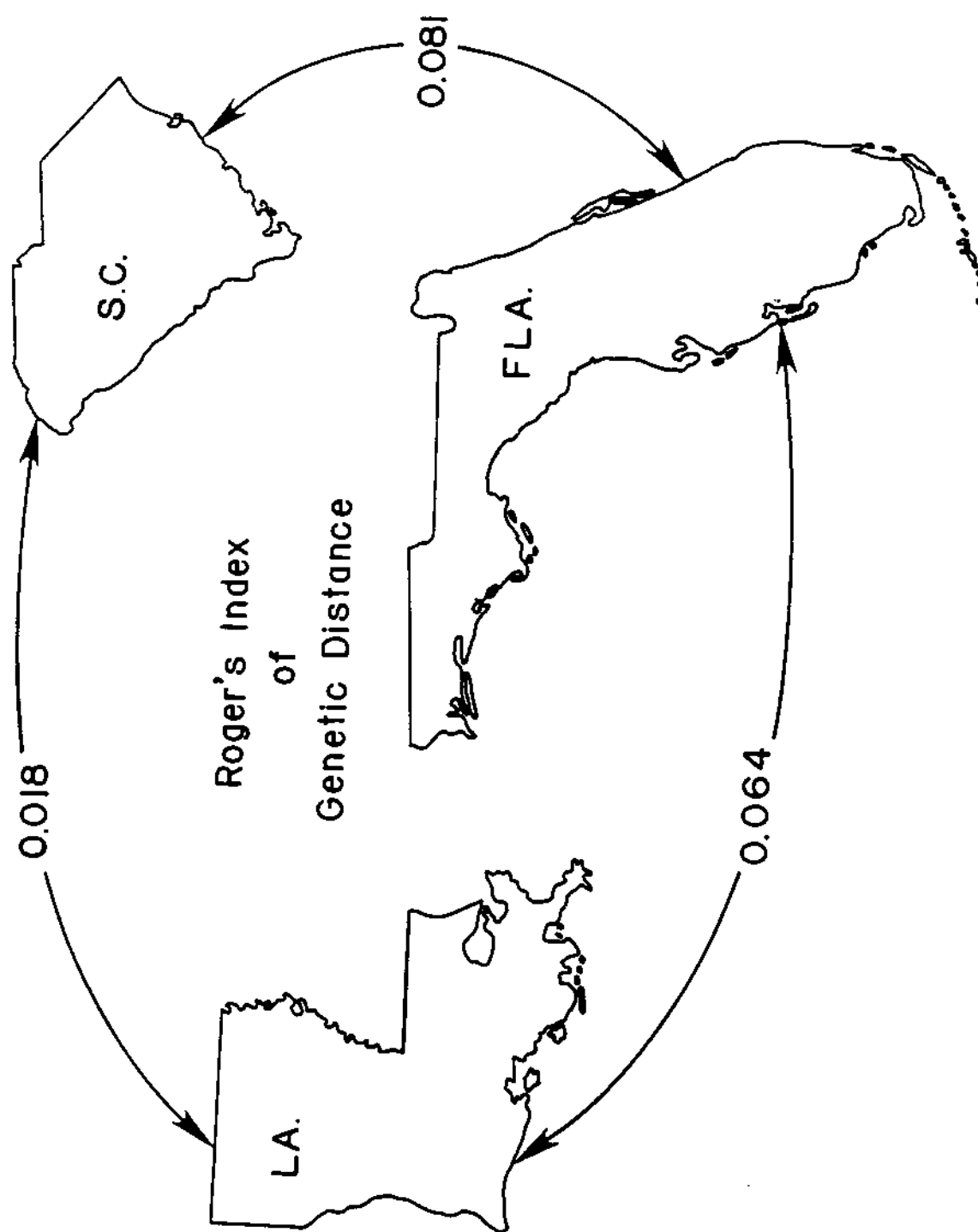


Figure 2. Roger's index of genetic distance between populations of American alligators from three southeastern states. Indices were calculated on the basis of electrophoretic analyses of tissue samples. (Drawn from data presented by Adams et al. 1980).

Table 1. Comparisons of literature values quantifying levels of genetic variability in populations of the American alligator in the southeastern United States.

Population	Number of Loci	Proportion of Loci which are Variable (P)	Average Heterozygosity per Individual (H) ( $\pm 2$ S.E.)	Reference
Southwestern Louisiana	49	0.06	0.021 ( $\pm 0.024$ )	Gartside et al. (1977)
	27	0.074	0.012 ( $\pm 0.004$ )	Adams et al. (1980)
Florida: Everglades National Park	44	0.045	0.0086 ( $\pm 0.016$ )	Menzies et al. (1979)
Florida: Loxahatchee National Wildlife Refuge	21	0.19	0.02 ( $\pm 0.006$ )	Adams et al. (1980)
South-central South Carolina	27	0.19	0.034 ( $\pm 0.006$ )	Adams et al. (1980)

Several different indices may be calculated to quantify and compare the overall degree of genetic variability within and between species populations. These indices include P, the proportion of all loci examined which are variable (i.e., show more than one allele) and A, the average number of alleles per locus (Adams et al. 1980). Probably the most useful index of overall genetic variability, however, is H, the average heterozygosity per individual. H represents the population average of the number of heterozygous loci over the total possible loci assayed per individual. Heterozygosity, then, is distinct from P, which measures the potential variability at loci in the population sampled, whether or not these loci are heterozygous for any individual. Because statistical procedures are available for calculating confidence limits for estimates of heterozygosity (e.g., Nei and Roychoudhury 1974), this index is particularly useful for comparing levels of genetic variability between populations.

A comparison of all available values for H and P which have been calculated for alligator populations are presented in Table 1. As pointed out by Adams et al. (1980), values of H for alligator populations are quite low in comparison to those of other non-mammalian vertebrate species (Nevo 1978, Nevo et al. 1983). Lewontin (1974) and Selander and Johnson (1973) indicate that heterozygosity values typically range from 0.05 to 0.18. All alligator heterozygosity values are below the lower limit of this range (Table 1). However, Adams et al. (1980) point out that most of their P values for alligator populations (Table 1) are within the range typically reported for other vertebrates (0.1-0.2; Avise 1974). The former authors suggest that this observed pattern of relatively high P values in combination with low values for H, would be reasonable for a species such as the alligator with a large geographic range and limited gene flow between populations (resulting in a higher P), in combination with a large body size and relatively small breeding populations (which typify species with a relatively low H). These data need to be interpreted with some caution. H and P are not independent of one another. H is also sensitive to other variables not traditionally standardized among electrophoretic studies, such as the type of enzymes assayed, enzyme function and molecular size (Johnson 1974, 1976; Ward 1977). As an example of problems that may arise in interpretations of comparisons of genetic variability across studies, Simon and Archie (1985) demonstrated that subsampling

enzymes from a study of 38 loci in the milkfish, *Chanos chanos*, produced a range of heterozygosity values from 5.6% to 11.4%. These values include the differences in means between vertebrates and invertebrates found in Nevo's (1978) analysis of 227 species. Therefore, we recommend comparisons across studies be made for a standardized set of loci.

For the present, we must rely on H, P, and A as the necessary indices of genetic variability within and across populations, and keep in mind that conflicting hypotheses may be the result of artifacts in our ability to measure variability accurately at this time. The pros and cons of supplementary, complementary or contradictory hypotheses to explain the observed patterns of genetic variability in alligator populations have also been discussed by others (Gartside et al. 1977; Menzies et al. 1979). These hypotheses include genetic "bottlenecking" and genetic drift during periods of low population numbers, environmental grain, and directional selection, all of which may help to explain the observed patterns of genetic variability. More information concerning long-term patterns of gene flow between alligator populations is needed, however, before the roles of such hypotheses can be properly evaluated (Adams et al. 1980). To complicate the issue further, low levels of heterozygosity may be characteristic of some taxa, but may be the result of population bottlenecking for others. The cattail genus *Typha* is homozygous for all 10 loci examined (Mashburn et al. 1978), largely because of its clonal method of reproduction. On the other hand, the northern elephant seal (Bonnell and Selander 1974) experienced a drastic population reduction at the turn of the century. They have now recovered in population numbers, but still show no genetic variation at the 24 loci examined. The cheetah, *Acinonyx jubatus*, (O'Brien et al. 1983, 1985; Wayne et al. 1986) also shows little genetic variation, and this has been attributed to an unobserved bottleneck since the Pleistocene. The low levels of heterozygosity in both of these mammalian examples may be the result of the real or inferred bottlenecks, with prolonged recovery predicted by population genetics theory, (Nei et al. 1975), or, alternately, they may be a result of the demographic strategies of these particular species. Sibley and Ahlquist (in press) suggest, with their data on birds, that some groups show slower rates of molecular evolution. These slower rates seem to be correlated with longevity, later age to first reproduction, and fewer young produced per reproductive effort. These demographic factors may feed back into the overall genetic variability of the species as a whole, resulting in fewer mutations being incorporated per generation, and consequently, less genetic variability (Gilpin and Soule 1986). If this is the case, then species like the alligator may have always had low levels of heterozygosity and have adapted to the low variability through demographic factors, such as dispersal.

What this means is that there are many factors influencing genetic variability, and numerous ways that genetic variability can influence the success of a species (Nevo 1978). We have little understanding of how the organization of the genome influences the long-term survival of a species, which in turn, influences the short-term genetic variability (Meffe 1986). We need more basic research in natural population structure and effects of genetic variability on the viability of populations. A more thorough understanding of genome organization - such as the role of introns, regulators, transposable elements and the like - will make it easier to comprehend the differing strategies species employ in responding to their environment. We concur with policies based on efforts to remain conservationally conservative; that is, efforts should be made to retain as much genetic variability as possible, regardless of how basic our techniques are, until we are better able to understand the influence of genetic variability on the health and survival of the species being managed. Additionally, we must always keep in mind that outbreeding depression may be as problematical as inbreeding depression (Templeton 1986; see below).

An examination of the levels of heterozygosity calculated for all available studies of alligators (Table 1) suggests that while there may be considerable variation in the degree of heterozygosity shown by different alligator populations, there is a broad general overlap of the 95% confidence intervals (+ 1.96 S.E.) about these estimates, and indeed, the magnitude of these confidence intervals may themselves show considerable variation. Part of the differences in the sizes of confidence intervals about estimates of heterozygosity for alligator populations may be due to differences in the techniques used in their computation. Adams et al. (1980) used standard parametric statistical procedures to calculate their confidence limits, (but see Archie 1985) while Gartside et al. (1977) used the method of Nei and Roychoudhury (1974). Nevertheless, the data for heterozygosity presented by Adams et al. (1980; Table 1)

suggest that the alligators from their South Carolina sample may have had a significantly higher level of average genetic variability than those from Louisiana.

### APPLICATIONS OF GENETIC STUDIES

As discussed earlier, genetic studies may have direct application to two main aspects of concerns for crocodilian conservation: (1) management of wild populations, and (2) development of programs of captive propagation. The present and possible future contributions of studies using starch gel electrophoretic techniques will be discussed for each of these areas separately.

**Management of Wild Populations:** A model for the application of genetic studies to the management of free-living wildlife populations is provided by Manlove et al. (1975) and Smith et al. (1978), for management of the white-tailed deer (*Odocoileus virginianus*). As pointed out by these authors, electrophoretic studies of blood and/or tissue samples can, through the calculation and comparison of gene frequencies across space and time, help to define functional management units in terms of population cohorts sharing common gene pools. The definition and delineation of such management units is, of course, a critical prerequisite for devising management plans for a species across its range of geographic occurrence. As an example, the failure of nesting populations of loggerhead sea turtles (*Caretta caretta*) to share a common gene pool between coastal barrier islands of South Carolina and Georgia (Smith et al. 1978), indicates that intensive management efforts designed to help this species on one island would probably have little or no effect on nesting populations on some other islands in the same southeast region. Similar arguments may be made for management programs designed for crocodilian populations which are also comprised of spatially discrete genetic units, as illustrated by Figure 1.

Another potential value of genetic studies for the management of wild populations lies in the possibility of identifying so-called "marker" genes which may help to identify the racial or geographic origin of individuals found in captive collections or confiscated through law enforcement activities. In the case of the three alligator populations studied by Adams et al. (1980), for example, electrophoretic studies of the blood from a confiscated animal found in a shipment illegally destined for export might reveal the presence of the uncommon allele of peptidase-1, which is found in 16% of the Florida alligators, but which is absent from the populations in South Carolina or Louisiana (Fig. 3). This would indicate a Florida origin for the specimen in question, if these were the only populations under consideration. Obviously, the usefulness of this technique will be increased in proportion to the number of different population units that can be surveyed from throughout the species range. It should also be remembered, however, that in the example cited above, 84% of the Florida animals could not be separated from those from the other two states on the basis of the peptidase-1 system alone. Thus, the greater the number of electrophoretically variable systems that can be demonstrated for a given species, the more likely it is that this procedure will be able to positively identify the population of origin for a given individual.

Finally, as demonstrated by Ryman et al. (1981), the precise forms of management and harvest schemes which may be proposed for a given species can significantly alter both its patterns and levels of genetic variability and thereby alter the roles of any factors related to this variability as discussed in this report. Such possibilities must be borne in mind when devising management schemes and quotas for the sustained-yield harvest of species such as the American alligator (Nichols et al. 1976). Of particular concern in this regard would be the possibility that improper harvest schemes might, through the inadvertent alteration of population sex ratios and/or age structure, reduce effective population size and thereby increase the probability of a reduction of overall genetic variability (Ryman et al. 1981; Gilpin and Soule 1986).

**Programs for Captive Propagation:** The general application of genetic studies to the captive propagation of endangered species have been outlined by Chessier et al. (1980). While specific examples chosen by these authors are taken from the zoo literature on captive-breeding populations of ungulates and field studies of



Peptidase -1  
( $\chi^2 = 15.39$ ;  $P \leq 0.001$ )

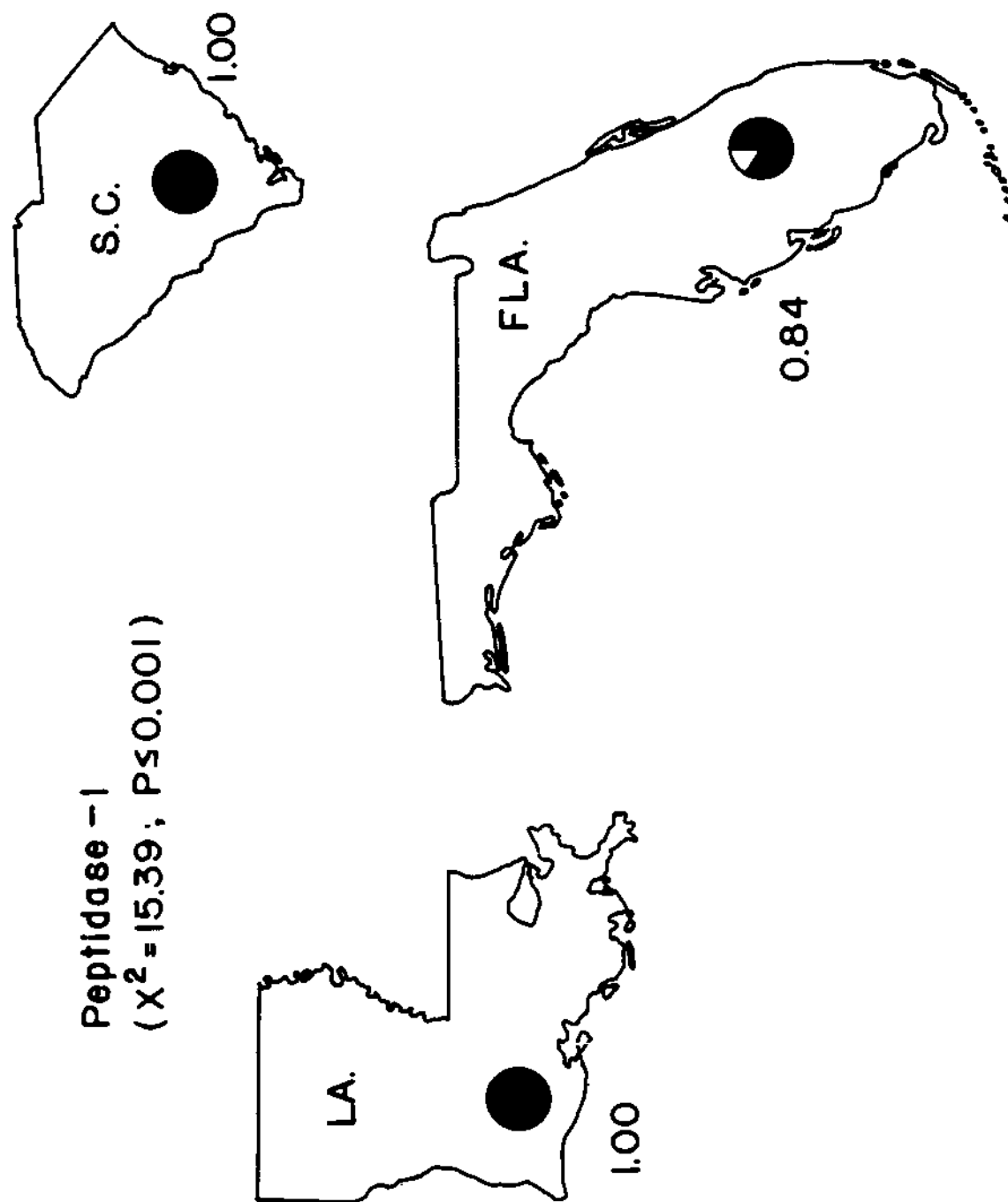


Figure 3. Frequencies of two alternate alleles of the gene encoding peptidase-1, as determined by electrophoretic analyses of tissue samples from American alligator populations in three southeastern states. Blackened portions of each pie diagram represent the frequency of the common allele in each population and indicate the potential for the use of the rarer allele from the Florida population as a "marker gene" to help to identify specimens of unknown geographic origin. (Drawn from data presented by Adams et al. 1980).

the genetics of white-tailed deer, many of the general principles presented are also applicable to the captive propagation of crocodilians. A generalized breeding scheme has been proposed by these authors, which would preserve maximum amounts of genetic variability in captive breeding populations. This scheme closely mimics the general procedures by which most species of crocodilians are currently being bred in either zoos or in more specialized farming operations - namely, the maintenance of relatively small closed breeding populations in which the loss of genetic variability and fixation of rare alleles would occur at a relatively rapid rate. In order to avoid deleterious effects of the inbreeding depression that may occur in such situations (Ralls et al. 1979), breeding stock should then be exchanged between zoos or farms to increase outbreeding. Such outbreeding should occur at pulsed intervals, which are determined by the times at which the greatest reversal of the deleterious effects of inbreeding depression can be achieved.

In selecting breeding stock for exchange, profitable use can be made of electrophoretic genetic profiles which would indicate which matings would produce the greatest increase in overall heterozygosity. As will be pointed out later, there is evidence that significant increases in general vigor, viability and reproductive output can be expected to be associated with pairings that maximize levels of heterozygosity in the offspring (Mitton and Grant 1984). In order to realize these goals, Chesser et al. (1980) emphasize that the actual choice of animals as breeders should be made at random, within the guidelines suggested by electrophoretic genetic profiles. In larger breeding groups, such as are often maintained in commercial crocodilian farming operations, allowing animals to select their own mates allows a closer approximation of some of the selective forces which may be operative in wild populations of the same species. The preservation and exchange of frozen semen between institutions (Anon. 1980) can also produce a pulsed outbreeding which can counteract the effects of inbreeding depression.

Starch gel electrophoretic studies can also be of importance in helping to evaluate the degree to which captive breeding programs have been successful in approximating the levels and patterns of genetic variability actually found in wild populations. Thus, the fact that reduced levels of heterozygosity may be found in certain captive breeding groups need not necessarily be a cause for concern - particularly if the genetic surveys of successful wild populations of the same or closely related species should also reveal similarly reduced levels of heterozygosity. If, for example, a genetic survey of the few available captive Chinese alligators (*Alligator sinensis*) should reveal low heterozygosity values of 0.005 - 0.010, this fact in itself would not necessarily be a cause for concern since it has now been shown that vigorous and viable populations of wild American alligators may have heterozygosity levels that are not any higher (Gartside et al. 1977; Menzies et al. 1979; Adams et al. 1980; Table 1).

Still another potential application of genetic analyses to captive breeding programs lies in the ability of such studies, under appropriate conditions, to identify those individuals which are actually siring offspring in large mixed breeding groups. Such information could be of great practical value since it would allow the identification of non-breeding males which could then be removed from such breeding groups and either disposed of or transferred to other breeding groups where the social structure or other factors might permit them to start mating and producing offspring. As in the case of identifying unknown individuals as to racial or geographic origin on the basis of electrophoretic profiles, the probability of successfully using this same technique to identify paternity will be increased in proportion to the number of electrophoretically detectable variable gene loci that can be identified. A total of ten variable gene loci have already been demonstrated for the American alligator using starch gel electrophoresis (Gartside et al. 1977; Adams et al. 1980) and while the demonstration of more variable loci would be helpful, useful paternity information could now be collected in appropriate situations, with the use of only those ten variable gene loci which have already been demonstrated for this species.

Finally, one of the most exciting and potentially useful aspects of electrophoretic genetic surveys of captive breeding populations lies in the fact that certain traits related to the maximization of reproductive output and the maintenance of health and vigor have been shown to be positively correlated with increased levels of genetic variability in certain environments (Mitton and Grant 1984; Allendorf and Leary 1986). Significant relationships have been found, for example, between genetic variability and higher reproductive rates (Smith et al. 1975; Johns et al. 1977), higher growth rates (Singh and Zouros 1978) and increased

levels of aggression and dominance (Garten 1976). These studies suggest a pattern which, if it holds for crocodilians as it has been shown to hold for other species such as shellfish and deer, could provide a means for making effective decisions concerning the selection of breeding animals for either captive matings, release and restocking into wild populations, or transfer between wild population subunits. The implications of these genetic studies for the captive management and propagation of endangered species in a general sense have been discussed by Chesser et al. (1980). Alternately, if populations are so small that there is no hope of avoiding inbreeding depression, then the only recourse would be to force the population through a controlled bottleneck in order to purge it of deleterious alleles, as was done for the Speke's Gazelle (Templeton and Read 1983). Moreover, if crocodilians are predisposed to strong population structuring at local levels but population mixing at regional levels (Fig. 2), then programs attempting to enhance outbreeding may result in outbreeding depression, where coadapted gene complexes are broken up, to the detriment of the locally adapted population (Alstad and Edmunds 1983; Templeton 1986). Starch gel electrophoresis can help us decide which strategy to follow in our conservation efforts.

As illustrated by the foregoing examples, the majority of genetic studies related to the management of wild populations and captive propagation have not yet dealt directly with crocodilians. However, those genetic surveys that have been undertaken with the American alligator indicate that this species and thus possibly other species of crocodilians as well, can also be profitably studied with the use of starch gel electrophoresis, using blood and/or tissue samples which can be collected with little or no risk of harm to the animal involved. The collection of such genetic information from larger numbers of individuals and from additional species of crocodilians could not only contribute significantly to the wise management, captive propagation and conservation of such crocodilian species themselves, but could also provide valuable data which could help to increase our general understanding of the population genetics of many kinds of wildlife species throughout the world.

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#### LITERATURE CITED

- Anonymous. 1980. Semen preservation and artificial insemination could make the difference. *Endangered Species Tech. Bull.* 5:4-7.
- Adams, S.E., M.H. Smith, and R. Baccus. 1980. Biochemical variation in the American alligator. *Herpetologica* 36:289-296.
- Allendorf, F.W., and R. F. Leary. 1986. Heterozygosity and fitness in natural populations of animals. In M. E. Soule, ed. *Conservation Biology*. Sinauer Assoc., Inc., Sunderland, Mass.
- Alstad, D.L., and G.F. Edmunds, Jr. 1983. Selection, outbreeding depression, and the sex ratio of scale insects. *Science* 220: 93-95.
- Archie, J.W. 1985. Statistical analysis of heterozygosity data: independent sample comparisons. *Evolution* 39:623-637.
- Awise, J.C. 1974. Systematic value of electrophoretic data. *Syst. Zool.* 23:465-481.

- \_\_\_\_\_. 1976. Genetic differentiation during speciation. In F.J. Ayala, ed. *Molecular Evolution*. Sinauer Assoc., Inc., Sunderland, Mass.
- Bonnell, M.L., and R.K. Selander. 1974. Elephant seals: genetic variation and near extinction. *Science* 184:908-909.
- Chambers, S.M., and J.W. Bayless. 1983. Systematics, conservation and the measurement of genetic diversity. In C.M. Schoenewald-Cox, S.M. Chambers, B. MacBryde, and W.L. Thomas, eds. *Genetics and Conservation*. Benjamin/Cummings Publ. Co., Inc. Menlo Park, Ca.
- Chesser, R.K. 1980. Computer Systems and Programming for the Analysis of Population Genetics Data. Report No. 3, Dept. of Genetics, Univ. of Stockholm. Stockholm, Sweden.
- \_\_\_\_\_, M.H. Smith, and I.L. Brisbin, Jr. 1980. Management and maintenance of genetic variability in endangered species. *Intern. Zoo Yearbook* 20:146-154.
- \_\_\_\_\_, M.H. Smith, P.E. Johns, M.N. Manlove, D.O. Straney, R. Baccus. 1982. Spatial, temporal, and age-dependent heterozygosity of beta-hemoglobin in white-tailed deer. *J. Wildl. Manage.* 46:983-990.
- Garten, C.T. 1976. Relationships between aggressive behavior and genic heterozygosity in the old-field mouse. *Evolution* 30:59-72.
- Gartside, D.F., H.C. Dessauer, and T. Joanen. 1977. Genic homozygosity in an ancient reptile (*Alligator mississippiensis*). *Biochem. Genet.* 15:655-663.
- Gilpin, M.E., and M.E. Soule. 1986. Minimum viable populations: Processes of species extinction. In M.E. Soule, ed. *Conservation Biology*. Sinauer Assoc., Inc., Sunderland, Mass.
- Harris, L.D., M.E. McGlothlen, and M.N. Manlove. 1984. Genetic resources and biotic diversity. In L.D. Harris. *The Fragmented Forest: Island Biogeography Theory and the Preservation of Biotic Diversity*. Univ. of Chicago Press. Chicago, Ill.
- Johns, P.E., R. Baccus, M.N. Manlove, J.E. Pinder III, and M.H. Smith. 1977. Reproductive patterns, productivity and genetic variability in adjacent white-tailed deer populations. *Proc. Ann. Conf. S.E. Assoc. Game and Fish Comm.* 31:167-172.
- Johnson, G.B. 1974. Enzyme polymorphism and metabolism. *Science* 184:28-37.
- \_\_\_\_\_. 1976. Genetic polymorphism and enzyme function. In: F.J. Ayala, ed. *Molecular Evolution*. Sinauer Assoc., Inc., Sunderland, Mass.
- Lewontin, R.C. 1974. *The Genetic Basis of Evolutionary Change*. Columbia Univ. Press. New York.
- Manlove, M.N., J.C. Avise, H.O. Hillestad, P.N. Ramsey, M.H. Smith, and D.O. Straney. 1975. Starch gel electrophoresis for the study of population genetics of white-tailed deer. *Proc. Ann. Conf. S.E. Assoc. Game and Fish Comm.* 29:392-403.
- \_\_\_\_\_, M.H. Smith, H.O. Hillestad, S.E. Fuller, P.E. Johns, and D.O. Straney. 1976. Genetic subdivision in a herd of white-tailed deer as demonstrated by spatial shifts in gene frequencies. *Proc. Ann. Conf. S.E. Assoc. Game and Fish Comm.* 30:487-492.
- Mashburn, S.J., R.R. Sharitz, and M.H. Smith. 1978. Genetic variation among *Typha* populations of the southeastern United States. *Evolution* 32:681-685.

- Meffe, G.K. 1986. Conservation genetics and the management of endangered fishes. *Fisheries* 11:14-23.
- Menzies, R.A., J. Kushlan, and H.C. Dessauer. 1979. Low degree of genetic variability in the American alligator (*Alligator mississippiensis*). *Isozyme Bull.* 12:61.
- Mitton, J.B., and M.C. Grant. 1984. Associations among protein heterozygosity, growth rate, and developmental homeostasis. *Ann. Rev. of Ecol. and Syst.* 15:479-499.
- Nei, M., and A. Roychoudhury. 1974. Sampling variances of heterozygosity and genetic distance. *Genetics* 76:379-390.
- \_\_\_\_\_, T. Maruyama, and R. Chakraborty. 1975. The bottleneck effect and genetic variability in populations. *Evolution* 29: 1-10.
- Nevo, E. 1978. Genetic variation in natural populations: patterns and theory. *Theoret. Pop. Biol.* 13:121-177.
- \_\_\_\_\_, A. Beiles, and R. Ben-Shlomo. 1983. The evolutionary significance of genetic diversity: Ecological demographic and life history correlates. In S. Levin, ed. *Evolutionary Dynamics of Genetic Diversity*. Springer-Verlag, New York.
- Nichols, J.D., L. Viehman, R.H. Chabreck, and B. Fenderson. 1976. Simulation of a commercially harvested alligator population in Louisiana. La. State Univ. Agric. Exp. Sta. Bull. No. 691, Baton Rouge.
- O'Brien, S.J., D.E. Wildt, D. Goldman, C.R. Merrill, and M. Bush. 1983. The Cheetah is depauperate in genetic variation. *Science* 221:459-462.
- \_\_\_\_\_, M.E. Roelke, L. Marker, A. Newman, C.A. Winkler, D. Meltzer, L. Colly, J.F. Evermann, M. Bush, and D.E. Wildt. 1985. Genetic basis for species vulnerability in the Cheetah. *Science* 227:1428-1434.
- Ralls, K., K. Brugger, and J. Balou. 1979. Inbreeding and juvenile mortality in small populations of ungulates. *Science* 206:1101-1103.
- Rogers, J.S. 1972. Measure of genetic similarity and genetic distance. In M. H. Wheeler, ed. *Studies in Genetics VII*. Univ. Texas Publ. No. 7213. Austin.
- Ryman, N., R. Baccus, C. Reuterwall, and M.H. Smith. 1981. Effective population size, generation interval, and potential loss of genetic variability in game species under different hunting regimes. *Oikos* 36:257-266.
- Selander, R.K. 1983. Evolutionary consequences of inbreeding. In C.M. Schoenewald-Cox, S.M. Chambers, B. MacBryde, and W.L. Thomas, eds. *Genetics and Conservation*. The Benjamin/Cummings Publ. Co., Inc., Menlo Park, California.
- \_\_\_\_\_, and W.E. Johnson. 1973. Genetic variation among vertebrate species. *Ann. Rev. Ecol. Syst.* 4:75-91.
- Sibley, C.G. and J. Ahlquist. (In press). *Phylogeny and Classification of the Birds of the World*. Yale Univ. Press, New Haven, Conn.
- Simon, C., and J. Archie. 1985. An empirical demonstration of the lability of heterozygosity estimates. *Evolution* 39:463-467.

- Singh, S. M., and E. Zouros. 1978. Genetic variation associated with growth rate in the American oyster (*Crassostrea virginiana*). *Evolution* 23:342-353.
- Smith, M.H., C. T. Garten, and P.E. Ramsey. 1975. Genetic heterozygosity and population dynamics in small mammals. In C.L. Markert, ed. *Isozymes IV, Genetics and Evolution*. Academic Press, New York.
- \_\_\_\_\_, H.O. Hillestad, M.N. Manlove, and R.L. Marchinton. 1976. Use of population genetics data for the management of fish and wildlife populations. *Trans. No. Amer. Wildl. Nat. Resour. Conf.* 41:119-133.
- \_\_\_\_\_, H.O. Hillestad, M.N. Manlove, D.O. Straney, and J.M. Dean. 1978. Management implications of genetic variability in loggerhead and green sea turtles. *Proc. 13th Intern. Congr. Game Biol.* 302-312.
- Templeton, A.R. 1986. Coadaptation and outbreeding depression. In M.E. Soule, ed. *Conservation Biology*. Sinauer Assoc., Inc., Sunderland, Mass.
- \_\_\_\_\_, and B. Read. 1983. The elimination of inbreeding depression in a captive herd of Speke's Gazelle. In C.M. Schoenewald-Cox, S.M. Chambers, B. MacBryde and W.L. Thomas, eds. *Genetics and Conservation*. Benjamin/Cummings Publ. Co., Inc., Menlo Park, Ca.
- Vrijenhoek, R.C., M.E. Douglas, and G.K. Meffe. 1985. Conservation genetics of endangered fish populations in Arizona. *Science* 229:400-402.
- Ward, R.D. 1977. Relationship between enzyme heterozygosity and quaternary structure. *Biochem. Genet.* 15:123-135.
- Wayne, R.K., W.S. Modi, and S.J. O'Brien. 1986. Morphological variability and asymmetry in the Cheetah (*Acinonyx jubatus*), a genetically uniform species. *Evolution* 40:78-85.

# APPLICATIONS OF LIMNOLOGY AND HYDROLOGY TO CROCODILIAN CONSERVATION AND MANAGEMENT

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## SUMMARY

Limnological data were gathered from 7 *Paleosuchus trigonatus* localities, 15 *Caiman crocodilus* localities, and 7 *Caiman crocodilus* (Llanos subspecies) localities. The mean temperatures (C), conductivities (MHOS) and total cations (ueq/l) were 22.4/6.6/49.3, 29.1/48.5/215.8, and 32.4/125.6/1,052.2 respectively. Hydrological data were processed for 27 *Crocodylus intermedius* localities and 16 *P. trigonatus* localities. Mean annual rainfall (mm) and runoff (mm) were 1,797/734 and 2,422/1,441 respectively. It is suggested that these correlations indicate ecological relationships between habitats and crocodilians. Limnological and hydrological data are easily obtainable, and could be applied to survey planning, ecological studies, site selection for reintroductions, and environmental impact assessment.

## RESUMEN

Se recolectó información limnológica en 7 localidades de *Paleosuchus trigonatus*, 15 de *Caiman crocodilus crocodilus*, y 7 de *Caiman crocodilus* de Llanos. Los promedios de temperaturas (C), conductividades (MHOS) y cationes totales (ueq/l) fueron 22.4/6.6/49.3, 29.1/48.5/215.8, y 32.4/125.6/1,052.2 respectivamente. Información hidrológica fue procesada para 27 localidades de *Crocodylus intermedius* y 16 de *Paleosuchus trigonatus*. Los promedios de lluvias anuales (mm) y escurrimientos anuales (mm) fueron 1,797/734 and 2,422/1,441 respectivamente. Se sugiere que estas correlaciones indican relaciones ecológicas entre hábitats y crocodilidos. La información limnológica e hidrológica es fácilmente obtenible, y podría ser aplicada en inventarios, estudios ecológicos, selección de sitios para reintroducciones, y evaluación de impacto ambiental.

## INTRODUCTION

In Venezuela government and non-government organizations are working on a conservation program of the Orinoco crocodile (*Crocodylus intermedius*), and on a smaller scale for the American crocodile (*C.*

*acutus*). An experimental harvest has been carried out with the spectacled caiman (*Caiman crocodilus*). The two other species of crocodilians, Schneider's smooth-fronted caiman (*Paleosuchus trigonatus*) and Cuvier's smooth-fronted caiman (*P. palpebrosus*) are poorly known.

Effective management and conservation plans for crocodilians require knowledge about the geographical distributions and the ecology of the species under consideration. In Venezuela (with a surface area of almost 1,000,000 km<sup>2</sup>) there are no records of any crocodilians being present in 72% of the country, although many such areas probably contain crocodilian populations. This implies that extensive surveying of crocodilians is a research priority in the short term. However, traditional surveying techniques need time, money and people. In this paper we present some preliminary data on limnological and hydrological characteristics of the habitats of three species of crocodilians. The results suggest that some easily obtainable data may help to define more precisely the habitats of individual crocodilian species, and thus facilitate survey planning and other related studies.

## MATERIALS AND METHODS

**Nomenclature** - Medem (1983) recognizes the existence of various demes in the subspecies *C. crocodilus crocodilus* and discusses the unpublished revision that was begun by the late Karl P. Schmidt of the Chicago Natural History Museum, who had intended to describe the form from the Llanos of Venezuela and Colombia as a new subspecies (*C. c. humboldti*). Gorzula (1987) notes that there are differences in behavior, population structure, population dynamics and average size of adults between *C. crocodilus* from the Llanos and the Venezuelan Guayana. In order to distinguish between what are most probably two distinct subspecies, in this paper *C. crocodilus* from the Venezuelan Llanos is referred to as *C. crocodilus* (Llanos) and *C. crocodilus* from Venezuelan Guayana as *C. c. crocodilus*.

**Study Sites and Limnology Data** - Seven water samples of *P. trigonatus* habitat were collected at different sites in the Gran Sabana and Rio Carrao (Fig. 1). Fifteen water samples of *C. c. crocodilus* habitat were taken from the El Manteco area (Gorzula 1978) and in areas to the southwest of Ciudad Guayana (Fig. 1). Water samples were taken from *C. crocodilus* (Llanos) habitat at seven sites in the Venezuelan Llanos in the ranches (Hatos): Masaguaral and Terecay (Fig. 1). Detailed locality data (name, geographical coordinates, altitude in meters above sea level, date and time the samples were taken) are given in the appendix.

Superficial water samples were taken directly into 0.25 l plastic bottles. The following measurements and determinations were carried out in the field: air and water temperature, pH and conductivity. For laboratory analyses the samples were filtered through membrane filters or precombusted glass filters (Paolini et al. 1983).

**Hydrological Data** - The exact locations of 27 *C. intermedius* localities and 16 *P. trigonatus* localities were obtained from Ayarzagüena (pers. comm.), Fitzgerald (pers. comm.), Franz et al. (1985), Godshalk (1978), Gorzula and Paolini (1986), Ludlow (pers. comm.), Ramo and Busto (1986), Sequías (pers. comm.), Taphorn (pers. comm.), and direct observations by two of us (JT and SG).

Geographical coordinates and elevations were calculated from 1:100,000 and 1:25,000 scale maps of Venezuela (MARNR, 1979). Catchment areas above the locality were calculated from maps of scales 1:1,500,000 to 1:25,000 depending on the size of the river basin.

Rainfall and runoff data was taken from COPLANARH (1972) and the EDELCA data base. Flow rates were estimated by calculation from the existing data for the river basin or interpolated from data for adjacent basins.



## RESULTS AND DISCUSSION

**Limnology** - Table 1 shows the mean values and standard deviations for the eight parameters that were measured for habitats of *P. trigonatus*, *C. c. crocodilus* and *C. crocodilus* (Llanos). The limnological results for individual localities are given in the appendix.

Apart from pH, the data for all other parameters separate out into three distinct groups, showing only small overlaps in the standard deviations of 3 of the individual cations ( $\text{Ca}^{++}$ ,  $\text{Na}^{+}$  and  $\text{K}^{+}$ ).

Apart from a single low value of pH 4.2 for *P. trigonatus* and a single high value of pH 9.3 for *C. crocodilus* (Llanos) the values for all three crocodilians are in the same general range from pH 5 to pH 7. However, the acidity of a body of water may be due to one or more independent factors. An increase in cations usually results in a tendency towards a higher pH, but an increase in  $\text{CO}_2$  will lower the pH. Thus, in enclosed bodies of water it may be important to take oxygen concentrations into account. In rivers and streams that drain off from forested areas or peat bogs (such as in the Gran Sabana) high concentrations of organic acids will also lower the pH (Folster, pers. comm.). Thus, for this parameter further sampling may change the initial picture.

The differences in mean temperatures of the three crocodilian habitats may be partly explained by the effect of an altitudinal gradient in that the localities for *P. trigonatus* are highland sites from 450 to 940 m, whereas all the other localities are below 300 m. It is interesting to note that Magnusson et al. (1985) report that *P. trigonatus* in amazonian forest habitat construct nests with the egg chamber next to an active termite mound. Metabolic heat from the termite mound incubates the eggs. If this strategy is used by *P. trigonatus* in southern Venezuela, it would explain the presence of this species at almost subtropical altitudes. The majority of the temperatures for *C. c. crocodilus* were measured at night when the bodies of water were cooling, whereas those for the other two crocodilians were measured during the day (see appendix). This probably biased downwards the temperatures for *C. c. crocodilus* habitat. The temperatures of standing water (lagoons and ponds) show greater diurnal variation when compared to rivers. The adjacent vegetation can also affect temperature, and small rivers in forests will be cooler than similar sized rivers in savannas at the same altitude. Therefore, altitude should not be regarded as the only factor that affects the water temperatures of crocodilian habitats.

Figure 2 shows the relationship between total cations and conductivity for the three crocodilian habitats and an additional 17 rivers from the Venezuelan Llanos and Venezuelan Guayana. Total cations are proportional to the conductivity ( $r = 0.82$ ). It should be noted that, although all of the *P. trigonatus* habitats that were analyzed are rivers whereas most of the *Caiman* habitats are lagoons, the two *C. c. crocodilus* habitats that are flowing water (Yuruari and La Devuelta) fall well within the limnological range for the lagoon localities for that subspecies. Likewise, the values for two samples sites on the Apure river are within the upper range of the values for *C. crocodilus* (Llanos). It appears that the limnological differences are not a case of flowing versus standing water.

The majority of the data reported here were from samples taken during the rainy season from June to August. However, conductivity and cation concentrations in the Orinoco and Caroní rivers may increase by a factor of 2 during the dry season (Paolini et al. 1983). A similar effect is seen in two out of five Llanos lagoons (Table 2) sampled during February and June.

The grouping of the limnological characteristics of the habitats for the three crocodilians could be explained by the basic geology and geomorphology of the three study areas. The Gran Sabana is an area which drains off of an old erosion surface of Precambrian quartzites dominated by sandstone table-mountains which reach elevations of 2,800 m (Schubert et al. 1986). The waters which drains off of these table mountains are acidic and with a very low concentration of cations (Grupo Científico Chimanta 1986). The Venezuelan Llanos is an alluvial flood plain that receives nutrient rich waters from the Venezuelan Andes.

If the distributions of the three crocodilians were simply due to biogeography and if the limnological characteristics of their habitats have no direct ecological relationship, then one would not expect to find any one of these crocodilians outside of the defined geological areas. This, however, is not the case. *P. trigonatus* has been reported from the Llanos in the Rio Cinaruco (Godshalk 1982). This river (Figure 1) is exceptional in that its head waters are palm swamps within the Orinoco flood plain and that it does not receive waters from the Andes. The limnological characteristics of the Cinaruco are within those values that are characteristic of *P. trigonatus* habitats in the Gran Saban (Figure 2). Thus, two different geological and geomorphological situations have given rise to rivers with the same limnological characteristics and the same crocodilian is found in both. Within the lowlands of the Venezuelan Guayana both *C. c. crocodilus* and *P. trigonatus* occur over the same general geological area, and have also been occasionally found to occur sympatrically (Gorzula and Paolini 1986). In the latter situations it is not known whether this is a permanent or a seasonal phenomenon. This suggests that there is an ecological relationship between the limnological characteristics of the habitat and the crocodilian that occurs there.

**Hydrology** - Tables 3 and 4 show the individual, maximum and minimum elevations above sea level, catchment areas that drain down to the locality, annual rainfall, annual runoff, and estimated flowrates for *C. intermedius* and *P. trigonatus* habitats, respectively. Means and standard deviations are given for rainfall and runoff.

It can be seen that, apart from a single elevation of 300 m, the localities for *C. intermedius* are at very low elevations on the Orinoco floodplain, whereas *P. trigonatus* shows a wide altitudinal range from 50 - 1,340 m.

Catchment areas and estimated flowrates for the habitats of both species are somewhat inconclusive. Although it seems that *C. intermedius* occurs in "larger rivers", we do not have sufficient information to separate which localities represent resident breeding populations from those that are merely used partially or seasonally by individual crocodiles. In the case of *P. trigonatus* many (if not all) of the localities may be of "surplus" males, with the true populations being in side creeks. Studies in the Manaus area by Magnusson (pers. comm.) show that *P. trigonatus* inhabits small forest streams.

With regard to rainfall and runoff there seems to be a reasonable degree of separation with *C. intermedius* localities being in areas of somewhat lower rainfall and much lower runoff.

## CONCLUSIONS

It is shown in this paper that *P. trigonatus*, *C. c. crocodilus* and *C. crocodilus* (Llanos) habitats may be differentiated on the basis of limnological characteristics, and that *P. trigonatus* and *C. intermedius* habitats may be separated on the basis of hydrological characteristics.

The limnological data presented in this paper may be gathered directly, quickly and economically in the field (water temperature, pH and conductivity), or obtained by the laboratory analyses of small easily obtainable water samples ( $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{Na}^{+}$ ,  $\text{K}^{+}$  and total cations). The hydrological data presented in this paper may be calculated and/or interpolated from existing maps and water resources data that, in Venezuela at least, are readily available. In the case of the hydrological data the principal limitation is the knowledge of the exact localities of the crocodilians, which greatly restricts the use of literature sources of locality information, because many authors give only imprecise data. The data are not vulnerable to uncontrolled subjective interpretations during collection and subsequent manipulation, and the information is scientifically defensible and repeatable. For this paper we were unable to assemble sufficient data with regard to the annual hydrological regime of the rivers under consideration, but on the basis of the general information that exists for the Llanos (Zinck 1977) we consider that this could be an essential parameter for riverine crocodilian species that are hole-nesters. Additional geomorphological and surface water

descriptors such as permanence, relief, grain, slope and drainage channel density for rivers and their valleys, and permanence, frequency and area for ponds, lagoons, lakes and swamp (Laut et al. 1977), which are also easily obtainable from existing thematic cartography, could also be applied in this type of study.

If, as it is suggested in this paper, these are real correlations between limnological and hydrological characteristics of both channeled and enclosed bodies of water and the crocodilian species that inhabit them, a system of classifying crocodilian habitats based on limnology and hydrology would have several applications in management and conservation:

- 1) Hydrological and relevant geomorphological data could be gathered and processed prior to surveying, and used to establish the areas that should be given priority.
- 2) Censuses could relate densities to measurable physical and chemical parameters, which in turn may help in explaining differences in population dynamics, carrying capacity, etc.
- 3) In the case of plans for reintroducing a species into areas where it is assumed to have occurred previously the optimum sites could be more easily selected.
- 4) A concise knowledge of the limnological and hydrological requirements of crocodilian species would enable environmental impact assessments of large scale water resource projects, such as dams and canalizations, to be made.

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#### LITERATURE CITED

- COPLANARH. 1972. Plan nacional de aprovechamiento de los recursos hidráulicos. Comisión del Plan Nacional de Aprovechamiento de los Recursos Hidráulicos. Tomos I y II, Caracas, Venezuela, 188 and 375 pp.
- Franz, R., S. Reid, and C. Puckett. 1985. Discovery of a population of Orinoco crocodile *Crocodylus intermedius* in southern Venezuela. *Biological Conservation* 32:137-147.
- Godshalk, R.E. 1978. El caimán del Orinoco, *Crocodylus intermedius*, en los Llanos occidentales de Venezuela con observaciones sobre su distribución en Venezuela y recomendaciones para su conservación. Unpublished manuscript presented to Fundación para la Defensa de la Naturaleza (FUDENA), Caracas, Venezuela. 84 pp.
- \_\_\_\_\_. 1982. The habitat and distribution of *Paleosuchus* in Venezuela. Pages 39-53 in D. Dietz, F. W. King, and R. J. Bryant, eds. *Crocodiles - Proceedings of the 5th Working Meeting of the Crocodile Specialist Group SSC/IUCN*. IUCN, Gland, Switzerland.
- Gorzula, S. 1978. An ecological study of *Caiman crocodilus* inhabiting savanna lagoons in the Venezuelan Guayana. *Oecologia (Berl.)* 35:21-34.

- \_\_\_\_\_. 1987. The management of crocodilians in Venezuela. Pages 91-101 in G. J. W. Webb, S. C. Manolis and P. J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- \_\_\_\_\_, and A. Paolini. 1986. La ecología y el estado actual de los aligatónidos de la Guayana Venezolana. Pages 37-54 in S. Gorzula, ed. *Crocodiles - Proceedings of the 7th Working Meeting of the Crocodile Specialist Group SSC/IUCN*. IUCN, Gland, Switzerland.
- Grupo Científico Chimantá. 1986. Reconocimiento preliminar del macizo del Chimantá, Estado Bolívar (Venezuela). *Acta Científica Venezolana* 37:25-42.
- Laut, P., P.C. Heyligers, G. Keig, E. Löffler, C. Margules, and R. M. Scott. 1977. *Environments of South Australia Handbook*. Division of Land Use Research, Commonwealth Scientific and Industrial Research Organization. Canberra, Australia. 72 pp.
- Magnusson, W.E., A.P. Lima, and R.M. Sampaio. 1985. Sources of heat for nests of *Paleosuchus trigonatus* and a review of crocodilian nest temperatures. *J. Herp.* 19:199-297.
- MARNR. 1979. *Atlas de la Region Sur*. Ministerio del Ambiente y de los Recursos Naturales Renovables, Dirección General de Información e Investigación del Ambiente. Caracas, Venezuela. 67 pp.
- Medem, F. 1983. *Los Crocodylia de Sur America. Volumen 1. Los Crocodylia de Colombia*. Colciencias, Bogota, Colombia. 354 pp.
- \_\_\_\_\_. 1983. *Los Crocodylia de Sur America. Volumen II*. Colciencias, Bogota, Colombia. 270 pp.
- Paolini, J., R. Herrera, and A. Nemeth. 1983. Hydrochemistry of the Orinoco and Caroní Rivers. *Mitt. Geol.-Paleont. Inst. Univ. Hamburg, SCOPE/UNEP Sonderband Heft 55*:223-236.
- Ramo, C., and B. Busto. 1986. Censo Aereo de Caimanes (*Crocodylus intermedius*) en el Río Tucupido (Portuguesa, Venezuela) con Observaciones sobre su Actividad de Solamiento. Pages 109-119 in S. Gorzula, ed. *Crocodiles - Proceedings of the 7th Working Meeting of the Crocodile Specialist Group SSC/IUCN*. IUCN, Gland, Switzerland.
- Schubert, C., H.O. Briceño, and P. Fritz. 1986. Paleoenvironmental aspects of the Caroní-Paragua River Basin (Southeastern Venezuela). *Interciencia* 11(6):278-289.
- Zinck, A. 1977. *Ríos de Venezuela. Cuadernos Lagoven, Cromotip*. Caracas, Venezuela. 63 pp.

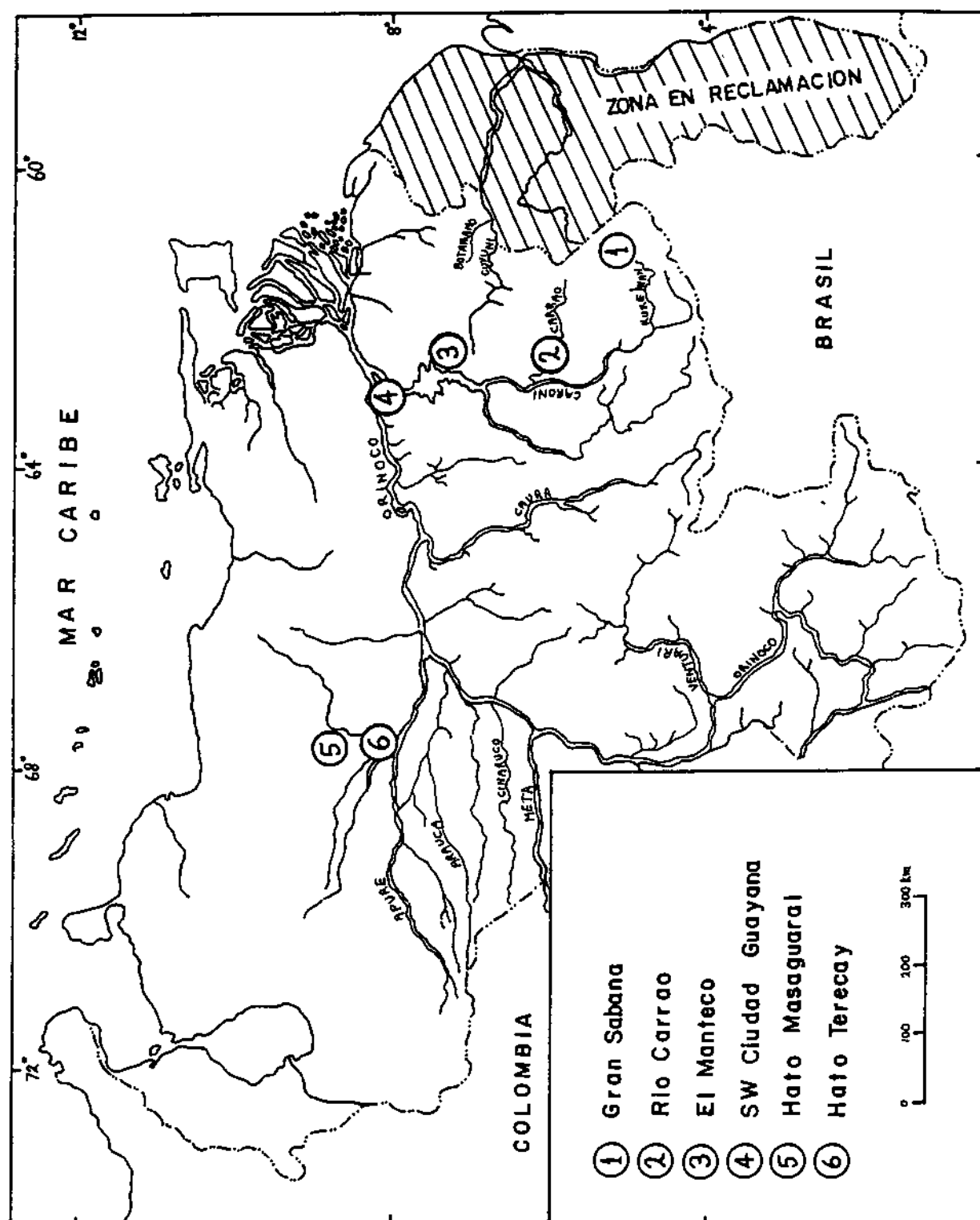


Figure 1. Map of Venezuela showing the 6 principal areas where limnological data was gathered for *Paleosuchus trigonatus* (1 and 2), *Caiman crocodilus crocodilus* (3 and 4), and *Caiman crocodilus* (Llanos) (5 and 6).

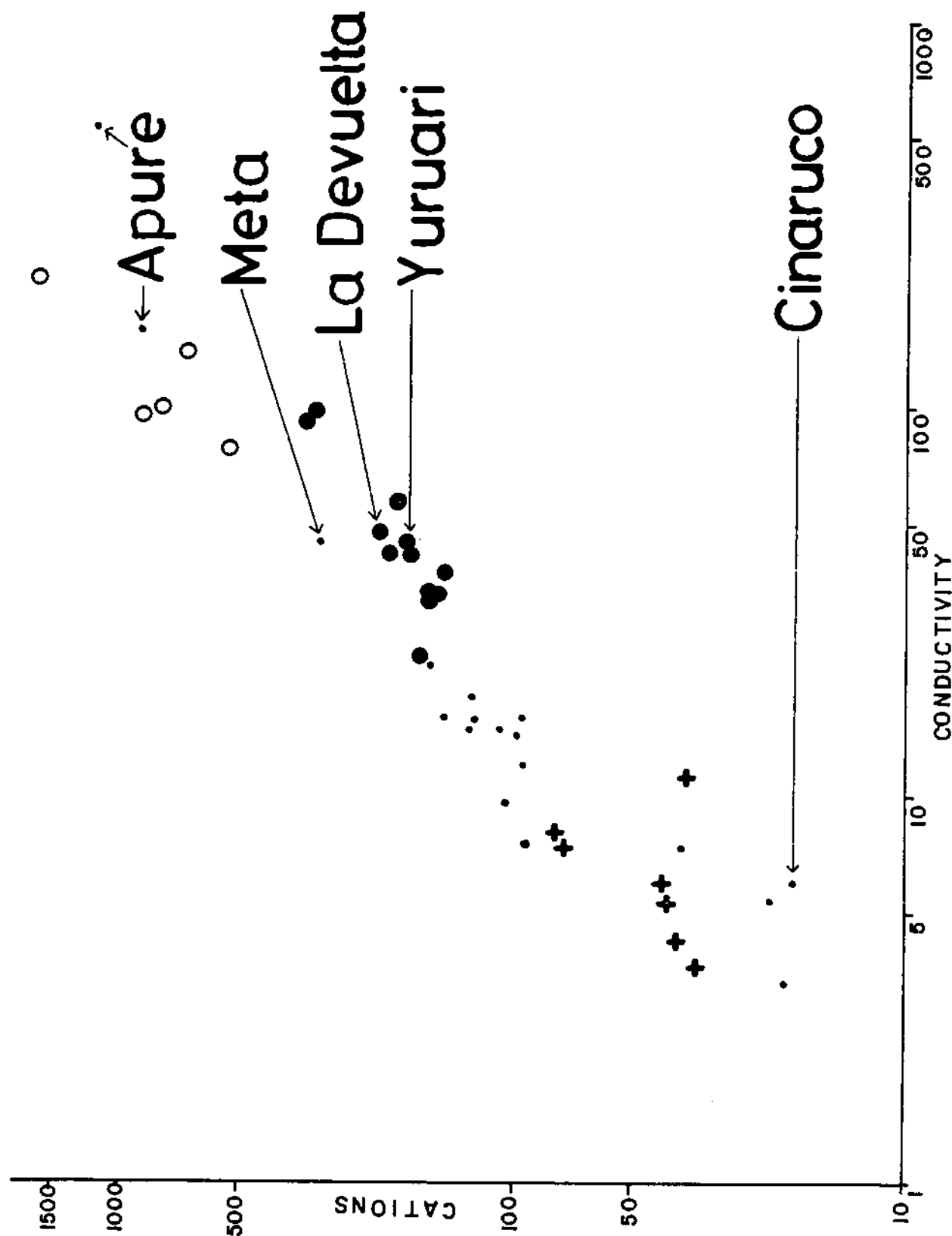


Figure 2. Plot total cations (Ueg/l) against conductivity (MHOS) for *Paleosuchus trigonatus* (crosses), *Caiman crocodilus crocodilus* (closed circles), and *Caiman crocodilus* (Llanos) (open circles), and a series of Venezuelan rivers (dots).

Table 1. Physio-chemical parameters of the aquatic habitats of *Paleosuchus trigonatus*, *Caiman crocodilus crocodilus* and *Caiman crocodilus* (Llanos). The mean values with their standard deviations in parenthesis are shown, except for pH where the maximum and minimum values are given.

	<i>Paleosuchus trigonatus</i>	<i>Caiman crocodilus crocodilus</i>	<i>Caiman crocodilus</i> (Llanos)
Water temperature (C)	22.4 (0.34)	29.1 (2.69)	32.4 (1.51)
pH	4.2 - 6.7	5.2 - 7.0	5.7 - 9.3
Conductivity (MHOS)	6.6 (2.0)	48.5 (13.3)	125.6 (54.9)
Total cations (ueq/l)	49.3 (19.2)	215.8 (77.8)	1,052.2 (735.1)
Ca++ (ppm)	0.26 (0.12)	1.16 (1.05)	9.73 (10.56)
Mg++ (ppm)	0.07 (0.05)	0.55 (0.31)	2.96 (1.56)
Na+ (ppm)	0.41 (0.34)	1.89 (0.96)	16.07 (17.13)
K+ (ppm)	0.48 (0.23)	1.17 (0.83)	4.25 (2.08)
Number of samples	7	15	7

Table 2. Changes between dry season (FEB) and wet season (JUN) in pH and conductivity (COND) in lagoons inhabited by *Caiman crocodilus* (Llanos) in Hato Masaguaral, Estado Guarico, Venezuela. The sampling dates (DATES) and hours (TIME) are shown along with water temperatures (WATER) and air temperatures (AIR) in C.

Lagoon	Date	Time	Water	Air	pH	Cond.
Prestamo #09	22 FEB 1986	1725	28.0	33.0	6.6	135
	14 JUN 1986	1436	31.0	32.4	6.8	95
Prestamo #14	22 FEB 1986	1755	29.0	32.5	9.3	264
	14 JUN 1986	1420	32.0	32.4	9.3	215
Prestamo #19	22 FEB 1986	1810	28.0	32.0	9.0	271
	14 JUN 1986	1405	31.0	30.3	6.6	100
Alta Vanega	22 FEB 1986	1903	28.0	30.0	6.1	65
	14 JUN 1986	1459	34.0	33.2	6.1	78
El Guacimo	22 FEB 1986	1235	27.0	28.0	6.1	93
	14 JUN 1986	1539	34.0	33.0	6.6	140



Table 3. Hydrological characteristics of rivers with *Crocodylus intermedius*, giving the name of the locality (LOCALITY), geographical coordinates (COORDINATES), elevation above sea level in meters (ELEV.), catchment area that drains to the locality (CATCHMENT), mean annual rainfall (mm) in the catchment area (RAIN), mean annual runoff (mm) in the catchment area (RUNOFF), and the estimated flowrate (m<sup>3</sup>/s) of the river at the locality (FLOW).

Locality	Coordinates	Elev.	Catchment	Rain	Runoff	Flow
Orinoco 1	0624N-6711W	40	---	---	---	---
Orinoco 2	0837N-6214W	5	1,123,000	2,550	926	33,000
Orinoco 3	0755N-6434W	10	---	---	---	---
Caura 1	0737N-6453W	10	48,100	2,950	1,800	2,745
Caura 2	0623N-6436W	150	28,435	2,950	2,040	1,840
Cuchivero	0720N-6549W	35	14,520	2,440	1,135	520
Guaniamo	0704N-6547W	35	6,350	2,440	1,135	230
Ventuari	0415N-6625W	100	34,030	3,150	1,745	1,180
Cinaruco 1	0634N-6845W	70	3,930	1,950	405	50
Cinaruco 2	0632N-6814W	60	5,445	1,950	405	70
Capanaparo 1	0656N-6720W	40	17,700	1,800	185	105
Capanaparo 2	0656N-6807W	50	14,820	1,800	185	90
Arauca	0702N-7110W	125	---	1,900	460	---
Apure	0800N-6811W	45	53,240	2,200	780	1,320
Manapire	0751N-6611W	40	7,260	1,300	100	23
Rabanal	0819N-6710W	45	18,450	1,100	300	175
Guarico	0856N-6724W	105	7,865	1,100	300	75
Camatagua	0948N-6654W	300	1,815	1,100	300	17
Chirgua	0856N-6755W	70	3,025	1,150	510	50
Portuguesa	0815N-6738W	55	52,030	1,300	510	840
Guanare	0820N-6808W	40	6,960	1,600	1,035	230
Cojedes	0900N-6825W	60	7,865	1,200	510	130
Camoruco	0922N-6845W	110	605	1,200	510	10
Tucupido	0857N-6950W	135	393	1,700	1,035	13
Boconó	0847N-6952W	130	1,695	1,700	1,035	55
Tinaco	0926N-6825W	100	1,240	1,200	510	20
San Carlos	0920N-6833W	105	1,996	1,200	510	32
	MAXIMUM:	300	1,123,000	3,150	2,040	33,000
	MINIMUM:	5	393	1,100	100	10
	MEAN:	---	---	1,797	734	---
	STANDARD DEVIATION:	---	---	644	526	---

Table 4. Hydrological characteristics of rivers with *Paleosuchus trigonatus*, giving the name of the locality (LOCALITY), geographical coordinates (COORDINATES), elevation above sea level in meters (ELEV.), catchment area that drains to the locality (CATCHMENT), mean annual rainfall (mm) in the catchment area (RAIN), mean annual runoff (mm) in the catchment area (RUNOFF), and the estimated flowrate (m<sup>3</sup>/s) of the river at the locality (FLOW).

Locality	Coordinates	Elev.	Catchment	Rain	Runoff	Flow
Cinaruco	??-??	50	17,700	1,800	185	105
Uruey	0542N-6226W	480	155	2,400	1,660	8
Cuyuni	0643N-6105W	110	31,160	2,000	750	740
Botanamo	0652N-6052W	100	7,560	1,600	750	180
La Escalera	0554N-6125W	1,340	5	3,200	1,660	0.25
Carrao	0614N-6247W	450	7,585	2,500	1,660	400
Kukenan 1	0455N-6123W	820	5,060	2,000	1,610	260
Kukenan 2	0455N-6112W	830	3,015	2,000	1,610	155
Yuruani 1	0458N-6115W	830	1,480	2,000	1,610	75
Yuruani 2	0503N-6107W	840	1,240	2,000	1,610	65
Jaspe	0456N-6106W	940	21	1,850	1,610	1.1
Yureba	0403N-6601W	130	38	2,800	1,680	2
Puruname	0325N-6618W	100	1,930	3,300	1,610	100
Baria	0105N-6625W	150	1,285	3,000	1,720	70
Mawarinuma	0050N-6612W	150	245	3,000	1,720	13
Yagua	0332N-6646W	120	2,955	3,300	1,610	150
	MAXIMUM:	1,340	31,160	3,300	1,720	740
	MINIMUM:	100	5	1,600	185	0.25
	MEAN:	---	---	2,422	1,441	---
	STANDARD DEVIATION:	---	---	591	453	---

## APPENDIX

## Raw Data for Localities and Physico-chemical Parameters Used in This Paper.

[Name of locality: geographic coordinates; elevation above sea level in meters; date; hour sample taken; air temperature (°C); water temperature (°C); pH; conductivity (MHOS); total cations in ueq/l; Calcium (Ca++) in ppm; Magnesium (Mg++) in ppm; Sodium (Na+) in ppm; Potassium (K+) in ppm. For *Caiman crocodilus crocodilus* those lagoons that were letter coded in Gorzula (1978) have the corresponding code indicated in parenthesis.]

*Paleosuchus trigonatus*:

RIO YURUANI: 05057N-6140W; 870m; 08 AUG 1985; ?? hours; air ??; water 23.0; pH 5.7; conductivity 3.7; cations 34.4; Ca++ 0.11; Mg++ 0.03; Na+ 0.39; K+ 0.37. RIO YURUANI: 0507N- 6104W; 870m; 04 AUG 1984; 1745 hours; air 21.7; water 22.5; pH 5.8; conductivity 4.1; cations 37.9; Ca++ 0.37; Mg++ 0.16; Na+ 0.16; K+ 0.32. QUEBRADA DE JASPE: 0455N-6106W; 940m; 04 AUG 1984; 1515 hours; air 23.3; water 22.2; pH 6.1; conductivity 6.0; cations 41.9; Ca++ 0.38; Mg++ 0.06; Na++ 0.19; K+ 0.37. QUEBRADA DE JASPE: 0455N-6106W; 940m; 08 AUG 1985; ?? hours; air ??; water 22.5; pH 6.7; conductivity 7.6; cations 76.8; Ca++ 0.23; Mg++ 0.14; Na+ 0.75; K+ 0.83. RIO CARRAO: 0615N-6249W; 450m; 01 SEP 1984; 1000 hours; air ??; water 22.7; pH 4.2; conductivity 11.5; cations 36.0; Ca++ 0.12; Mg++ 0.14; Na+ 0.23; K+ 0.33. RIO KUKENAN: 0455N-6612W; 830m; 04 AUG 1984; 0950 hours; air 23.6; water 22.2; pH 5.2; conductivity 5.3; cations 40.5; Ca++ 0.39; Mg++ 0.08; Na+ 0.15; K+ 0.32. RIO URUYEN: 0542N-6226W; 480m; 16 JAN 1986; 0920 hours; air 26.0; water 22.0; pH 6.2; conductivity 8.0; cations 77.3; Ca++ 0.22; Mg++ 0.01; Na+ 1.03; K+ 0.81.

*Caiman crocodilus crocodilus*:

KM 15 SOUTH EL MANTECO: 0714N-623W; 290m; 05 AUG 1985; 2004 hours; air 25.0; water 28.0 pH 6.5; conductivity ??; cations 122.8 Ca++ 0.72; Mg++ 0.29; Na+ 0.45; K+ 1.70. CANAOTALES (LAGOON "T"): 0721N-6231W; 280m; 31 JUL 1984; 2150 hours; air 26.0; water 28.0; pH 6.3 conductivity 38.0 cations 151.7; Ca++ 0.69; Mg++ 0.60; Na+ 1.25; K+ 0.53. EL MURO: 0720N-6229W; 260m; 31 JUL 1984; 1800 hours; air 27.0; water 33.0; pH 5.2; conductivity 33.0; cations 156.0; Ca++ 0.41; Mg++ 0.54; Na+ 1.86; K+ 0.40. EL PILON (LAGOON "J"): 0721N- 6231W; 280m, 31 JUL 1984; 2115 hours; air 24.0; water 29.5; pH 6.0; conductivity 33.0; cations 161.6; Ca++ 0.74; Mg++ 0.92; Na+ 0.89; K+ 0.40. LA ATARAYA: 0717N-6228W; 280m; 31 JUL 1984; 1705 hours; air 26.5; water 34.0; pH 7.0; conductivity 31.5; cations 166.8; Ca++ 0.45; Mg++ 0.23; Na+ 2.56; K+ 0.55. EL ZAMURO: 0719N-6228W; 260m; 31 JUL 1984; 1730 hours; air 26.5; water 33.0; pH 5.9; conductivity 23.1; cations 170.9; Ca++ 0.34; Mg++ 0.06; Na+ 2.28; K+ 1.95. RAJA IZQUIERDA (LAGOON "F"): 0722N-6230W; 280m; 31 JUL 1984; 2220 hours; air 23.5; water 27.7; pH 5.8; conductivity 42.0; cations 184.5; Ca++ 0.41; Mg++ 0.20; Na 3.17; K+ 0.38. RIO YURUARI: 0720N-6229W; 260m; 31 JUL 1984; 1745 hours; air 27.5; water 24.5; pH 6.5 conductivity 45.5; cations 190.1; Ca++ 0.72; Mg++ 0.74; Na+ 1.78; K+ 0.62. LAPA MATA (LAGOON "E"): 0721N-6231W; 280m; 31 JUL 1984; 2130 hours; air 23.5; water 28.5; pH 5.8; conductivity 57.0; cations 198.2; Ca++ 0.55; Mg++ 0.50; Na+ 2.44; K+ 0.92. RAJA (LAGOON "F"): 0722N-6230W; 280m; 31 JUL 1984; 2205 hours; air 24.0; water 28.0; pH 5.6; conductivity 42.0; cations 212.5; Ca++ 0.42; Mg++ 0.18; Na+ 3.70; K+ 0.62. LA DEVUELTA: 0720N-6231W; 260m; 31 JUL 1984; 1820 hours; air 23.5; water 26.0; pH 6.2; conductivity 47.5; cations 222.9; Ca++ 0.93; Mg++ 0.82; Na+ 2.23; K+ 0.47. CALCETA LARGA: 0717N-6234W; 250m; 03 AUG 1985;

2038 hours; air 24.0; water 31.0; pH 7.0; conductivity ??; cations 245.5; Ca++ 2.21; Mg++ 0.48; Na+ 1.06; K+ 1.94. 4 KM SUR KM 70: 0808N-6257W; 100m; 11 JAN 1986; 1430 hours; air ??; water 30.0; pH 6.5; conductivity 98.0; cations 321.2; Ca++ 2.16; Mg++ 0.81; Na+ 2.07; K+ 2.22. 5 KM SUR KM 70: 0808N-6257W; 100m; 11 JAN 1986; 1445 hours; air ??; water 27.0 pH 6.1; conductivity 92.0; cations 337.8; Ca++ 3.44; 1.03 Mg++; Na+ 0.29; K+ 2.69. RIO YURUARI: 0720N- 6229W; 260m; 02 JUN 1985; 1612 hours; air ??; water 28.0; pH 6.9; conductivity ??; cations 395.3; Ca++ 3.19; Mg++ 0.92; Na+ 2.39; K+ 2.21.

*Caiman crocodilus* (Llanos):

MASAGUARAL ALTA VANEGAS: 0840N-6838W; 75m; 14 JUN 1986; 1459 hours; air 33.2; water 34.0; pH 6.1; conductivity 78.0; cations 537.1; Ca++ 1.64; Mg++ 0.72; Na+ 4.36; K+ 8.07. MASAGUARAL EL GUACIMO: 0840N-6838W; 75m; 14 JUN 1986; 1539 hours; air 33.0; water 34.0; pH 6.6; conductivity 140.0; cations 690.7; Ca++ 2.23; Mg++ 1.91; Na+ 7.14; K+ 4.37. PALMA MOROCHA PRESTAMO 19: 0840N-6838W; 75m; 14 JUN 1986; 1405 hours; air 30.3; water 31.0; pH 6.6; conductivity 100.0 cations 788.4; Ca++ 3.59; Mg++ 3.27; Na+ 5.90; K+ 3.27. PALMA MOROCHA PRESTAMO 09: 0840N-6838W; 75m; 14 JUN 1986; 1436 hours; air 32.4; water 31.0; pH 6.8; conductivity 95.0; cations 881.2; Ca++ 3.30; Mg++ 3.54; Na+ 7.49; K+ 3.89. PALMA MOROCHA PRESTAMO 14: 0840N-6838W; 75m; 14 JUN 1986; 1420 hours; air 32.4; water 32.0; pH 9.3; conductivity 215.0; cations 1,640.0; Ca++ 7.50; Mg++ 4.48; Na+ 18.85; K+ 3.03. HATO TERCAY 01: 0800N-6736W; 65m; 20 MAY 1985; 1555 hours; air ??; water 34.0; pH 7.3; conductivity ??; cations 2,448.4; Ca++ 23.69; Mg++ 5.31; Na+ 15.82; K+ 5.53. HATO TERCAY 02: 0800N-6836W; 65m; 19 MAY 1985; 1100 hours; air ??; water 31.0; pH 5.7; conductivity ??; cations 3,769.4; Ca++ 26.15; Mg++ 1.50; Na+ 52.92; K+ 1.57.

## CROCODILIAN UTILIZATION AND PUBLIC EDUCATION: DIFFICULTIES IN EXPLAINING CONSERVATION

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Until recently, the commercial utilization of crocodilian skins was met exclusively by hunting wild crocodilians. The decline in wild populations due to over-hunting and habitat destruction alerted conservationists throughout the globe. They campaigned against the use of crocodilian products. Politically active conservation organizations succeeded nationally in setting up sound conservation laws. On an international front CITES was set up in 1975, thus bringing to halt almost all trade in Appendix I species between party nations and somewhat controlling the trade volume of Appendix II species.

The worldwide demand for the classical crocodile skins, such as *Crocodylus niloticus* and *Crocodylus porosus* shifted to *Caiman* skins and pressed different agencies to define the term 'captive bred' to CITES at the San Jose meeting in 1979.

At the Delhi meeting of CITES parties in 1981 the term 'ranching' was introduced, whereby populations of species in Appendix I which would benefit from ranching could be transferred to Appendix II. Ranching is defined as the rearing in a controlled environment of specimens taken from the wild, for the purpose of the trade. The ranching scheme must be beneficial to the wild populations and the products must be marked to be easily distinguished from products of other populations of the same species in Appendix I.

At the Buenos Aires meeting of CITES parties in 1985, another more liberal measure for trade in crocodilian products was introduced. This was the setting of quotas for each country wishing to trade in a species, in conjunction with an approved management plan.

Besides crocodilian products from ranching enterprises and from the quota system, there are now skins (e.g., *Alligator mississippiensis*) available from harvesting systems. Compared to the earlier figures of the hide trade, the number of crocodilian skins originating from legal sources is still relatively small, but the trend is increasing.

The question is open to debate. Should we as conservationists support this increasing trend or should we still work against commercial utilization of all crocodilian products - i.e., campaign against the use of crocodilian skins in the fashion trade? Looking at this eminent query we must keep in mind that there is an ecological and an economic aspect to it.

On the ecological side it is known that crocodilians are an important part (foodchains, species diversification, habitat forming) within all ecosystems they originally live in. This influence remains true for all artificial operations - captive breeding and/or farming for genetic enhancement - and harvesting systems. Crocodilian farming does not require forest cleaning, planting or alien plants and the use of biocides. The intimately associated economic aspect is the crucial point: without considering it, all our efforts to save crocodilians from becoming extinct will be in vain. We no longer can depend merely on the goodwill of the people living in the tropics among crocodilians to understand our ethical efforts 'to save crocodilians', but we must accept their willingness to utilise crocodilians as a source of their regular income, similar to their revenue from wetland fisheries, crabfishing, hunting and plant harvesting. Hopefully the Convention on

Wetlands of International importance (Ramsar Convention) with 40 contracting state parties will provide such benefits not only through fishery and timber production, but also from crocodilian harvesting.

Crocodilian exploitation under sound management criteria or under international control, such as provided by CITES for quotas can reduce economic pressure for wetland reclamation. This will assist in the conservation of other species.

All legal crocodilian exploitation is overshadowed by widespread and well organized poaching and smuggling of products. The efforts to internationally control such developments must become enforced (CITES). Despite that last fact, I consider it essential for the survival of all crocodilians throughout the globe that their products should be traded within strict national and international limits and controls.

To return to the title question: How do we answer the consumer question about the trading of 'endangered crocodilians' without bias? Naively, I could say by availing ourselves of an excellent opportunity for a close cooperation between the conservationists and the traders, perhaps in the beginning with the mediation of conservation agencies.

# AN OVERVIEW OF CROCODILE MANAGEMENT IN AUSTRALIA 1985-86, WITH PARTICULAR REFERENCE TO THE NORTHERN TERRITORY

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This paper summarizes the progress made in crocodilian management within Australia during the period 1985-86. It deals with both the Australian freshwater crocodile, *Crocodylus johnstoni*, and the estuarine crocodile, *Crocodylus porosus*. Both species are found within the three northern States of Australia (Western Australia, Queensland and the Northern Territory), where their management is the responsibility of the respective State Wildlife Services. A Federal Wildlife Service (Australian National Parks and Wildlife Service - ANPWS) is responsible for crocodile management within Federal National Parks (including Kakadu National Park in the Alligator Rivers region of the Northern Territory). ANPWS is also the designated authority under CITES and is responsible for regulating the import and export of crocodiles, or products derived from them.

Australian policy on matters to do with crocodiles and other wildlife is coordinated by the Council of Nature Conservation Ministers (CONCOM), and its supporting committees, which include representatives from all Wildlife Services within Australia.

## CITES LISTING OF CROCODILES IN AUSTRALIA

*Crocodylus johnstoni* is listed on Appendix II of CITES. The Australian population of *C. porosus* was on Appendix II until 1979, when the world population was shifted to Appendix I (with the exception of the population being utilized in Papua New Guinea). The detailed proposal to have the Australian population of *C. porosus* replaced on Appendix II for the purposes of management (Webb et al. 1984) was strongly supported by the SSC Crocodile Specialists Group, the IUCN General Assembly and finally by the members attending the 1985 meeting of the parties to CITES in Buenos Aires. The Australian population has now been replaced on Appendix II, and appropriate amendments have been made to the scheduling of *C. porosus* within the Federal legislation. Australia has complied with the requirements of Resolution 5.16 of CITES regarding trade in ranched products and the intended methods of product identification have been approved.

## APPROVED MANAGEMENT PROGRAMS

Under the Australian Wildlife Protection (Regulation of Exports and Imports) Act 1982, the export for commercial purposes of products derived from wild crocodilians and other native wildlife is subject to detailed management programs being formulated by State Authorities and approved at the Federal level. Permits, but not approved management programs, are required for the commercial export of products derived from captive bred animals. Management programs for both *C. johnstoni* and *C. porosus* within the Northern Territory have been refined during the 1984-86 period and have now been submitted by the Northern Territory Minister for Conservation to the Federal Minister for Arts, Heritage and the Environment (September 1986).

## CROCODILE MANAGEMENT CONFERENCE

Under the auspices of CONCOM and the Conservation Commission of the Northern Territory, an internationally attended conference on crocodilian management was held in Darwin, on 13-18 January 1985. Participants came from eleven countries (Australia (74); India (3); Israel (1); Papua New Guinea (4); South Africa (1); Thailand (3); United States of America (5); United Kingdom (2); Venezuela (2); Zambia (1); Zimbabwe (5)) and presented fifty-one papers. The emphasis of the conference was on the ways in which crocodilian populations can and are being successfully managed in different parts of the world - the techniques which have been developed, the problems that have been encountered and overcome and the research advances that have been made, particularly in reproductive biology, embryology, monitoring methods, population modelling and crocodilian farming.

The conference allowed full and open debate of both the background research incorporated into the successful Australian submission to CITES and the management programs being developed for both *C. porosus* and *C. johnstoni* within the Northern Territory. It also allowed international participants to see the wild populations of *C. porosus* in both tidal and freshwater swamp habitats, and to participate in some aspects of the *C. porosus* nesting research in freshwater swamps.

The proceedings of the conference are to be published (late 1986) in a hard-bound book entitled: "Wildlife Management: Crocodiles and Alligators." It contains 51 chapters subdivided into ten parts, each of which deals with a specific aspect of crocodilian conservation and management [Part I, World Crocodilians; Part II, Crocodilian Management Programs; Part III, Crocodile Management and Indigenous People; Part IV, Studying Crocodilian Populations; Part V, Public Education; Part VI, Capturing Crocodilians; Part VII, Understanding Crocodilian Behavior and Temperature Regulation; Part VIII, "Farming" Crocodilians; Part IX, Crocodilian Skins; Part X, Understanding Crocodilian Eggs and Embryos]. It is hoped that the compendium of crocodilian management information contained within the book will be of assistance to people attempting to manage wild crocodilian populations throughout the world.

## FATALITIES

*C. porosus* have been responsible for two severe maulings and three fatalities in Australia during 1985-86. Such attacks highlight the public safety factor involved with *C. porosus* conservation and management in northern Australia. Unless the public perception of the wild *C. porosus* populations is enhanced in synchrony with their increasing numbers, such attacks represent a very real threat to the existence of high densities of the species in the wild. Public safety and public education about crocodiles are essential requisites of crocodile management programs in northern Australia.

If minor incidents are ignored, there have now been seven fatal and three near-fatal attacks caused by *C. porosus* in Northern Australia since protection (Fig. 1); one in Western Australia, six in the Northern Territory and three in Queensland. Of these ten, seven involved people swimming in areas that contain *C. porosus* (the others occurred when people were washing beside a billabong, wading on the edge of a swamp and canoeing). Five of the attacks involved people who were locals and the other five were either tourists or recent residents from other parts of Australia. Seven of the attacks resulted from voluntary actions which were unnecessary, whereas three arose in the course of necessary work activities. Alcohol consumption prior to the attack, which may have dampened normal caution, was involved in four of the ten attacks.

Fatalities caused by crocodiles are tragic and represent a real threat to public tolerance of high densities of wild crocodiles. However, they invariably result in Australia-wide media coverage about crocodiles and their conservation, which is a positive side-effect. Hundreds of thousands of tourists from



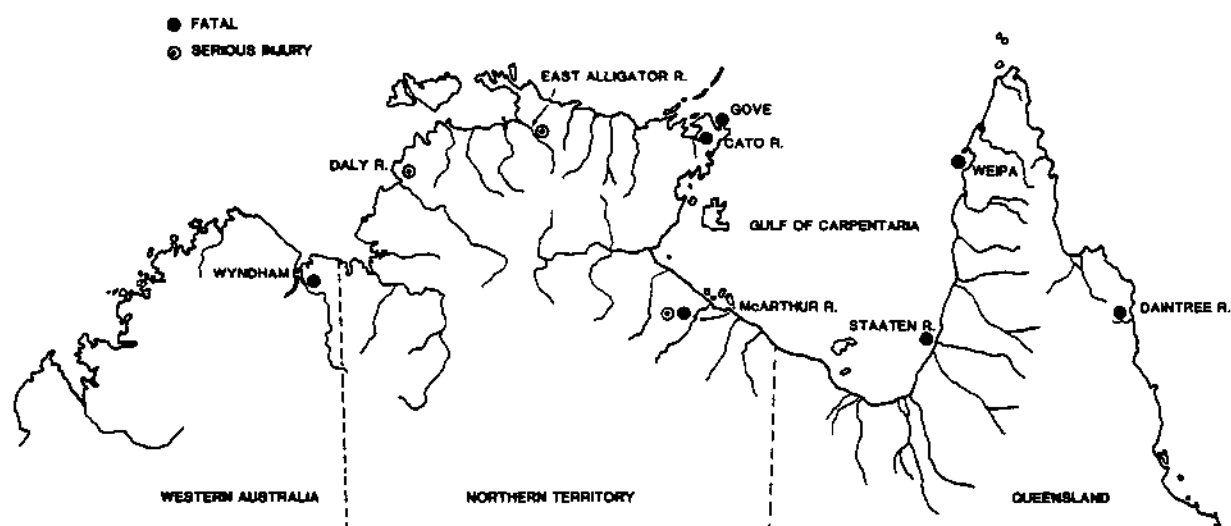


Figure 1. The locations where serious attacks by *C. porosus* on people have occurred since protection (in 1969-74).

the southern States visit the north annually, and such media attention creates "crocodile awareness" among them.

### CROCODILE FARMING

The Edward River Crocodile Farm in North Queensland is now exporting skins, and the three farms within the Northern Territory are expected to begin exporting by the end of 1986. Husbandry research has continued to improve hatchling survival with *C. porosus*, and at least 80% survival from hatching to slaughter is now attainable. The approximate number of crocodiles maintained in captivity within each State in Australia is summarized in Table 1; the total captive population is some 19,220 crocodiles.

Table 1. The approximate numbers of crocodiles currently maintained in captivity within the three northern States of Australia.

State	<i>C. porosus</i>	<i>C. johnstoni</i>	Totals
Western Australia	36	13	49
Northern Territory	4,232	8,593	12,825
Queensland	5,876	470	6,346
<b>TOTALS</b>	<b>10,144</b>	<b>9,076</b>	<b>19,220</b>

### HIGHLIGHTS OF THE CROCODILE MANAGEMENT PROGRAM IN THE NORTHERN TERRITORY

#### 1. Management Programs

Formal management programs for *C. porosus* (CCNT 1986a) and *C. johnstoni* (CCNT 1986c) within the Northern Territory have been submitted, and additional supporting information on the biology and history of management for both species has been prepared (CCNT 1986b, d). As outlined elsewhere (Webb et al. 1984, 1987), both programs make provision for ranching, based on the collection of eggs (*C. johnstoni* and *C. porosus*) and hatchlings (only *C. johnstoni*), followed by incubation and raising within three commercial crocodile farms.

#### 2. Public Education

The public education program within the Northern Territory has continued with the aid of brochures, posters, a television advertisement, school talks by rangers, an educational slide kit and "no-swimming" signs which feature a crocodile. The metal signs and a miniaturized version made into a "sticker", can both be purchased by the public as souvenirs. A high profile media interest in crocodiles has been encouraged

as a means of disseminating information about crocodiles nationally. A recent one hour documentary entitled "Living with Crocodiles" was produced as part of the public education program. It is made available to schools, clubs and isolated communities.

As is often the case with dangerous animals, media attention reaches a peak when there are serious interactions between *C. porosus* and people. Public response in the Territory to three serious attacks on people during 1985-86 (including 1 fatality) has been both calm and rational.

### 3. Public Safety

Within the Northern Territory, "problem" crocodiles are broadly defined as:

1. Crocodiles within settled areas or areas of priority recreational use where that recreation is inconsistent with the risks associated with having *C. porosus* present; and,
2. Animals which are attacking stock in pastoral areas (CCNT 1986a).

During the period July 1984 to June 1986, 71 problem animals were removed from the wild and relocated into the crocodile farms. Of these, 57 came from Darwin harbour, making a total of 354 removed from there since protection and a total of 451 removed from the wild throughout the Northern Territory since protection.

### 4. Harvests from the Wild

During 1985, 1335 *C. johnstoni* eggs were harvested from the wild within the management areas defined in the Management Program (CCNT 1986c). The harvest was carried out by crocodile farmers under the supervision of the Conservation Commission of the Northern Territory (CCNT). Management areas were surveyed before (1985) and after (1986) the harvests.

Collections of wild *C. porosus* eggs have been restricted to research exercises carried out by CCNT staff and consultants within 140 km of Darwin. In the 1984/85 season, 3517 eggs were harvested and in the 1985/86 season 3470 eggs were harvested. The areas harvested have been surveyed by spotlight annually, and preliminary analyses indicate the impact on wild populations is negligible (see Webb et al. [this volume] for details).

### 5. Crocodile Farms

There are three crocodile farms within the Northern Territory. As of 30 June 1986, Crocodile Farms N.T. Pty. Limited contained 2830 *C. porosus* and 3274 *C. johnstoni*. During the 1984/85 and 1985/86 nesting seasons, 29 and 27 *C. porosus* nests were made on the farm. *Crocodylus johnstoni* nesting in captivity increased from 15 nests in 1985 to 32 in 1986. The other two farms are currently building facilities to house *C. porosus* breeding stock, which should begin breeding by the 1987/88 season. Stocks at Letaba Crocodile Farm on 30 June 1986 were 999 *C. porosus* and 3407 *C. johnstoni*. At Janamba Crocodile Farm stocks were 394 *C. porosus* and 1904 *C. johnstoni*. Three additional *C. porosus* nests are made annually in captivity each season at zoos, which contain an additional 9 *C. porosus* and 8 *C. johnstoni*.

No skins or other crocodile products have yet been sold from the farms, and they are currently stocked to capacity with problem crocodiles. Skin sales will begin following approval of the management programs in late 1986.

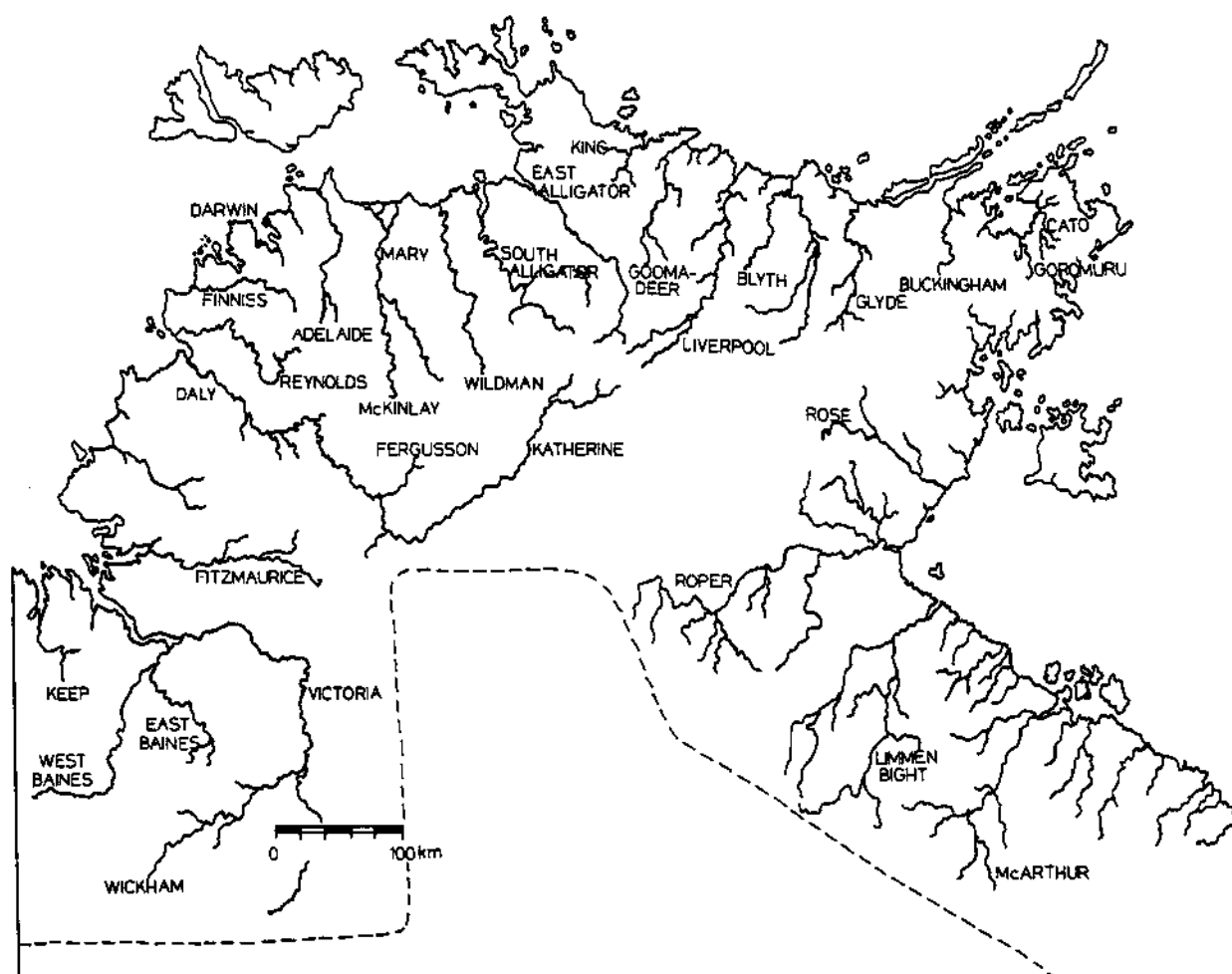


Figure 2. Locations of some of the major river systems within the Northern Territory.

## 6. Surveys and Monitoring

The locations of some of the major river systems within the Northern Territory are shown on Figure 2.

### *L. Crocodylus johnstoni*

Annual spotlight surveys in each of the *C. johnstoni* management areas have been carried out in 1985 and 1986, and a detailed analysis of the impact of harvesting is underway with data from 1982 to 1986. Preliminary results (Table 2; CCNT 1986d) indicate no major effects of the harvests could be detected; 6331 eggs and hatchlings were harvested from the areas included in Table 2, yet the sighted population increased from 2859 to 3316 animals.

Table 2. Preliminary data on the impact of harvesting *Crocodylus johnstoni* eggs and hatchlings. Data included are from isolated pools and sections of mainstream in which the entire area was surveyed before and after harvests. First surveys were in 1982 or 1983 and the latest surveys in 1985. Numbers harvested are accumulated totals of eggs and hatchlings.

Area	Interval	Harvest		Surveys	
		Eggs	Hatchlings	First	Last
Finniss/Reynolds	1983-85	1817	81	196	207
Finniss/Reynolds	1983-85	396	26	108	89
Upper Daly	1983-85	-	985	503	450
Lower Daly	1983-85	434	1117	664	494
Baines	1983-85	-	384	272	421
Lower Victoria	1983-85	-	128	152	318
Lower Victoria	1983-85	-	187	180	233
Upper Victoria	1982-85	-	480	318	331
Wickham	1982-85	-	71	166	135
Wickham	1982-85	-	24	97	100
TOTALS		2647	3684	2859	3316

*Crocodylus johnstoni* is a difficult species to survey by spotlight, because many of the areas they occupy recede to small isolated pools in the dry season. Helicopter survey offers a viable alternative to spotlight counting (Bayliss et al. 1986), and in 1985 all areas surveyed for *C. johnstoni* by spotlight were also surveyed from helicopters.

ii. *Crocodylus porosus*

During 1985 and 1986, spotlight surveys have been carried out by the CCNT in the three river systems from which eggs were collected (Adelaide, Finniss and Reynolds) and in a series of rivers from which eggs were not collected. In addition, helicopter surveys were carried out in some rivers. These data are discussed by Webb et al. (this volume), but are also summarized in Table 3 (1984 data are included for comparison). Additional spotlight surveys within the Northern Territory (1985-86) have been carried out by ANPWS and Messel et al. (1986).

Table 3. Densities of *C. porosus* recorded in spotlight counts carried out in major river systems 1985-86 by CCNT, ANPWS<sup>1</sup> and Messel et al. (1986)<sup>2</sup>, with the results of 1984 surveys for comparison. Densities are numbers of *C. porosus* sighted per kilometer subdivided into "all crocodiles" (T) and "non-hatchlings" (NH). "\*" indicates helicopter survey corrected to spotlight counts (no hatchlings are accounted for).

Area	1984		1985		1986	
	T	NH	T	NH	T	NH
Adelaide	2.72	2.41	2.41	1.96	2.59	2.14
Blyth-Cadell R.	4.00	3.53	2.48	2.03	5.65	3.25
Daly R.	1.94	1.94	2.62	2.49	3.13	2.93
East Alligator R. <sup>1</sup>	4.05	3.23	4.65	3.59	-	-
Finniss R.	3.14	3.09	3.93	3.79	2.86	2.86
Liverpool-Tomkinson R.	2.19	2.03	-	-	2.89	1.75
Limmen Bight R.	-	-	0.24 <sup>2</sup>	0.23 <sup>2</sup>	-	0.29*
Mary R.	1.55	1.55	1.54	1.54	2.20	2.20*
McArthur R.	-	-	0.21	0.20	-	0.22
Reynolds R.	4.38	4.18	5.04	4.93	5.21	4.99
Roper R. <sup>2</sup>	-	-	1.52	1.36	-	-
Towns R. <sup>2</sup>	-	-	0.49	0.49	-	-
Wearyan-Foelsche R.	-	-	0.12	0.12	-	0.15*
Wearyan-Foelsche R. <sup>2</sup>	-	-	0.14	0.14	-	-

In 1986, helicopter and spotlight counts were carried out in rivers of the southern Gulf of Carpentaria as a check on the previously derived calibration between the two methods (Bayliss et al. 1986). The results (Webb et al. [this volume]) fully supported the use of the Adelaide River calibrations in the Gulf of Carpentaria.

Nest counts appear to be the only usable index of the population size in heavily vegetated freshwater swamps, and correction factors have now been derived for relating nest counts to absolute numbers of *C. porosus* (see Webb et al. [this volume]). These indicate one nest is the equivalent of 17.6 *C. porosus* (15.5 non-hatchlings), or that 5.7% of the population in breeding areas are nesting females. This value is almost identical to that found with *Alligator mississippiensis* in Louisiana (Joanen and McNease 1987).

Rates of *C. porosus* population increase within the Northern Territory have been calculated for all rivers in which survey data span three or more years (Webb et al. [this volume]). The mean rate of increase is +8.3% p.a. for all crocodiles and +9.7% p.a. for non-hatchlings.

## 7. Research

A variety of research programs on crocodiles are being undertaken in the Northern Territory by the CCNT. The students and staff of various Universities and other institutions [Australian National University (ANU); N.T. Department of Primary Production (DPP); Macquarie University (MU); University of New South Wales (UNSW); University of New England (UNE); University of Manchester (UMan) and the University of Sydney (USyd)] are also carrying out research on crocodiles in the Northern Territory, and the CCNT collaborates with these workers in every possible way. The major research programs listed below are discussed in more detail by Webb (this volume):

1. The effects of incubation environment on hatchling sex and post-hatching survivorship and growth in both *C. johnstoni* and *C. porosus* (CCNT; ANU; UNSW);
2. Embryo mortality in *C. porosus* nests (CCNT);
3. General embryology of crocodilians (CCNT; UNE; MU; UNSW; UMan);
4. Factors affecting growth and survivorship of *C. johnstoni* and *C. porosus* in captivity (CCNT; DPP);
5. Parasitology in wild and captive crocodiles (CCNT; DPP);
6. Population dynamics of *C. johnstoni* in Katherine Gorge National Park (CCNT; UNE);
7. Rates of population recovery of *C. porosus* and *C. johnstoni* in the wild (CCNT; USyd);
8. The impact on wild populations of harvesting *C. johnstoni* and *C. porosus* eggs and/or hatchlings (CCNT);
9. Improved methods for quantifying the distribution and abundance of *C. porosus* and *C. johnstoni* in tidal and non-tidal wetland habitats (CCNT) (see Webb et al. [this volume]).

## WESTERN AUSTRALIA

The Kimberley region of Western Australia remains one of the most remote areas of northern Australia. It includes much rugged, rocky country, and in the 1981 census had a total human population of 19,296, about half of which was in the four major towns (Kununurra, Wyndham, Derby, Broome). Relative to the Northern Territory and Queensland, opportunities for interactions between people and crocodiles are much reduced.

At Wyndham, on the Ord River, *C. porosus* are present and are accepted by the local residents as a tourist attraction. There are no commercial crocodile farms in Western Australia, although a facility that caters to the tourist industry by having crocodiles on display is located at Broome, adjacent to a large, privately owned nature park. It contains 9 *C. johnstoni* and 29 *C. porosus* (Malcolm Douglas, personal communication). At present there are no management plans to utilize either species of crocodile within Western Australia. The total captive population of crocodiles in zoos and private holdings within Western Australia is 13 *C. johnstoni* and 36 *C. porosus*.

The Western Australian Department of Conservation and Land Management has recently produced a public safety brochure entitled "Take Care in Crocodile Areas," which warns against swimming in areas that contain *C. porosus* and gives helpful hints about what not to do in areas that contain *C. porosus*. They are also erecting "no-swimming" advisory signs in some areas.

The construction of a large dam on the Ord River has provided new habitat for *C. johnstoni* and a survey of one area (in 1979) revealed 1000 *C. johnstoni* (Burbridge 1987). Spotlight surveys of *C. porosus* in tidal rivers of the Kimberley region were carried out in 1977 (Messel et al. 1977) and 1978 (Burbridge and

Messel 1979), and, in conjunction with the University of Sydney these areas have now been re-surveyed (1986).

The detailed results of the 1986 *C. porosus* surveys are in preparation for publication, but in general terms there was a 30.5% increase in the number of non-hatchlings sighted, and the proportion of large crocodiles (6') increased from 16% to 39% (an increase of approximately 144% in this segment of the population). Annual rates of population increase were approximately +3.1% for non-hatchlings, +0.2% for all crocodiles, and +11.0% for 6' crocodiles (Burbidge, personal communication).

Relative to the Northern Territory, there is considerably less tidal and non-tidal habitat suitable for *C. porosus* in Western Australia (Messel et al. 1981), and the total population there is thought to be about 2500 non-hatchlings (Burbidge, personal communication). Apart from the 1986 surveys, there has been no new research effort directed at either species of crocodile in Western Australia during the 1985-86 period.

## QUEENSLAND

### 1. Management Programs

Queensland National Parks and Wildlife Service is currently preparing a plan (QNPWS 1986) which will address the conservation and management of both *C. johnstoni* and *C. porosus* within Queensland. In the first instance, the emphasis will be almost exclusively on *C. porosus*. There are no immediate proposals for ranching wild populations of either species or for harvesting from the wild, and the plan will deal extensively with the rationale for handling "problem" *C. porosus*, the regulation of current farms within the State, the facilitation of crocodile farming through captive breeding from wild-caught and captive-reared parental stock, and the derivation of strategies that will allow sustained-yield harvesting of wild populations in the future. Public education with the theme that "living with crocodiles is an acceptable proposition" is an integral part of the program.

For the purposes of crocodile conservation and management, the State of Queensland has been subdivided into regions of high, medium and low conservation "value" (Fig. 3). This concept takes into account the quality of *C. porosus* habitat, both generally and for nesting, and the extent to which habitats and crocodile populations are affected by agriculture, human density pressures, national parks, Aboriginal reserves, the fishing industry etc. (QNPWS 1986; Taplin 1987).

### 2. Public Education

An information brochure entitled "Crocodiles in Queensland" has been produced for distribution to school children and tourists. It provides general information on both species and highlights activities that should be avoided in areas that contain crocodiles. Crocodile warning signs, in combination with a "no-swimming" advisory sign have been erected in crocodile areas where people are likely to swim. Newspaper and magazine articles about crocodiles are used to promote public awareness.



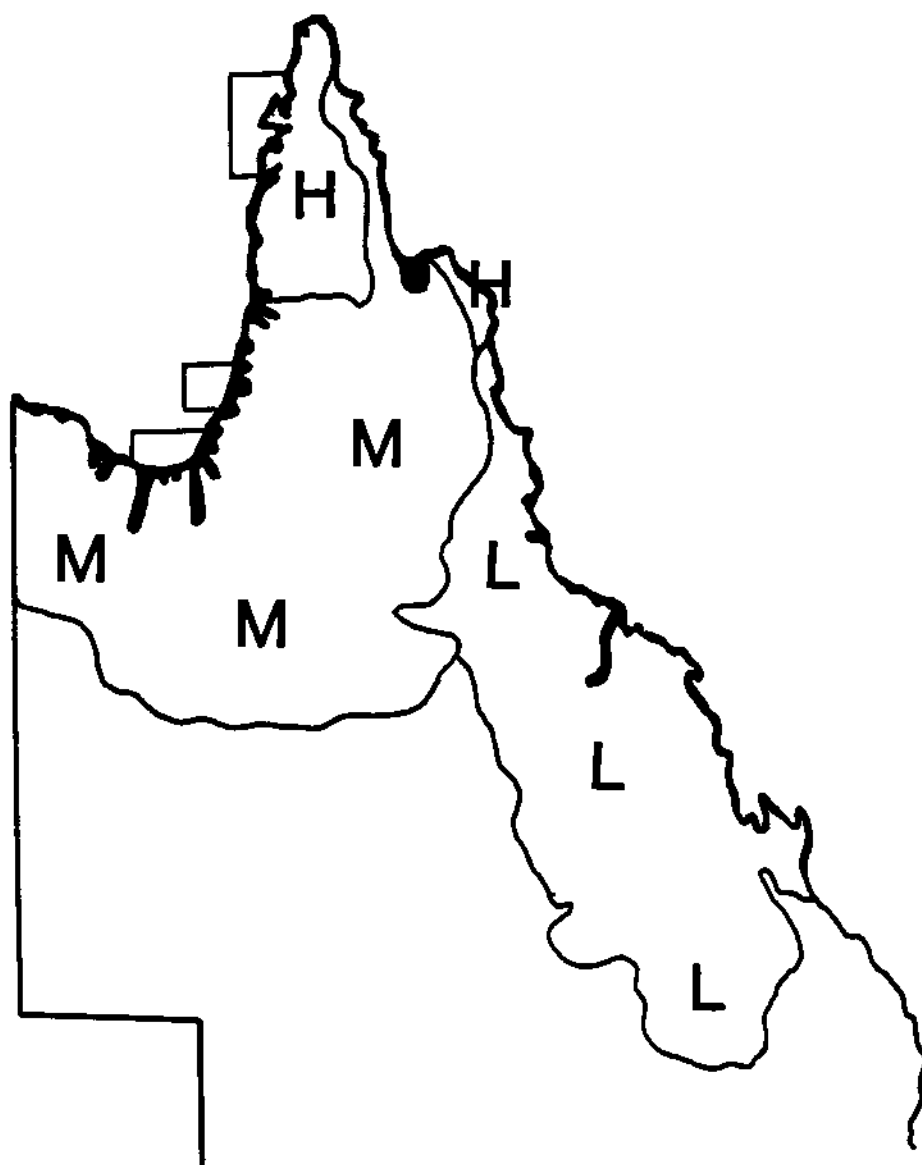


Figure 3. Broad regions within Queensland with Taplin's (1986) assessment of *C. porosus* conservation value: H=high; M=moderate; L=low. Areas in squares are where surveys have been carried out between 1985 and 1986.

### 3. Public Safety

Interactions between crocodiles and people along the east coast of Queensland pose serious management problems. Reports of problem crocodiles are common in this region and they are assessed and investigated case by case by the QNPWS. Generally, only *C. porosus* over 2 m long are considered a "problem," and where possible these are caught alive and moved to zoos or crocodile farms. Between April 1984 and September 1986, 171 problem *C. porosus* reports, involving 217 wild crocodiles were received. Eighty-eight percent of these reports were from the heavily populated east coast. In all, 22 problem *C. porosus* have been removed from the wild since 1985 as part of the new problem crocodile control program. An additional 182 *C. porosus* and 202 *C. johnstoni* have been removed as establishment stock for the developing crocodile farms since protection.

Public safety issues came to a head in Queensland when, in separate incidents, two women were taken by *C. porosus* within 2 months. The first fatality was followed by a strong public reaction. Some reports indicated that 20-50 crocodiles were killed in the Daintree River, where the attack occurred, but it now appears some deliberate exaggeration may have been involved. A coroner's inquest into the death of this woman is yet to be held. Some crocodiles were reportedly shot after the second attack, but no confirmation of these reports is available (the coroner's inquest was held within two weeks).

### 4. Surveys and Monitoring

Spotlight surveys were conducted by QNPWS in four rivers within the southern Gulf of Carpentaria (Table 4). In all, 127 *C. porosus* were sighted, 26 of which were "young-of-the-year." There is a scarcity of nesting habitat and minimal recruitment in these rivers.

Spotlight surveys were also conducted in the Port Musgrave region of North Queensland in November 1985 and rivers further south in the Gulf of Carpentaria in 1986. Some of the same areas had been surveyed in 1979 by Messel et al. (1981), and thus rates of recovery could be quantified (Table 5).

### 5. Crocodile Farms

There are currently two established crocodile farms in Queensland, one at Edward River on western Cape York Peninsula, and the other at Rockhampton on the central east coast of Queensland. Plans for a third major farm north of Cairns are currently under review. The Edward River farm was originally stocked with juveniles taken from the wild and is now a closed breeding farm with 5300 *C. porosus*. Nesting in the 1985/86 season resulted in 103 nests, and both skins and crocodile meat are now being marketed annually. The farm at Rockhampton had 15 *C. porosus* nests during the 1985/86 season and has a total stock of 400 *C. porosus* and 170 *C. johnstoni*. An additional 176 *C. porosus* and 300 *C. johnstoni* are maintained in zoos within the State. The total captive population is thus about 5876 *C. porosus* and 470 *C. johnstoni*.

### 6. Research

Research programs being undertaken in Queensland are:

1. The distribution and abundance of *C. porosus*, and *C. johnstoni* nesting habitats in Queensland (QNPWS);



2. Continuation of a nine year study of the population dynamics, growth and reproductive biology of *C. johnstoni* in the Lynd River (QNPWS);
3. Investigation of reproductive status of *C. porosus* through laparoscopy (QNPWS);
4. Diseases of captive *C. porosus* at the Edward River Crocodile Farm (James Cook University);
5. Haematology of captive *C. porosus* at the Edward River Crocodile Farm (James Cook University).

#### ACKNOWLEDGEMENTS

This report was compiled with information supplied by the Western Australian Department of Land Conservation and Management, the Queensland National Parks and Wildlife Service and the Australian National Parks and Wildlife Service. The assistance of Andrew Burbidge, Laurie Taplin and our research consultants, G. Webb Pty. Limited, is kindly acknowledged.

#### LITERATURE CITED

- Bayliss, P., G.J.W. Webb, P.J. Whitehead, K. Dempsey, and A.M.A. Smith. 1986. Estimating the abundance of saltwater crocodiles, *Crocodylus porosus* Schneider, in tidal wetlands of the Northern Territory: a mark-recapture experiment to correct spotlight counts to absolute numbers and the calibration of helicopter and spotlight counts. *Aust. Wildl. Res.* 13(2):309-320.
- Burbidge, A.A. 1987. The management of crocodiles in Western Australia. Pages 125-127 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- \_\_\_\_\_, and H. Messel. 1979. The status of the saltwater crocodile in the Glenelg, Prince Regent and Ord River systems, Kimberley, Western Australia. Dept. Fish. Wildl. West. Aust. Rept. No. 34. Dept. Fish. Wildl., Perth.
- CCNT. 1986a. A management program for *Crocodylus porosus* in the Northern Territory of Australia. Conserv. Comm. N.T., Darwin.
- \_\_\_\_\_. 1986b. *Crocodylus porosus* in the Northern Territory: Biology and history of management. Conserv. Comm. N.T. Tech. Rep. No. 31.
- \_\_\_\_\_. 1986c. A management program for *Crocodylus johnstoni* in the Northern Territory of Australia. Conserv. Comm. N.T., Darwin.
- \_\_\_\_\_. 1986d. *Crocodylus johnstoni* in the Northern Territory: Biology and history of management. Conserv. Comm. N.T. Tech. Rep. No. 32.
- Joanen, T., and L. McNease. 1987. The management of alligators in Louisiana, USA. Pages 33-42 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- Messel, H., A.A. Burbidge, A.G. Wells, and W.J. Green. 1977. The status of the salt-water crocodile in some river systems of the north-west Kimberley, Western Australia. Dept. Fish. Wildl. West. Aust. Rept. No. 24. Dept. Fish. Wildl., Perth.

- \_\_\_\_\_, G.C. Vorlicek, A.G. Wells, W.J. Green, H.S. Curtis, C.R.R. Roff, C.M. Weaver, and A. Johnson. 1981. Surveys of tidal waterways on Cape York Peninsula, Queensland, Australia and their crocodile populations. Monograph 16. Pergamon Press, Sydney.
- \_\_\_\_\_, G.C. Vorlicek, A.G. Wells, W.J. Green, I.C. Onley, and F.W. King. 1986. Surveys of tidal river systems in the Northern Territory of Australia and their crocodile populations. Monograph 19. Pergamon Press, Sydney.
- QNPWS. 1986. Crocodile conservation and management in Queensland. Unpublished preliminary draft, Qld. Nat. Parks Wildl. Ser., Brisbane.
- Taplin, L.E. 1987. The management of crocodiles in Queensland, Australia. Pages 129-140 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. Wildlife Management: Crocodiles and Alligators. Surrey Beatty and Sons, Chipping Norton, Australia.
- Webb, G.J.W., S.C., Manolis, P.J. Whitehead, and G.A. Letts. 1984. A proposal for the transfer of the Australian population of *Crocodylus porosus* Schneider (1801), from Appendix I to Appendix II of C.I.T.E.S. Conserv. Comm. N.T. Tech. Rept. No. 21. Conserv. Comm. N.T., Darwin.
- \_\_\_\_\_, P.J. Whitehead, and S.C. Manolis. 1987. The management of crocodiles in the Northern Territory of Australia. Pages 107-124 in G.J.W. Webb, S.C. Manolis and P.J. Whitehead, eds. Wildlife Management: Crocodiles and Alligators. Surrey Beatty and Sons, Chipping Norton, Australia.

# SOUTH AMERICAN EXPORTS OF CROCODILE SKINS

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**SUMMARY:** This work presents a partial analysis of South American crocodilian skin exports generated from trade statistics during 1980-1984.

## METHODOLOGY

This study is based on statistics provided by the Wildlife Trade Monitoring Unit (WTMU) and from records made available through the TRAFFIC (SUDAMERICA) office. The information included in this work refers to exports of skins or flanks. Since records in kilograms, meters, or other measures such as pieces or tails were not available, it consequently was impossible to specify with accuracy the numbers of the concerned specimens. I must make clear that the data herein are partial in that they fail to account for the majority of illicit, unregistered exports.

## INTRODUCTION

In 1973 the Convention on International Trade of Endangered Species of Fauna and Flora (CITES) was drafted. This treaty entered into force in 1975 when Uruguay became the tenth country to be a signatory. Since then, 93 countries have ratified the CITES agreement making it the world's most successful international conservation/environmental treaty.

Every one of the South American countries are signatory members of CITES, and by virtue of that they are committed to apply the rules of the treaty. These include, among others, to provide the export, re-export and import permits for the species included in the three CITES Appendices. Also, signatories must present annual reports to the Secretariat General that must detail the exports and imports performed during that year. Despite the Secretariat and management authorities efforts, the application of CITES is still not satisfactory. The trading of fauna and flora reaches unimaginably high levels and many countries lack the necessary means to perform proper controls. Being conscious of this reality, the countries of our region proposed during the First American Seminar on CITES Application in 1983, the need of having a TRAFFIC office that would help obtain better application of the Convention through the monitoring of regional commerce that would permit detection of treaty evasions and illegal exports. With the approval of the TRAFFIC Network and support from the CITES Secretariat and the World Wildlife Fund (WWF), the first and only regional office of the TRAFFIC Network, TRAFFIC (SUDAMERICA), was established in Montevideo. In this first year and a half of activities, TRAFFIC (SUDAMERICA) has detected numerous problems and has made recommendations to the governments to improve their controls. The richness and variety of neotropical fauna and flora have originated a commerce as variable as themselves. Reptiles form the substantial part of this trade, both for their skins and as pets. However, the latter element does not even approach the volume of the former. It is for that reason that this paper focuses on skin exports.

The main species of South American herpetofauna affected are "boa constrictor" (*Constrictor constrictor*), "lagartos o tejus" (*Tupinambis* sp.), and practically all caiman species, the object of the analysis

in this paper. Every species of the order Crocodilia are included in the CITES Appendices. The position of the South American species are as follows: *Crocodylus acutus*, *Melanosuchus niger*, *Caiman crocodilus apoporiensis*, and *Caiman latirostris*, are in Appendix I and therefore their trade is prohibited. All other species and subspecies of caiman are in Appendix II and therefore their commerce is allowed but must be adjusted to the established conditions of CITES regulations.

### SPECIES INCLUDED IN TRADING

It can be confirmed that the South American species of the family Alligatoridae comprise the major part of the skin trade. The exports of the following species were recorded: *Caiman crocodilus* (including the subspecies *crocodilus*, *fuscus*, and *yacare*), *Caiman latirostris*, *Melanosuchus niger*, and *Paleosuchus palpebrosus*. Also, exports of *Crocodylus acutus* and *Alligator mississippiensis* were recorded, but these probably are misidentifications as the export country appears to be Paraguay.

### EXPORT COUNTRIES

The export countries of record, in accordance with each species and subspecies are:

*Caiman crocodilus*: Colombia, Ecuador, Guyana, French Guiana, Paraguay, and Peru.  
*Caiman c. crocodilus*: Argentina, Bolivia, Colombia, Guyana, Paraguay, and Venezuela.  
*Caiman crocodilus fuscus*: Colombia and curiously Haiti<sup>1</sup>.  
*Caiman crocodilus yacare*: Argentina and Paraguay (also Brazil and Ecuador, but only 5 skins).  
*Caiman latirostris*: Colombia and Paraguay.  
*Melanosuchus niger*: Bolivia.  
*Paleosuchus palpebrosus*: Colombia.  
*Alligator mississippiensis*: Paraguay.

### EXPORTS

Table 1 represents the export data for the period 1980-1984. These data are from those included in the annual reports presented by the export countries (and in some cases re-exporter and importers) to the CITES Secretariat, and compiled by the World Trade Monitoring Unit (WTMU).

### CONCLUSIONS

These data must be considered as partial since most of the skin exports are made illegally. Therefore, they do not appear in the official records of the exporter countries or the importer countries, but they can point to some basic conclusions:

A) The lack of technicians and specialists in the respective official agencies in charge of the enforcement of CITES implementations to faunal trade is evident with the appearance of mistaken identifications. In

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<sup>1</sup> According to W. King, the Haitian records were re-exports of hides from the former Hoyt and Worthen tannery in Port-au-Prince.

Table 1.

	1980	1981	1982	1983	1984	1980-1984
CITES APPENDIX I						
<i>Caiman latirostris</i>	--	13,443	3,218	80	--	7,461
<i>Melanosuchus niger</i>	--	254	--	--	--	254
<i>Crocodylus acutus</i>	29,210	2,991	--	--	--	32,201
Crocodylidae spp.	--	--	5,805	--	--	5,805
CITES APPENDIX II						
Alligatoridae spp.	--	46,716	93,600	--	--	140,316
<i>Alligator mississippiensis</i>	--	--	--	2,000	--	2,000
<i>Caiman crocodilus</i>	100	53	8,346	9,021	17,530	35,050
<i>Caiman c. crocodilus</i>	446,983	293,476	107,826	121,955	313,542	1,283,782
<i>Caiman c. fuscus</i>	180,874	46,330	9,109	26,607	4,550	267,470
<i>Caiman c. yacare</i>	16,122	145,739	313,671	233,560	85,172	794,264
<i>Paleosuchus palpebrosus</i>	--	15,231	--	--	--	15,231
Totals	673,289	564,233	541,575	393,943	420,794	2,593,834

particular, identification of the subspecies of *Caiman crocodilus* is quite uncertain, and because of that surely derives the alterations registered in the period.

B) The trade of species included in Appendix I is registered until 1983, which is wholly forbidden. This includes exports of skins and live animals of *Caiman latirostris* from Colombia, a country where this species does not occur. Something similar happened with the Paraguayan exports of *Crocodylus acutus* to Italy (29,210 skins in 1980 and 2,991 in 1981).

C) Also, in regard to exports of species on Appendix II, there appear some records that do not coincide with the distribution of the species. The most glaring example is that of 2,000 skins of *Alligator mississippiensis* from Paraguay in 1983.

D) The application of internal laws, as well as the CITES regulations, are not satisfactory because otherwise there would not appear records of exports from countries that have forbidden such exports. The most representative case is Paraguay, where full protection has existed for all species of native fauna since 1975, even though it is one of the main exporters. This further shows that enforcement of legal implementations in the importing countries, mainly Japan and Italy, is deficient; otherwise, they should not accept exports from a country that has repeatedly informed the CITES Secretariat, and through it all the Parties to CITES, that it has not issued any CITES export permits in the past five years.

E) Numerous export countries have not ever forwarded an annual report to provide comparative statistics with those issued by import countries. For example, I can mention what is occurring in Guyana, a



country I have just visited. The officially declared exports for 1984 total approximately 40,000 skins more than those stated by import countries.

As a general conclusion, let me state positively that there are a series of encouraging signs toward reaching a better application of legal implementations to promote a rational use of such an important natural resource. The fact that each day more countries are adhering to CITES provides a progressively representative importance in the international arena. Added to the combined efforts of the Secretariat, member countries, TRAFFIC Network offices, and the Wildlife Trade Monitoring Unit (WTMU), such increasing cooperation will induce positive effects despite the aforementioned problems. Certainly, the project being performed by the Secretariat of the Convention, directed by Dr. Wayne King, is the most important of those encouraging signs.

#### ACKNOWLEDGEMENT

The Wildlife Trade Monitoring Unit (WTMU) provided the statistics that made possible the achievement of this paper.

## ILLEGAL TRADE IN CROCODILIAN SKINS

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The objective of this report is to present the results of an investigation during the years 1984 and 1985 in Montevideo, Uruguay. Uruguay was the tenth country to ratify CITES, and consequently has the honor of enforcing the Convention.

By virtue of the landlocked situation of Paraguay, Uruguay granted that country some port concessions. Therefore with cotton, peanuts and some other products, Paraguayan exporters began to use the free zones and the Uruguayan ports to export products derived from fauna. For several reasons such activities were difficult to document. However, with the inauguration of the Democratic Government in 1985, the Dirección Nacional de Aduanas (the customs service authority), took a series of measures to avoid past irregularities.

In October 1985, 6,000 peccary skins (Mammalia, Tayassuidae) of Paraguayan origin consigned to the German Federal Republic were seized by Uruguayan customs officials. Since that date I am positive that additional such shipments have not passed customs. However, customs authorities remain permanently alert, since a new illegal skins cargo can be tried to pass at any moment.

Due to measures taken by Japan, as a consequence of dealings between CITES and TRAFFIC (JAPAN), the trade of illegal crocodilian skins from Paraguay seems to have been redirected to Singapore since the end of 1984. I thank the Dirección Nacional de Aduanas de Uruguay very much for its cooperation in allowing me to obtain information on shipments that were carrying caiman skins.

In closing, I present the following table to illustrate the volume reached by the illegal trade of these reptiles.

### PARAGUAYANS EXPORTS OF CROCODILIAN SKINS

In transit through Montevideo, 1984-1985

Species	Quantity	Date	Destination
<i>Caiman crocodilus</i>	1,840 kg	26/04/84	JAPAN
<i>Crocodylus</i> spp.	3,211 kg	8/08/84	JAPAN
<i>Caiman crocodilus</i> and <i>Tupinambis</i>	20,587 kg	11/09/84	JAPAN
<i>Caiman crocodilus</i>	1,500 kg	20/11/84	JAPAN
<i>Caiman crocodilus</i> and <i>Tupinambis</i>	3,979 kg	20/11/84	JAPAN
<i>Crocodylus</i> spp.	1,300 kg	25/11/84	JAPAN
<i>Caiman yacare</i>	10,000 skins	8/08/85	SINGAPORE
<i>Crocodylus</i>	31,390 skins	2/10/85	SINGAPORE

Source: Official records of the Dirección Nacional de Aduanas del Uruguay.

## **CROCODILES**

**Supplement to the Proceedings of the 8th Working Meeting of the Crocodile Specialist Group  
of the Species Survival Commission of the International Union for  
Conservation of Nature and Natural Resources**

**Quito, Ecuador**

**13 to 18 October 1986**

**International Union for Conservation of Nature and Natural Resources**

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**1989**

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## FOREWORD

This volume is a supplement to the Proceedings of the 8th Working Meeting of the Crocodile Specialist Group (CSG) in Quito, Ecuador, 13 to 18 October 1986. It contains two papers that were presented at that meeting, but were not published in the Proceedings volume (IUCN Publications New Series, 1989, ISBN 2-88032-968-X).

Publication of this volume was supported by contributions from Professor Harry Messel and the University Foundation for Physics, University of Sydney, Australia; the Nixon Griffis Wildlife Conservation Fund of the University of Florida Foundation, Gainesville, U.S.A.; and Jacques Lewkowicz of Société Nouvelle France Croco, Paris. The opinions expressed herein are those of the individuals identified and are not the opinions of the International Union for Conservation of Nature and Natural Resources or its Species Survival Commission. Phil Hall was scientific editor and managing editor, Rhoda Bryant was copy and style editor.

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The International Union for Conservation of Nature and Natural Resources (IUCN) was founded in 1948, and has its headquarters in Gland, Switzerland; it is an independent international body whose membership comprises states, irrespective of their political and social systems, government departments, and private institutions as well as international organizations. It represents those who are concerned at man's modification of the natural environment through the rapidity of urban and industrial development and the excessive exploitation of the earth's natural resources, upon which rest the foundations of his survival. IUCN's main purpose is to promote or support action which will ensure the perpetuation of wild nature and natural resources on a world-wide basis, not only for their intrinsic cultural or scientific values but also for the long-term economic and social welfare of mankind.

This objective can be achieved through active conservation programs for the wise use of natural resources in areas where the flora and fauna are of particular importance and where the landscape is especially beautiful or striking, or of historical, cultural, or scientific significance. IUCN believes that its aims can be achieved most effectively by international effort in cooperation with other international agencies, such as UNESCO, FAO, and UNEP, and international organizations, such as World Wild Fund for Nature (WWF).

The mission of IUCN's Species Survival Commission (SSC) is to prevent the extinction of species, subspecies, and discrete populations of fauna and flora, thereby maintaining the genetic diversity of the living resources of the planet. To carry out its mission, the SSC relies on a network of over 2,000 volunteer professionals working through 100 Specialist Groups and a large number of affiliate organizations, regional representatives, and consultants, scattered through nearly every country in the world.

**THE DISTRIBUTION OF *CROCODYLUS POROSUS* AND  
*CROCODYLUS JOHNSTONI* ALONG TYPE 1 TIDAL WATERWAYS  
IN NORTHERN AUSTRALIA  
AND  
SURVEY OF THE UPSTREAM NON-TIDAL SECTIONS OF THE ROPER  
RIVER, 1986**

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**ABSTRACT**

This paper discusses in general terms the distribution of *Crocodylus porosus* and *C. johnstoni* along Type 1 tidal water ways in northern Australia. The important Type 1 tidal waterways are classified into four broad groups on the basis of their distributional diagrams, and each group is explained in terms of the model of *C. porosus* population dynamics developed in previous publications. Alternative habitat, crocodile interactions, exclusion, and losses are the key features to the understanding of the distribution.

Results are also presented for the first survey carried out on the non-tidal sections of the Roper River upstream from the Roper Bar at km 145.3. On 77 km of waterway surveyed, 307 *C. johnstoni* were sighted and only one *C. porosus*, which was just 0.7 km up from the Roper River.

**INTRODUCTION**

In Monographs 1 to 19 and the two Western Australia Reports listed in the present publication, we documented, analyzed, and discussed the detailed results of the first systematic survey, since settlement of the continent of some 100 northern Australian tidal waterways and their crocodile populations. In this paper we assemble for the first time and discuss generally sample distributional diagrams for all the more important Type 1 tidal systems surveyed. We also present the results of a 1986 survey of the extreme upstream, non-tidal sections of the Roper River System (Monographs 12 and 19).

In the introduction to Monograph 20 we emphasized (also see Monographs 1, 18, and 19) that the analysis of the number, distribution, and size structure of crocodiles sighted during the general surveys of northern Australian tidal systems indicates that one of the most important parameters characterizing a tidal waterway is its salinity profile and that the profile and habitat type image one another. They appear to largely determine the suitability or otherwise of the tidal waterway for breeding, nesting, and rearing. We also gave a detailed description of the model that we developed

for the dynamics of *C. porosus* populations and which enabled us to account in a consistent fashion for the results we obtained for some 1100 tidal systems in northern Australia. In this model, we pointed out that the tidal waterways of northern Australia have been classified according to their salinity signatures into Type 1, Type 2, and Type 3 systems as shown in Figure 1 (see pages 100-105, Monograph 1). Type 1 systems are the main breeding ones, and non-Type 1 systems are usually poor non-breeding systems. It is the Type 1 systems and the freshwater billabongs and semipermanent and permanent freshwater swamps associated with them which account for the major recruitment of *C. porosus*; the other systems contribute to a lesser degree, and they must usually depend largely upon Type 1 systems and their associated freshwater complexes for the provision of their crocodiles. Non-Type 1 systems also sometimes have freshwater complexes associated with them but these are normally quite minor.

The information summarized in Figure 1 is of great importance for the understanding of the dynamics of *C. porosus* populations. In Type 1 systems some 27% of the crocodiles are hatchlings, whereas in Type 2-3 systems this figure falls to 14% and in Type 3 systems down to 4%, showing a much decreased hatchling recruitment in non-Type 1 systems. In Type 3 systems the percentage of crocodiles in the hatchling, 2-3', and 3-4' size classes combined is some 11%, whereas in Type 1 systems it is at least 52%. On the other hand the percentage of crocodiles in the  $\geq 4-5'$  size classes is some 39% in Type 1 systems and 73% on Type 3 systems. Some 79% of the non-hatchling crocodiles are sighted on Type 1 waterways and 21% on non-Type 1 waterways.

However, as mentioned above, we concern ourselves, in this paper, with the distribution of crocodiles in the more important Type 1 systems only and refer the reader to the series of Monographs for a complete treatment of all tidal waterways surveyed. Though the results for every Type 1 system surveyed were analyzed, discussed, and accounted for on the basis of our population model in the relevant Monographs, at no stage have we brought together sample distributional diagrams for each of the more important Type 1 tidal waterways surveyed in northern Australia, so that they could be compared easily and to see what salient features they have in common. We do so in this paper.

On page 440 of Monograph 1 we stated that the establishment of a University of Sydney field station at Urapunga on the Roper River would not only allow us to monitor the river (see Monographs 12 and 19 for the results) but would also permit us to carry out land-based studies of its long non-tidal freshwater section above Leichhardt's Roper Bar. The Roper River System is one of the largest and best Type 1 tidal waterways in northern Australia. It not only has a long navigable freshwater section, from about km 70 to Roper Bar at km 145.3, but also has a number of sections between km 145.3 and km 353.0 which are surveyable by small boat and which can be reached by bush track. These sections of the river are beyond the tidal limit and consist of intermittent waterholes. Between them the many branches of the river are usually dry during the dry season. Sporadic *C. porosus* were believed to occur and the more plentiful *C. johnstoni* were known to occur in the permanent waterholes, but no systematic night spotlight survey had been carried out of them. Many wild claims (pers. comm.) have been made about the 'hundreds' of *C. porosus* in them. Thus we decided to survey the larger upstream waterholes and obtain direct and quantitative evidence for the relative abundances of the two species on the non-tidal sections of this long and important waterway.

Work maps for the Roper System, from its mouth to Roper Bar at km 145.3, are given in Monograph 15. The additional 18 work maps covering the sections between km 145.3 and km 375 are presented in Figures 2 to 19. A helicopter was used to verify and increase the accuracy of the maps prepared from aerial photographs (see Introduction to Monograph 15) and to find the best tracks into the waterholes to be surveyed. Two Toyota Land Cruisers, a 12 foot dinghy with a 9.9



hp outboard motor, and our standard survey and camping gear were used for the surveys which were carried out during the period 7-15 July 1986.

## RESULTS

Sample distributional diagrams for 20 of the more important Type 1 tidal systems surveyed are taken directly from the relevant Monographs and are shown in Figures 20 to 50. Small Type 1 systems, such as the Goomadeer (Monograph 5), and systems with only a few crocodiles remaining in them have been omitted. An example of the latter is the McArthur River System (Monographs 13 and 19).

We surveyed six lagoons on the upstream non-tidal section of the Roper River as follows: km 145.3-160.2, km 207.0-228.1, km 236.2-241.5, km 252.5-267.0, km 318.5-335.8, plus a sidecreek of 0.6 km and km 349.2-352.5. These sections are shown on the work maps, Figures 2 to 19. In Tables 1 to 7 we give the results for the night spotlight surveys of the individual lagoons and show the size structure, situation, and number of *C. johnstoni* sighted. *C. porosus* are not shown in the Tables as only one animal was sighted during the course of the surveys, and this was a 5-6' animal, at km 146.0, only 0.7 km above Roper Bar.

## DISCUSSION

### Distributional Diagrams

In northern Australia, Type 1 tidal systems normally meander through coastal floodplains, often have large drainage basins, and have a heavy freshwater input during the wet season. The inflow decreases but remains sufficient as the dry season progresses to prevent the salinity upstream (though moving upstream gradually) from rising above the sea water values measured at the mouth of the system (see pages 100-105 Monograph 1). There are exceptions, however, for the Type 1 systems in the north-west Kimberley usually run through rugged gorges and fault lines. It is also to be noted that major Type 1 systems often contain non-Type 1 waterways as well. The Adelaide (Monographs 3 and 19), Liverpool (Monographs 7 and 18), and Roper (Monographs 12 and 19) Systems are excellent examples of such systems. Such matters were discussed in Chapter 9 of Monograph 1, where all the tidal system mainstreams were classified according to their salinity signatures.

One might be tempted into believing that the distributional pattern of *C. porosus* along all Type 1 tidal waterway mainstreams should be essentially similar. As will be seen by inspection of the distributional diagrams in Figures 20 to 50, this is not the case. There can be considerable variation from one Type 1 system to another; however, the shapes of the various distributional patterns appear to fall into four rather broad groups, with considerable overlap between them. We have grouped the 20 major Type 1 systems as follows:

#### Group 1

Blyth-Cadell  
Liverpool-Tomkinson

Figs. 20, 21  
Figs. 22-24

#### Group 3

Prince Regent  
Roe

Fig. 43  
Fig. 44

Ducie	Fig. 25	Mitchell	Fig. 45
Roper	Figs. 26-29	Glenelg-Gairdner	Fig. 46
Daly	Fig. 30	Wenlock	Fig. 47
Adelaide	Figs. 31-33	Goromuru	Fig. 48
Victoria	Figs. 34, 35		

## Group 2

Murgenella	Fig. 36
East Alligator	Figs. 37, 38
South Alligator	Figs. 39, 40
West Alligator	Fig. 41
Wildman	Fig. 42

## Group 4

Ord	Fig. 49
Glyde	Fig. 50

An acceptable model for the dynamics of populations of *C. porosus* must be able to account for the salient features of the distributional pattern of the animals sighted, as summarized in the distributional diagrams for each river system. In fact our model, as described in Monographs 1, 18, 19, and in the Introduction to Monograph 20, grew out of our endeavors to explain the important features of an ever increasing database, summarized by the distributional diagrams for the tidal river systems surveyed. It is thus not surprising that our model can explain the main features of the distributional diagrams not only for Type 1, but for non-Type 1 tidal systems as well.

The first critical break-through towards deriving our model was achieved when we found that we could classify the tidal river systems in northern Australia by their salinity profiles and, surprisingly, that the size structure of the animals sighted in them varied as shown in Figure 1. Almost concurrently with that came the start of even more surprising results concerning the missing crocodiles, now summarized and developed in our model as follows:

1. It appears that the populating of non-Type 1 systems (hypersaline or partially hypersaline coastal and non-coastal waterways) results mostly from the exclusion of a large fraction of the sub-adult crocodiles from Type 1 systems and any freshwater complexes associated with them. Adult crocodiles appear generally to tolerate hatchling, 2-3', and sometimes even 3-4' sized crocodiles in their vicinity (but not always—they sometimes eat them, page 43 Monograph 14—or kill them, page 334 Monograph 1), but not larger crocodiles. Thus once a crocodile reaches the 3-4' and 4-5' size classes, it is likely to be challenged increasingly not only by crocodiles near or in its own size class (pages 454-458 Monograph 1) but by crocodiles in the larger size classes and to be excluded from the area it was able to occupy when it was smaller. A very dynamic situation prevails with both adults and subadults being forced to move between various components of a system and between systems. Crocodile interactions or aggressiveness between crocodiles in all size classes increases around October—during the breeding season (page 445 Monograph 1 and page 109 Monograph 18)—and exclusions, if any, normally occur around this period. A substantial fraction (~80%) of the subadults, mostly in the 3-6' size classes but also including immature larger crocodiles, are eventually excluded from the river proper or are predated upon by larger crocodiles.
2. Of those crocodiles that have been excluded, some may take refuge in freshwater swamp areas and billabongs associated with the waterway from which they were

excluded or in the waterways' non-Type 1 creeks if it has any. Others may travel along the coast until by chance (?) they find a non-Type 1 or another Type 1 waterway; however, in this latter case they may again be excluded from it. Others may go out to sea and possibly perish, perhaps because of lack of food, as they are largely shallow water on edge feeders, or they may be taken by sharks. Those finding non-Type 1 systems, or associated freshwater complexes, frequent these areas, which act as rearing stockyards, for varying periods until they reach sexual maturity, at which time they endeavor to return to a Type 1 breeding system. Since a large fraction of the crocodiles sighted in non-Type 1 systems must be derived from Type 1 systems and their associated freshwater complexes, they are, as seen in (1) above, predominantly subadults in the  $\geq 3'$  size classes or just mature adults (page 431 Monograph 1). Both subadults and just mature adults might attempt to return and to be forced out of a system many times before finally being successful in establishing a territory in a Type 1 system or in its associated freshwater complex. Crocodiles may have a homing instinct (this important point requires further study), and even though a fraction of crocodiles may finally return to and remain in a Type 1 system or in its associated freshwater complex, the overall sub-adult numbers missing-presumed dead remain high and appear to be at least 60-70%.

3. Normally, the freshwater complexes (swamps and/or billabongs) associated with tidal systems are found at the terminal sections of small and large creeks running into the main waterway, or at the terminal sections of the mainstream(s). Though this alternative habitat is usually very limited in extent, sporadic (and sometimes extensive yearly) nesting does take place on it. There are, however, several fairly extensive freshwater complexes associated with Type 1 tidal systems, and these are important as they may act both as rearing stockyards and as breeding systems, just as the Type 1 waterway does itself. Examples of these are the Glyde River with the Arafura Swamp (Monograph 9), the Alligator Region Rivers with their wetlands (Monographs 4, 14, and 19), and the Daly, Finnis, Reynolds, and Moyle Rivers with their wetlands (Monograph 3). Not only can the loss factor, which appears to occur during the exclusion stage, be expected to be lower for movements into and out of swamp areas associated with a Type 1 waterway, than for movement into and out of coastal non-Type 1 systems, but the loss of nests due to flooding can also be expected to be less. We have observed nests made of floating grass cane mats in the Daly River Aboriginal Reserve area. Thus recovery of the *C. porosus* population on Type 1 tidal waterways, with substantial associated freshwater complexes, can be expected to be faster than on other systems (page 445 Monograph 1, page 98 Monograph 14, and also see important results for the 1984 resurvey of Alligator Region and Adelaide River systems appearing in Monograph 19 where we verified this prediction).
4. Though there are wide fluctuations, especially after "dry wet" seasons when the animals are concentrated into the tidal waterways, it appears that as the number of large crocodiles in a tidal waterway increases, there is a tendency for the number of subadults in the 3-6' size classes to decrease or increase marginally only. This density dependent behavior has an important bearing on the rate of population growth and on the size structure of the population.
5. An important and remarkable fact becomes evident in Type 1 tidal systems if one excludes the 3-4' size class and focuses on the 4-5' and 5-6' size classes only. Regardless of how large the recruitment may be, the number of animals sighted

in the 4-5' and 5-6' size classes seems to remain essentially constant or increases slowly only. Thus a major bottleneck occurs for these size classes. It is as if there are a definite number of slots for these animals on a given river system, and that the number of these slots increases slowly only--if at all (note especially the results for the Blyth-Cadell and Liverpool-Tomkinson waterways in Monographs 1 and 18 and the 1984 results for the Alligator Region and Adelaide River systems appearing in Monograph 19). The crocodiles themselves appear to be primarily responsible for the very heavy losses of about 70 % that occur in the process of trying to secure these slots or to increase them in number.

6. If one considers a group of 100 of the sub-adult crocodiles in a Type 1 tidal system without a substantial freshwater complex associated with it, one can expect some 80 to be excluded from it, at least 60-70 of the original 100 to end up missing-presumed dead, less than 15-20 to successfully establish territories on the system without having to leave it, and the remainder might eventually also return and establish a territory, especially after becoming sexually mature. The very nature of this matter is such as to preclude precise figures, and they must be looked upon as broad estimates only; however, detailed study of our results (Monograph 18) now indicates that the missing-presumed dead figure is likely to be in excess of 70. For systems with substantial freshwater complexes associated with them, this figure is likely to be considerably less.
7. When there is an exclusion from Type 1 systems of sub-adult animals, mostly 3-6' in size but also including immature larger animals, this takes place mainly in the breeding season, normally commencing around September-October and apparently lasting throughout the wet season. Any influx of animals in the 3-6' and/or large size classes appears to occur mainly in the early dry season and to be completed in the June-early September period, but may in some years be earlier.
8. After a single "dry wet" season there is a substantial influx of large and sometimes 3-6' animals, forced out of freshwater complexes, into the tidal waterways and these are sighted during June-July surveys. Surveys made in October-November of the same year usually reveal a substantial decrease in the number of 3-6' and/or large animals sighted; however, the number of large animals sighted sometimes remains higher than previously, and hence a number of the new large animals do not return from whence they came. These animals appear successful in establishing a territory on the waterway, and it could be the waterway from which they had originally been excluded. The "dry wet" variation in the number of animals sighted appears to be superimposed upon the variations normally found during surveys following usual wet seasons--which generally result in extensive flooding on the upstream sections of the tidal waterways. Hatchling recruitment on the tidal waterways is generally greatly enhanced during "dry wet" seasons but appears to be greatly reduced in major swamp habitat. The reverse appears to be true during normal or heavy wet seasons.

The key to the understanding of the distributional diagrams--the where, the how, the why, and the when--is contained essentially in the eight points of the model River above, all centered in one way or another, around the matter of crocodile habitat, interactions, exclusions, and losses. Consider the essentially "bell shaped" distributions of the tidal systems shown in Group 1 (Figs. 20 to 26, 30, 32, and 34). In the case of each of these waterways, nesting appears to occur largely on the midsections of the waterway--either on the brackish and/or early freshwater sections. The

position of the peak of the distribution, that is the mean distance upstream (page 333 Monograph 1), varies for each size class and is roughly inversely proportional to size: the mean distance upstream of the hatchling peak is greater than that for 2-3' sized crocodiles: in turn, the mean distance of 2-3' sized crocodiles is greater than that for (3-4') crocodiles. The peak is usually still quite distinct for the 4-5' size class, but sometimes is not so evident for the 5-6' size class and specially not for larger crocodiles, which, for the Group 1 systems, appear to be more evenly distributed along the river. On the basis of the interactions and exclusions discussed in (1) above, these distributional diagrams are easily understandable. The gradual shifting of the distributional peak downstream, of crocodiles in the 2-3', 4-5' and 5-6' size classes, may be understood, at least in part, on the basis of these crocodiles being on their way out of the river system, as they are forced gradually downstream by the larger crocodiles, which are more evenly distributed along the river system (page 334 Monograph 1). However, there are modifying features imposed upon this general picture, the most important of which is the availability of alternative habitat to which the 3-6' animals may be excluded rather than being forced out of the river system totally. This alternative habitat for the Group 1 systems may consist of small freshwater swamps, as on the Adelaide and Roper Systems, or of non-Type 1 creeks, as in the case of the Adelaide (Fig. 33), Roper (Fig. 27), Liverpool (Figs. 22 and 23), and Ducie (Fig. 25); or the limited extreme upstream tidal and non-tidal sections as on the Liverpool-Tomkinson (note specially the Tomkinson) and Blyth-Cadell Systems. For both of these latter systems we have shown the distributional diagrams for July and October-November surveys in order to highlight the fact that exclusions of animals in the 3-6' size classes appears to set in with the onset of the breeding season around October (see [7] above). Note particularly in Figure 20, for the June 1982 survey of the Blyth, the  $\geq 4-5'$  animals on the river mouth section, apparently on their way into the river system.

The surveyable length of the tidal freshwater section of each of the Group 1 systems varies. It can be small as in the cases of the Blyth-Cadell (about 25 km), Liverpool-Tomkinson (about 15 km), and Ducie (nil) or large as in the cases of the Roper (some 70 km) and Adelaide (some 70 km). On a map, the non-tidal freshwater section can appear to be very long, in fact usually much longer than the tidal section. However, great caution is needed when studying river systems on Australian maps. Beyond the tidal limit, the rivers usually consist of intermittent waterholes with sections in between which are dry during the dry season. We discuss a survey of the upstream non-tidal section of the Roper System later in this paper. Examination of the distributional diagrams for the Group 1 systems shows the drop in *C. porosus* numbers past the midsection of the mainstreams. This decrease in *C. porosus* numbers is particularly striking in the cases of the long Group 1 tidal systems—the Roper, the Daly, the Victoria, and to a lesser degree for the Adelaide.

If one is able to proceed beyond the tidal limit (as we did on the Roper), the sighting of *C. porosus* becomes sporadic only, and the sighting of *C. johnstoni* becomes common. It was on the Adelaide River in 1977 (pages 39 and 40 Monograph 3), that the surprising sightings of *C. johnstoni* on the tidal saltwater sections were recorded for the first time by us and was then to be repeated many times over by other tidal systems (see page 459 Monograph 1; pages 19 and 20 Monograph page 16 Monograph 8; pages 25, 58, 59, and 79 Monograph 12; pages 20, 30, 61, 72, and 80 Monograph 13; pages 30, 45, 71, and 110 Monograph 16; pages 56, 57, 71, 72, 75, and 80 Monograph 19). This evidence supports the second point in the hypothesis we first put forward in 1978 (page 20 Monograph 2):

"Could it be that all stages of *C. johnstoni* can indeed tolerate salinities higher than those in which they have heretofore been found? Is it then the case that the scarce observations of *C. johnstoni* in tidal rivers reflect exclusion by *C. porosus* rather than an intrinsic intolerance of saline conditions?"

Our prediction about *C. johnstoni* being able to tolerate salinities greater than those of freshwater was also proven correct when Taplin and Grigg (Science 1981, 212:1045-1047) discovered lingual salt glands both in *C. porosus* and *C. johnstoni*.

The shape of the distributional diagrams for the tidal systems shown in Group 2 (Figs. 36 to 42) are strikingly different from those for Group 1. Unlike the generally bell-shaped distributions for the Group 1 systems, those for Group 2 are skewed heavily towards the upstream freshwater sections of the waterways. These waterways are all in the Alligator Region and have one thing in common—excellent alternative habitat on their upstream sections, in the form of substantial freshwater swamps (see point [3] above in our model). The distributions show, to varying degrees, signs that the mean distance downstream of the peak of the distribution varies for each size class, roughly inversely proportional to size, and hence indicate that some of the animals are being forced downstream and probably out of the waterways. However one can plainly see the input of animals in size classes  $\geq 4.5'$  on the extreme upstream sections of the East Alligator (Fig. 37) and the South Alligator (Fig. 39)—note especially Nourlangie Creek. One can see a similar occurrence for all size classes on the Wildman System. These animals can only come from the upstream swamps that act both as breeding and rearing areas.

The shapes of the distributional diagrams for the tidal systems in Group 3 (Figs. 43 to 48) are quite similar to those of Group 2, but the reasons for them being so are quite different. None of these systems, with the exception of the Wenlock (Fig. 47) has freshwater swamps of any import upstream. The Wenlock does have some freshwater swamp (see page 85 Monograph 16) and perhaps could be included in Group 2 as easily as in Group 3. In the cases of the Prince Regent (Fig. 43), the Roe (Fig. 44), the Mitchell (Fig. 45), the Glenelg (Fig. 46), and the Goromuru (Fig. 48), the distributions are all skewed upstream because suitable nesting habitat is essentially all located on the upstream sections. For the exception of the Wenlock and Goromuru, the downstream sections of the Group 3 waterways have either wide bays, rocky gorges, and/or turbulent waters. One should note that for the waterways in Group 3, one again sees the shifting downstream of the distributional peak with increasing size class. Excellent examples of the important role that alternative habitat can play for excluded animals in the  $\geq 4.5'$  size classes can be seen in Figures 43 and 44 for the Prince Regent and Roe Systems respectively. The North and South Arms at the mouth of the Prince Regent show that some 95 such animals were sighted in them and that Creeks A to F at the mouth of the Roe System held a number of excluded animals as well.

We grouped the Ord and Glyde Systems separately into Group 4 (Figs. 49 and 50), because they do not quite fit any of the other groups, though their distributional diagrams are interpreted easily. Inspection of the work maps for the Ord System (page 321-328 Monograph 15) shows that the Ord System is not quite like any other that we surveyed. Its zero point is to the north of Adolphus Island in the East Arm of Cambridge Gulf and it retains its gulf-like features until km 40; thereafter the river begins to meander. Between km 12 and 20, to the east of Mount Connection, there are three creeks which provide alternative habitat for  $\geq 3.4'$  animals excluded from the upstream breeding sections of the Ord. Move the crocodiles of the three creeks to the right on the distributional diagram, and you could be looking at the diagram for the Blyth System with similar reasoning pertaining to the distribution.

The Glyde River (see pages 108 and 141-145 Monograph 18) drains the Arafura Swamp, and the Goyder River runs into the swamp. It is a unique system and one of the most important for the understanding of the dynamics of the population of *C. porosus* on the northern Arnhem Land coast. The Swamp acts both as a breeding and rearing area and appears to hold animals excluded from Type 1 systems to the west of it, such as the Blyth-Cadell, Liverpool-Tomkinson, and Goomadeer Systems (see pages 100-158 Monograph 18). There appears to be continuing

movement of these animals to and from these systems, and the Glyde River is the conduit into and out of the Arafura Swamp. The distributional diagram (Fig. 50) reflects this beautifully, where one notes a peak for the animals at the mouth of the Glyde and a peak at the upstream swamp end. Minor nesting takes place on the Glyde, but the majority of animals sighted on it are likely to come from the swamp or elsewhere. Note the large number of EO animals, probably new animals entering the system.

### Survey of Non-tidal Sections of the Roper River

The 77 km of upstream lagoons surveyed and spotlighted on the Roper River between km 145.3 and km 353 constitutes 37% of the total upstream distance; the remainder is largely numerous dry watercourses. Tables 1 to 7 reveal a healthy population of *C. johnstoni* on the upstream non-tidal sections of the Roper River. Our surveys of the Roper in 1979 revealed the first *C. johnstoni*, on the km 80-85 section of the mainstream (page 66 Monograph 12) and between this and the Roper Bar at km 145.3, at least an additional 34 *C. johnstoni* as well as 27 *C. porosus* were sighted. During the 1985 survey of the Roper, the first *C. johnstoni* was sighted on the km 95-100 section, and thereafter at least a further 41 *C. johnstoni* were sighted on the tidal section to Roper Bar (an isolated *C. johnstoni* was in fact sighted on the km 45-50 section). Nineteen *C. porosus* were sighted on the same sections of the mainstream inhabited by the *C. johnstoni*.

The dramatic change in the relative abundance of *C. porosus* and *C. johnstoni* between the tidal section of the mainstream immediately below Roper Bar and the non-tidal section above it is seen by examining Tables 1 and 7. On the 14.9 km section immediately above Roper Bar, 73 *C. johnstoni* were sighted and only one *C. porosus*; between km 145.3 and km 353 on the 77 km surveyed above the Bar only that one *C. porosus* was sighted, whereas 307 *C. johnstoni* were counted.

On page 57 of Monograph 12 we made the statement that throughout our surveys of the northern Australian rivers we invariably have found that the density of *C. porosus* plummets as soon as the freshwater sections of rivers are reached. We intimated similarly on pages 334-335 of Monograph 1. As we have seen, this is essentially so in the case of the Group 1 tidal systems, but in the case of the non-Group 1 systems it certainly is not so. What one can say is that for those tidal systems not terminating in freshwater swamps but becoming a series of intermittent waterholes, the density of *C. porosus* is essentially zero on the non-tidal sections of the waterway.

A word of caution should be interpolated here. The fact that no *C. porosus* are at present found on the upstream Roper does not necessarily mean that there never were significant numbers of *C. porosus* on such sections. We are looking today at a depleted population, and one hundred years ago, when the population was much higher on the tidal sections, it is possible many more *C. porosus* were pushed up into the non-tidal sections. The same warning applies to the interpretation of the distributions on most other systems as well. They reflect severely depleted populations in many cases.

The density of *C. johnstoni* sighted in the six waterholes (sections) surveyed varied considerably, from 2.1/km on the km 207.0-228.1 section (Table 2) to 7.0/km on the km 349.2-352.5 one. The overall density for the six waterholes was 4.0/km. The waterholes on the upstream Roper River are coming under increasing tourist pressure, and we found definite evidence of poaching for *C. johnstoni*, using baited hooks, on the km 207.0-228.1 waterhole.

Food supply, in the way of small fish and specially freshwater turtles, appeared plentiful in the waterholes surveyed. Barramundi were nowhere to be seen and not a single tourist that we met had been successful in catching one. One wonders at the resource planning that allows the destruction of such an extremely valuable tourism asset as barramundi when only a few individuals benefit from this destruction. The waterholes do not appear to provide very suitable habitat for *C. porosus*; however, there is one exception, and that is the downstream portion of Red Lily Lagoon, km 318.5-335.8. At km 318.5 there is substantial freshwater swamp which appeared to provide excellent habitat for *C. porosus*. We were convinced that if *C. porosus* was to be found on the extreme upstream sections of the Roper River, then this was the area. On 15 July 1986 we chartered a helicopter so we could carry out careful low level surveys of the swamps, looking for signs of *C. porosus* and specially for old nests. None was found.

THIS WAS, AFTER 16 YEARS OF SURVEYING, OUR FINAL CROCODILE SURVEY IN THE NORTHERN TERRITORY.

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### MONOGRAPH SERIES

#### Surveys of Tidal Waterways in Northern Australia and Their Crocodile Populations

A series of monographs covering the navigable portions of the tidal rivers and creeks of northern Australia. Published by Pergamon Press, Sydney, Australia, 1979-1987.

1. The Blyth-Cadell Rivers System Study and the Status of *Crocodylus porosus* in Tidal Waterways of Northern Australia. Methods for analysis, and dynamics of a population of *C. porosus*. Messel, H.; Vorlicek, G. C.; Wells, A. G. and Green, W. J.
2. The Victoria and Fitzmaurice River Systems. Messel, H.; Gans, C.; Wells, A. G.; Green, W. J.; Vorlicek, G. C. and Brennan, K. G.
3. The Adelaide, Daly and Moyle Rivers. Messel, H.; Gans, C.; Wells, A. G. and Green, W. J.
4. The Alligator Region River Systems. Murgarella and Coopers Creeks; East, South and West Alligator Rivers and Wildman River. Messel, H.; Wells, A. G. and Green, W. J.
5. The Goomadeer and King River Systems and Majarie, Wuruguij and All Night Creeks. Messel, H.; Wells, A. G. and Green, W. J.



6. Some River and Creek Systems on Melville and Grant Islands Johnston River, Andranangoo, Bath, Dongau and Tinganoo Creeks and Pulloloo and Brenton Bay Lagoons on Melville Island; North and South Creeks on Grant Island. Messel, H.; Wells, A. G. and Green, W. J.
7. The Liverpool-Tomkinson Rivers Systems and Nungbulgarri Creek. Messel, H.; Wells, A. G. and Green, W. J.
8. Some Rivers and Creeks on the East Coast of Arnhem Land, in the Gulf of Carpentaria, Rose River, Muntak Creek, Hart River, Walker River and Koolatong River. Messel, H.; Elliott, M., Wells, A. G., Green, W. J. and Brennan, K. G.
9. Tidal Waterways of Castlereagh Bay and Hutchinson and Cadell Straits. Bennett, Darbitla, Djigagila, Djabura, Ngandadauda Creeks and the Glyde and Woolen Rivers.
10. Waterways of Buckingham and Ulundurwi Bays, Buckingham, Kalarwoi, Warawuruwoi and Kurala Rivers and Slippery Creek. Messel, H.; Vorlicek, G. C.; Wells, A. G. and Green, W. J.
11. Tidal Waterways of Arnhem Bay. Darwarunga, Habgood, Baralminar, Gobalpa, Goromuru, Cato, Peter John and Burungbirinung Rivers. Messel, H.; Vorlicek, G. C.; Wells, A. G. and Green, W. J.
12. Tidal Waterways on the South-Western Coast of the Gulf of Carpentaria. Limmen Bight, Towns, Roper, Phelp and Wilton Rivers; Nayarnpi, Wungguliyanga, Painnyilatya, Mangkurdurrungku and Yiwapa Creeks. Messel, H.; Vorlicek, G. C.; Wells, A. G., Green, W. J. and Johnson, A.
13. Tidal Systems on the Southern Coast of the Gulf of Carpentaria. Calvert, Robinson, Wearyan, McArthur Rivers and some intervening Creeks. Messel, H.; Vorlicek, G. C.; Wells, A. G.; Green, W. J. and Johnson, A.
14. Tidal Waterways of Van Diemen Gulf. Ilamaryi, Iwalg, Saltwater and Minimini Creeks and Coastal Arms on Cobourg Peninsula. Resurveys of the Alligator Region Rivers. Messel, H.; Vorlicek, G. C.; Wells, A. G. and Green, W. J.
15. Work maps of Tidal Waterways in Northern Australia. Messel, H.; Green, W. J.; Wells, A. G. and Vorlicek, G. C.
16. Surveys of Tidal Waterways on Cape York Peninsula, Queensland, Australia, and their Crocodile Populations. Messel, H.; Vorlicek, G. C.; Wells, A. G.; Green, W. J.; Curtis, H. S.; Roff, C. R. R.; Weaver, C. M. and Johnson, A.
17. Darwin and Bynoe Harbours and their Tidal Waterways. Messel, H.; Vorlicek, G. C.; Elliott, M.; Wells, A. G. and Green, W. J.
18. Population Dynamics of *Crocodylus porosus* and Status, Management and Recovery Update 1979-1983. Messel, H.; Vorlicek, G.C.; Green, W.J. and Onley, I.C.

19. Resurveys of the Tidal Waterways of Van Diemen Gulf and the Southern Gulf of Carpentaria, 1984 and 1985. Messel, H.; Vorlicek, G.C.; Green, W.J.; Onley, I.C.; and King, F. W.
20. Tidal Waterways of the Kimberley Surveyed during 1977, 1978 and 1986. Messel, H.; Burbidge, A.A.; Vorlicek, G.C.; Wells, A.G.; Green, W.J.; Onley, I.C. and Fuller, P.J.

Appearing in the same series and published by the Western Australian Government:

1. The status of the salt-water crocodile in some river systems of the north-west Kimberley, Western Australia. Dept. Fish. Wildl., West. Aust. Rept. No. 24:1-50(1977). Messel, H.; Burbidge, A. A.; Wells, A. G. and Green, W. J.
2. The status of the salt-water crocodile in the Glenelg, Prince Regent and Ord River Systems, Kimberley, Western Australia, Dept. Fish. Wildl. West. Aust. Rept. No. 34:1-38(1979). Burbidge, A. A. and Messel, H.

TABLE 1  
ROPER RIVER, KM145.3-160.2, JULY 7, 1986

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
HATCHLING	1					1		
2-3 (0.6-0.9)	8					8		1
3-4 (0.9-1.2)	24					24		
4-5 (1.2-1.5)	19			1		18		
5-6 (1.5-1.8)	5					5		
6-7 (1.8-2.1)	1					1		
>7 (>2.1)								
EO<6 (<1.8)	8					8		
EO>6 (>1.8)								
EO	7					5	2	
TOTAL	73	—	—	1	—	70	2	1

## ABBREVIATIONS:

IV — IN VEGETATION IVIW — IN VEGETATION IN WATER OM — ON MUD IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE MS — MIDSTREAM EO — EYES ONLY

## Table 1

Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River. One (5-6) *C. porosus* sighted at km146.0 not included in Table. Non-hatchling density is 4.8/km.

TABLE 2  
ROPER RIVER, KM207.0-228.1, JULY 8-9, 1986

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
HATCHLING								
2-3 (0.6-0.9)	2					2		
3-4 (0.9-1.2)	17					17		
4-5 (1.2-1.5)	15					15		
5-6 (1.5-1.8)	4			1		3		
6-7 (1.8-2.1)								
>7 (>2.1)								
EO<6 (<1.8)	5					4	1	
EO>6 (>1.8)								
EO	1					1		
TOTAL	44	—	—	1	—	42	1	—

## ABBREVIATIONS:

IV — IN VEGETATION IVIW — IN VEGETATION IN WATER OM — ON MUD IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE MS — MIDSTREAM EO — EYES ONLY

## Table 2

Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River. Non-hatchling density is 2.1/km.

**TABLE 3**  
**ROPER RIVER, KM236.2-241.5, JULY 10, 1986**

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
<b>HATCHLING</b>								
2-3 (0.6-0.9)	1					1		
3-4 (0.9-1.2)	8					8		
4-5 (1.2-1.5)	13					13		1
5-6 (1.5-1.8)	4					4		
6-7 (1.8-2.1)	1					1		
>7 (>2.1)								
EO<8 (<1.8)	4					3	1	
EO>6 (>1.8)								
EO								
<b>TOTAL</b>	<b>31</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>30</b>	<b>1</b>	<b>1</b>

## ABBREVIATIONS:

IV — IN VEGETATION    IVIW — IN VEGETATION IN WATER    OM — ON MUD    IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE    MS — MIDSTREAM    EO — EYES ONLY

## Table 3

Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River. Non-hatchling density is 5.8/km.

**TABLE 4**  
**ROPER RIVER, KM252.5-267.0, JULY 11, 1986**

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
<b>HATCHLING</b>								
2-3 (0.6-0.9)	1					1		
3-4 (0.9-1.2)	11					11		
4-5 (1.2-1.5)	19					18	1	
5-6 (1.5-1.8)	7			2		5		
6-7 (1.8-2.1)	1					1		
>7 (>2.1)	1			1				
EO<8 (<1.8)	18					18		
EO>6 (>1.8)								
EO								
<b>TOTAL</b>	<b>58</b>	<b>—</b>	<b>—</b>	<b>3</b>	<b>—</b>	<b>54</b>	<b>1</b>	<b>—</b>

## ABBREVIATIONS:

IV — IN VEGETATION    IVIW — IN VEGETATION IN WATER    OM — ON MUD    IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE    MS — MIDSTREAM    EO — EYES ONLY

## Table 4

Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River. Non-hatchling density is 4.0/km.

TABLE 5  
ROPER RIVER, KM318.5-335.8, JULY 13-14, 1986

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
HATCHLING								
2-3 (0.6-0.9)								
3-4 (0.9-1.2)	11					11		
4-5 (1.2-1.5)	25					25		
5-6 (1.5-1.8)	12					12		
6-7 (1.8-2.1)	2					2		
>7 (>2.1)								
EO<6 (<1.8)	27					27		
EO>6 (>1.8)								
EO	1					1		
TOTAL	78	—	—	—	—	78	—	—

## ABBREVIATIONS:

IV — IN VEGETATION IVIW — IN VEGETATION IN WATER OM — ON MUD IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE MS — MIDSTREAM EO — EYES ONLY

## Table 5

Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River. A sidecreek of 0.6 km was surveyed making a total distance of 17.9 km. Non-hatchling density is 4.4/km.

TABLE 6  
ROPER RIVER, KM349.2-352.5, JULY 12, 1986

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
HATCHLING								
2-3 (0.6-0.9)								
3-4 (0.9-1.2)	11			1		10		
4-5 (1.2-1.5)	4					4		
5-6 (1.5-1.8)	1					1		
6-7 (1.8-2.1)								
>7 (>2.1)								
EO<6 (<1.8)	7					7		
EO>6 (>1.8)								
EO								
TOTAL	23	—	—	1	—	22	—	—

## ABBREVIATIONS:

IV — IN VEGETATION IVIW — IN VEGETATION IN WATER OM — ON MUD IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE MS — MIDSTREAM EO — EYES ONLY

## Table 6

Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River. Non-hatchling density is 7.0/km.

TABLE 7  
OVERALL UPSTREAM ROPER RIVER, JULY 7-14, 1986

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
HATCHLING	1					1		
2-3 (0.6-0.9)	12					12		1
3-4 (0.9-1.2)	82			1		81		
4-5 (1.2-1.5)	95			1		93	1	1
5-6 (1.5-1.8)	33			3		30		
6-7 (1.8-2.1)	5					5		
>7 (>2.1)	1			1				
EO<6 (<1.8)	69					67	2	
EO>6 (>1.8)								
EO	9					7	2	
TOTAL	307	—	—	6	—	296	5	2

## ABBREVIATIONS:

IV — IN VEGETATION    IVIW — IN VEGETATION IN WATER    OM — ON MUD    IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE    MS — MIDSTREAM    EO — EYES ONLY

## Table 7

Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River from km145.3. One (5-6) *C. porosus* sighted at km146.0 not included in table. Total distance surveyed was 77 km, yielding a non-hatchling density of 4.0/km.

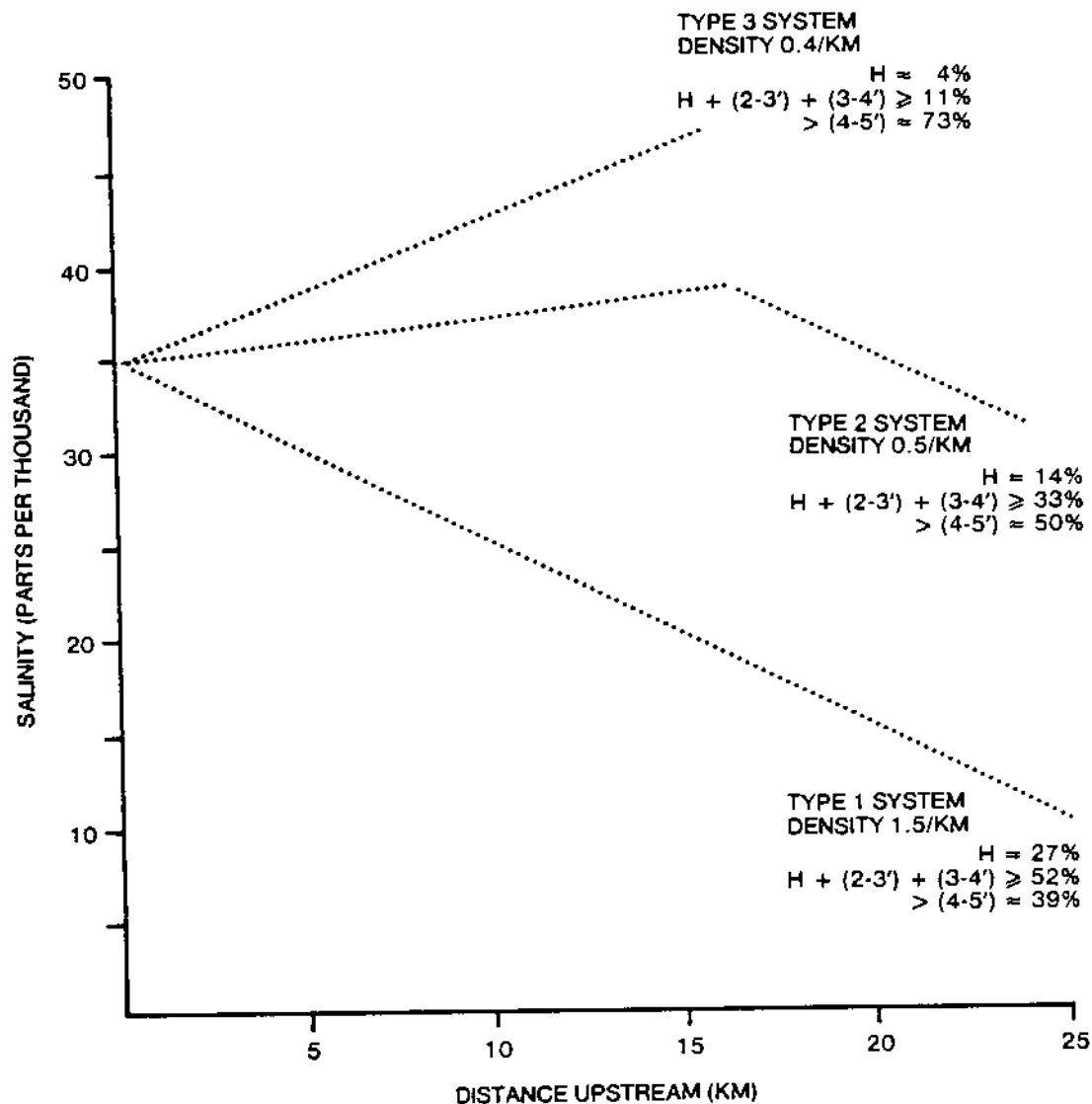


Figure 1. Typical dry season salinity profiles for the three types of tidal river systems occurring in the model's classification scheme. In a Type 1 system the salinity decreases steadily as one progresses upstream from that of seawater measured at the mouth of the waterway ( $\sim 35^{\circ}/\text{oo}$ ). In contrast, in a Type 3 system the salinity increases steadily as one progresses upstream. Type 2 systems fall somewhere between Type 1 and Type 3 systems and tend to show hypersaline tendencies as the dry season progresses (pages 100 and 101 Monograph 1). As shown above, the non-hatchling density and size structure of the crocodiles sighted in the three kinds of systems differ strikingly (Table 9.2.1, page 419 Monograph 1).

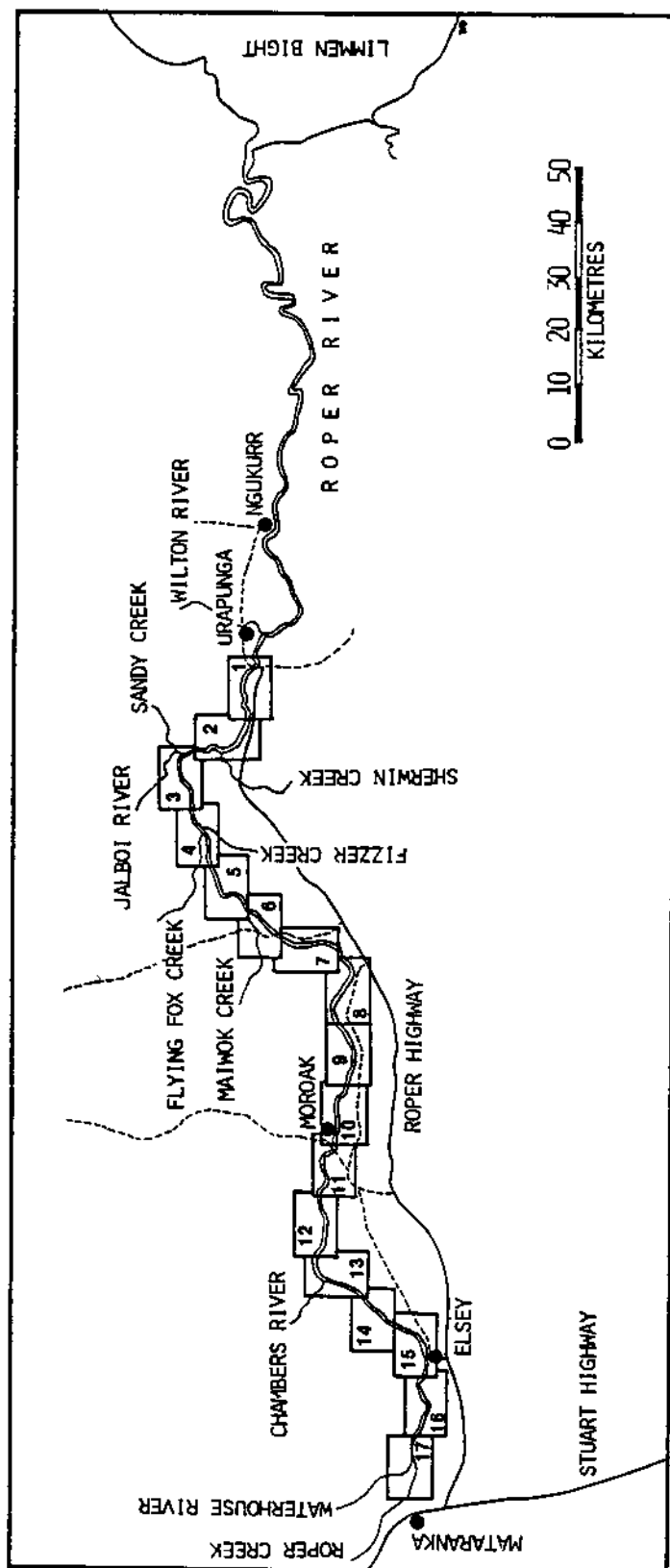


Figure 2. Legend to the river work maps of the upstream Roper River.



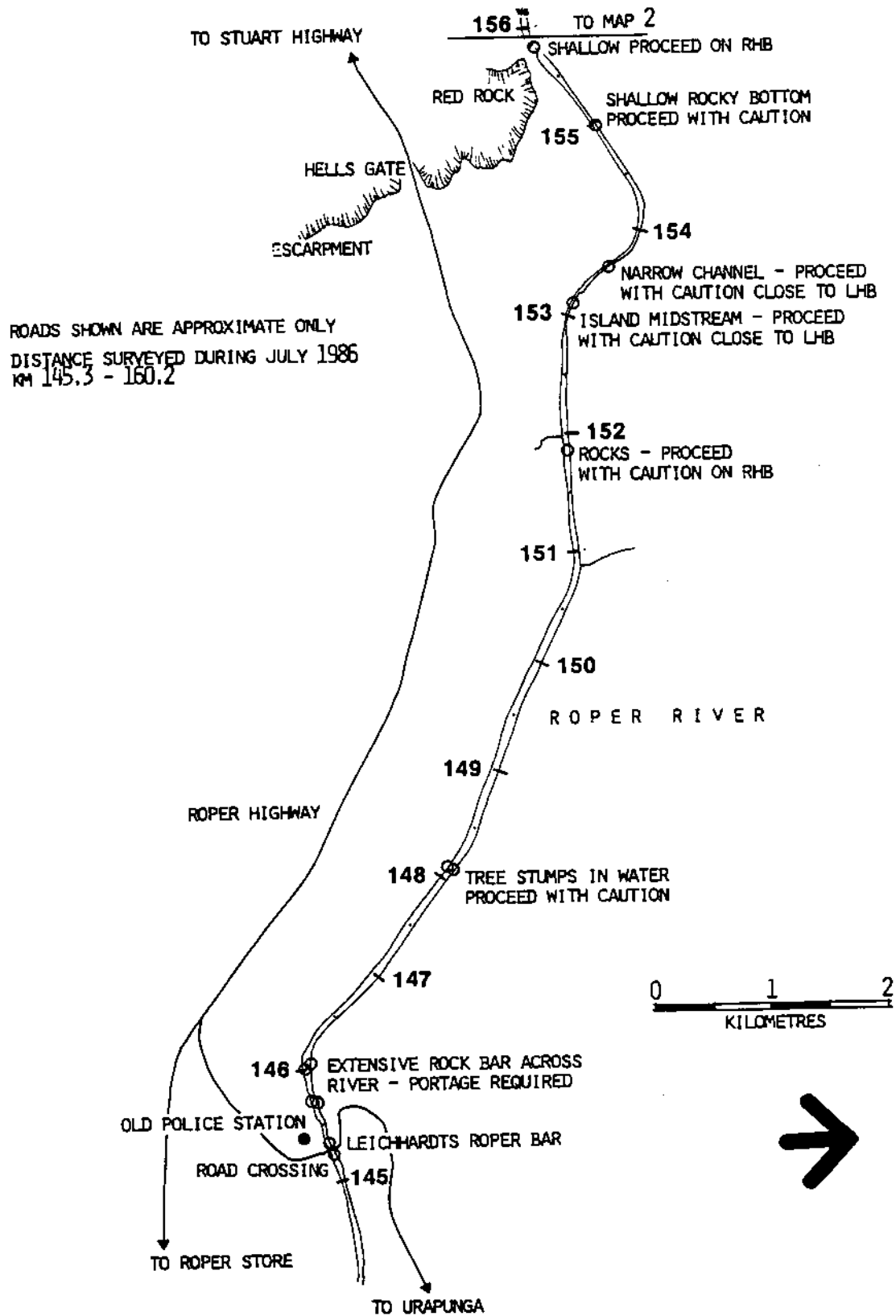


Figure 3. Upstream Roper River 1.

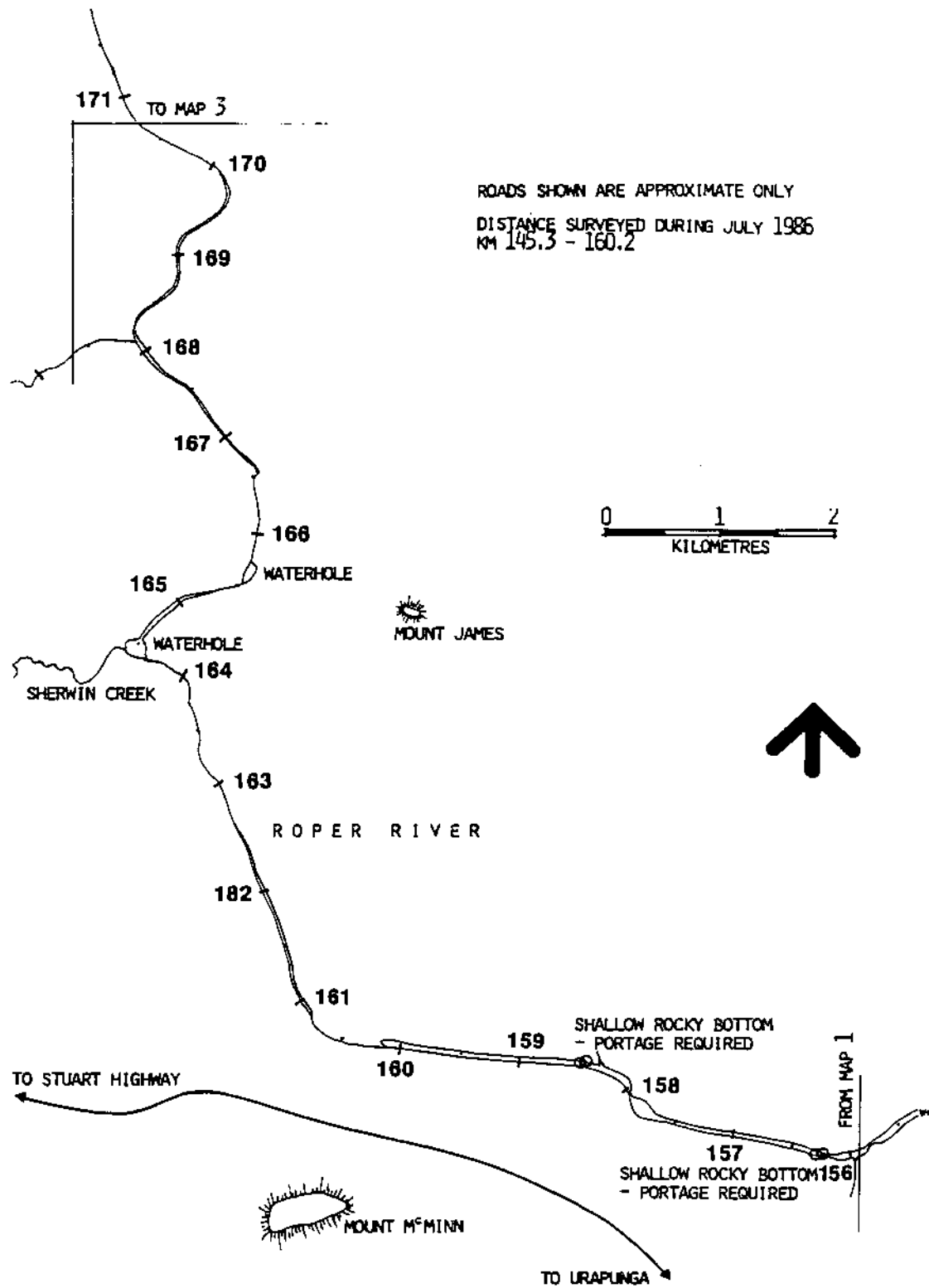


Figure 4. Upstream Roper River 2.

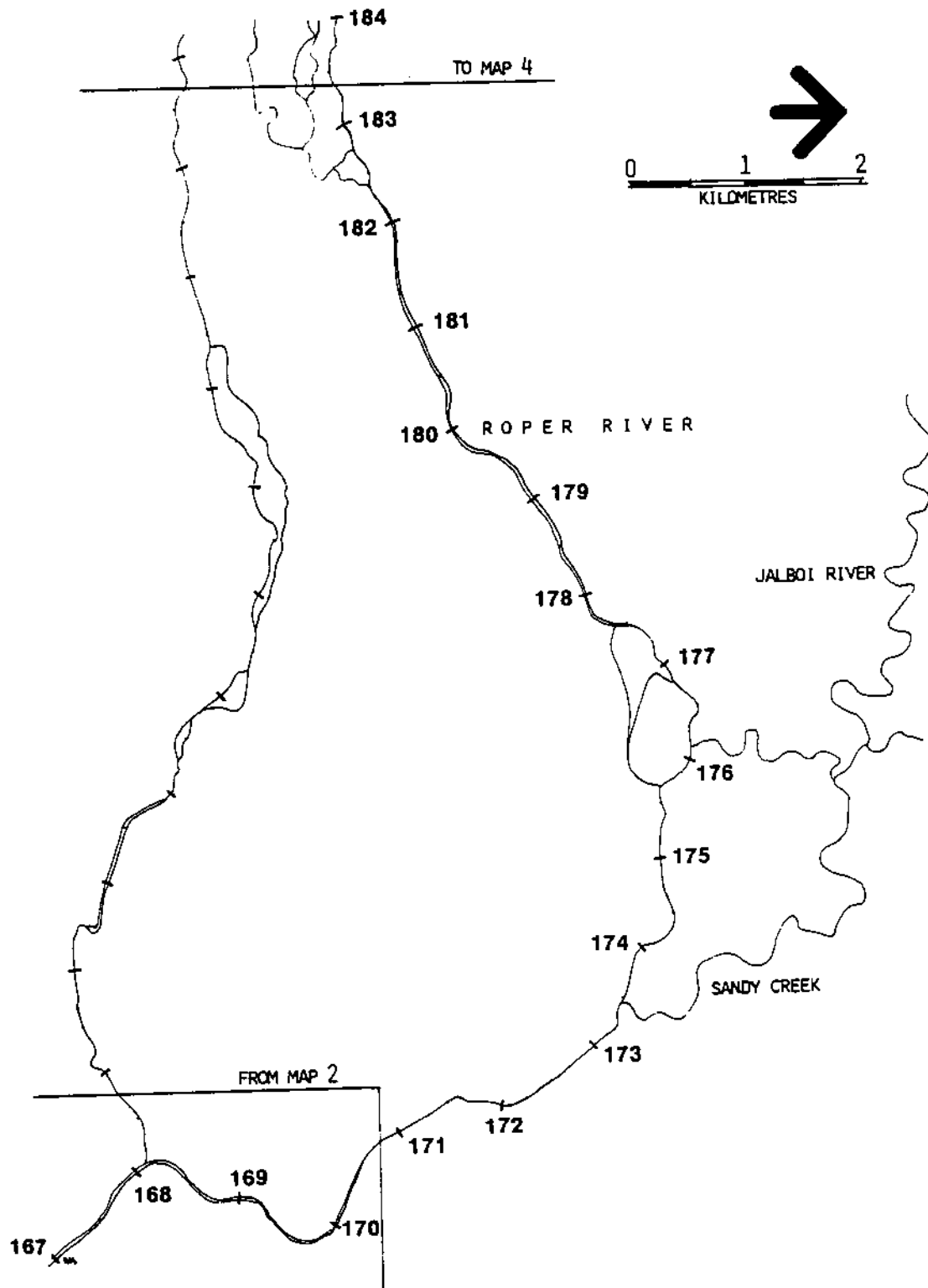


Figure 5. Upstream Roper River 3.

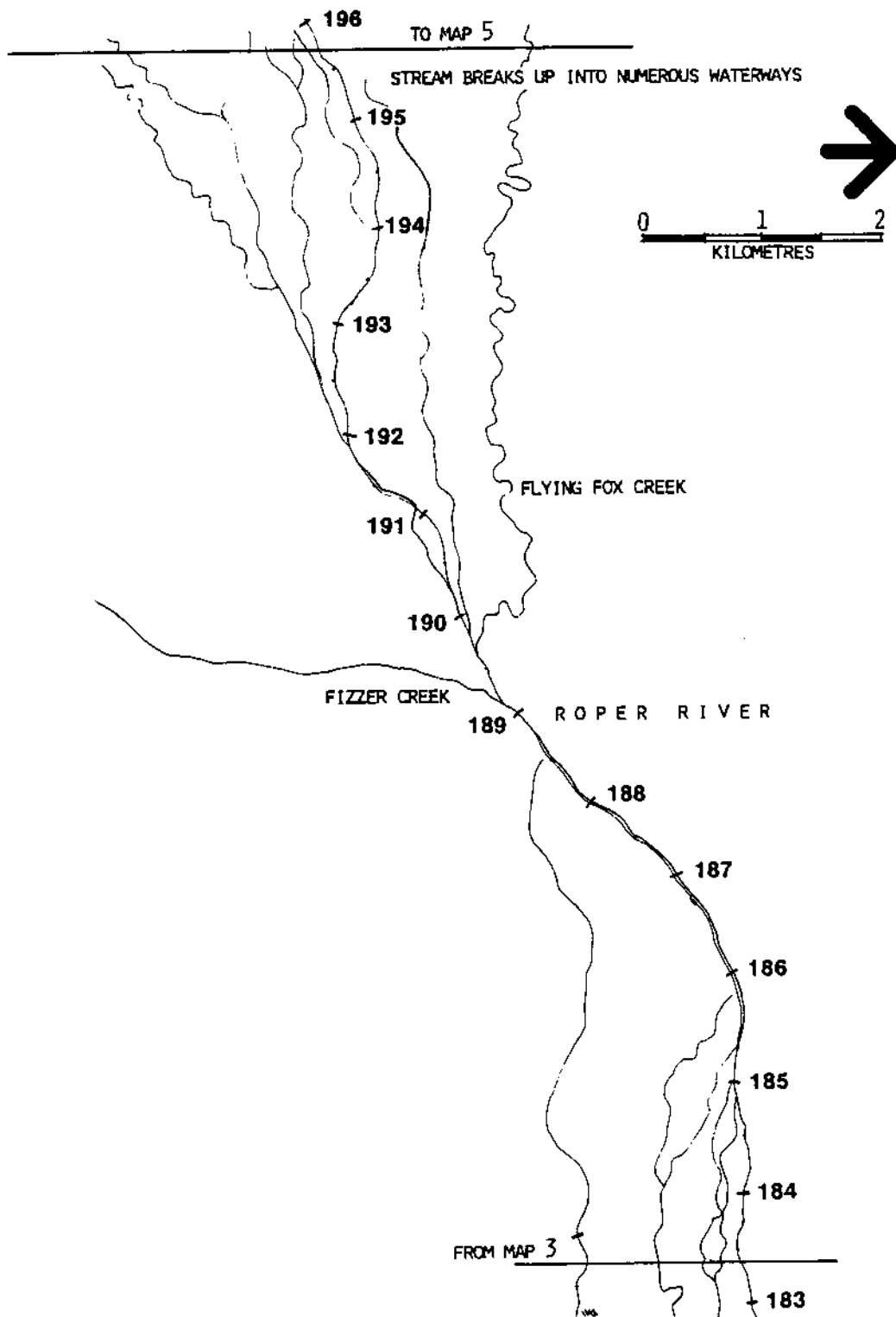


Figure 6. Upstream Roper River 4.

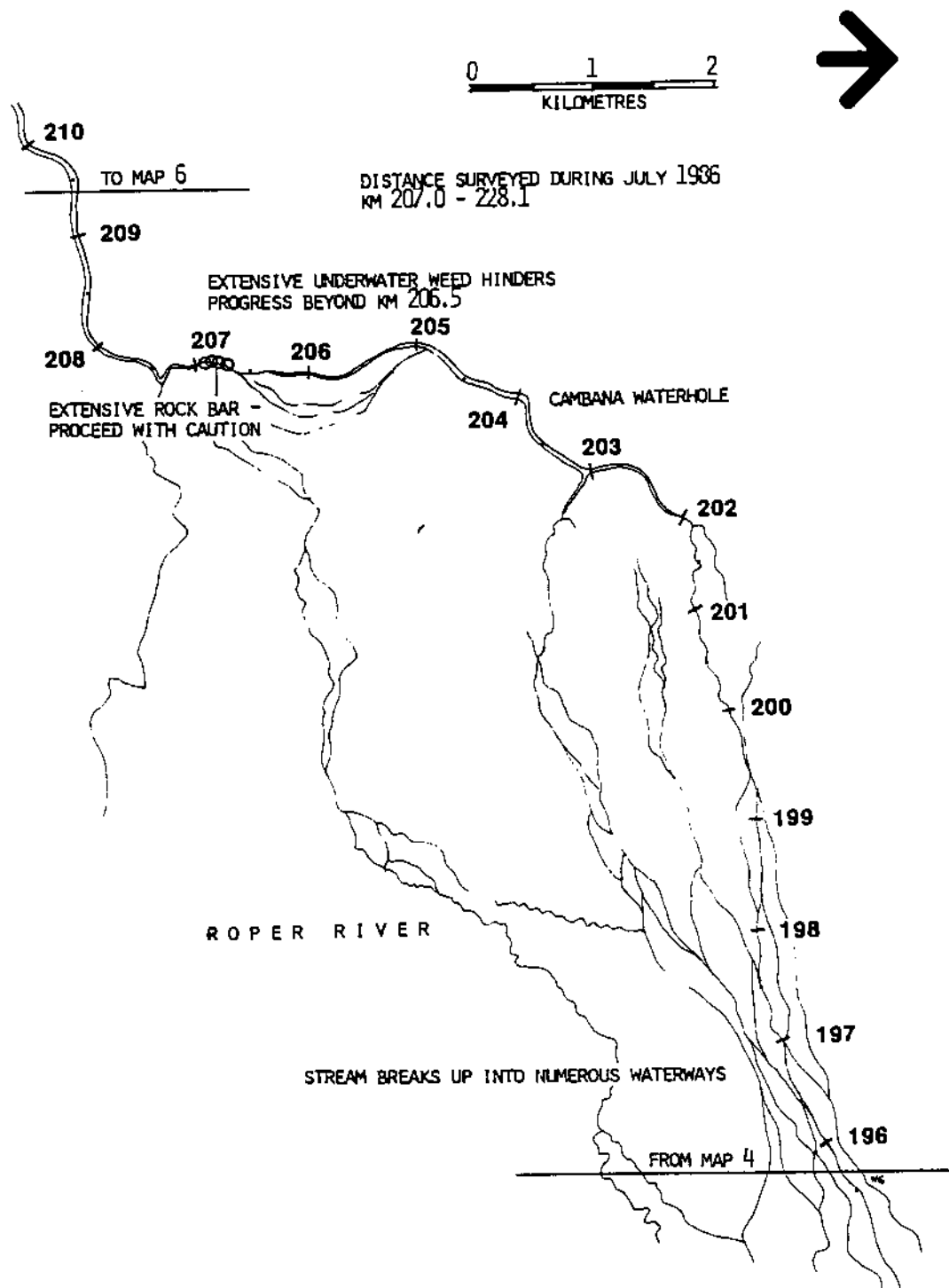


Figure 7. Upstream Roper River 5.

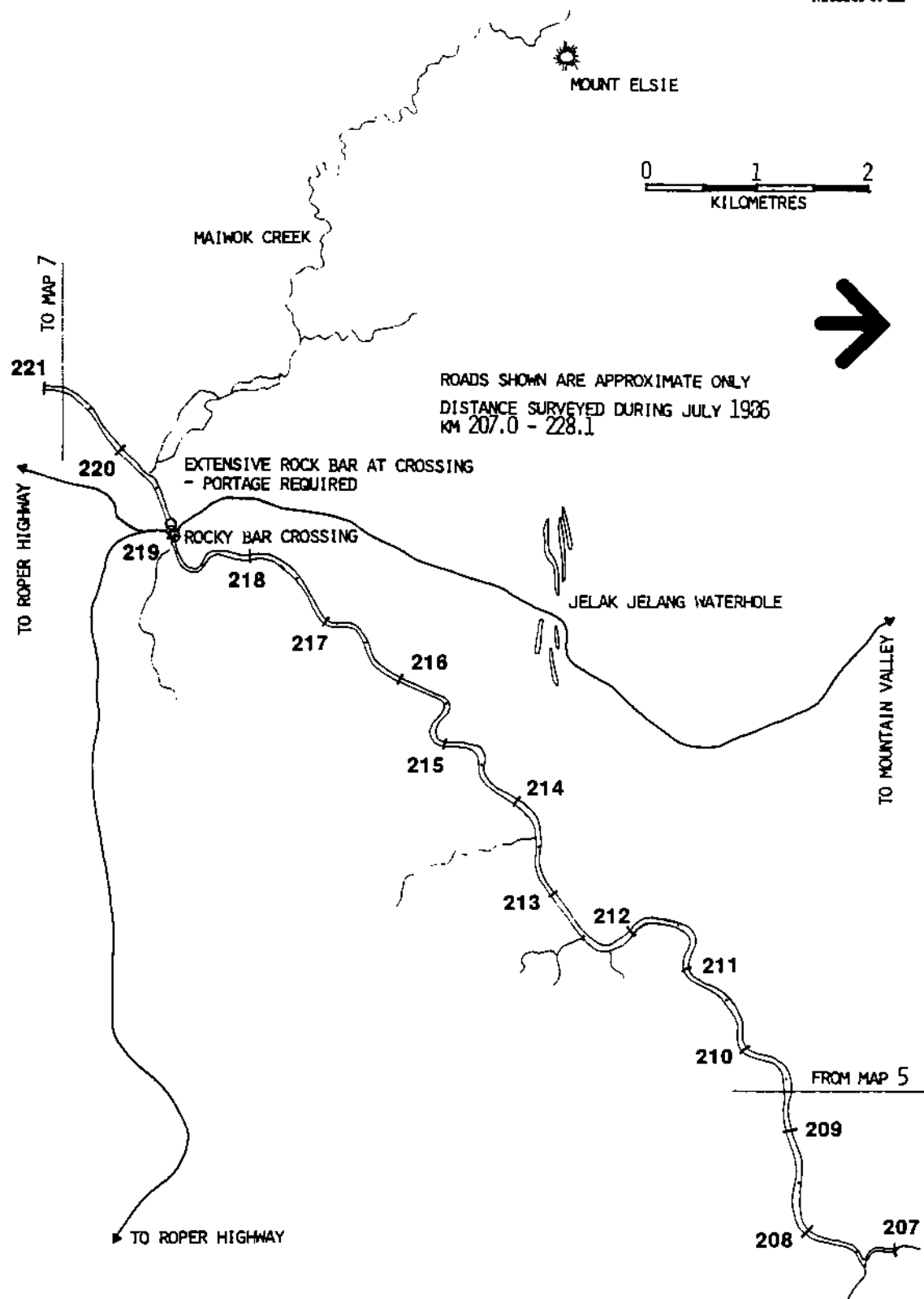


Figure 8. Upstream Roper River 6.

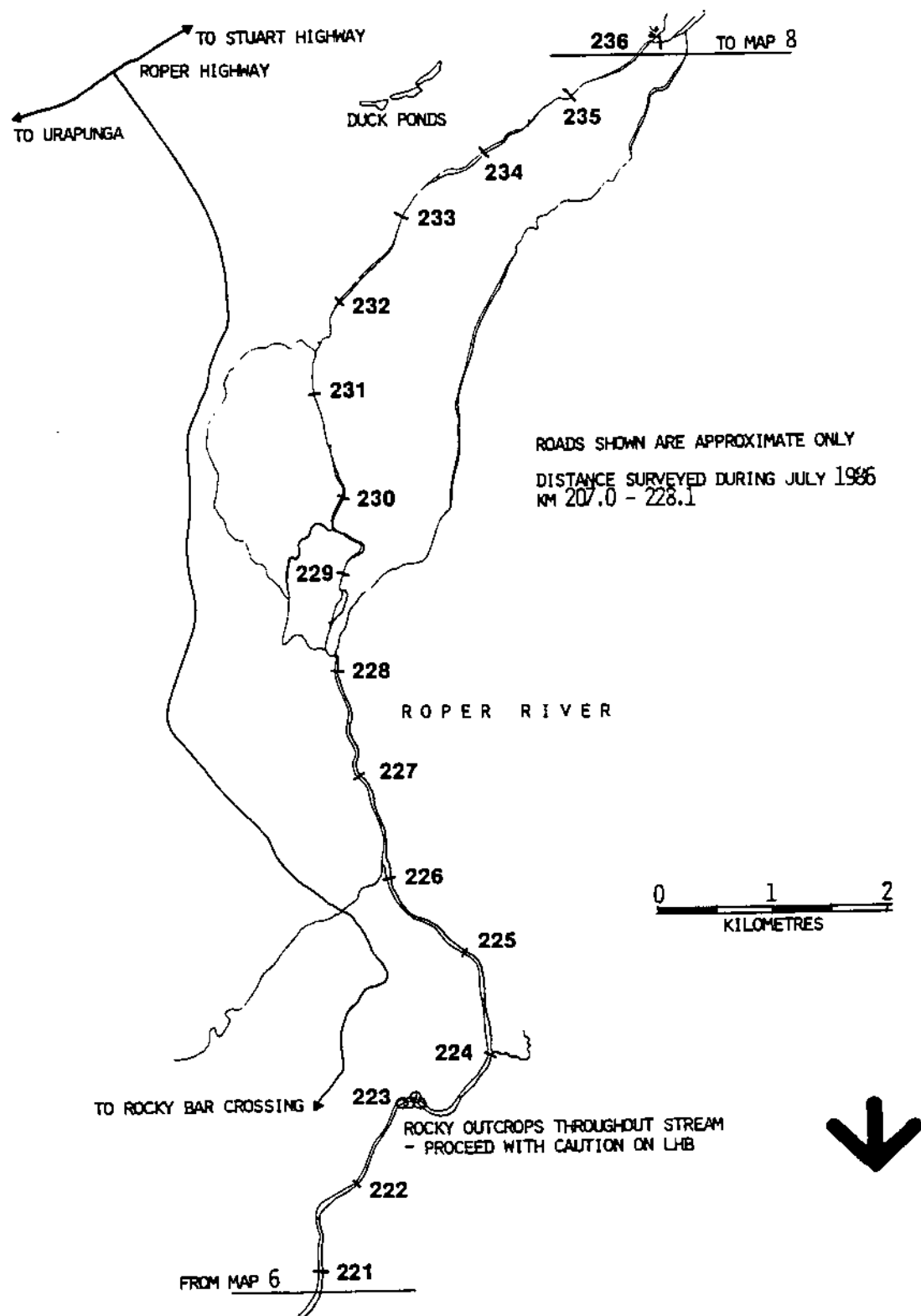


Figure 9. Upstream Roper River 7.

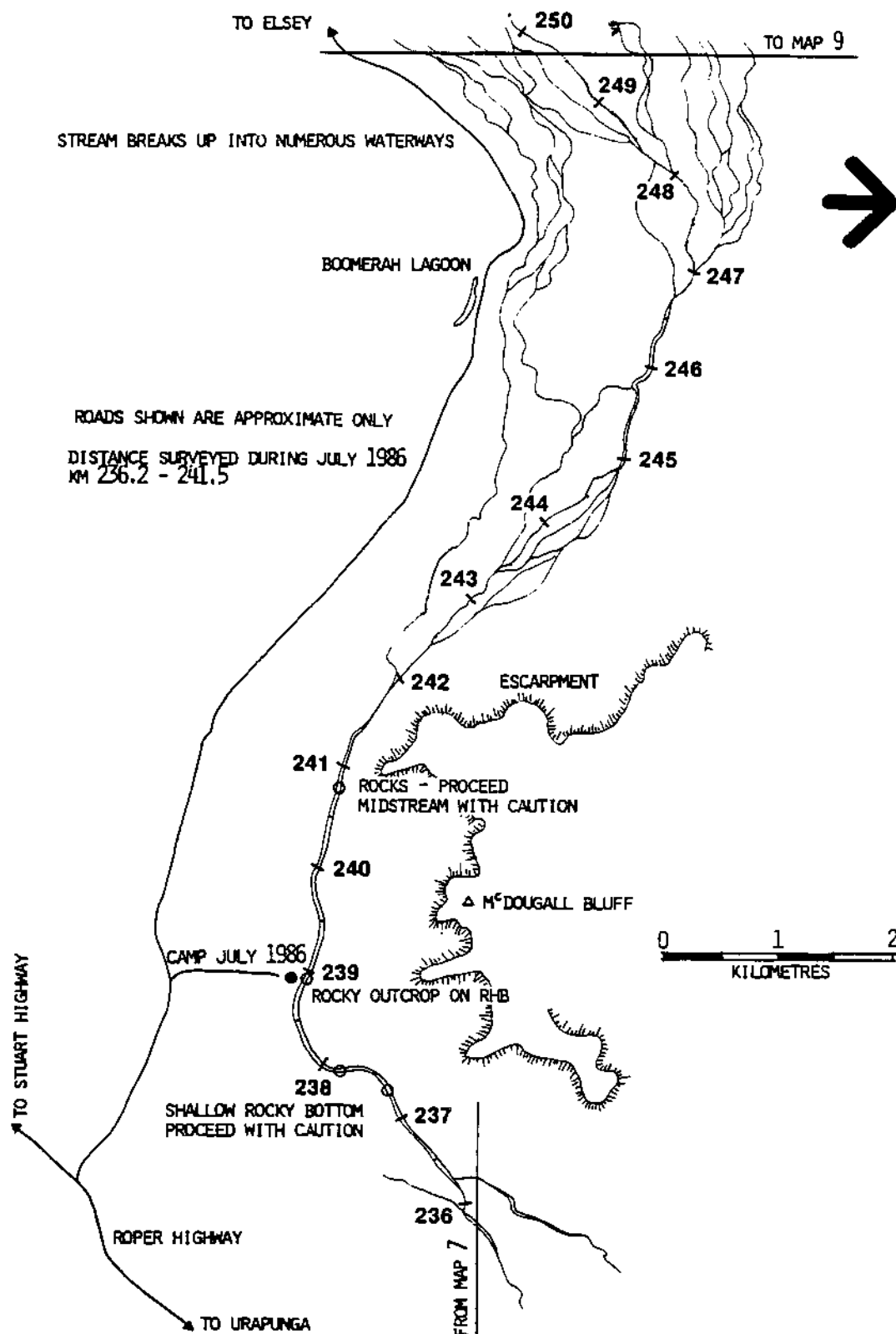


Figure 10. Upstream Roper River 8.



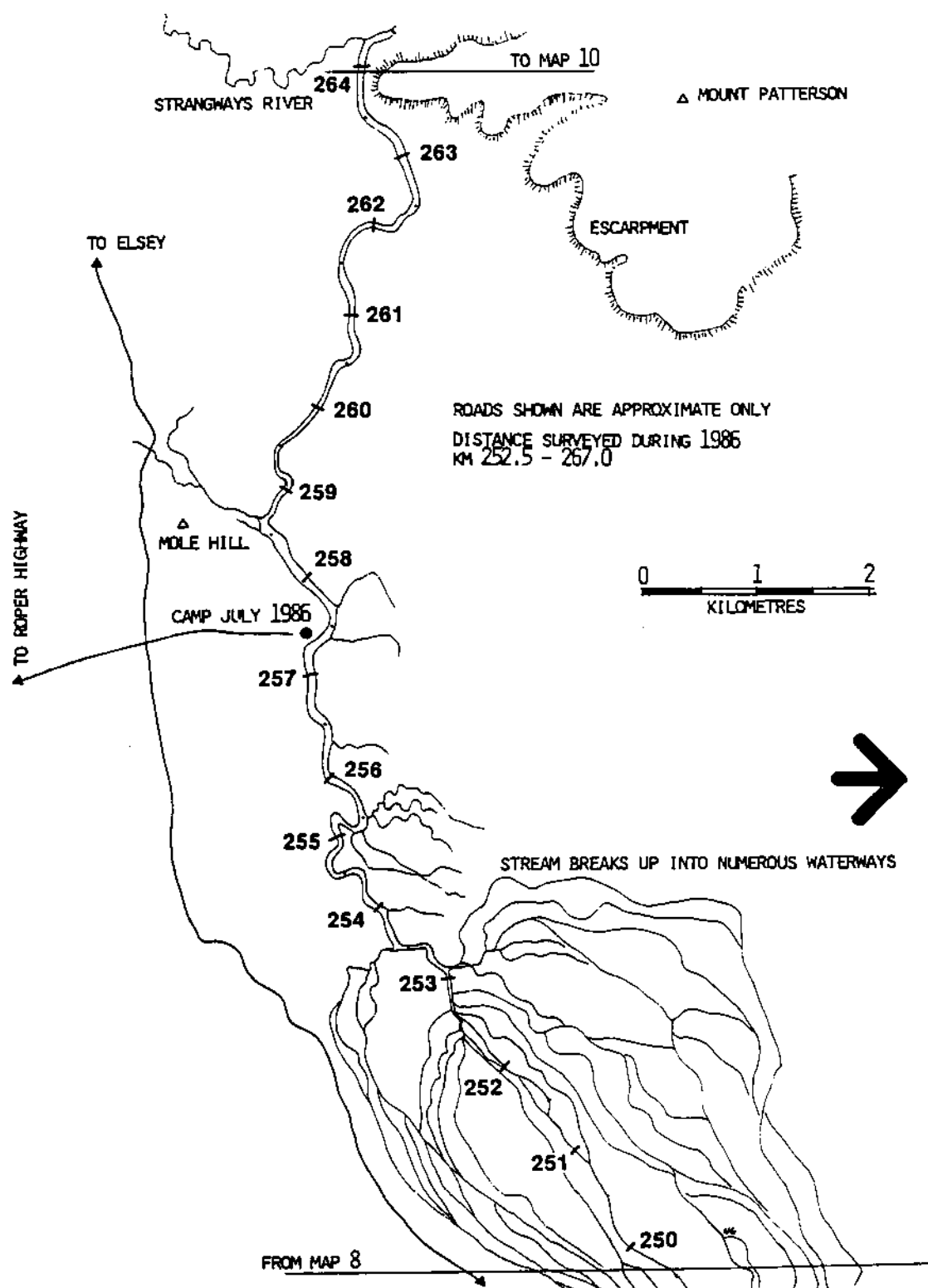


Figure 11. Upstream Roper River 9.

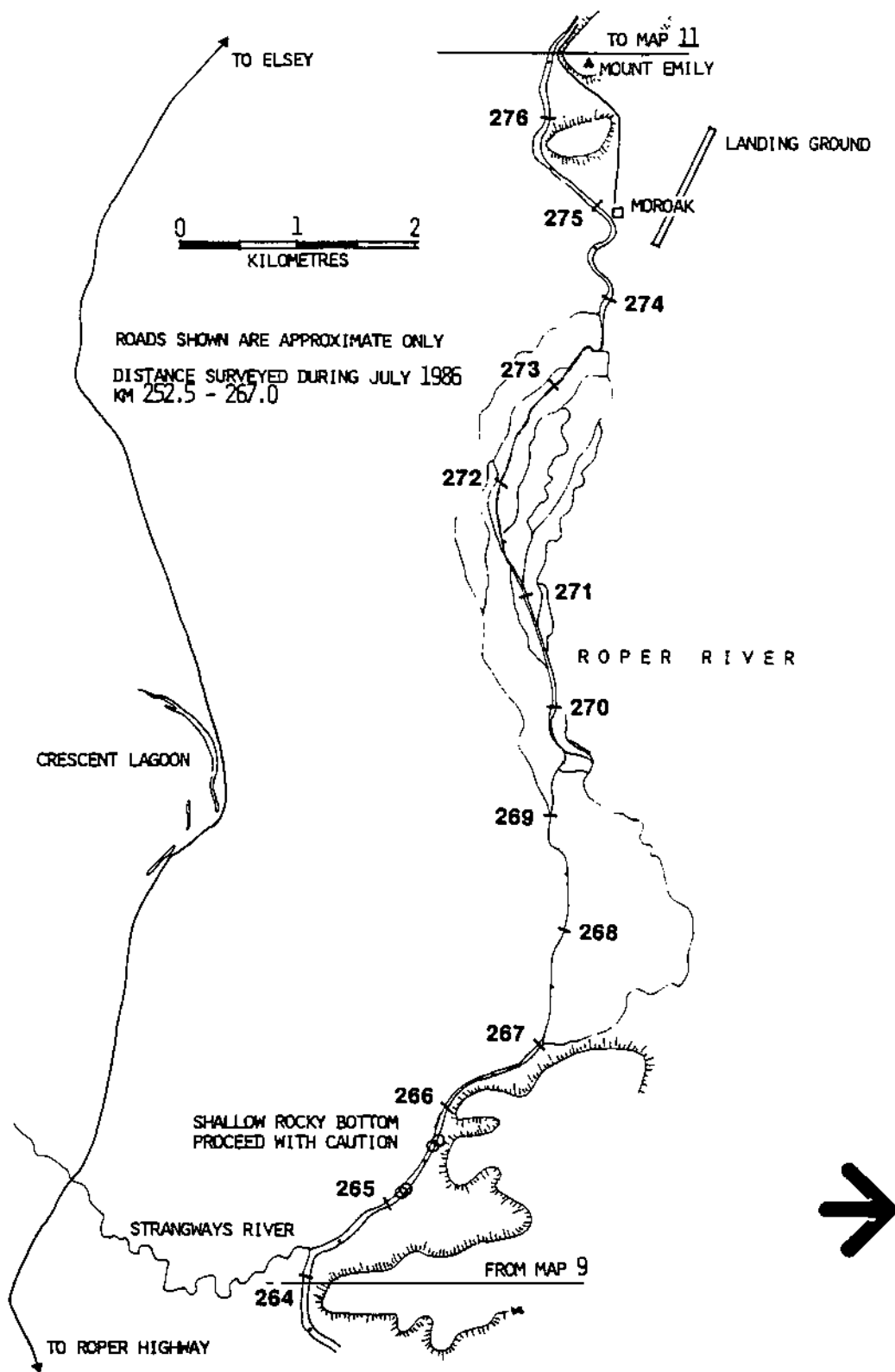


Figure 12. Upstream Roper River 10.

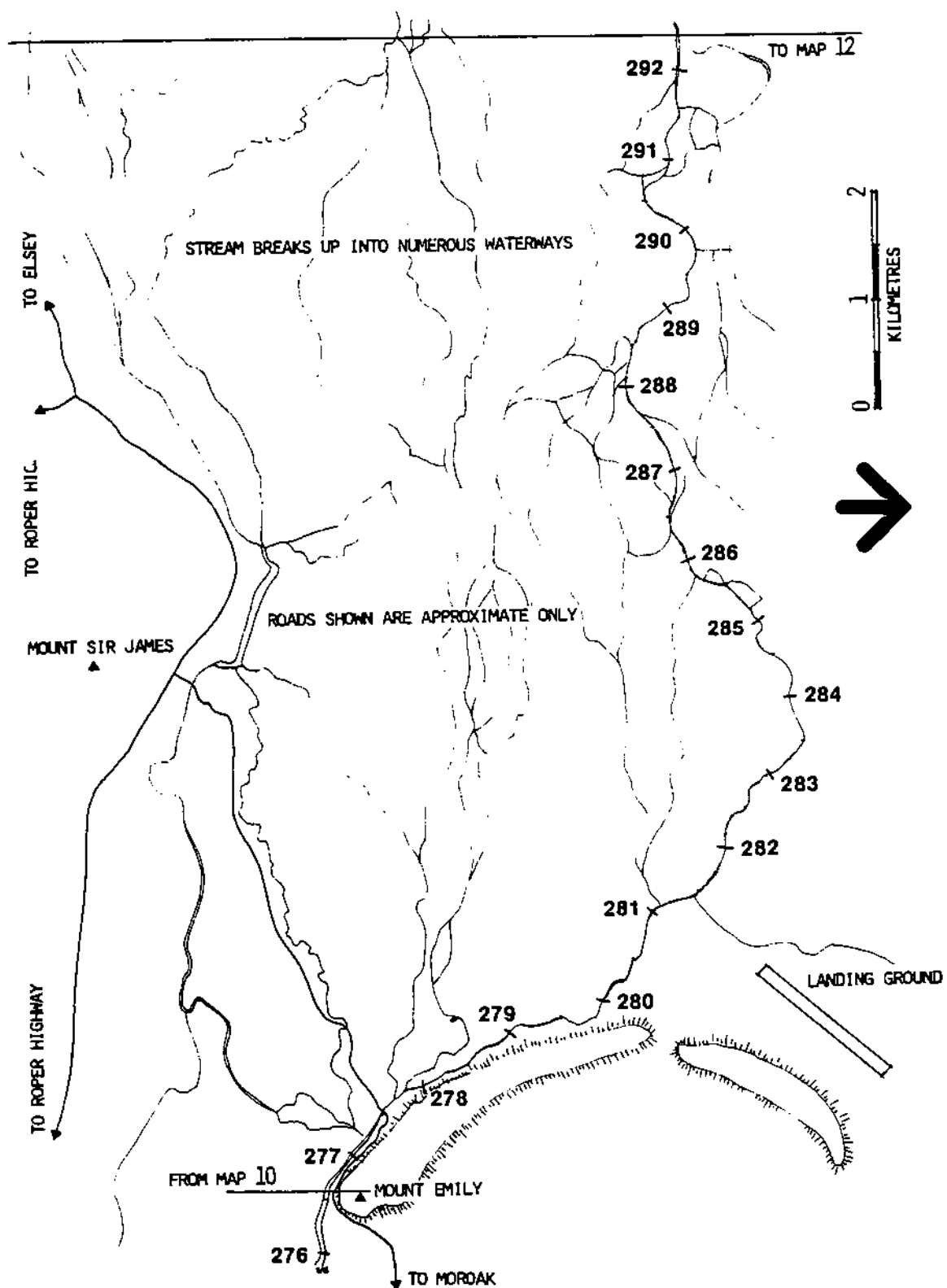


Figure 13. Upstream Roper River 11.

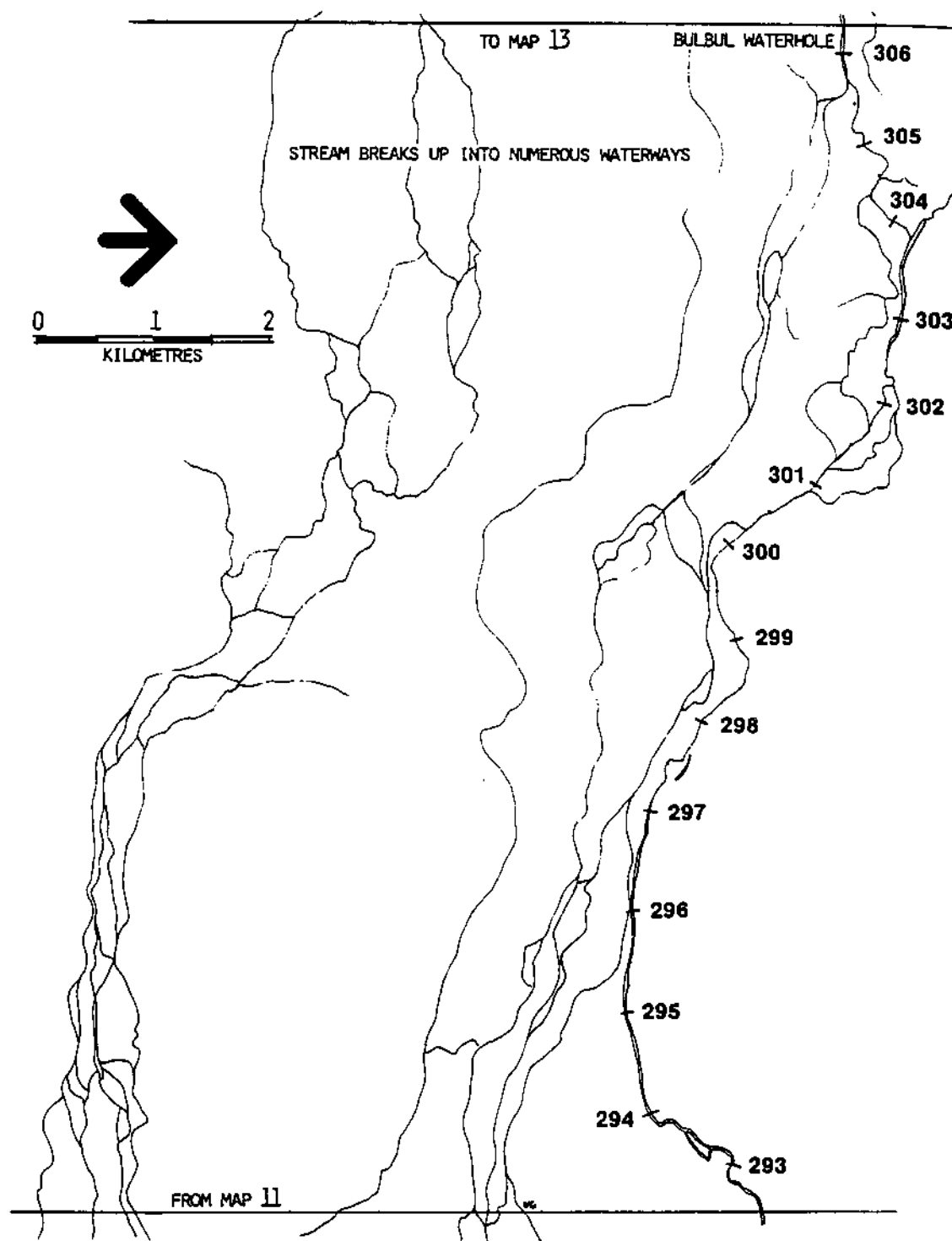


Figure 14. Upstream Roper River 12.

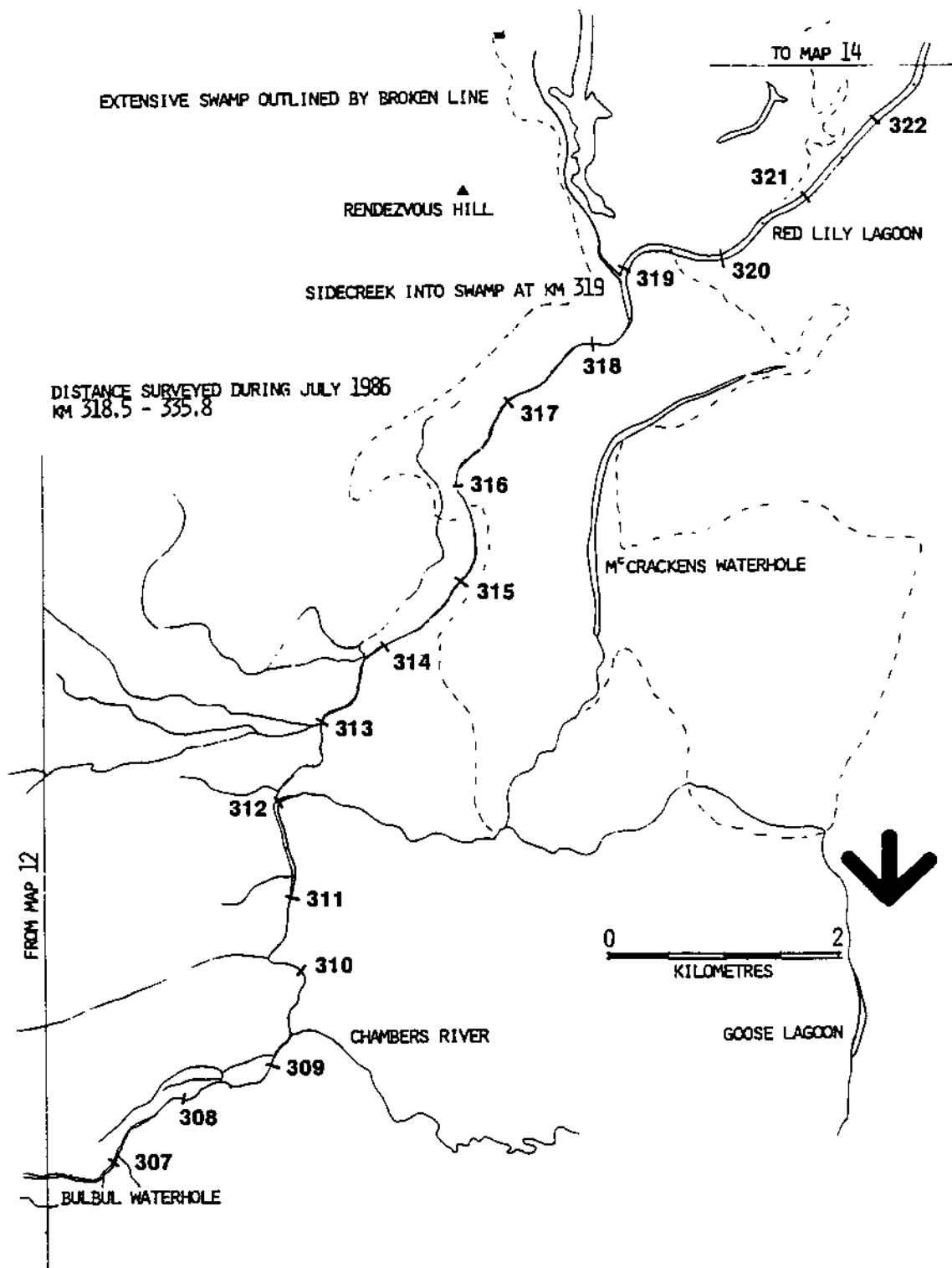


Figure 15. Upstream Roper River 13.

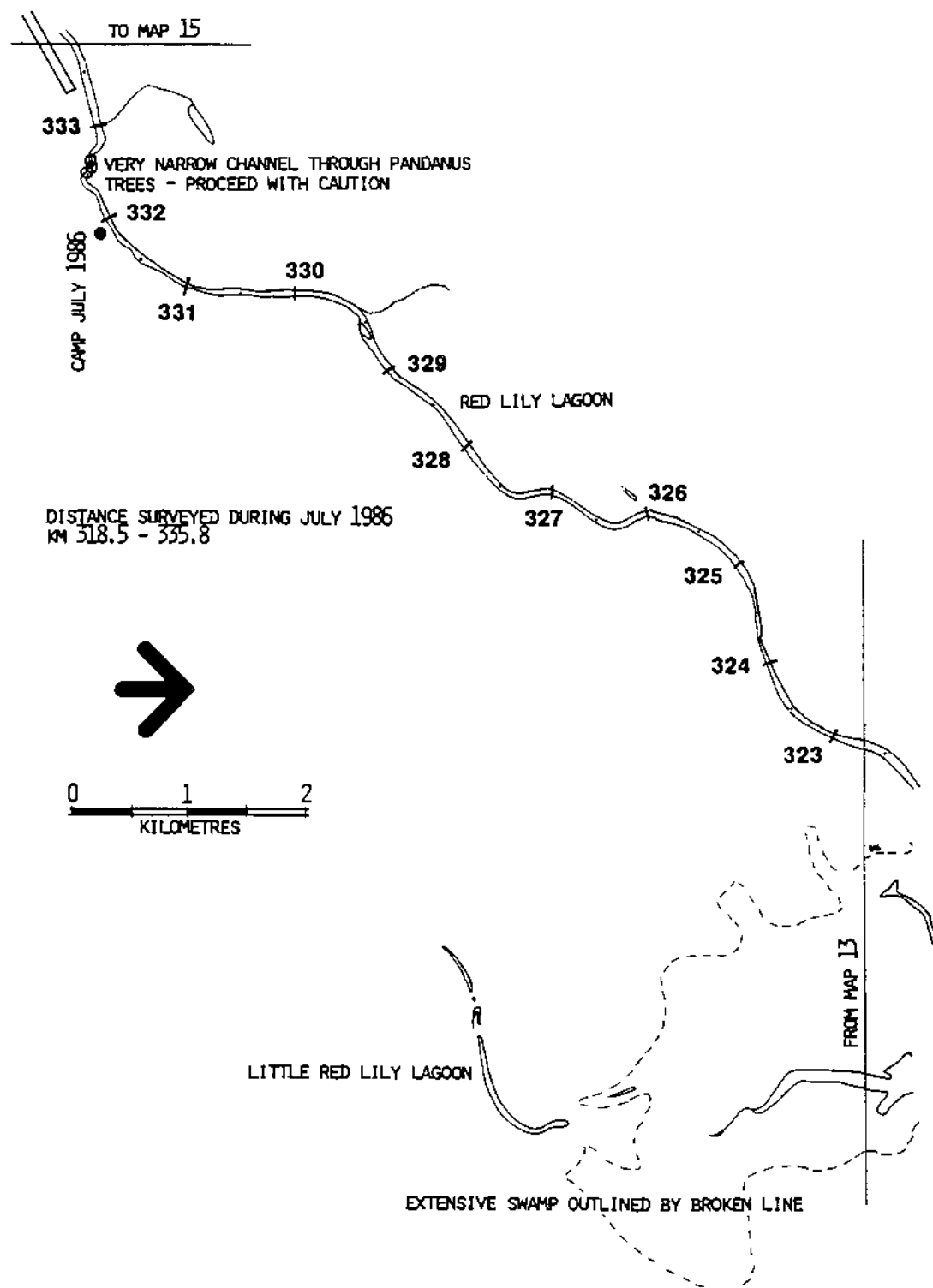


Figure 16. Upstream Roper River 14.

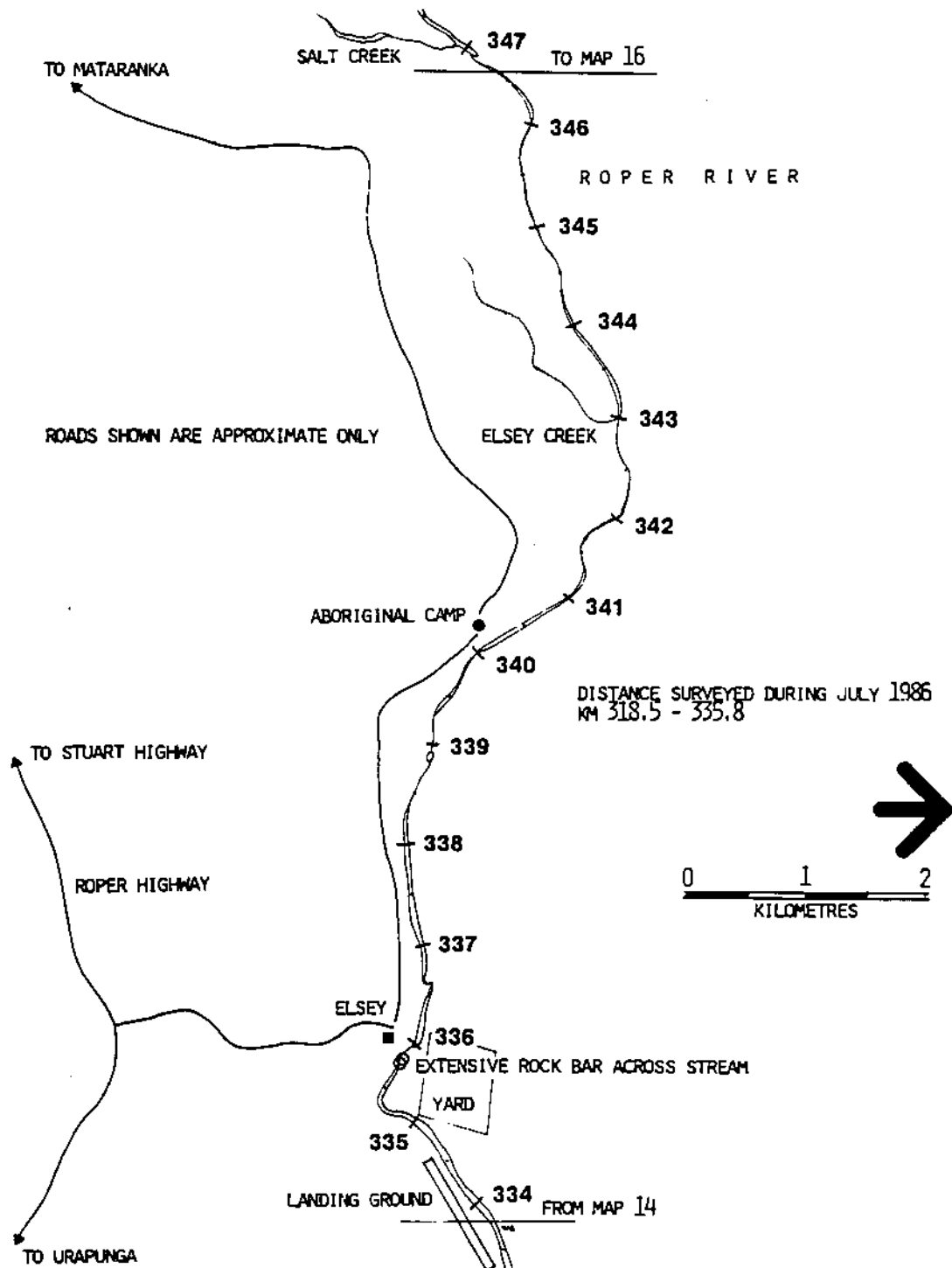


Figure 17. Upstream Roper River 15.

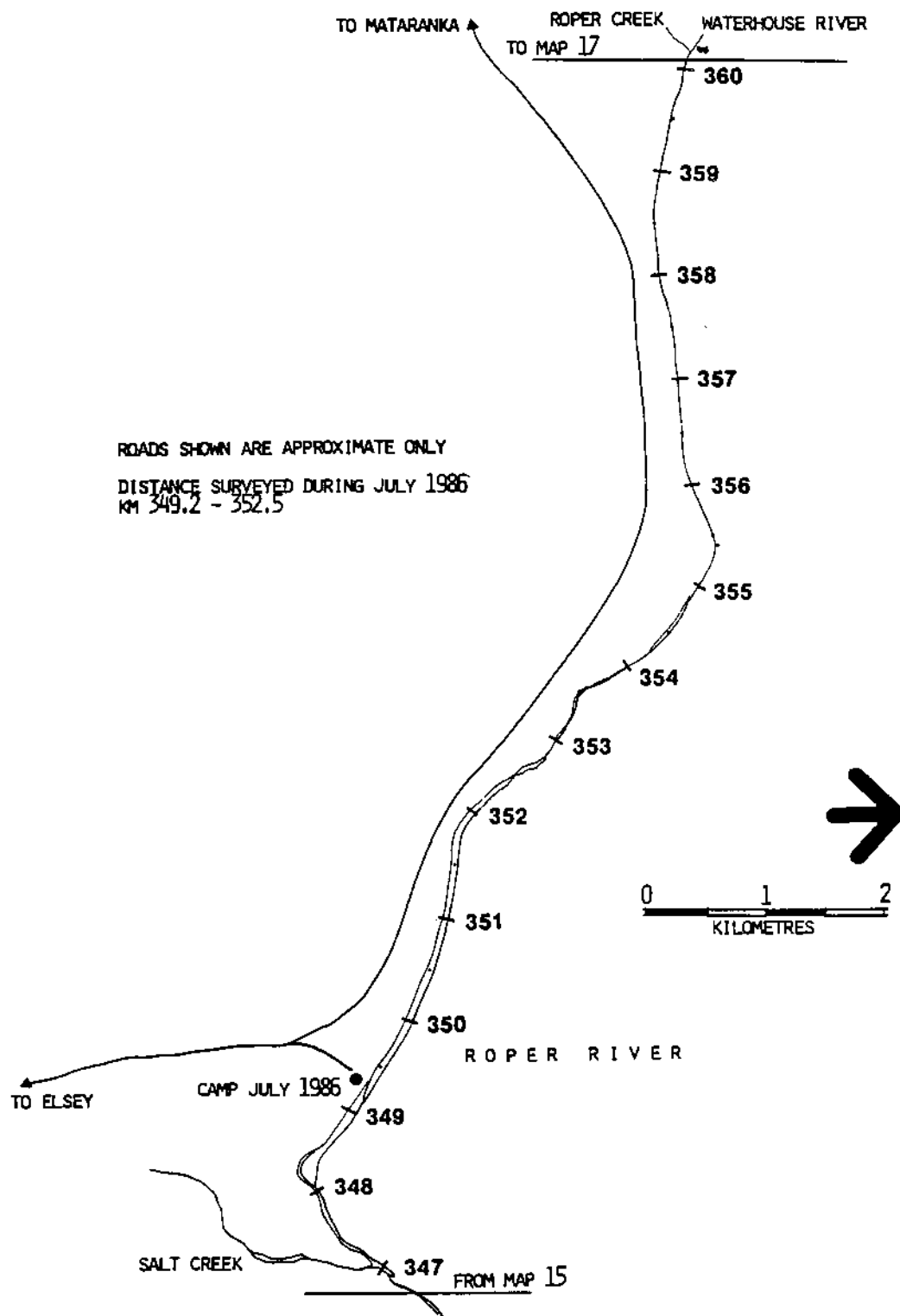


Figure 18. Upstream Roper River 16.



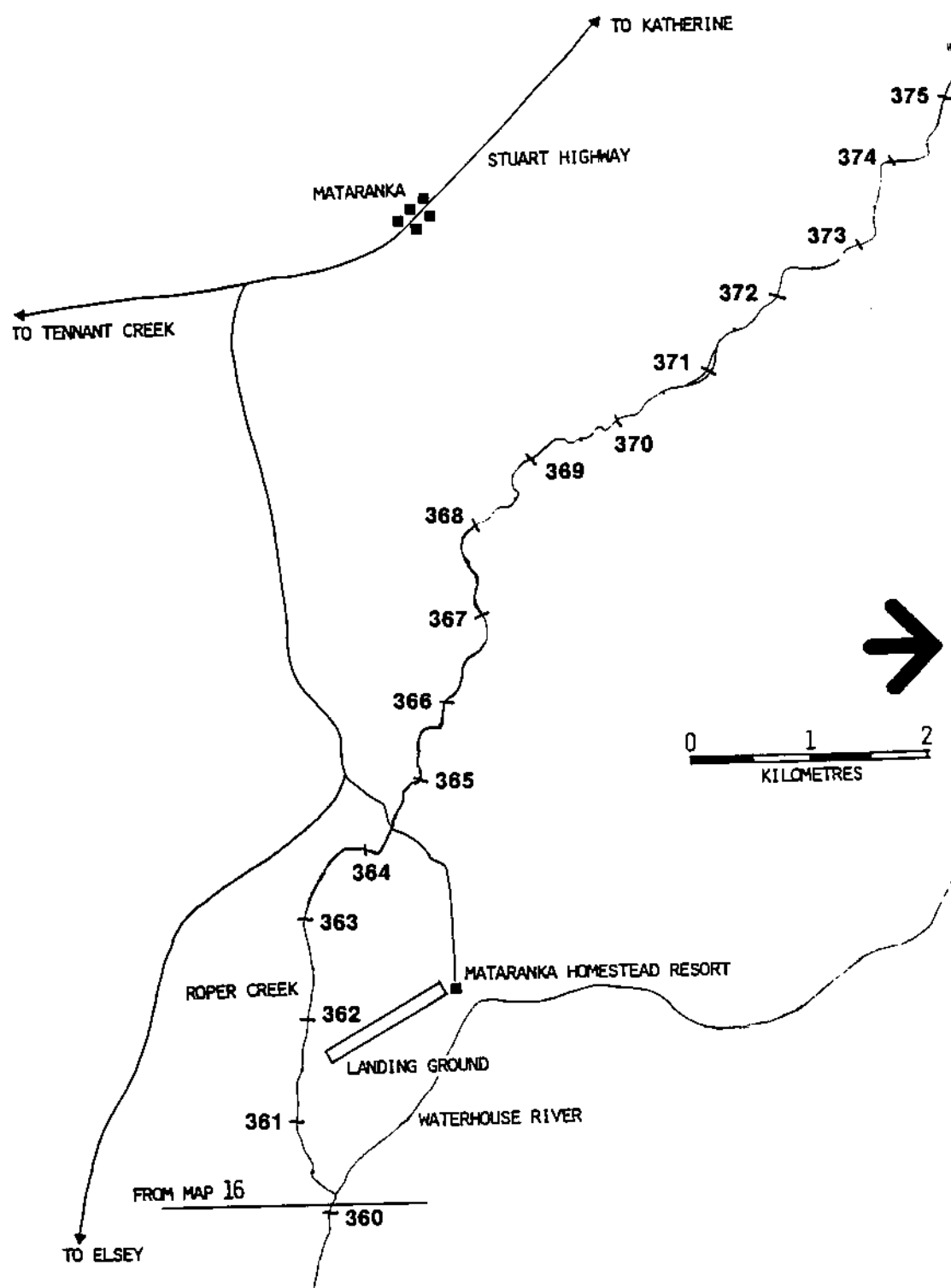


Figure 19. Upstream Roper River 17.



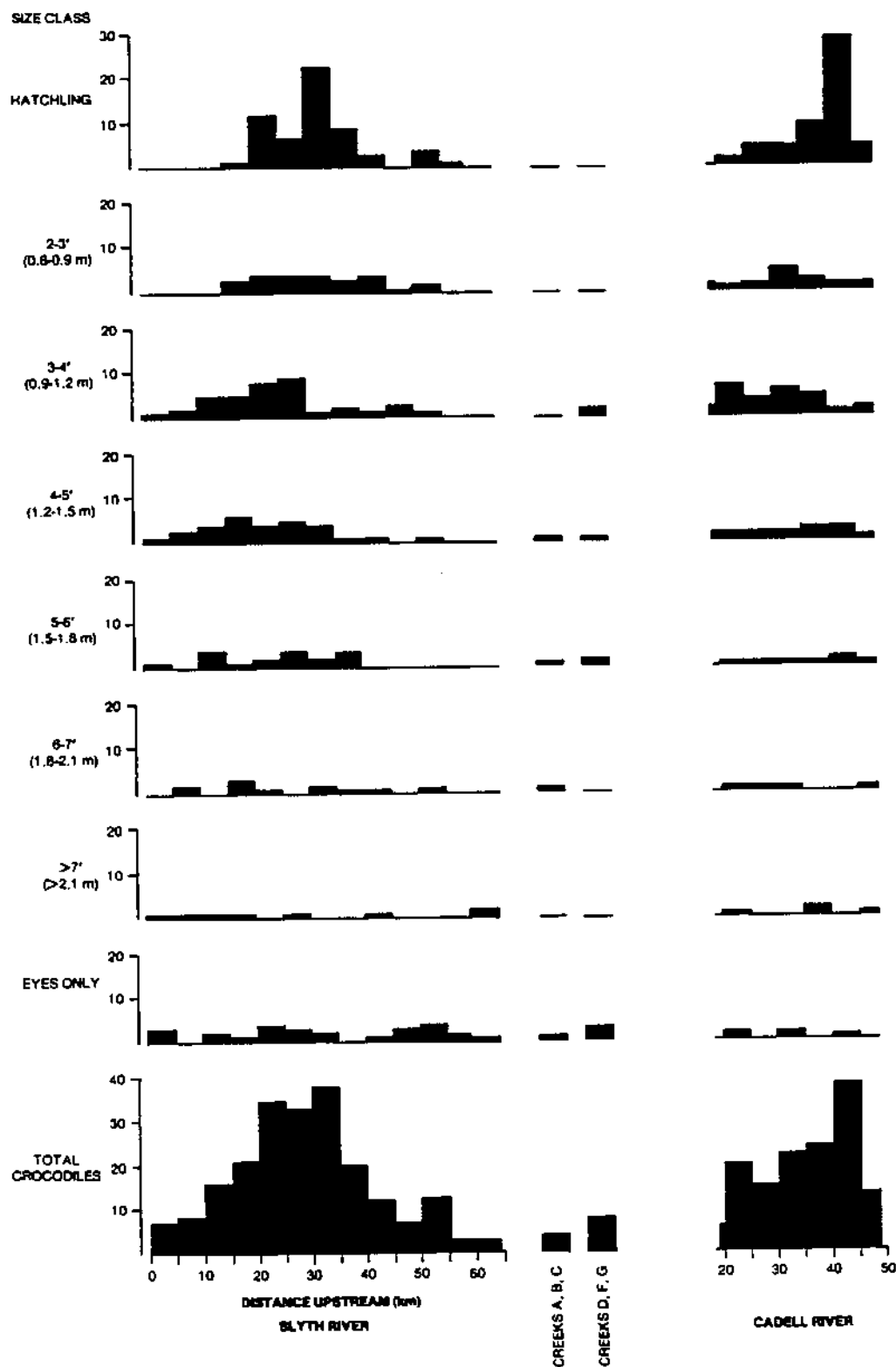


Figure 21. Distributional pattern of *Crocodylus porosus* in the Blyth-Cadell Rivers System during 6-8 November 1982 (from p. 176 Monograph 18).

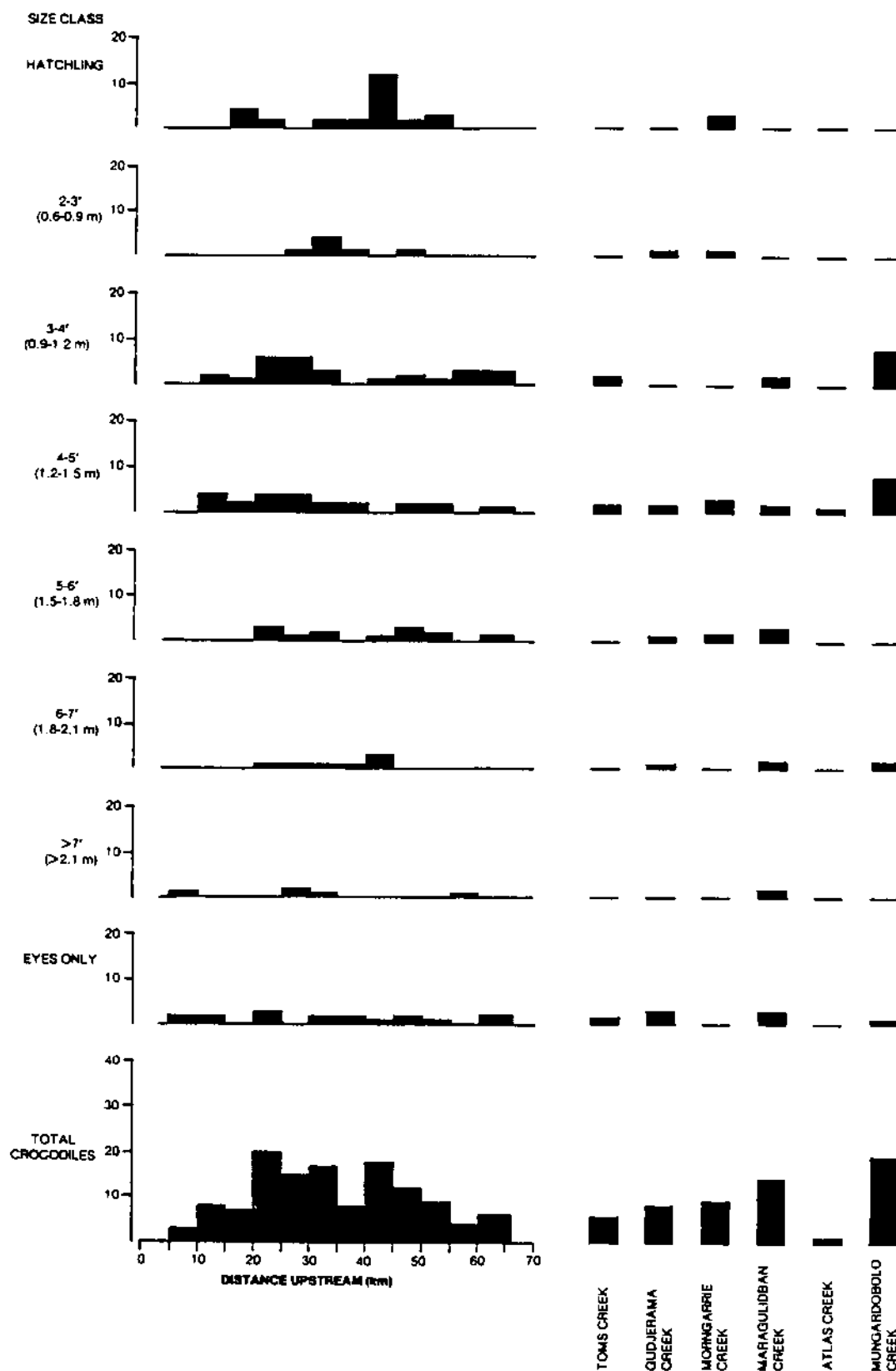


Figure 22. Distributional pattern of *Crocodylus porosus* on the Liverpool River and its creeks in July 1983 (from p. 286 Monograph 18); the distance scale has been corrected here as it was shown incorrectly in Monograph 18.

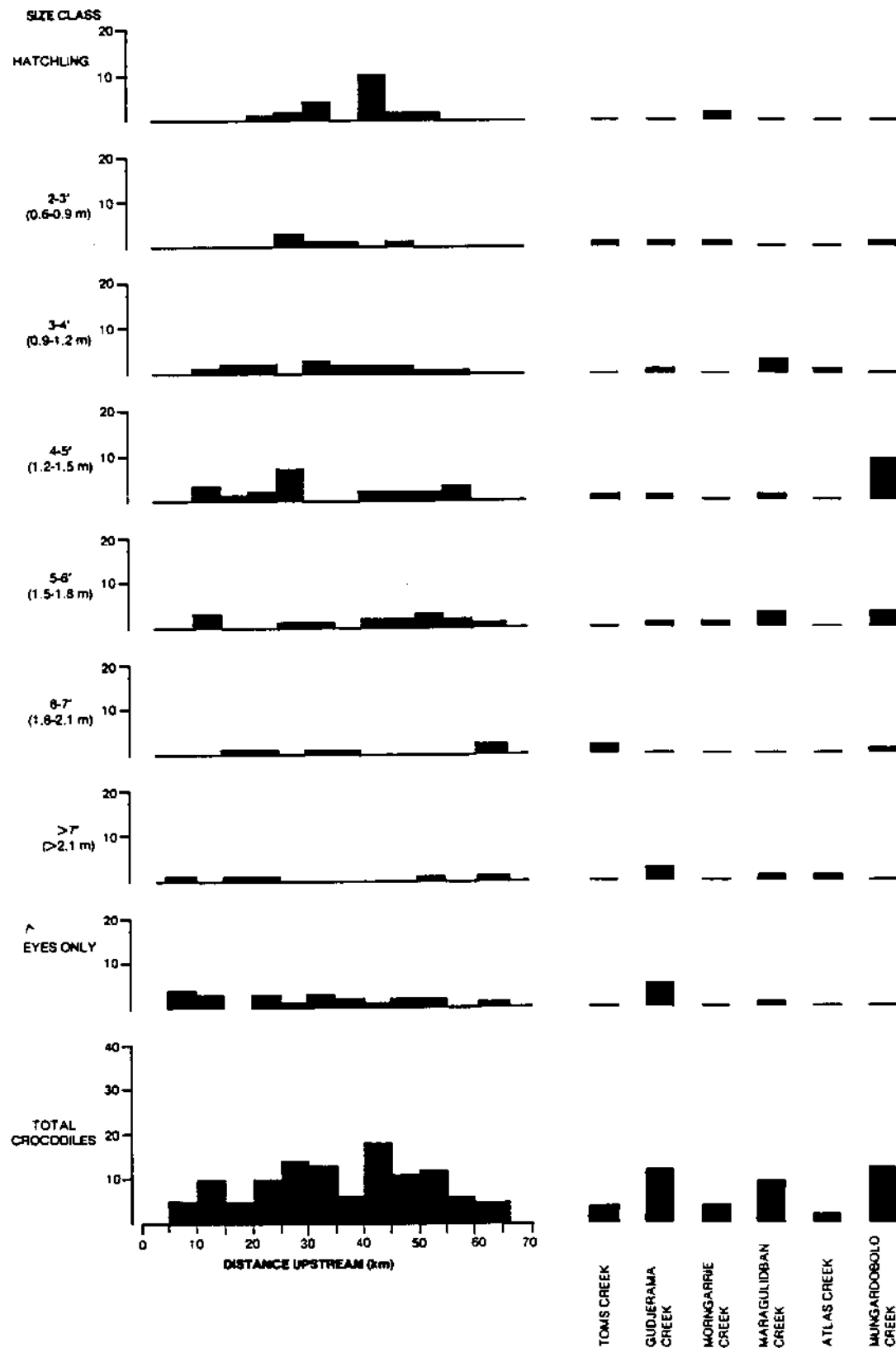


Figure 23. Distributional pattern of *Crocodylus porosus* on the Liverpool River and its creeks in October 1983 (from p. 287 Monograph 18).

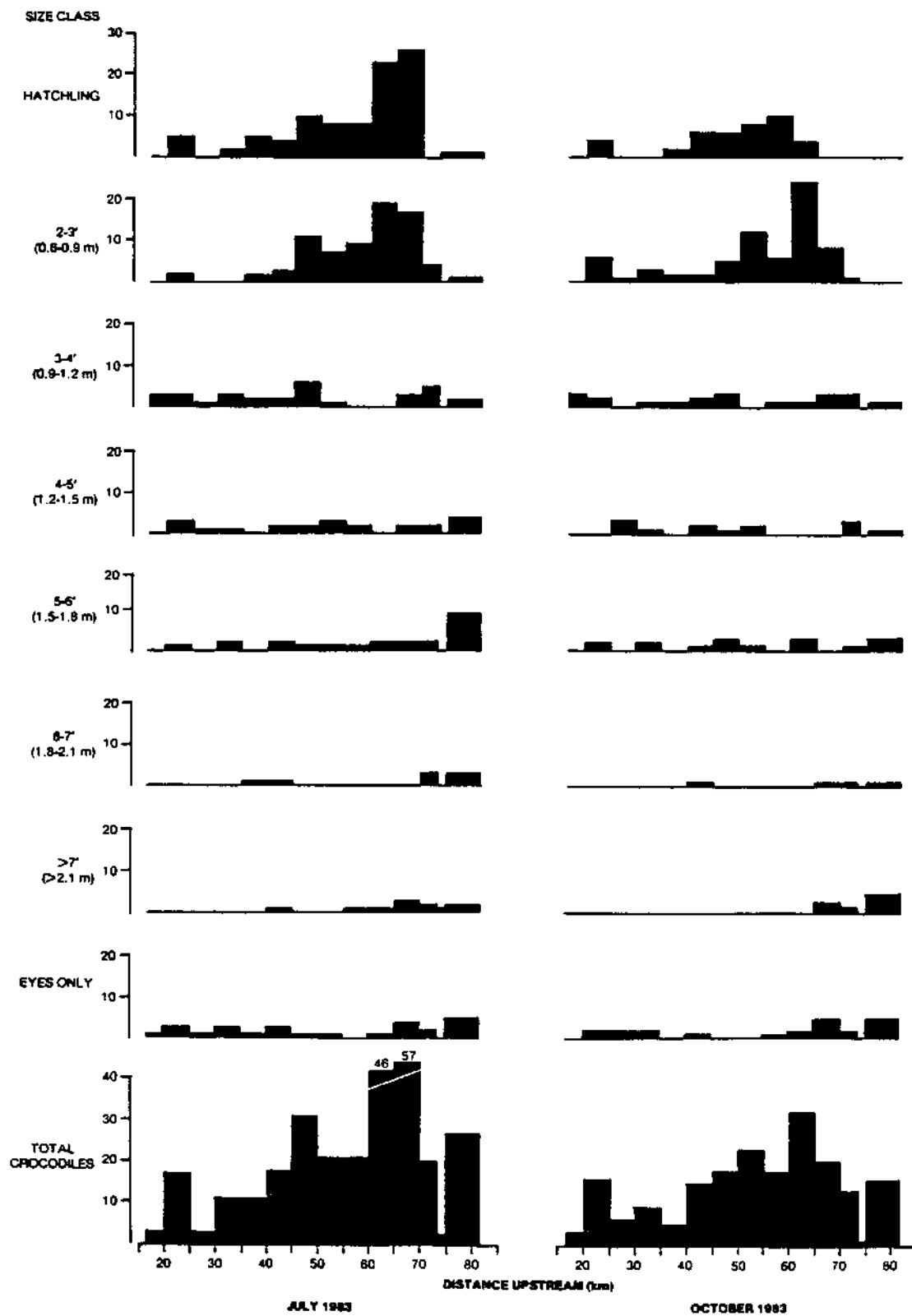


Figure 24. Distributional pattern of *Crocodylus porosus* on the Tomkinson River in July and October 1983 (from p. 288 Monograph 18).

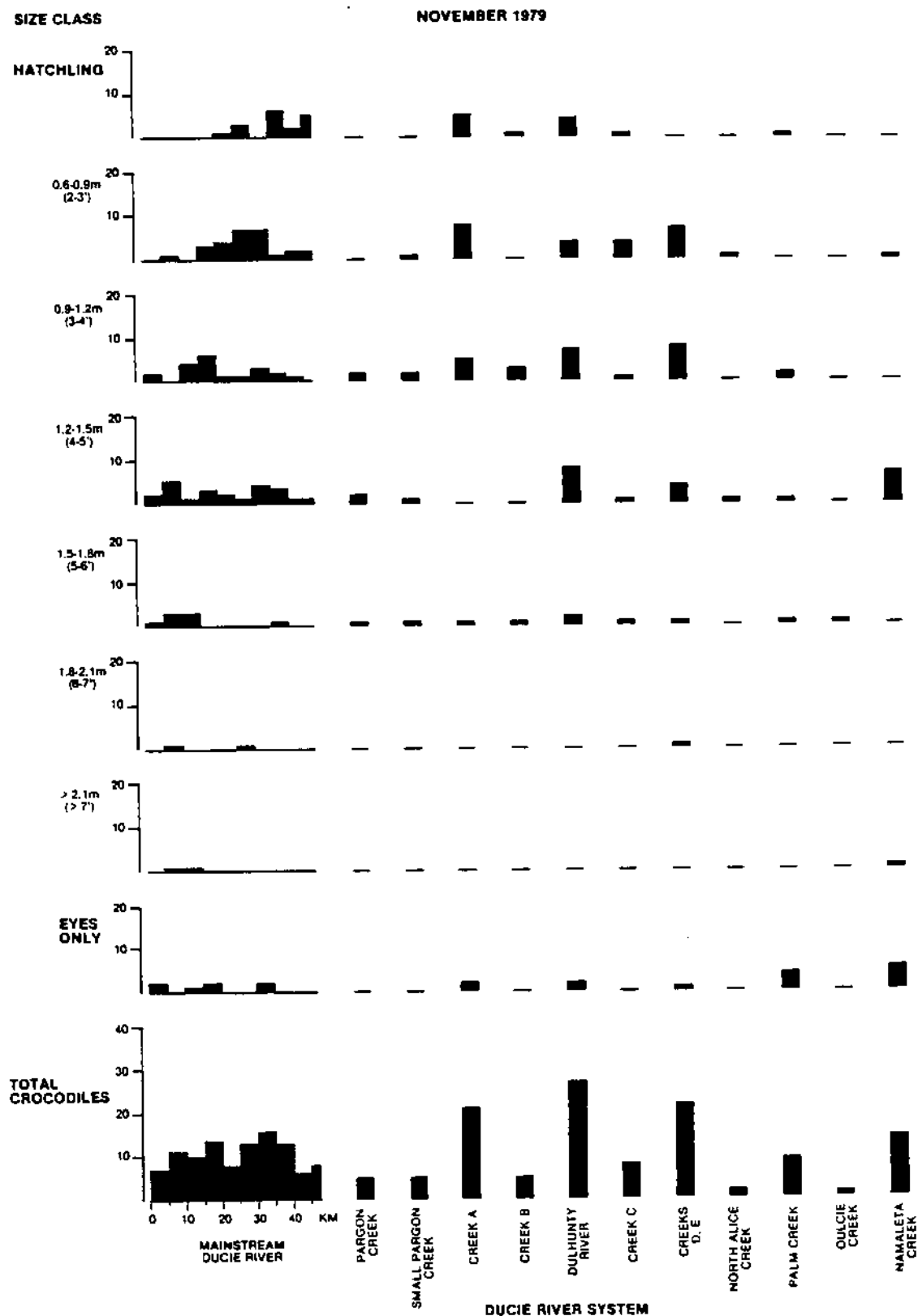


Figure 25. Distributional pattern of *Crocodylus porosus* on the Ducie River System and Palm, Dulcie, and Namaleta Creeks in Port Musgrave in November 1979 (from p. 90 Monograph 16).

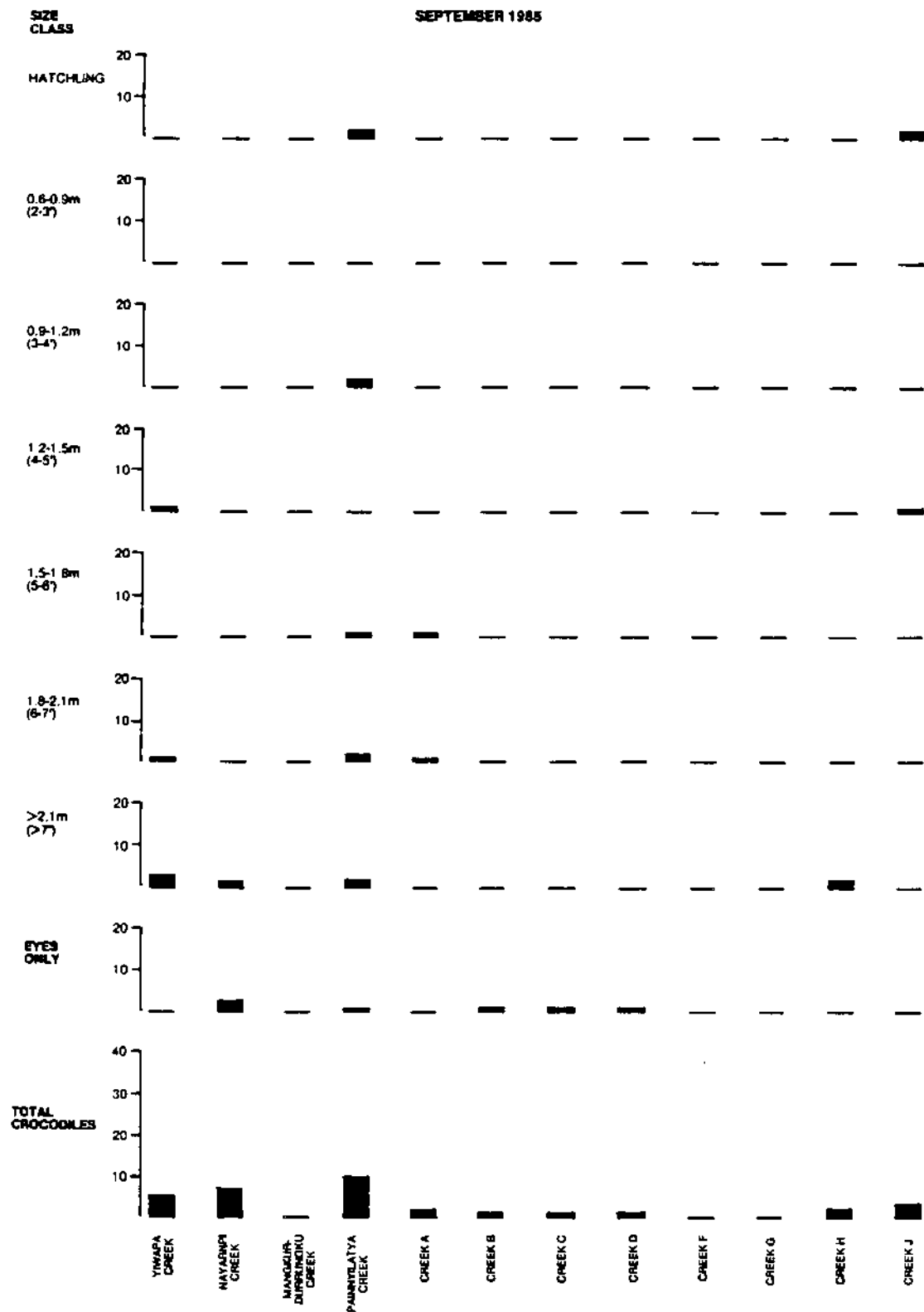


Figure 26. Distributional pattern of *Crocodylus porosus* on the coastal saltwater creeks and on the small creeks of the Roper River mainstream, downstream of km 25.0, in September 1985 (from p. 117 Monograph 19).



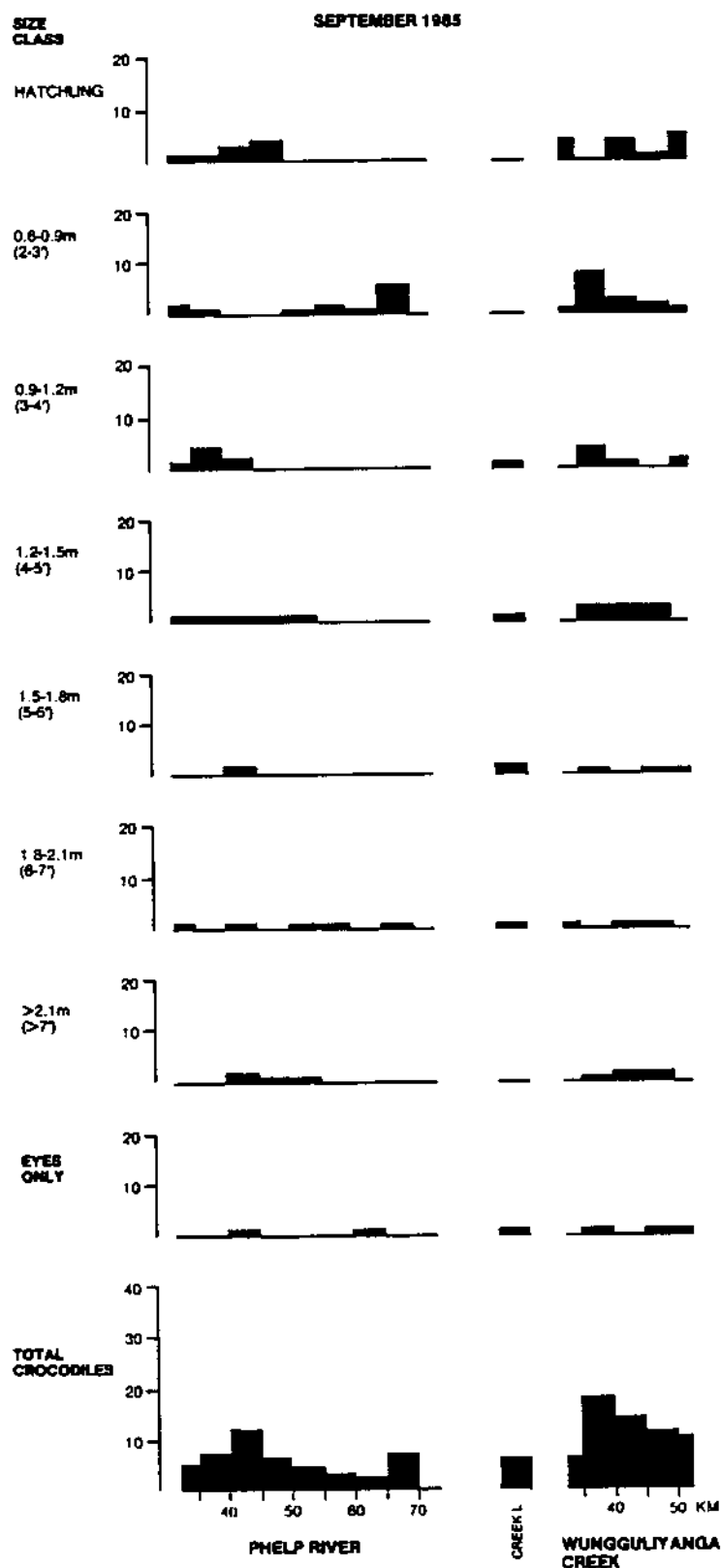


Figure 27. Distributional pattern of *Crocodylus porosus* on the Phelp River and Wungguliyanga Creek in September 1985 (from p. 118 Monograph 19).

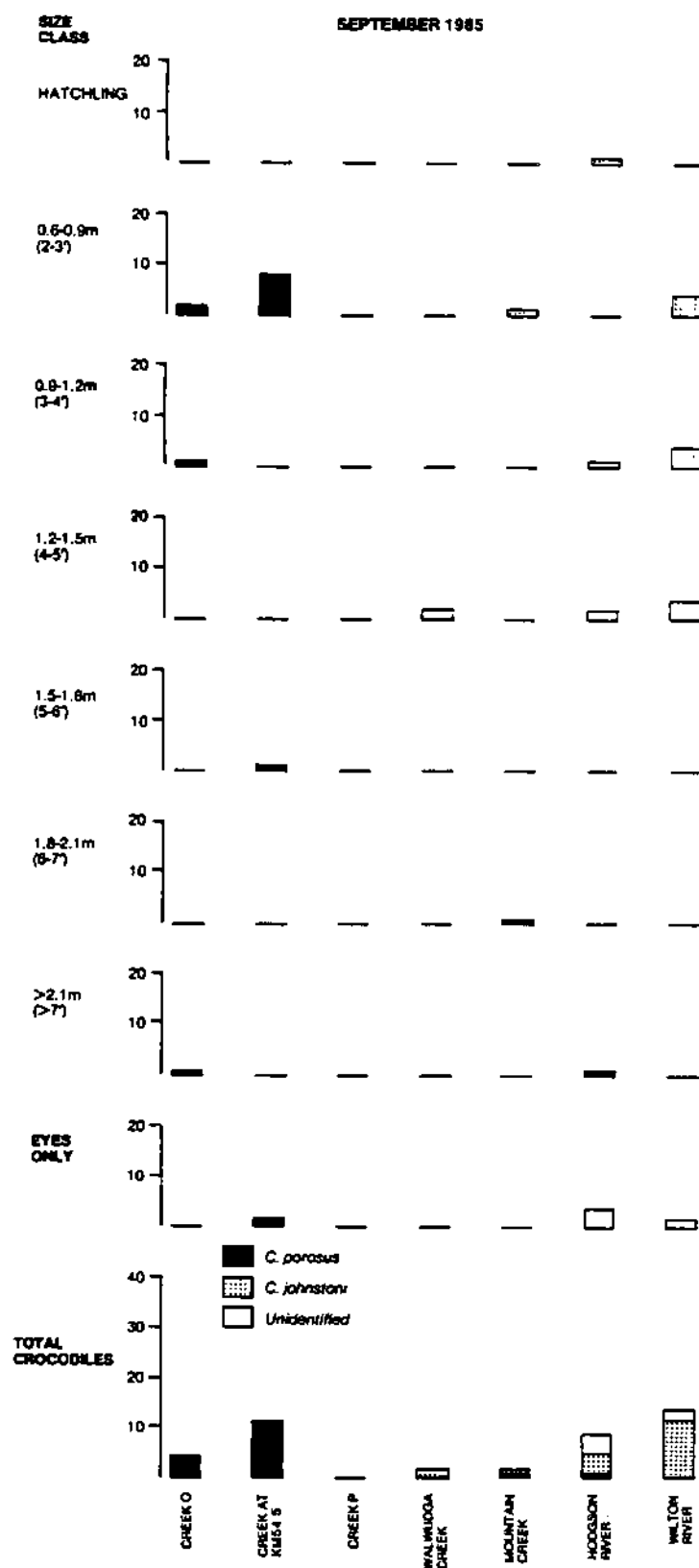


Figure 28. Distributional pattern of *Crocodylus porosus* and *C. johnstoni* on the Wilton and Hodgson Rivers and on the small creeks of the Roper River mainstream, upstream of km 25.0, in September 1985 (from p. 119 Monograph 19).

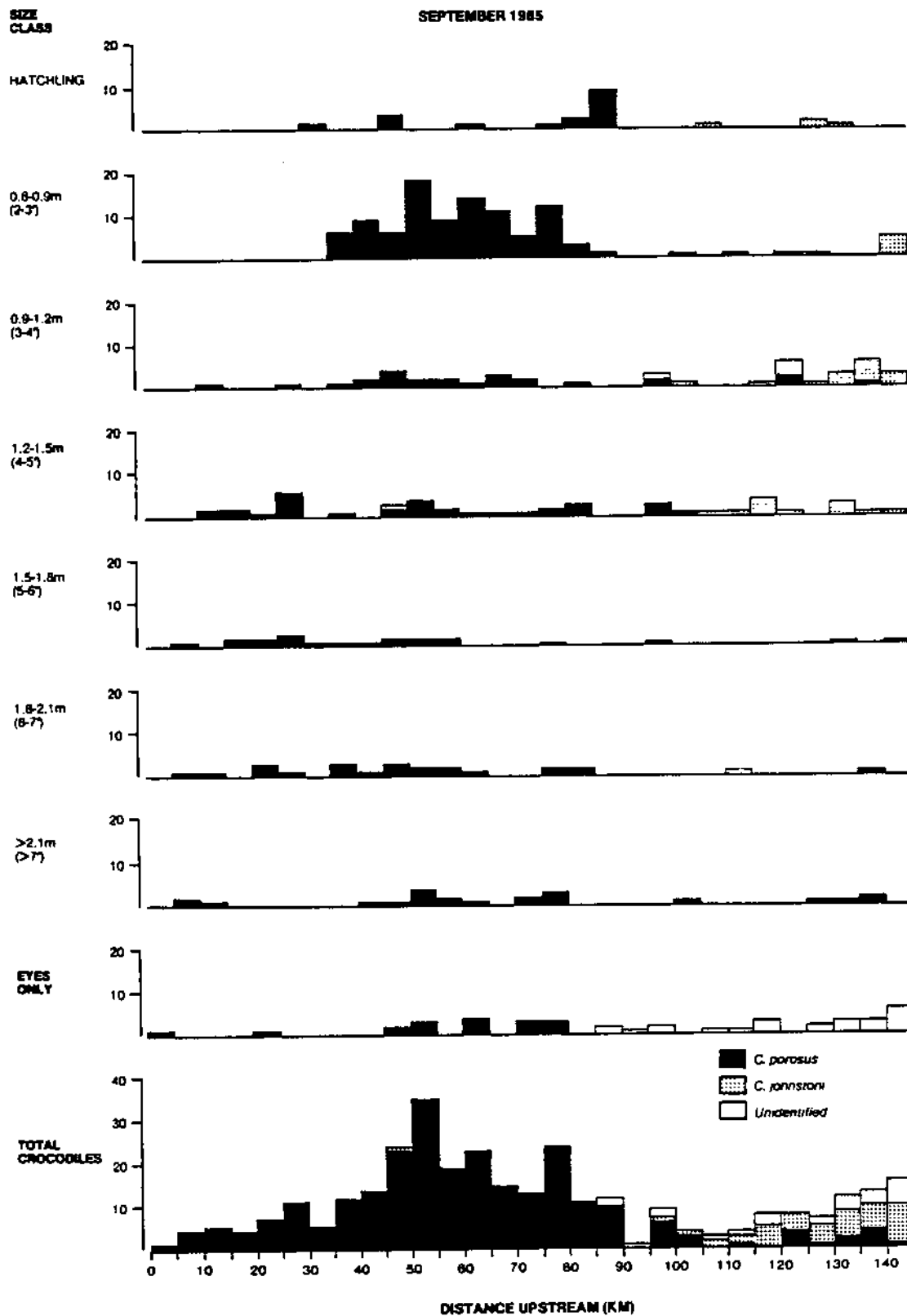


Figure 29. Distributional pattern of *Crocodylus porosus* and *C. johnstoni* on the Roper River mainstream in September 1985 (from p. 116 Monograph 19).

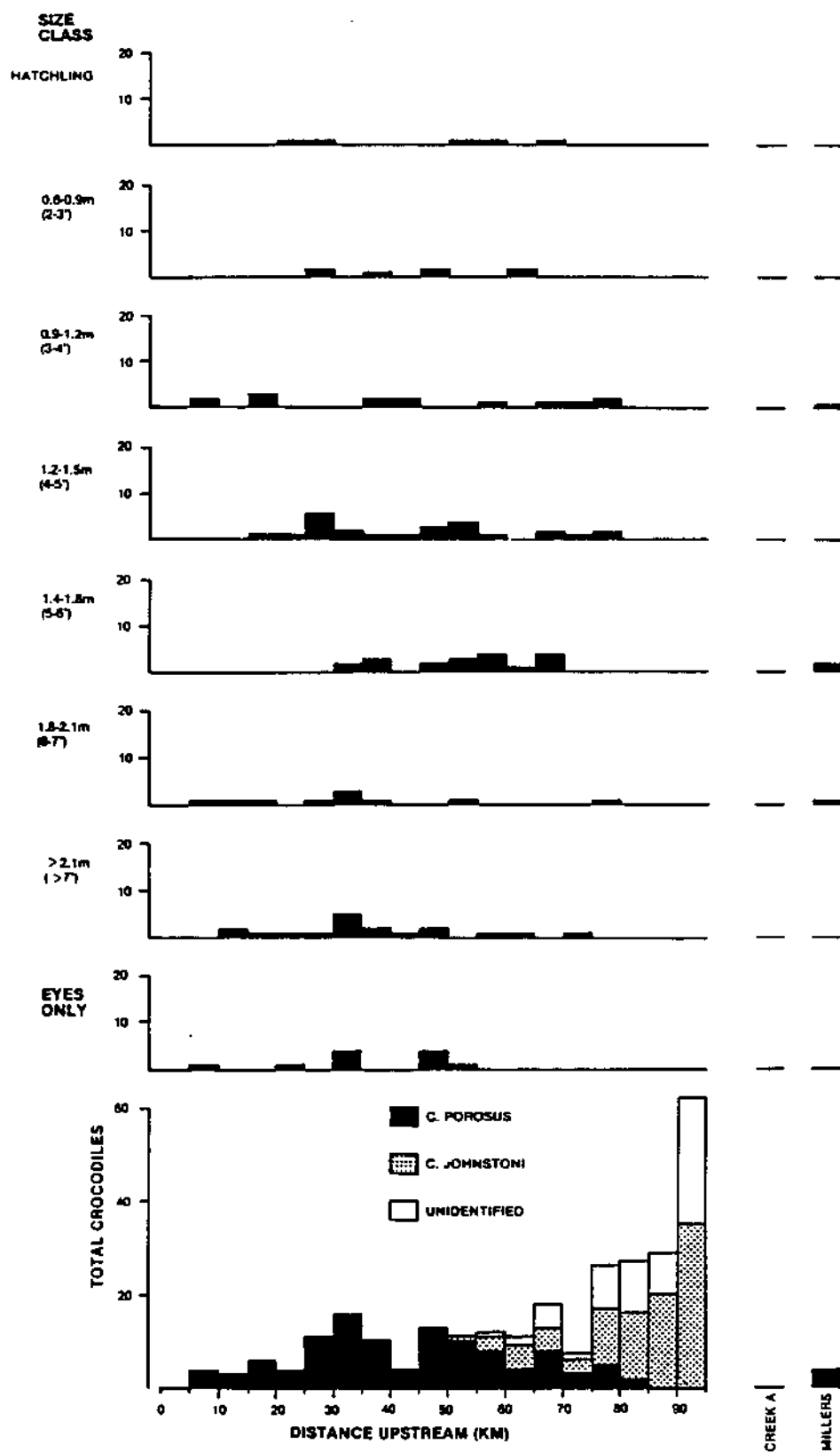


Figure 30. Distributional pattern of crocodiles on the Daly River System in August 1978 (from p. 51 Monograph 3).

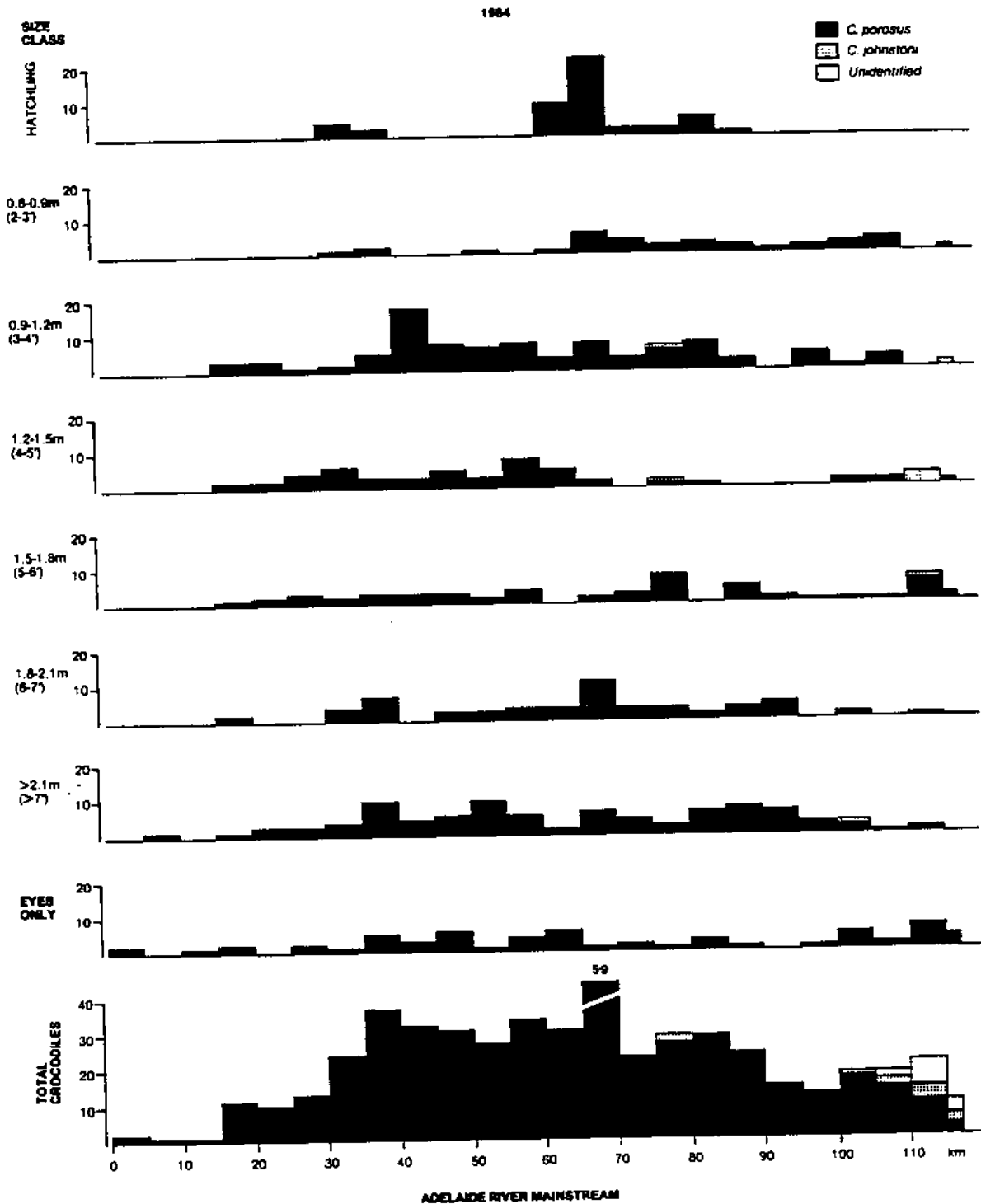


Figure 31. Distributional pattern of crocodiles on the mainstream of the Adelaide River in July 1984 (from p. 98 Monograph 19).

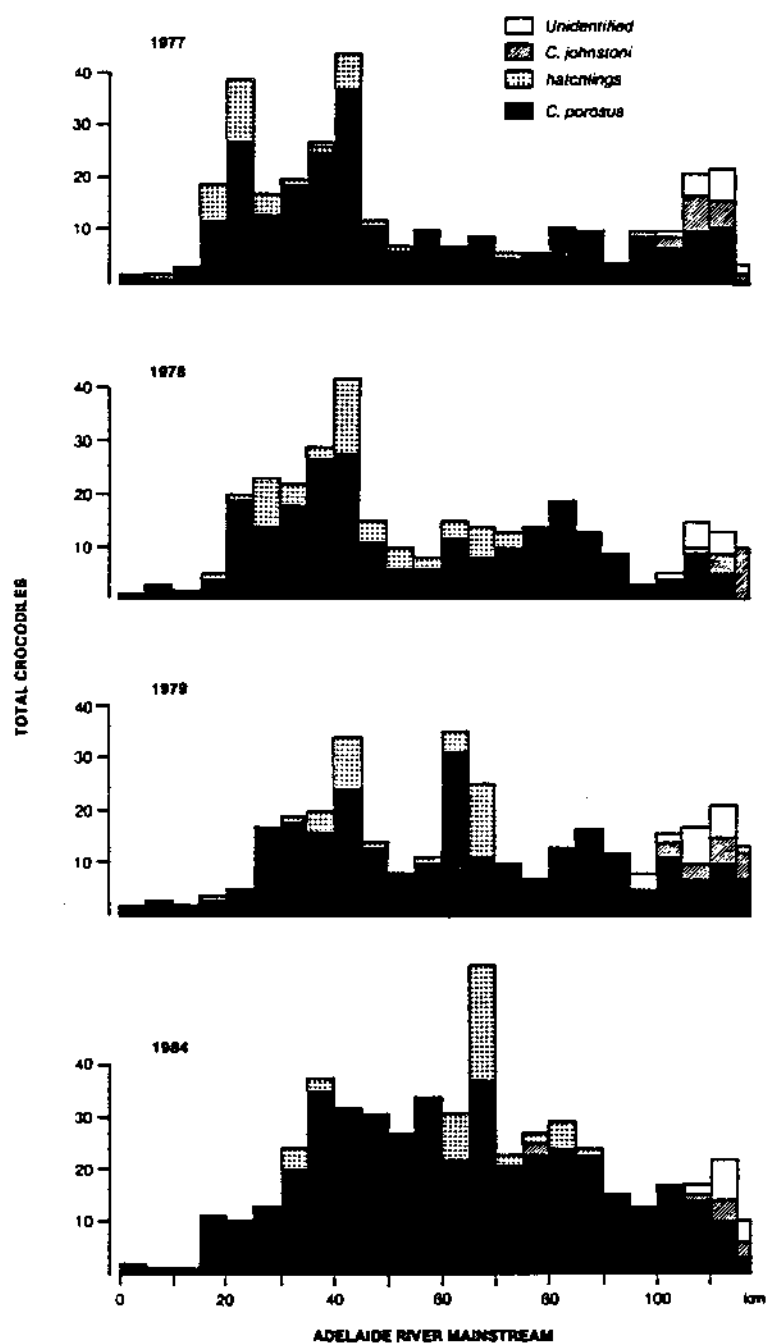


Figure 32. Distributional pattern of *Crocodylus porosus* on the Adelaide in July 1977, September 1978, September 1979, and July 1984 (from p. 100 Monograph 19).

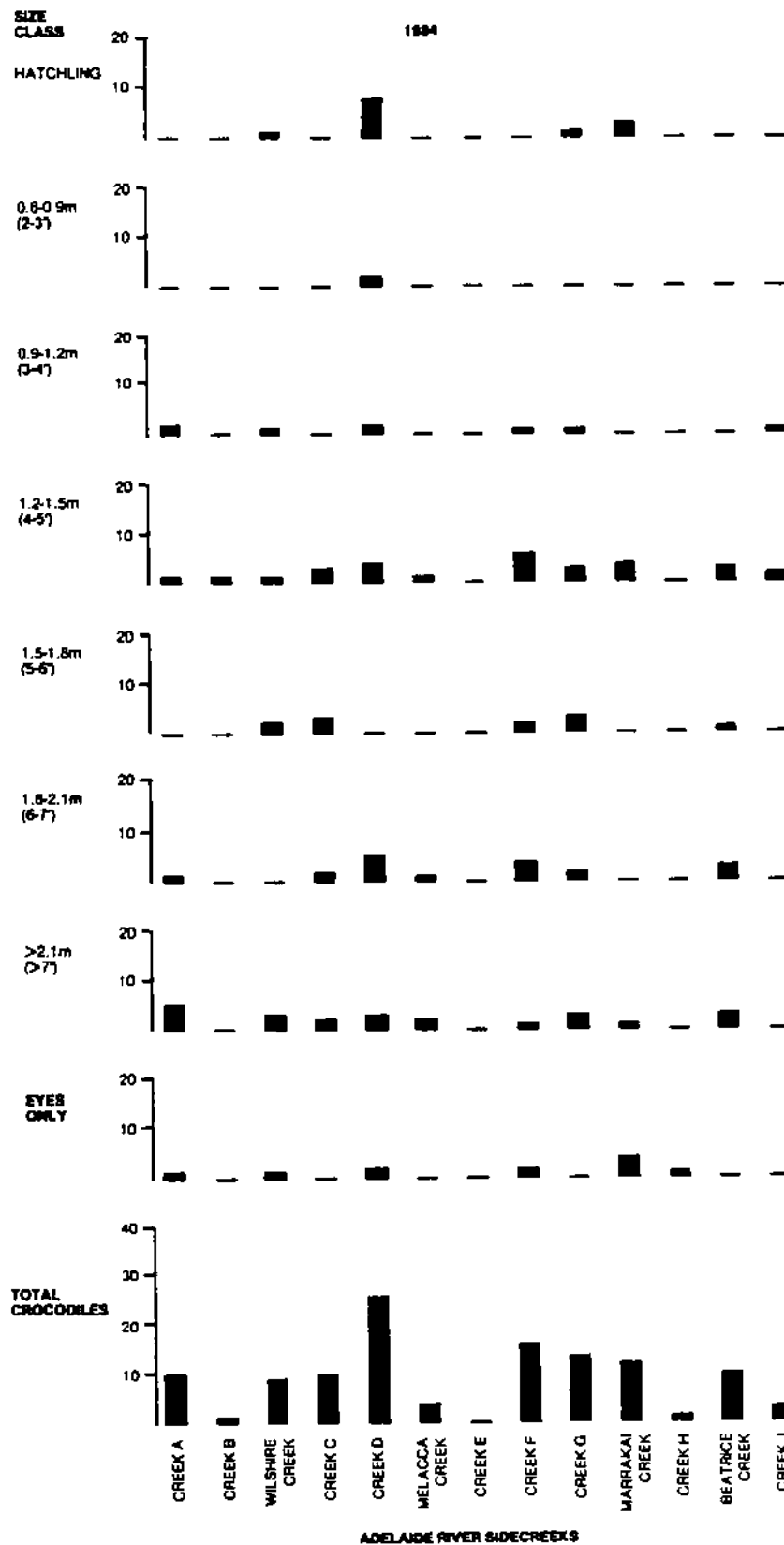


Figure 33. Distributional pattern of *Crocodylus porosus* on the sidecreeks of the Adelaide River in July 1984 (from p. 99 Monograph 19).

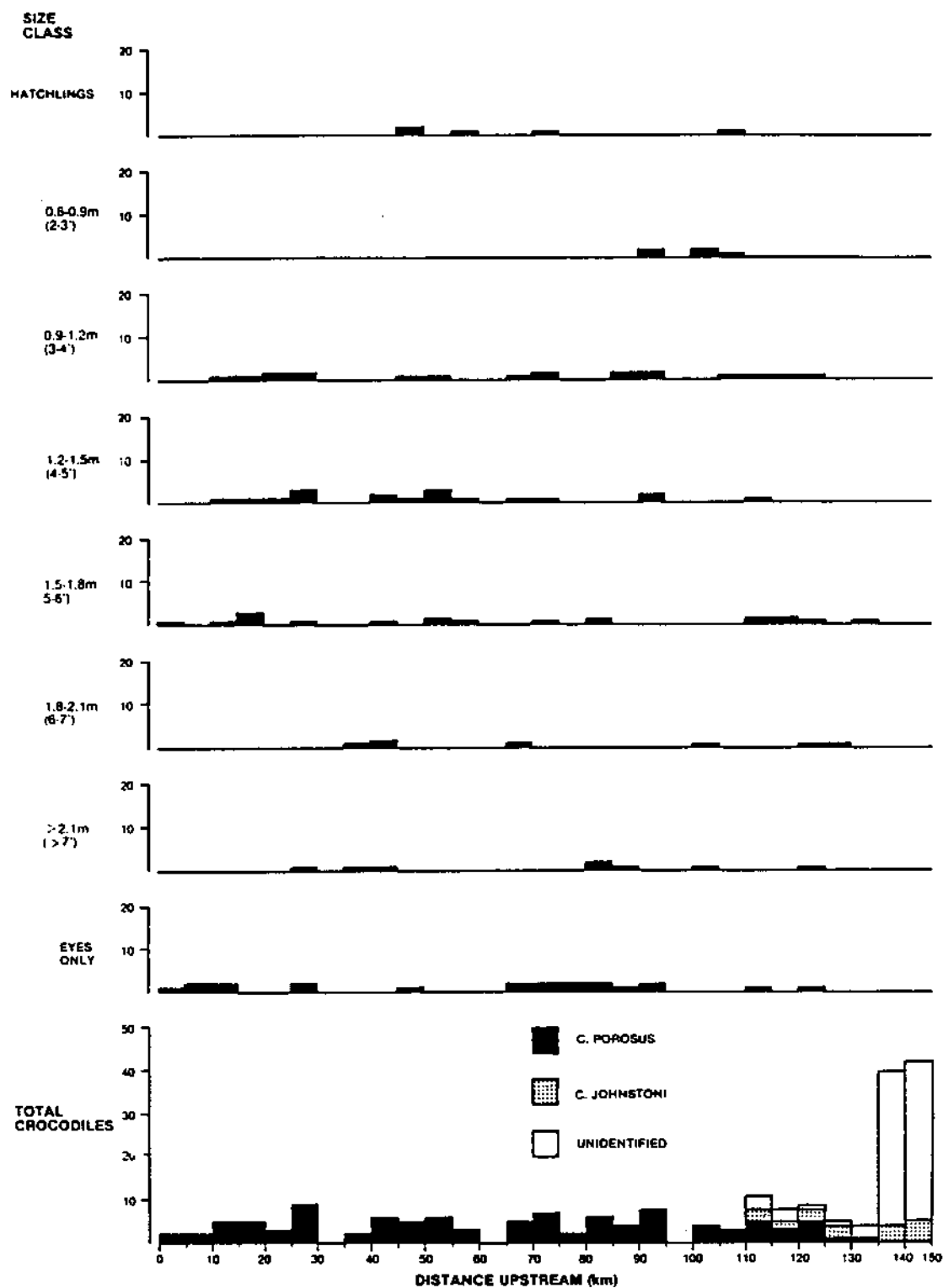


Figure 34. Distributional pattern of crocodiles on the mainstream of the Victoria River System in August 1978 (from p. 34 Monograph 2).



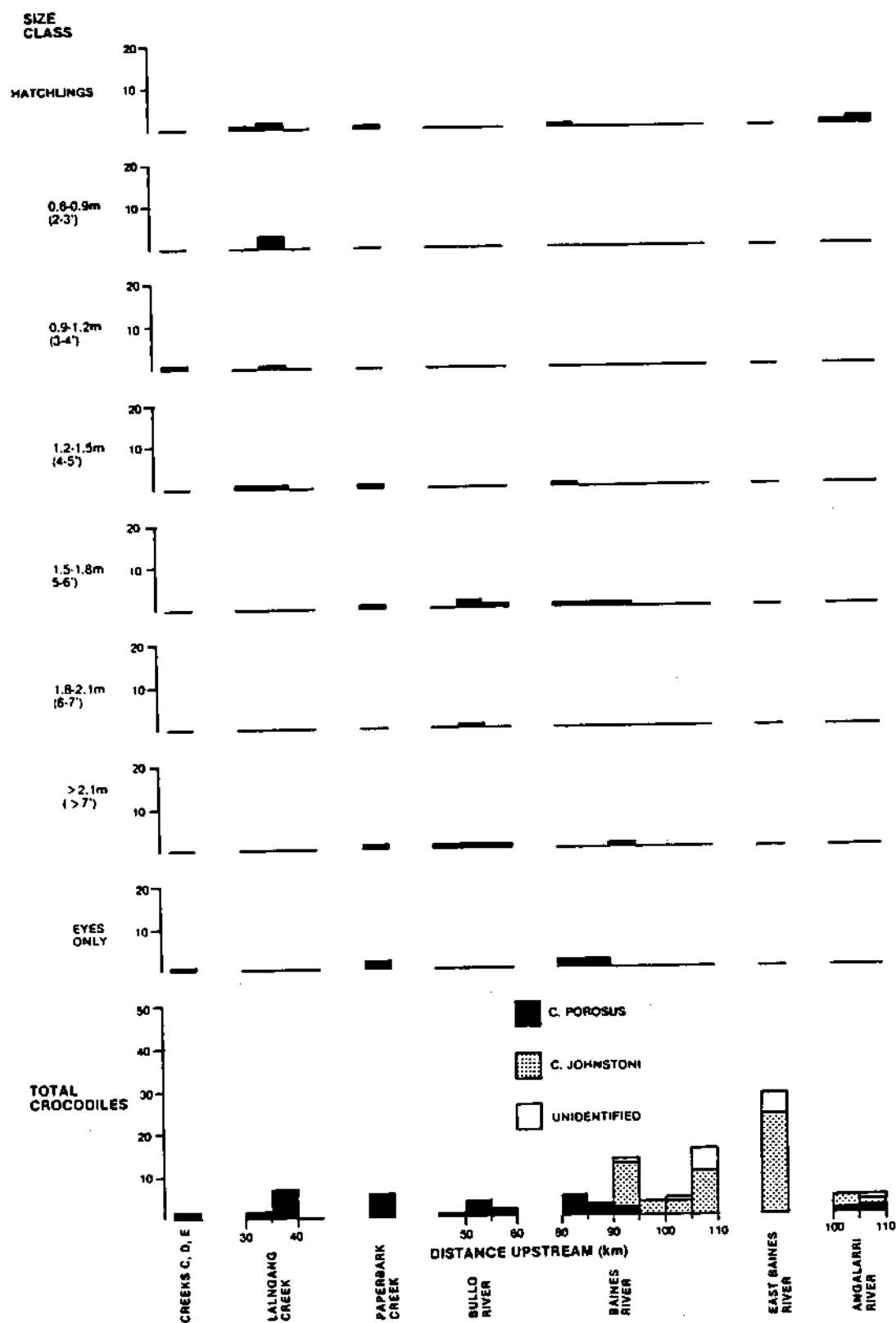


Figure 35. Distributional pattern of crocodiles on the sidecreeks and/or rivers of the Victoria River System in August 1978 (from p. 33 Monograph 2).

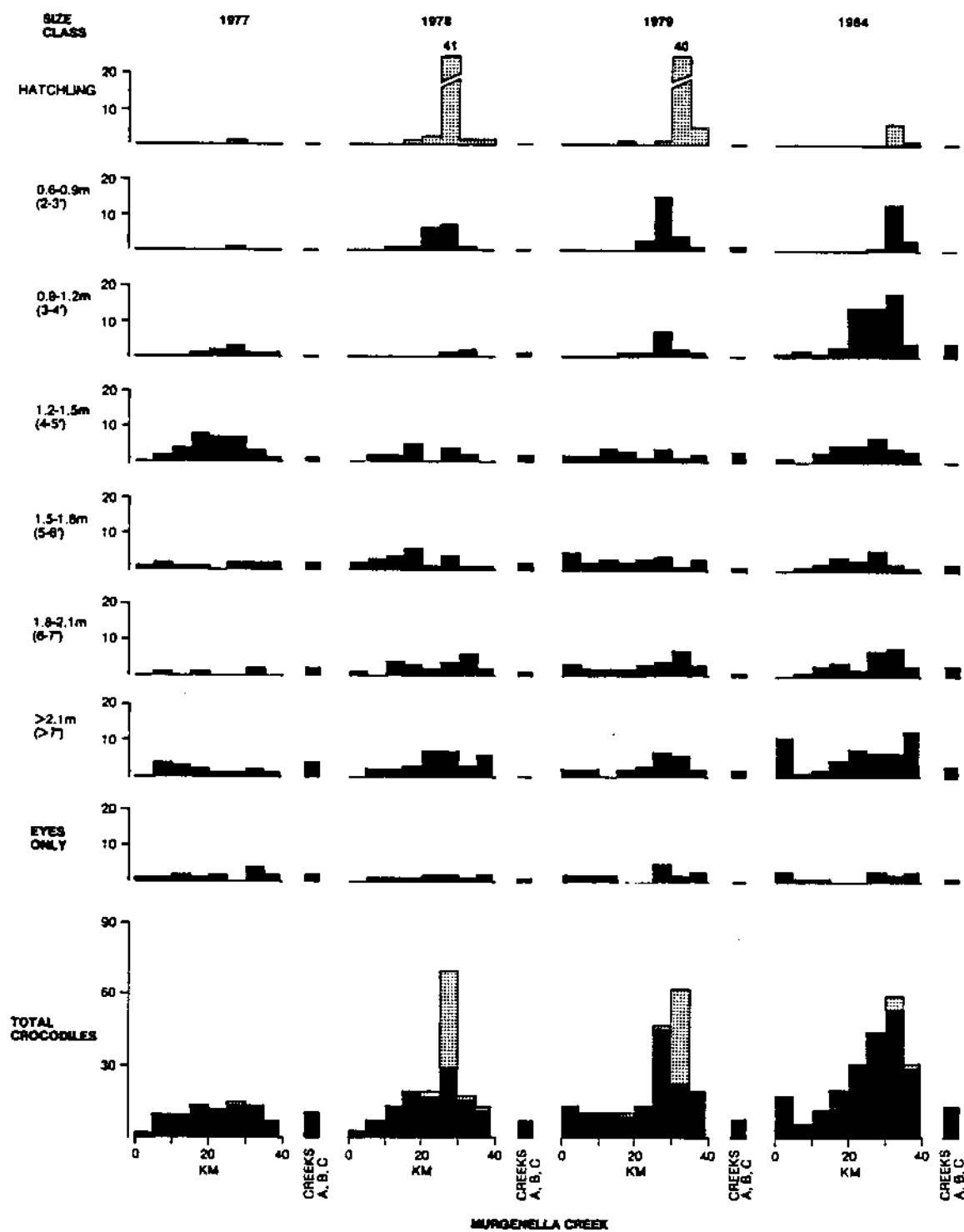


Figure 36. Distributional pattern of *Crocodylus porosus* on Murgarella Creek in October 1977, June 1978, August 1979, and July 1984 (from p. 177 Monograph 19).

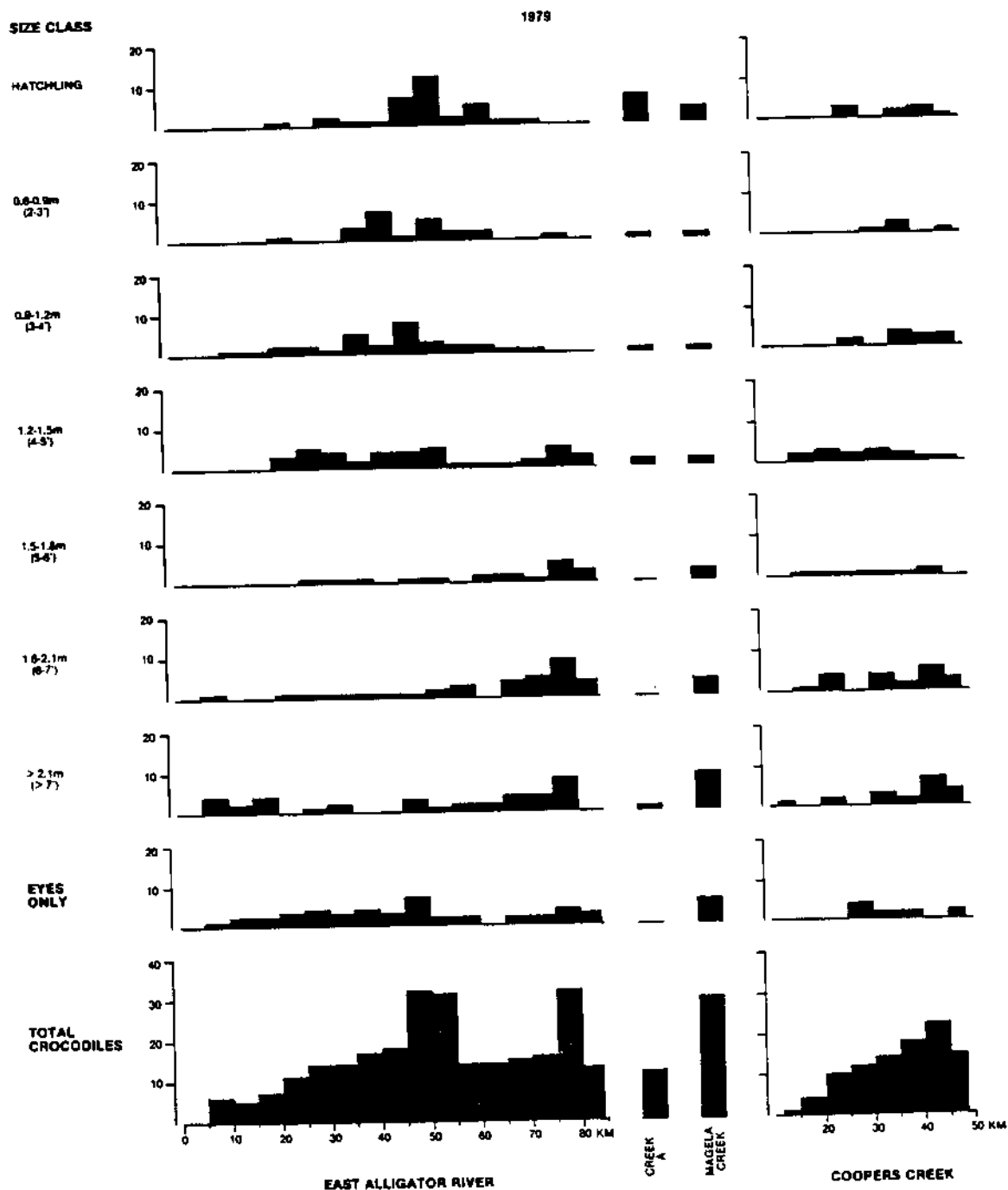


Figure 37. Distributional pattern of *Crocodylus porosus* on the East Alligator River System in August 1979 (from p. 87 Monograph 14).

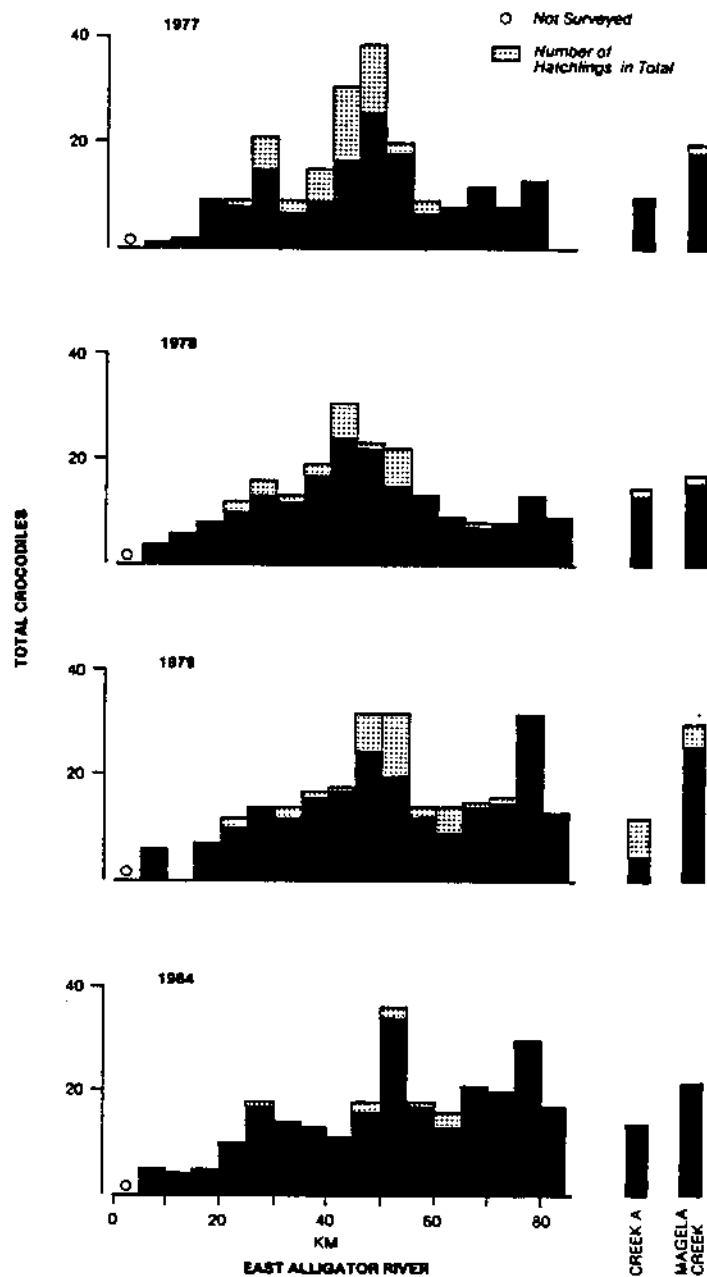


Figure 38. Distributional pattern of *Crocodylus porosus* on the East Alligator River in October 1977, June 1978, August 1979, and July 1984 (from p. 179 Monograph 19).

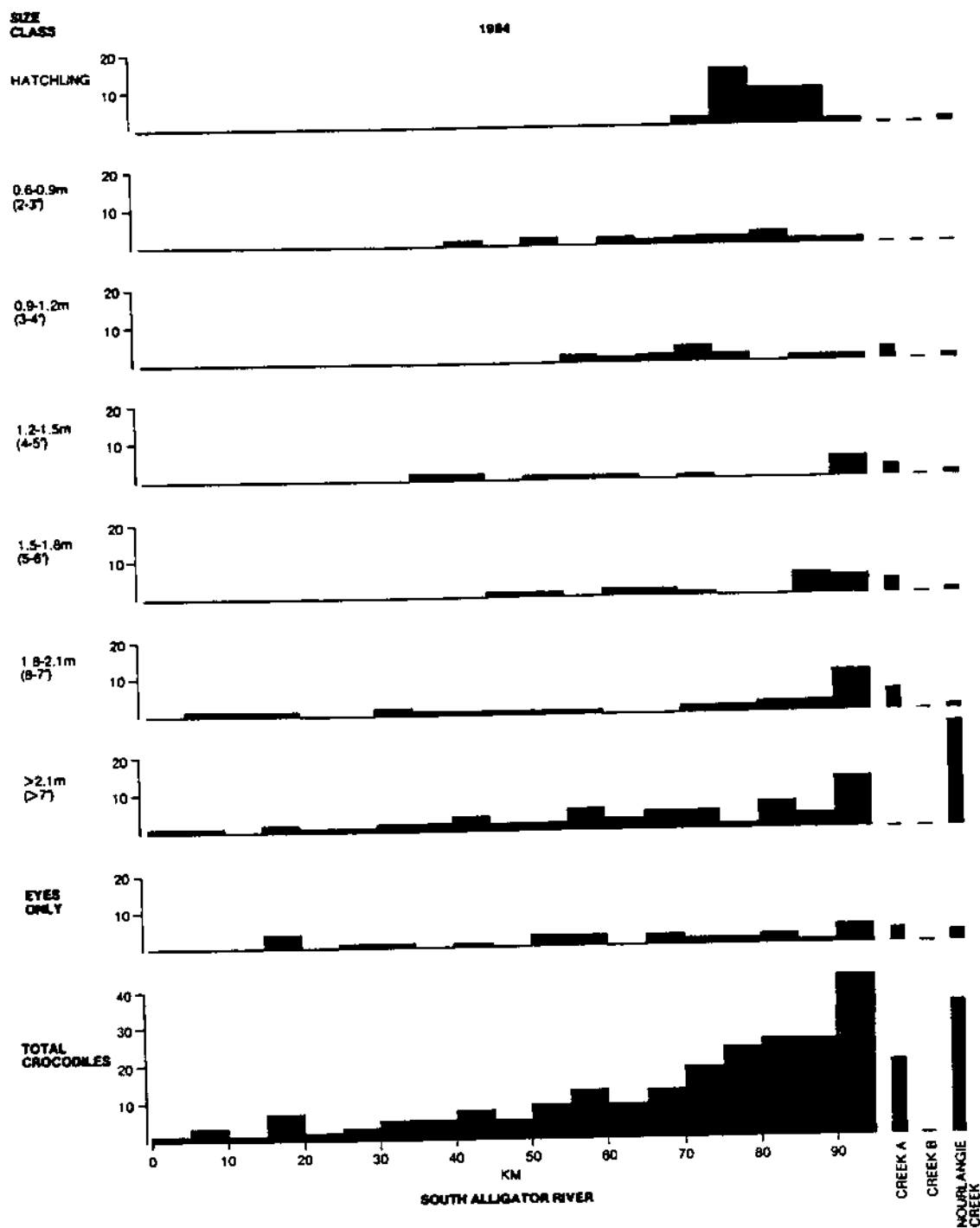


Figure 39. Distributional pattern of *Crocodylus porosus* on the South Alligator River in July 1984 (from p. 180 Monograph 19).

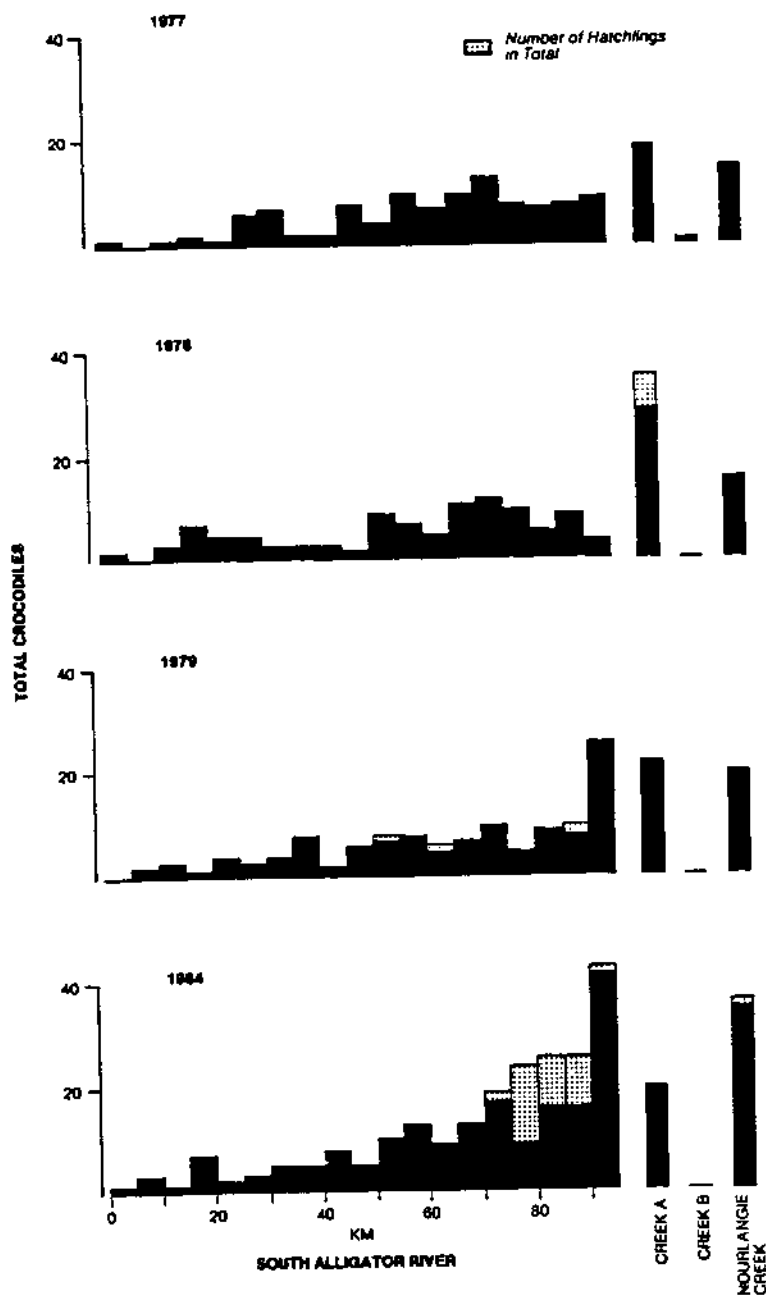


Figure 40. Distributional pattern of *Crocodylus porosus* on the South Alligator River in October 1977, July 1978, August 1979, and July 1984 (from p. 181 Monograph 19).

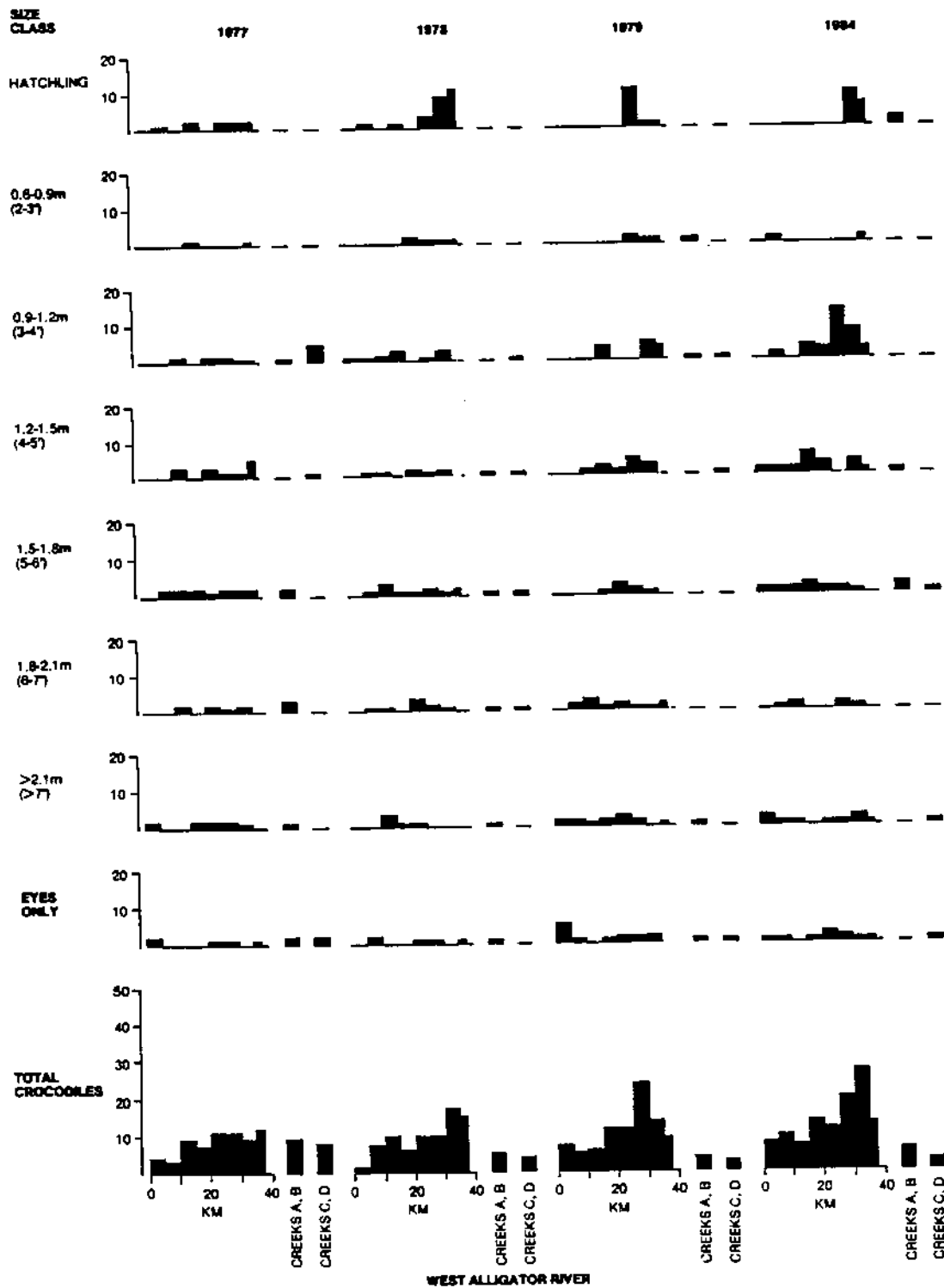


Figure 41. Distributional pattern of *Crocodylus porosus* on the West Alligator River in October 1977, July 1978, August 1979, and June 1984 (from p. 182 Monograph 19).

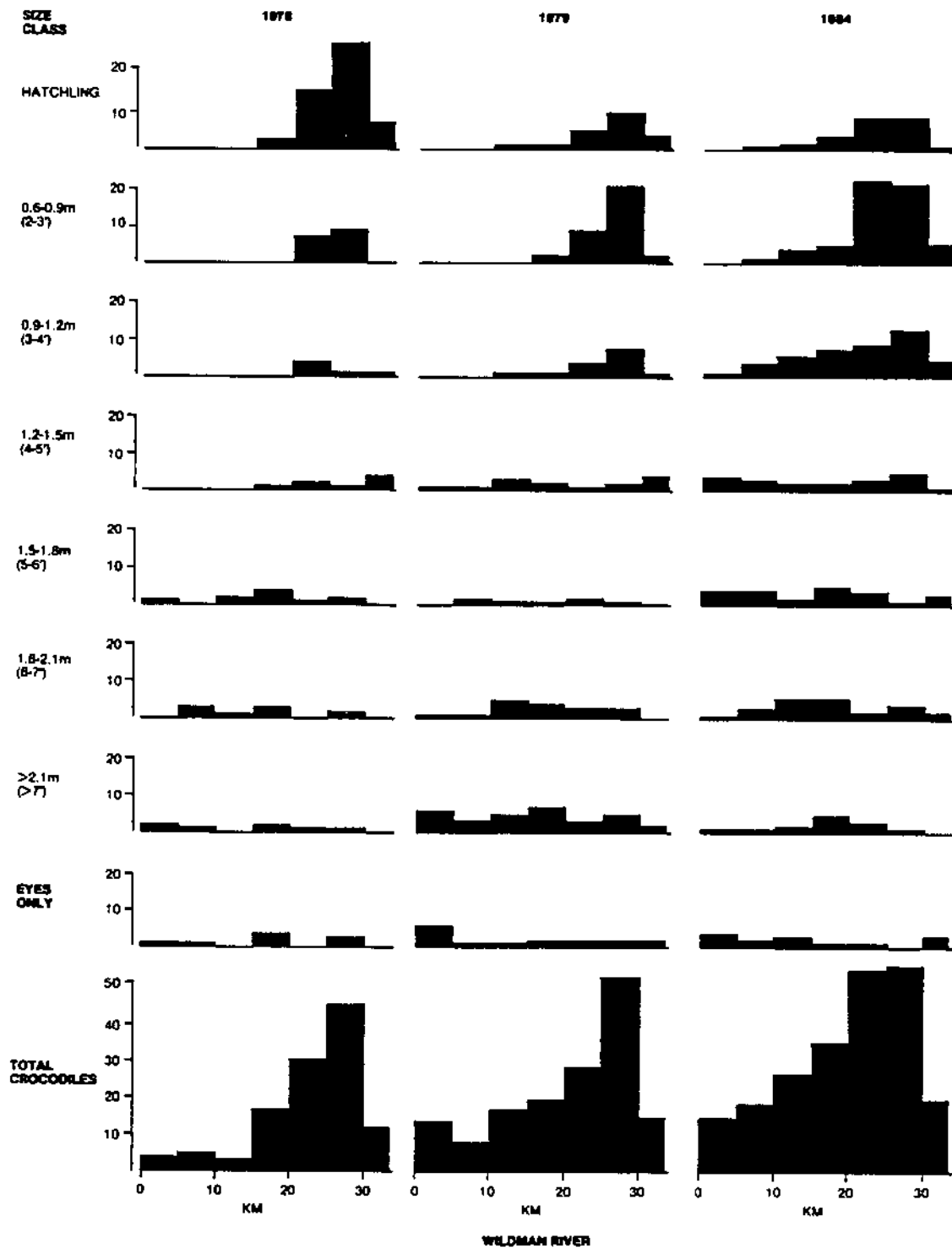


Figure 42. Distributional pattern of *Crocodylus porosus* on the Wildman River in September 1978, August 1979, and June 1984 (from p. 183 Monograph 19).



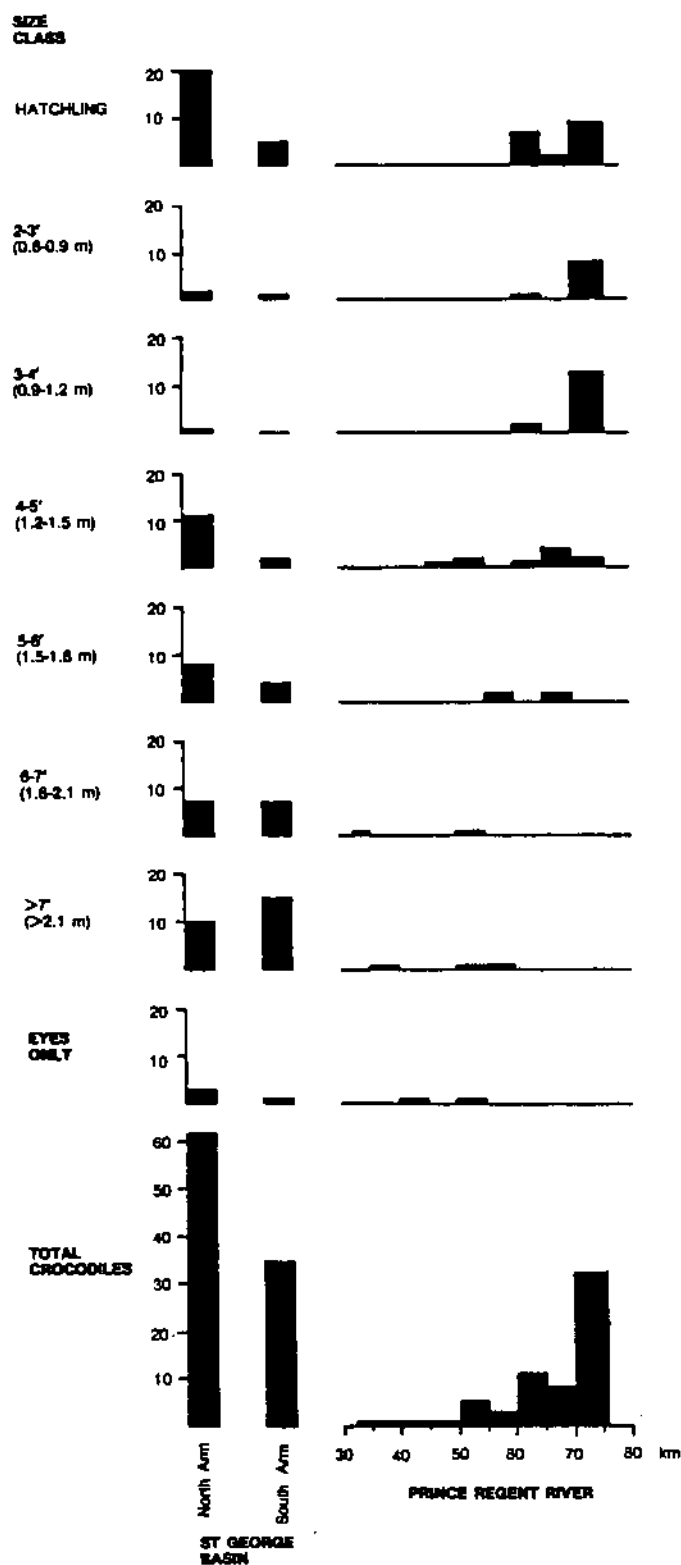


Figure 43. Crocodile distribution on the Prince Regent River and the St. George Basin in July 1978 (from p. 24, W.A. Report No. 34).

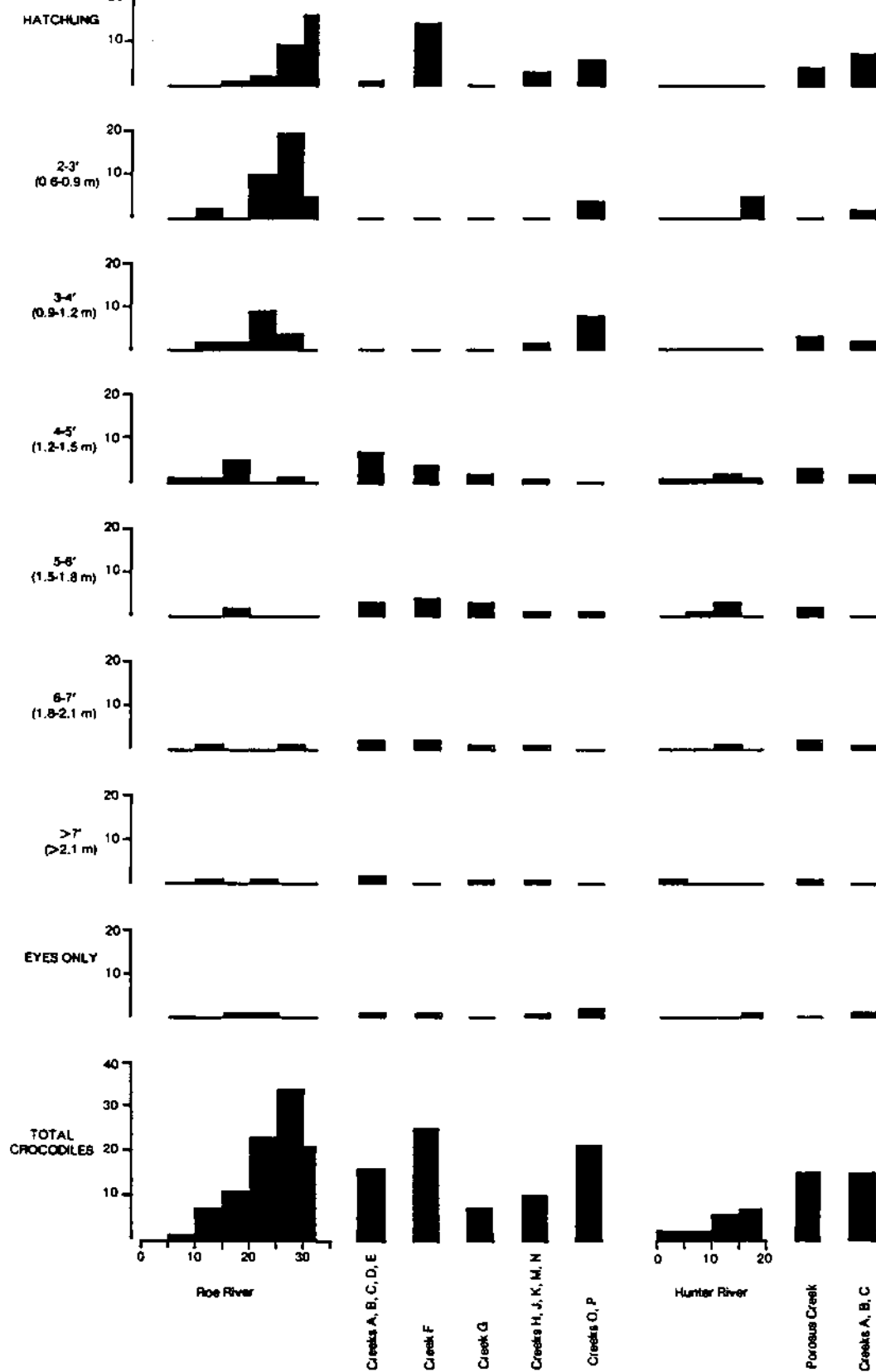


Figure 44. Crocodile distribution on the Roe River System in July 1977 (from p. 33 W.A. Report No. 24).

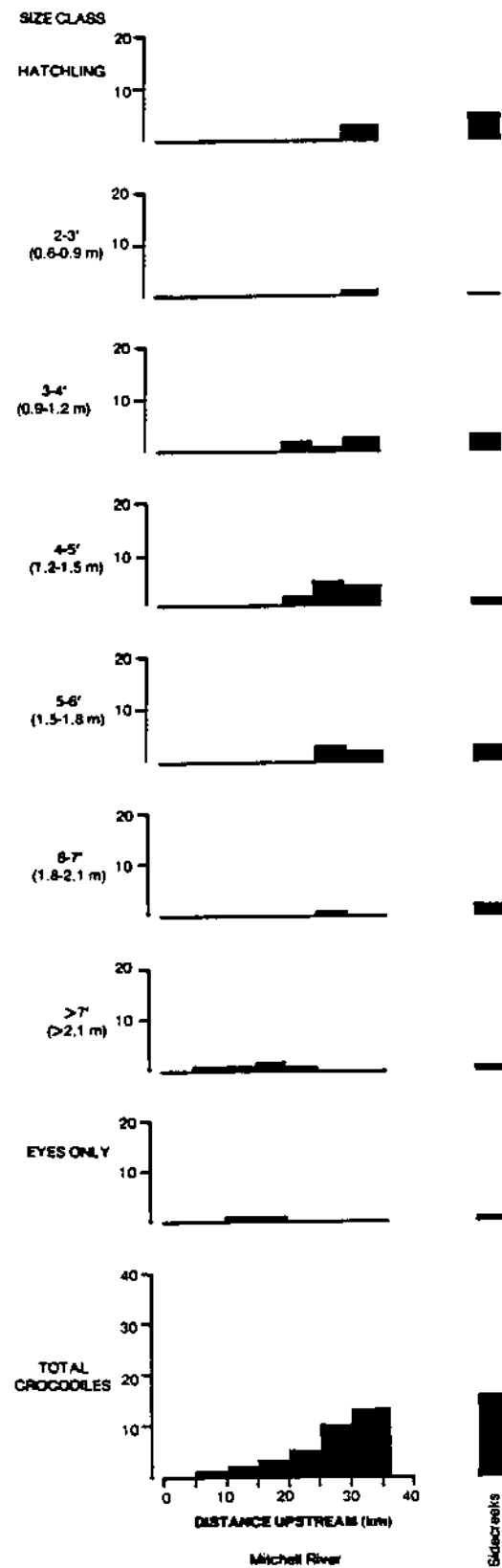


Figure 45. Crocodile distribution on the Mitchell River in July 1977 (from p. 28 W.A. Report No. 24).

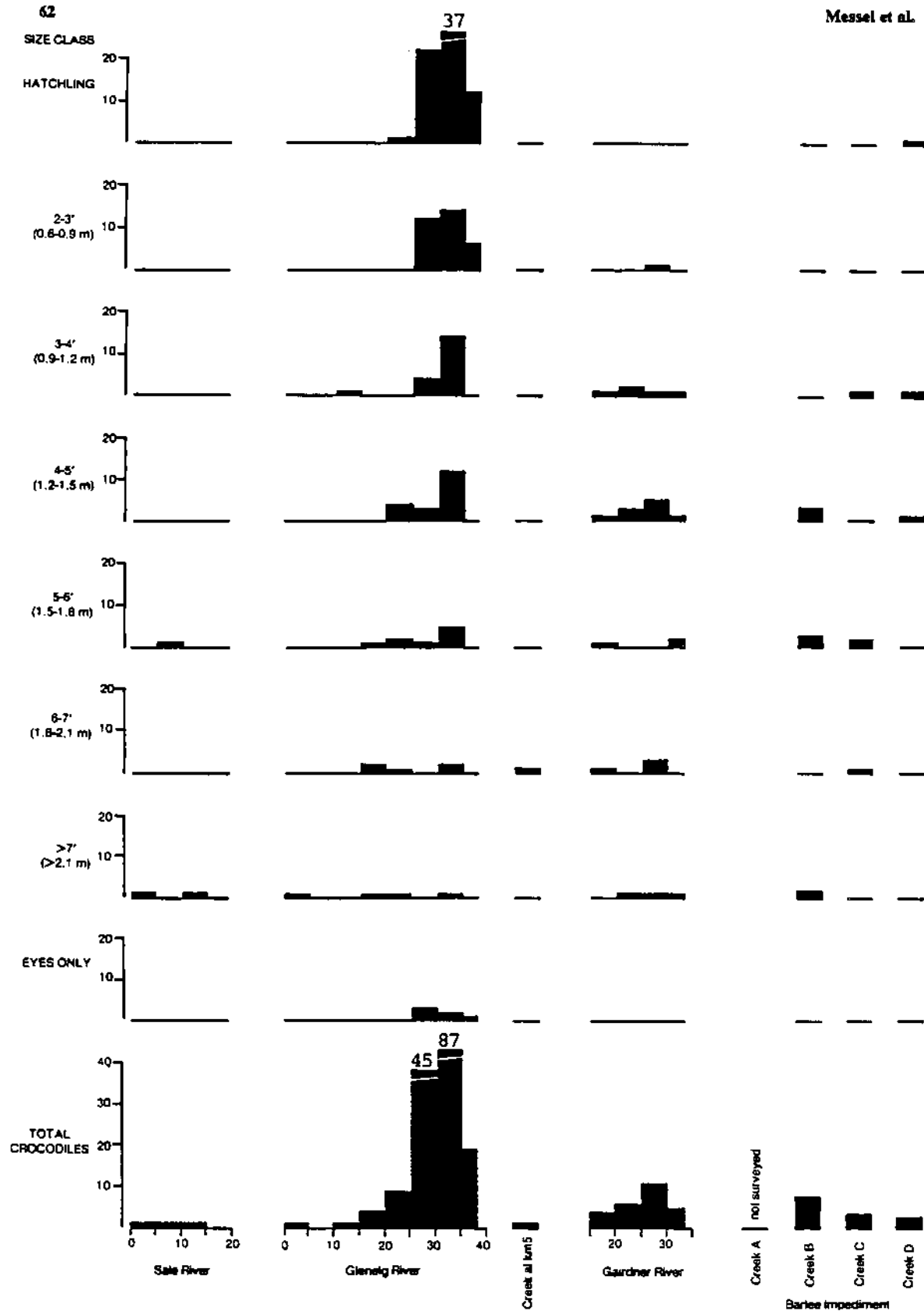


Figure 46. Crocodile distribution on the Glenelg and Gairdner Rivers in July 1978 (from p. 14 W.A. Report No. 34).

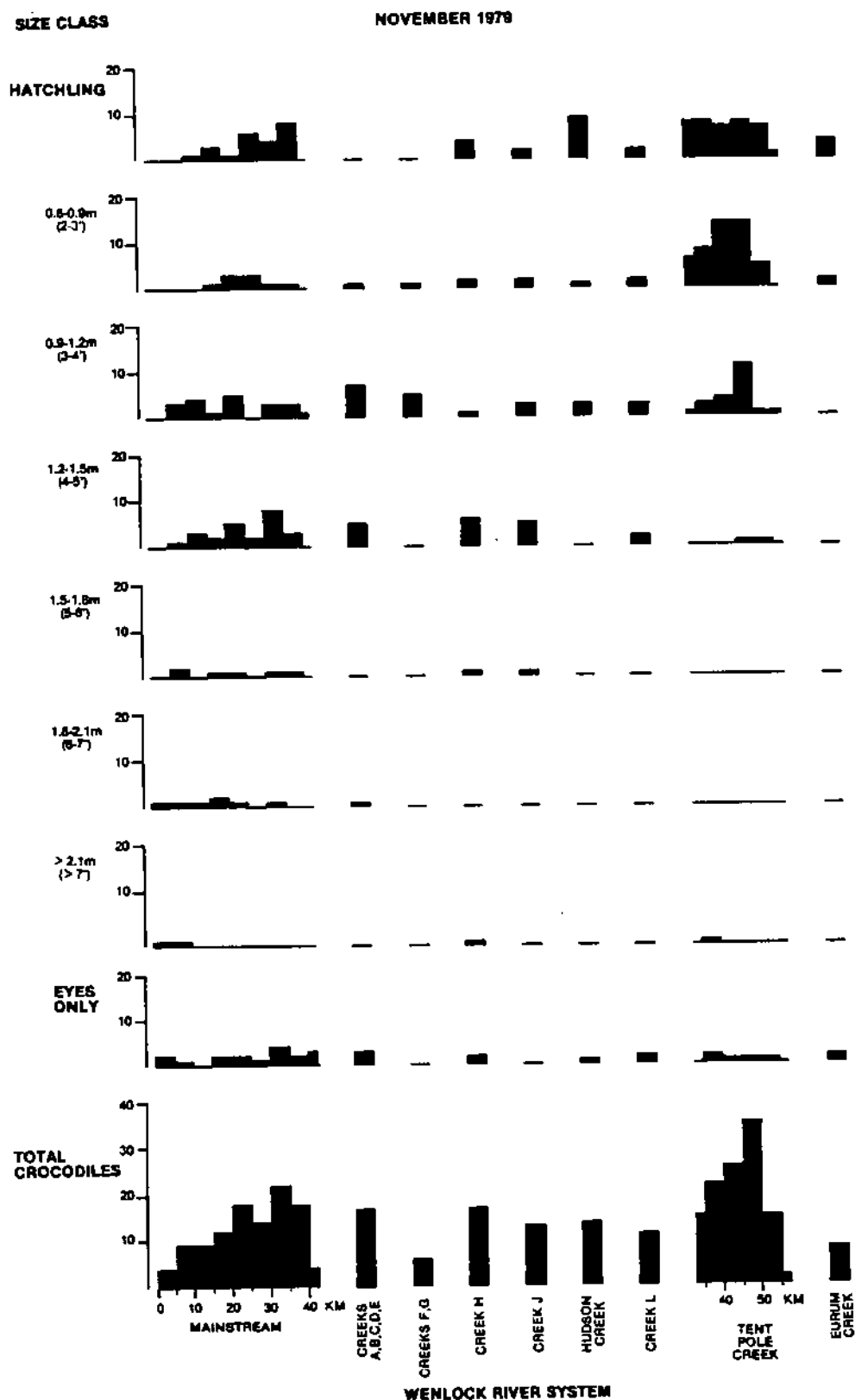


Figure 47. Distributional pattern of *Crocodylus porosus* on the Wenlock River System in November 1979 (from p. 89 Monograph 16).

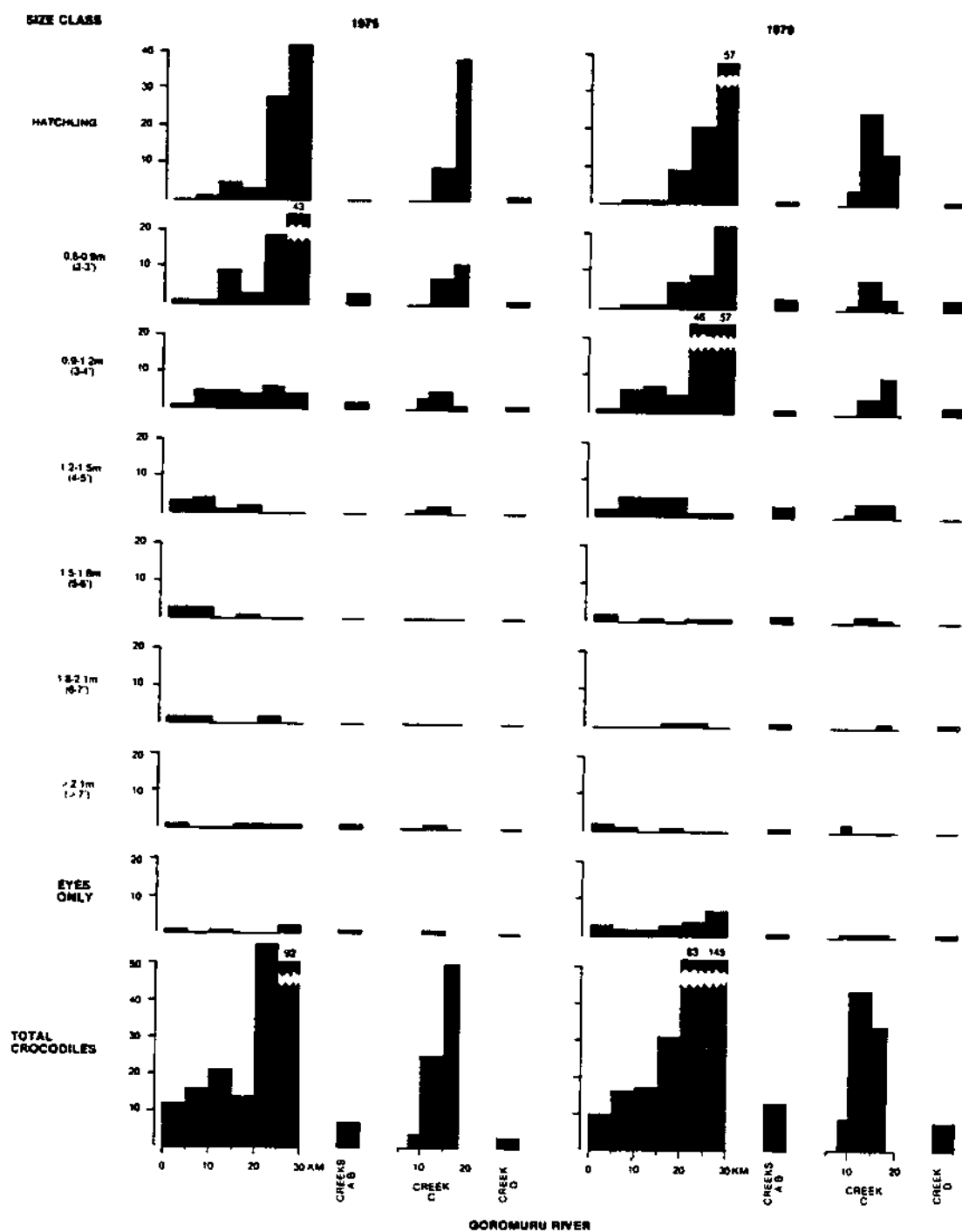


Figure 48. Distributional pattern of *Crocodylus porosus* on the Goromuru River in October 1975 and June 1979 (from p. 118 Monograph 11).

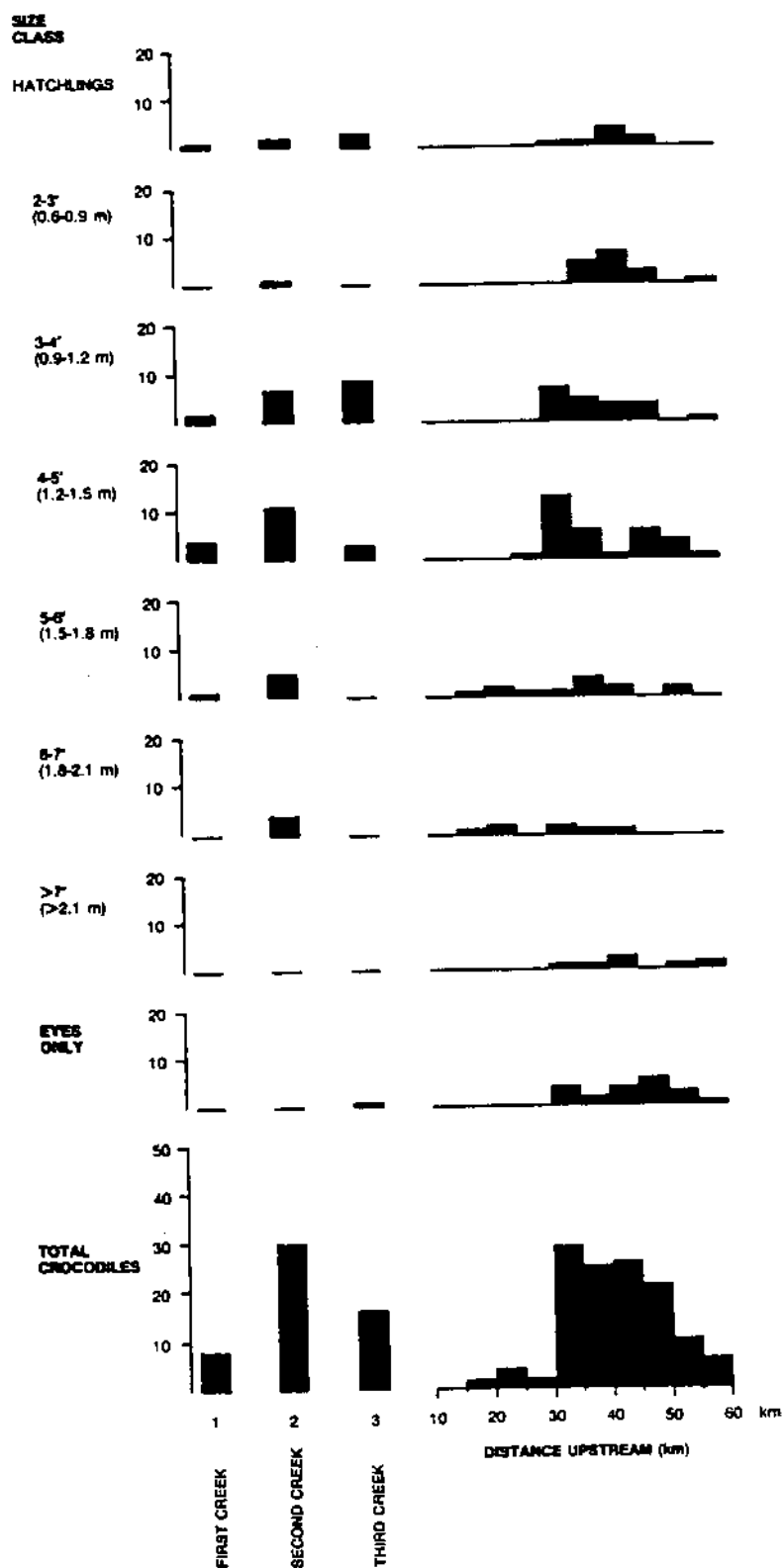


Figure 49. Crocodile distribution on the Ord River System in July 1978 (from p. 32 W.A. Report No. 34).

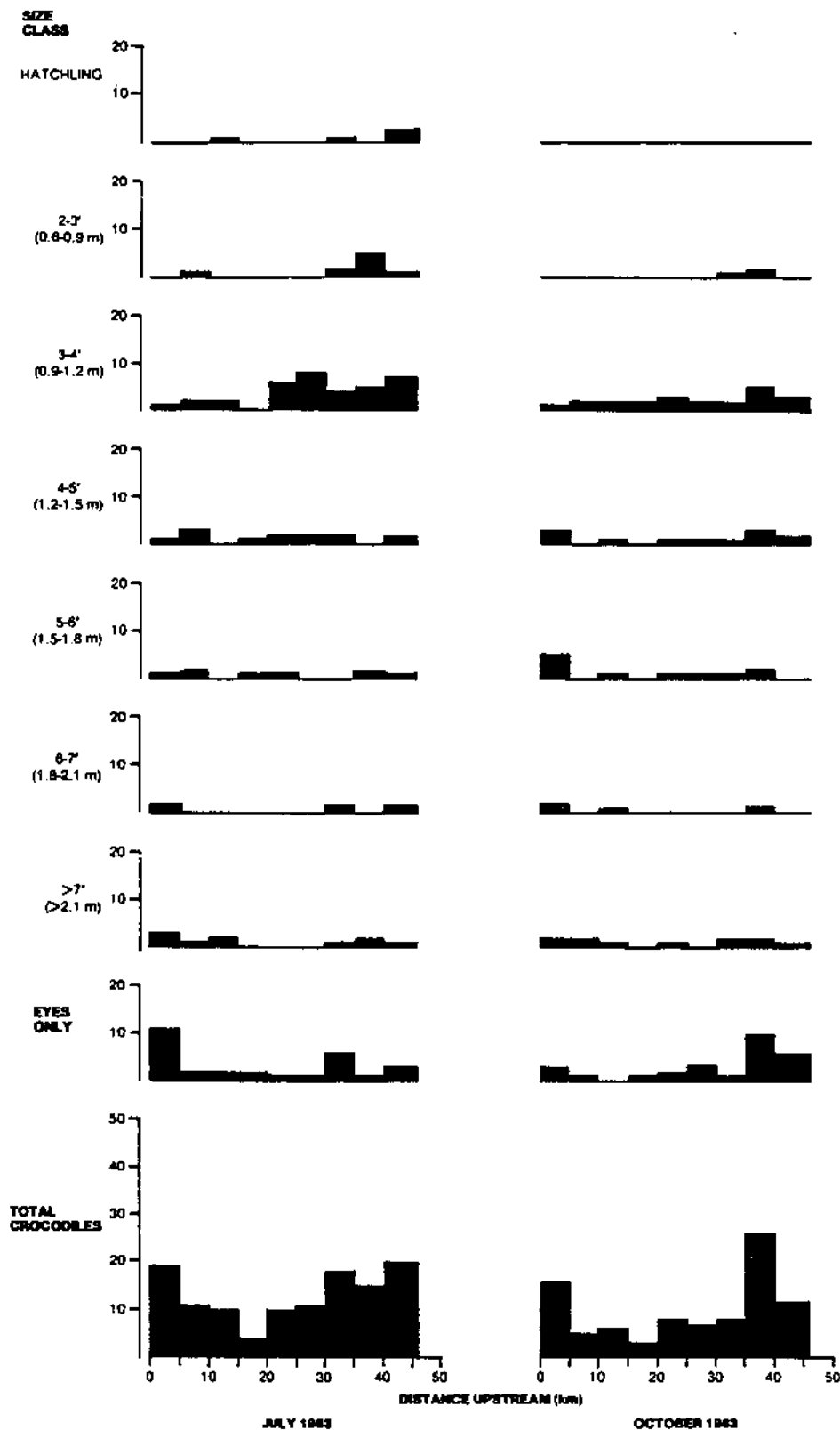


Figure 50. Distributional pattern of *Crocodylus porosus* on the Glyde River in July and October 1983 (from p. 307 Monograph 18).



**SUMMARY RESULTS OF SURVEYS OF THE TIDAL WATERWAYS  
IN THE KIMBERLEY OF WESTERN AUSTRALIA  
DURING THE YEARS 1977, 1978 AND 1986**

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**ABSTRACT**

Some 50% of the important *Crocodylus porosus* habitat in the Kimberley of Western Australia was surveyed for the first time during the years 1977 and 1978. In 1986 we resurveyed most of the tidal systems first surveyed in 1977 and 1978, and in addition surveyed the 203 km of tidal systems in the West Arm of Cambridge Gulf. A slow but important recovery appears to be on the way on the still remote tidal waterways of the Kimberley.

The recovery on the Ord and Glenelg Systems mimics that of the tidal waterways on the northern Arnhem Land coast and is understood on the basis of our population dynamics model for *C. porosus* but a number of intriguing questions remain. After an interval of 8 years, both of the Systems end up with a non-hatchling density less than what was found when the Systems were first surveyed by us in 1978. The number of (3-6') animals sighted remained closely the same or decreased, however the number of large animals sighted essentially doubled in both cases. The ratio of (3-6')/large animals decreased as predicted.

The Prince Frederick Harbor and Prince Regent Systems show a slow but important recovery. On these systems, with their non-Type rearing stockyards near the mouth of the mainstream, not only has the density of non-hatchlings increased but the number of large animals has almost trebled. The ratio of (3-6')/large animals also fell as predicted. Our population dynamics model is able to account for the results and in fact predicted such a finding.

In 1978 we gave an estimate for the number of non-hatchling *C. porosus* remaining in the tidal waterways of the Kimberley in Western Australia. Our estimate then was that a maximum of 2,000 non-hatchlings remained. What about our estimate now? A total of 978 non-hatchlings were sighted on the 790.4 km of tidal waterways surveyed. This yields an estimate for the actual number of non-hatchlings of between 1,541 and 1,667, at the 95% confidence level. We estimate that we have now surveyed some 67% of the important crocodile habitat in the Kimberley. This being the

case, the estimate for the total non-hatchling *C. porosus* population in Western Australia is between 2,300 and 2,488 animals. It is to be compared with the some 3,000 animals reportedly taken for their skins around the Admiralty Gulf area alone, during the period 1963-1965. Protection for *C. porosus* should continue, for it is now apparent that recovery of the population must be measured in decades.

Our results pose a number of interesting questions, especially about the paucity of hatchlings and crocodiles in the (2-3') size class sighted during the 1986 survey. The number of large crocodiles sighted increased by a factor of about 3. Could cannibalism by these animals be one of the reasons for the small hatchlings and (2-3') numbers sighted?

## INTRODUCTION

During the years 1977 and 1978 we systematically surveyed and charted the majority of the large Kimberley tidal river systems (Figs. 1 and 2) and inventoried *Crocodylus porosus* in them. The only significant areas not surveyed in those years were the Walcott Inlet-Secure Bay area and the West Arm of Cambridge Gulf—with their associated tidal rivers. During 1986 we resurveyed most of the systems we had done in 1977 and 1978 and surveyed the tidal systems of the West Arm of Cambridge Gulf for the first time.

The following tidal systems of the Kimberley in Western Australia were surveyed by us:

	Latitude	Longitude
Cambridge Gulf		
Ord River System (East Arm)	15°03'S	128°10'E
West Arm	15°11'S	128°06'E
Sellers Creek at km 12.5	15°17'S	128°08'E
Forrest River at km 15.0	15°18'S	128°04'E
Canal Creek at km 16.0	15°18'S	128°04'E
Parry Creek at km 18.0	15°20'S	128°08'E
King River at km 35.0	15°30'S	128°05'E
Durack River at km 61.0	15°36'S	127°50'E
Pentecost River at km 62.0	15°37'S	127°51'E
Port Warrender		
Lawley River System	14°33'S	125°53'E
Walmesly Bay		
Mitchell River System	14°24'S	125°42'E
Prince Frederick Harbor		
Hunter River System	15°02'S	125°23'E
Roe River System	15°08'S	125°21'E
St. George Basin		
Prince Regent River System	15°13'S	124°49'E
George Water		
Sale River	15°58'S	124°36'E
Glenelg River System	15°48'S	124°42'E

The coordinates shown are those for the km 0 point of the work maps given in Monographs 15 and 20.

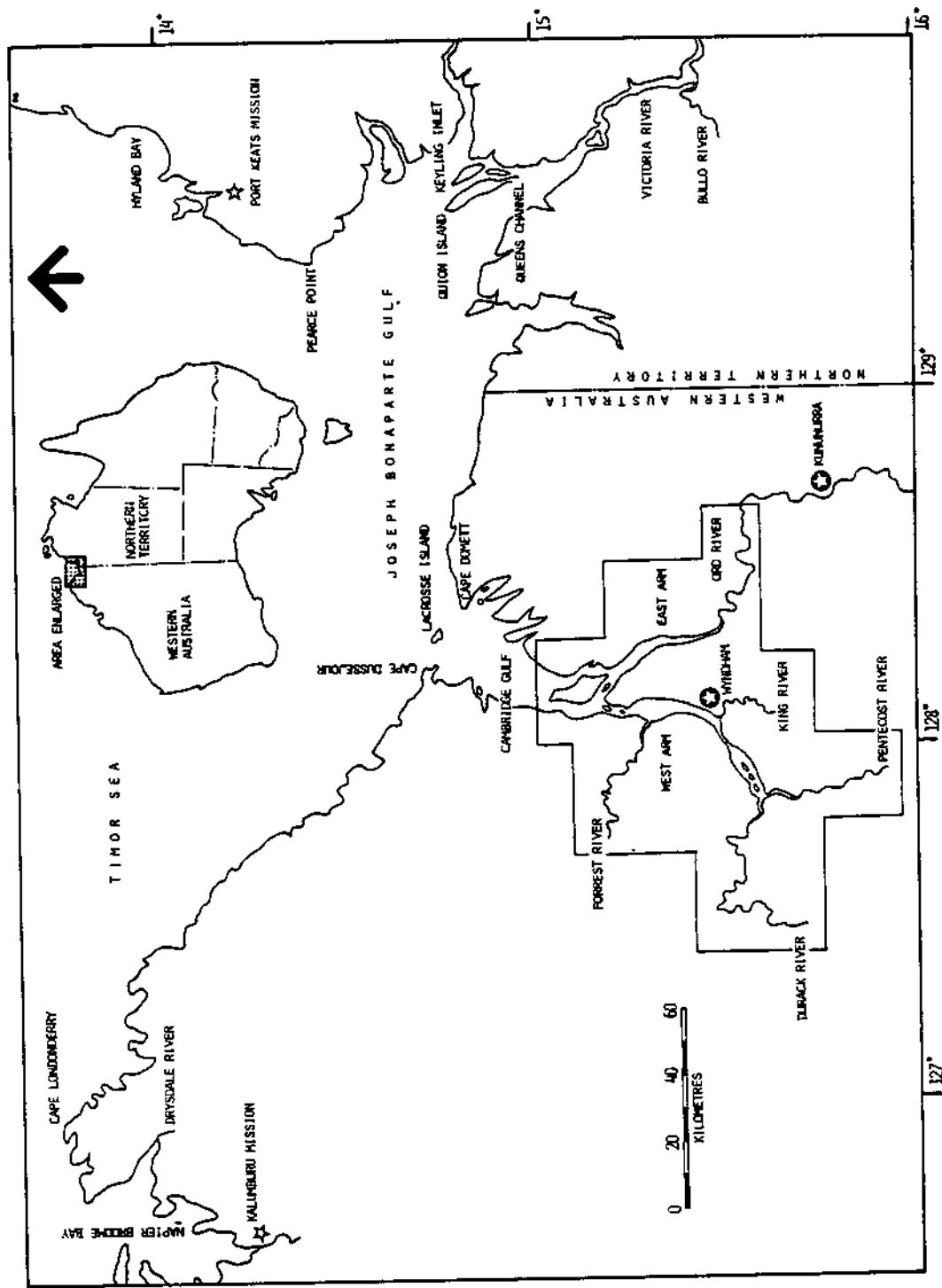


Figure 1. General area map 1: East Kimberley, Western Australia.



The surveys of 1986 essentially wind up our 15 year program of systematically surveying and charting over 100 tidal systems in northern Australia and studying and inventorying their crocodile populations. The results of this work have appeared in a series of 19 Monographs published by Pergamon Press (and two reports published by the Western Australian Government on the 1977 and 1978 surveys).

The work summarized very briefly in the present paper covers the surveys of 1977, 1978 and 1986 and will appear in detail in Monograph 20, a special volume devoted mainly to tidal systems in the Kimberley of Western Australia.

The surveys of the major tidal systems in the Kimberley carried out in 1977 and 1978 were important not just because we were able to ascertain the status of *C. porosus* in those systems, but even more importantly, it was results from these surveys that provided a number of the basic ideas about the dynamics of *C. porosus* populations.

When the 1977 and 1978 surveys were carried out in the Kimberley, we still did not have a model for the dynamics of *C. porosus* populations; in fact data from the 1977 survey of the Prince Regent River System provided us with one of the first clues for our model. On page 47 of Report 24 we stated:

"The distribution of crocodiles in the larger size classes in the main River and its creeks is similar to that of a badly depleted population, except for the almost complete absence of larger crocodiles near the mouth of the River (Table 8). The distribution of the size classes in St. George Basin (Table 7) is in striking contrast. Here the majority of crocodiles seen were greater than 1.2 km long, including 28 over 1.8 m."

Our resurvey of Prince Regent in 1978 then led us to make the following statements on pages 27 and 28 of Report 34:

"If one compares the number of crocodiles seen in 1977 and 1978 for those creeks surveyed in both years, then the 72 including 10 hatchlings, are to be compared with 75 including 25 hatchlings. The ten 1977 hatchlings would, if they survived, be in the non-hatchlings would, if they survived, be in the non-hatchling class by 1978 so the 72 crocodiles of 1977 are now to be compared with  $75-25=50$  crocodiles remaining in 1978. Thus, there is evidence for considerable mortality and/or emigration in this population. Comparison of the number in each size class indicates that this occurs not only in the hatchling but in the 3 to 4, 4 to 5 and 5 to 6 foot size classes as well. The decrease amounts to 31% and is similar to that found by one of us (HM) in many other river systems in northern Australia."...

"Examination of the size structure of the crocodiles observed in each of the north and south arm creeks (Table 4) provides evidence for a major input of small (2 to 6 feet, 0.6 to 1.8 m) and large (>6 feet or 1.8 m) crocodiles from the Prince Regent mainstream and its creeks. The small crocodiles which appear to have moved into the Basin creek complexes are in the 4 to 5 feet (1.2 to 1.5 m) and 5 to 6 feet (1.5 to 1.8 m) classes and appear to be almost evenly distributed among the Basin creeks, with perhaps some indication of a lower density further away from the River mouth."....

"The Prince Regent River and St. George Basin, as a whole, yielded 189 crocodiles, 133 of which were non-hatchlings. The combination of a river which provides nesting habitat upstream and large mangrove blocks at its mouth is unique, and further study of the system may lead to a better understanding of movement patterns in the Salt-water Crocodile."

"It is undoubtedly the existence of these arms which leads to the unusually high proportion of large (>6 foot or 1.8 m) compared to small (2 to 6 feet, 0.6 to 1.8 m) crocodiles in the Prince Regent River system. The ratio is 54/78, equivalent to 69%, whereas the mean ratio for all rivers counted in Australia is 27% (Messel et al. 1978b). It is possible that in other river systems where similar mangrove blocks do not exist the large crocodiles move out to sea and a proportion perish."

And on page 36 of the same report:

"One interesting difference between some Kimberley river systems and those in Arnhem Land has emerged from our studies. Some Kimberley rivers have extensive areas of mangrove-lined tidal creeks near the mouth of the main "breeding" river. This is especially evident in the Prince Regent River, and to a somewhat lesser extent, in the Glenelg River, but they also occur in the Ord, Roe and Lawley River systems. Except in the case of the Lawley these mangrove blocks have numbers of larger crocodiles living in them which have moved from the main river where they hatched. Further study of the relationships between these "holding areas" and their breeding rivers may give clues to the movement patterns of *C. porosus*, since in most Arnhem Land rivers there are not such "holding areas" and many crocodiles moving downstream apparently leave the river system entirely."

These remarks are to be compared with a number of the major points of our model given later in this section and will be seen to be very much in keeping with them. But more of this anon.

Analysis of the number, distribution and size structure of crocodiles sighted during the general surveys of northern Australian tidal systems indicates that one of the most important parameters characterizing a tidal waterway is its salinity profile. The profile and habitat type image one another and appear to largely determine the suitability or otherwise of the tidal waterway for breeding, nesting and rearing. It was in Monograph 5, on the Goomadeer and King River Systems, that we first classified the tidal rivers and creeks on the northern Arnhem Land coastline roughly into three different types of waterways (also see pages 100-105 of Monograph 1). This classification played a critical role in the unravelling of the dynamics of populations of *C. porosus* (especially see Monographs 1, 5, 9, 10 and 11) and is given by (see Fig. 3):

#### TYPE 1

Normally, these are tidal river systems meandering through coastal floodplains and having a major freshwater input during the wet season. However, in the Kimberley the rivers often run through rugged gorges and fault lines. The freshwater inflow decreases but remain sufficient, as the dry season progresses, to prevent the salinity upstream (though progressing upstream gradually) from rising above the sea water values measured at the mouth of the system. Systems usually running through coastal floodplains have good to excellent nesting habitat and could be expected to have good recruitment potential. The Blyth-Cadell Rivers System (Monograph 1) is one of the best examples of the Type 1 systems of the Kimberley is usually more limited and thus

the recruitment potential of these systems is decreased accordingly. The Ord, Roe, Prince Regent and Glenelg river Systems are examples of Type 1 waterways in the Kimberley.

### TYPE 3

Tidal waterways which also have a large freshwater input during the height of the wet season, but in which the freshwater input drops rapidly with the onset of the dry season. These waterways, which usually have short surveyable lengths and often have direct openings to the sea, are typified by salinities that, during the dry season, are above those measured at their mouths and that increase with increasing distance upstream—they are hypersaline and become increasingly so as the dry season progresses. Nesting habitat in such systems is minimal or non-existent. All Night Creek (Monograph 5) was given as an example of such a system; most of the coastal creeks surveyed on the southern coast of the Gulf of Carpentaria also fall into this category (Monograph 13). In the Kimberley "Porosus Creek" (Prince Frederick Harbor) is a Type 3 system.

### TYPE 2

Tidal systems which fall somewhere between Type 1 and Type 3 above and that tend to show hypersaline characteristics as the dry season progresses. Such systems usually have good to poor nesting habitat and equivalent recruitment potential depending upon how close they are to Type 1 or 3 above. The Hunter River in Prince Frederick Harbor is a Type 2 system.

It will be seen (see Fig. 3) that each of these three system types has its own characteristic type of salinity variation, both in respect of time of year and distance upstream, and that the salinity characteristics largely determine the nature of the system. The salinity profile of a system may be said to be its own unique signature. A river system may have multiple signatures, one for its mainstream and then other different signatures for the creeks and side creeks.

The model which we have built up and have been refining (see especially Monographs 1 and 18), as more data are obtained, not only enables us to account in a consistent fashion for the vast store of field observations and results we have accumulated for some 100 tidal waterways in northern Australia, but also enables us to predict successfully results expected on future individual surveys. The model runs as follows:

1. The tidal waterways of northern Australia have been classified according to their salinity signatures into Type 1, Type 2 and Type 3 systems shown in Fig. 3. Type 1 systems are the main breeding ones and non-Type 1 systems are usually poor or non-breeding systems. It is the Type 1 systems the freshwater billabongs and semipermanent and permanent freshwater swamps associated with them that account for the major recruitment of *C. porosus*; the other systems contribute to a lesser degree and they must usually depend largely upon Type 1 systems and their associated freshwater complexes for the provision of their crocodiles. Non-Type 1 system also sometimes have freshwater complexes associated with them but these are normally quite minor.
2. As indicated in Fig. 3, our results show that in Type 1 systems some 27% of the crocodiles sighted are hatchlings (of which some 50% are normally lost between June of one year and June of the next, page 394 Monograph 1), whereas in Type 3 systems down to 4%, showing a much decreased hatchling recruitment in non-Type 1 systems it is at least 52%. On the other hand the percentage of crocodiles in the  $\geq(4-5')$  size classes is some 39% in Type 1 systems and 73% on Type 3

systems. Some 79% of the non-hatchling crocodiles are sighted on Type 1 waterways and 21% on non-Type 1 waterways (page 419, Monograph 1).

3. The relatively few large, and more frequent small freshwater billabongs and semipermanent and permanent freshwater swamps associated with tidal waterways are known to contain *C. porosus* but have not been inventoried systematically, except in a few cases. The accurate extent of their non-hatchling *C. porosus* populations is unknown. Based upon the fact that the number of large freshwater swamp areas, with substantial perennial water (normally bordering old river channels), in northern Australia is very limited—perhaps 400 km<sup>2</sup> maximum—and upon limited observations, we estimated that in 1979 the non-hatchling *C. porosus* population was less than 20% of the non-hatchling population sighted in tidal systems. We now believe that the 20% figure was an overestimate for 1979—an unusual year associated with one of the "driest wet" seasons on record. In the Kimberley there are very few freshwater swamps or billabongs.
4. It appears that the populating of non-Type 1 systems (hypersaline or partially hypersaline coastal and non-coastal waterways) results mostly from the exclusion of a large fraction of the sub-adult crocodiles from Type 1 systems and any freshwater complexes associated with them. Adult crocodiles appear generally to tolerate hatchlings, (2-3') and sometimes even (3-4') size crocodiles in their vicinity—but not always: they sometimes eat them (page 43, Monograph 14) or kill them (page 334, Monograph 1). Larger crocodiles are not tolerated. Thus once a crocodile reaches the (3-4') and (4-5') size classes, it is likely to be challenged increasingly not only by crocodiles near or in its own size class (pages 454-458, Monograph 1) but by crocodiles in the large size classes. It is thus likely to be excluded from the area it was able to occupy when it was smaller. A very dynamic situation prevails with both adults and sub-adults being forced to move between various components of a system and between systems. Crocodile interactions, or aggressiveness between crocodiles, in all size classes increases around October—during the breeding season (page 445, Monograph 1 and page 109, Monograph 18) and exclusions, if any, normally occur around this period. A substantial fraction (=80%) of the sub-adults, mostly in the (3-6') size classes but also including immature large crocodiles, is eventually excluded from the river proper or is predated upon by larger crocodiles.
5. Of those crocodiles that have been excluded, some may take refuge in freshwater swamp areas and billabongs associated with the waterway from which they were excluded or in the waterway's non-Type 1 creeks if it has any. Others may travel along the coast until by chance (?) they find a non-Type 1 or another Type 1 waterway, however in this latter case they may again be excluded from it; others may go out to sea and possibly perish, perhaps because of lack of food, as they are largely shallow water on edge feeders, or they may be taken by sharks. Those finding non-Type 1 systems, or associated freshwater complexes, frequent these area, which act as rearing stockyards, for varying periods until they reach sexual maturity, at which time they endeavor to return to a Type 1 breeding system. Since a large fraction of the crocodiles sighted in non-Type 1 systems must be derived from Type 1 systems and their associated freshwater complexes, they are, as seen in (2) above, predominantly sub-adults in the ( $\geq 3'$ ) size just mature adults might attempt to return to and be forced out of a system many times before finally being successful in establishing a territory in a Type 1 system or in its associated freshwater complex. Crocodiles may have a homing instinct (this



important point requires further study) and even though a fraction of crocodiles may finally return to and remain in a Type 1 system or in its associated freshwater complex, the overall sub-adult numbers missing--presumed dead--remain high and appear to be at least 60-70%.

6. Normally, in the Northern Territory, the freshwater complexes (swamps and/or billabongs) associated with tidal systems, are found at the terminal sections or small and large creeks running into the main waterway, or at the terminal section of the mainstream(s). Though this alternative habitat is usually very limited in extent, sporadic (and sometimes extensive yearly) nesting does take place on it. There are, however, several fairly extensive freshwater complexes associated with Type 1 tidal systems and these are important as they may act both as rearing stockyards and as breeding systems, just as the Type 1 waterway does itself. Examples of these are the Glyde River with the Arafura Swamp (Monograph 9), the Alligator Region Rivers with their wetlands (Monographs 4, 14 and 19), and the Daly, Finnis, Reynolds and Moyle Rivers with their wetlands (Monograph 2). The loss factor, which appears to occur during the exclusions stage, can be expected to be lower for movements into and out of swamp areas associated with a Type 1 waterway, than for movement into and out of coastal non-Type 1 systems. The loss of nests due to flooding can also be expected to be less. We have observed nests made of floating grass cane mats in the Daly River Aboriginal Reserve area. Thus recovery of the *C. porosus* population and Type 1 tidal waterways, with substantial associated freshwater complexes (or with large non-Type 1 waterways associated with them), can be expected to be faster than on other systems (page 445, Monograph 1, page 98, Monograph 14 and also see important results for the 1984 resurvey of Alligator Region and Adelaide River systems, Monograph 19 where we verified this prediction). In the Kimberley, freshwater complexes are found only in the Cambridge Gulf area and do not occur to any extent on the north west coast.
7. Because of the ~80% exclusion and at least 60-70% losses of sub-adult crocodiles from Type 1 systems as they proceed toward sexual maturity, there appears to have been on significant sustained increase in the non-hatchling *C. porosus* population on the some 500 km of tidal waterways monitored in the Maningrida area of northern Australia since the commencement of our systematic surveys in 1974, a period of ten years (Monograph 18). With the exception of the Glyde River, these waterways have only freshwater complexes associated with them.
8. Though there appears to have been no sustained significant increase in the number of non-hatchling crocodiles sighted on the tidal waterways of the Maningrida area since our surveys started in 1974, the size structure of the animals sighted appears to have been changing slowly. Notwithstanding substantial fluctuations, the ratios of small (2-6') to large ( $\geq 6'$ ) and (3-6') to large animals were decreasing on the Blyth-Cadell; may have been decreasing on the Liverpool-Tomkinson; and were decreasing overall on the tidal waterways of the Maningrida monitoring area. Thus there was some indication of the commencement of a slow recovery phase.
9. For the 861 km of tidal waterways of the Alligator Region with their substantial freshwater complexes, and the Adelaide River System, there was strong evidence, as of July 1984, that an important and sustained recovery was underway, as predicted in (6) above.

10. Though there are wide fluctuations, especially after "dry wet" seasons when the animals are concentrated into the tidal waterways, it appears that as the number of large crocodiles in a Type 1 tidal waterway increases, there is a tendency for the number of sub-adults in the (3-6') size classes to decrease or increase marginally only. Thus the total number of (3-6') and large animals sighted appears generally to be holding steady or increasing slowly only. This density dependent recruitment has an important bearing on the rate of population growth and on the size structure of the population.
11. When a steady state is reached in a "recovered" population, the ratio of (3-6') to large animals might be considerably less than one.
12. An important and remarkable fact becomes evident in Type 1 tidal waterways (which are not overly exhausted and on the road to recovery) if one excludes the (3-4') size class and focuses on the (4-5') and (5-6') size classes only. Regardless of how large the recruitment may be, the number of animals sighted in the (4-5') and (5-6') size classes seems to remain essentially constant or increases slowly only. Thus a major bottleneck occurs for these size classes. It is as if there are a definite number of these slots increases slowly only--if at all (note especially the results for the Blyth-Cadell and Liverpool-Tomkinson waterways in Monographs 1 and 18 and the 1984 results for the Alligator Region and Adelaide River systems. Monograph 19). The crocodiles themselves appear to be primarily responsible for the very heavy losses of  $\approx 70\%$  that occur in the process of trying to secure these slots or to increase them in number.
13. If one considers a group of 100 of the sub-adult crocodiles in a Type 1 tidal system without a substantial freshwater complex associated with it, one can expect some 80 to be excluded from it, at least 60-70 of the original 100 to end up missing--presumed dead, less than 15-20 to successfully establish territories on the system without having to leave it and the remainder might eventually also return and establish a territory, especially after becoming sexually mature. The very nature of this matter is such as to preclude precise figures and they must be looked upon as broad estimates only. However, detailed study of our results (Monograph 18) now indicates that the missing--presumed dead figure is likely to be in excess of 70. For systems with substantial freshwater complexes or large non-Type 1 waterways associated with them, this figure is likely to be considerably less.
14. When there is an exclusion from Type 1 systems of sub-adult animals, mostly (3-6') in size but also including immature larger animals, this takes place mainly in the breeding season, normally commencing around September-October and apparently lasting throughout the wet season. Any influx of animals in the (3-6') and/or large size classes appears to occur mainly in the early dry season and to be completed in the June-early September period, but may be earlier in some years.
15. After a single "dry wet" season there is a substantial influx of large and sometimes (3-6') animals, forced out of freshwater complexes into the tidal waterways and these are sighted during June-July surveys. Surveys made in October-November of the same year usually reveal a substantial decrease in the number of (3-6') and/or large animals sighted. However the number of large animals sighted

sometimes remains higher than previously and hence a number of the new large animals do not return from whence they came. These animals appear successful in establishing a territory on the waterway; it could be the waterway from which they had been originally excluded. The "dry wet" variation in the number of animals sighted appears to be superimposed upon the variations normally found during surveys following usual wet seasons--which generally result in extensive flooding on the upstream sections of the tidal waterways. Hatchling recruitment on the tidal waterways is generally greatly enhanced during "dry wet" seasons but appears to be greatly reduced in major swamp habitat. The reverse appears to be true during normal or heavy wet seasons.

On the basis of the above model we made the following statement on page 61, Monograph 19:

"Furthermore, one would predict any recovery on many of the tidal waterways in the Kimberley of Western Australia to be similar to that found in the Maningrida area. The tidal waterways there are mostly devoid of freshwater complexes of any consequence, however the Glenelg and the Prince Regent Systems have extensive Type 3 systems--similar to the Cobourg Complex--at their mouths and these might help keep the exclusion and/or loss factor down. We surveyed these tidal waterways in 1977 and 1978 (W.A. Reports 24 and 34) and a resurvey in the near future could throw further light on our model and allow further refinement of it."

The 1986 surveys of the Kimberley tidal systems were carried out by the now "standard" University of Sydney Crocodile Research Team and staff from the Western-Australian Wildlife Research Center, Department of Conservation and Land Management. The charter vessel, the M.C. Piscean was used for the 1986 surveys and was crewed by Mr. Peter Satori (Master) and Glenice Munro. Mr. Warryn Braithwaite was their young and able assistant and also participated in the surveys. The University of Sydney research vessel, The Harry Messel was used for the 1977 and 1978 surveys. Details about staff and crew for these latter surveys are given in Monograph 20.

## RESULTS

Standard survey methods as laid down in detail in Chapter 2 of Monograph 1 were used for the spotlight surveys. Summary results for each of the tidal waterways surveyed in 1977, 1978 and 1986 are shown in Tables 1 and 2.

In order to obtain an estimate for the number of *C. porosus* there are in the systems we surveyed during 1977, 1978 and 1986, we have taken the results for the Lawley and Mitchell River Systems for 1977, added in the results for the Sale River surveyed in 1978 and then added in the results for all the systems we surveyed in 1986. The results are shown in Tables 1 and 2 under the heading "OVERALL KIMBERLEY--LATEST SURVEY".

Next, in order to see how great the recovery in the Kimberley has been since the 1977 and 1978 surveys, we took the latest of the 1977 or 1978 surveys for each of the systems resurveyed during 1986 and added the results for these together. We then added together the 1986 results for the same systems. The results for this are shown in Tables 1 and 2 under the heading "OVERALL KIMBERLEY--RESURVEYED SYSTEMS ONLY". The detailed results, including the distributional diagrams and much other relevant data and discussion are appearing in Monograph 20.

In Tables 1 and 2 we have also included results for some important tidal systems in the Northern Territory, so that the results found for the Kimberley systems could be compared with them. For comparison, we chose the Blyth-Cadell System, one of the best Type 1 systems on the northern Arnhem Land coast and a system which we understand in some detail (see Monograph 1 and 18). We show results for November 1975 and October 1983 surveys in order to demonstrate how in an excellent Type 1 system, not having substantial freshwater complexes or major non-Type 1 rearing stockyards associated with it, one can have good recruitment year after year (see Monographs 1 and 18 for more details) and yet not find the density of non-hatchling crocodiles increasing. After a period of 8 years only the size structure of the animals sighted appeared to change. As the number of large animals increased the number of animals in the (3-6') size classes decreased. We also show results for the Goomadeer System (Monographs 1, 5 and 18) whose size is close to that of the Glenelg.

The third waterway we chose to compare with was the Adelaide River System (Monographs 3 and 19). This large system is one which is showing a sustained and major recovery. We give results for the July 1977 and July 1984 surveys. One should note the big increase in the number of large animals sighted and the apparent constancy of the number of animals sighted in the (3-6') size classes. The Adelaide System has a number of small freshwater complexes associated with it, and importantly a number of large non-Type 1 creek systems on its mouth sections, which function as rearing stockyards.

The large McArthur River System is the fourth system chosen for comparison (Monographs 13 and 19). It is an example of a very large system in which the *C. porosus* population is nearing exhaustion with little hope of recovery as long as commercial net fishing for barramundi is permitted on much of the waterway. The depletion of *C. porosus* on that System continues through the drowning of crocodiles in barramundi nets.

We have also included results for tidal systems in two broad geographical areas so as to be able to compare the overall Kimberley results with these. Results are shown for the Adelaide plus Alligator Region (excluding the Wildman) for the years 1977 and 1984 (Monographs 3, 4, 14 and 19). It is in this large region, with its excellent Type 1 waterways and associated freshwater complexes, that one observes what appears to be a definite recovery. Results are also given for the Maningrida area, which includes the tidal systems on the northern Arnhem Land coast, from the Goomadeer in the west to the Blyth in the east (Monographs 1, 5 and 18). The recovery for the excellent Type 1 systems in this area is much less definite and is probably evidenced by the slow change in the size composition of the animals sighted rather than an increased density of non-hatchlings.

## DISCUSSION

What can we say about recovery on each of the Kimberley Systems surveyed? Both the Ord and Glenelg Systems demonstrated their ability to mimic the Type 1 tidal systems on the northern Arnhem Land coast (shown in Tables 1 and 2) even though they should not have, with their large non-Type 1 rearing stockyards. After an interval of eight years, both of these Systems end up with a non-hatchling density less than what was found when the Systems were first surveyed by us in 1978. The number of (3-6') animals sighted remained closely the same or decreased, however the number of large animals sighted essentially doubled in both cases. In Monograph 20, we ended up our discussion of the Ord System as follows:

We sum up our analysis of the overall results for the East Arm of Cambridge Gulf--the Ord River System, by stating that we remain baffled by a number of points. Why the almost negligible hatchling and (2-3') crocodile count during the 1986 survey? Is the doubling of the number of large animals on the System between 1978 and 1986 responsible for this, through the mechanism of cannibalism? And why is the excellent Type 1 Ord System behaving as if it was a Type 1 system on the northern Arnhem Land coast, but unlike those systems, the Ord has an excellent non-Type 1 creek system at its mouth, much like the Adelaide, to act as rearing stockyards for animals excluded from the mainstream. And then there is the very large non-Type 1 West Arm of Cambridge Gulf which is simple one large rearing stockyard for animals excluded from the Ord. Why then the large exclusion and/or loss factor of 73% on the Ord? We leave the search for answers to these fascinating questions to our successors. Perhaps 40 to 50 years hence they will find a non-hatchling density of 5.0/km on the Ord, consisting largely of animals in size classes (>6')?

And for the Glenelg we ended up with the statement"

The Glenelg System with the Barlee Impediment is a small excellent system, which at first sight appears to have excellent recovery potential. However, as we have seen, this potential will take several decades to be realized, as in the cases of the tidal systems on the northern Arnhem Land coast.

After the 1978 survey, we believed that recovery on the Glenelg System would be much like that on the Prince Regent, with its North and South Arms. However, this was not to be. The North and South Arms acted as major rearing stockyards for animals excluded from the Prince Regent mainstream, and the number of animals sighted in them increased from 27(3-6') plus 42(>6') in 1978 to 55(3-6') plus 91(>6') animals in 1986. We thought that the equivalent of the North South Arms of the Prince Regent would be the Barlee Impediment for the Glenelg and that there would be a substantial increase of animals sighted on the Impediment. This did not occur and we do not know why. Fifteen crocodiles were sighted on the Impediment in 1978 and again 15 in 1986. The mystery deepens when one considers, in addition, the results for Prince Frederick Harbor with the Roe, and the Prince Frederick Harbor Creeks A to F. These Creeks have a surveyable length of 24.8 km. The Creeks have a surveyable length of 19.0 km. As we saw in the section on Prince Frederick Harbor, Creeks A to F act as rearing stockyards for animals excluded from the Roe and the number of non-hatchling crocodiles sighted in them increased from 26 in 1978 to 56 for the 1986 survey. Again, why didn't more of the crocodiles excluded from the Glenelg use the Barlee Impediment as a rearing stockyard?

The Prince Frederick Harbor System, with the Roe, Hunter and non-Type 1 Harbor Creeks A to F, behaved as one would have predicted. The density of the sighted non-hatchlings increased significantly from 1.5/km to 2.5/km for the overall System and there was a major change in the size composition of the animals sighted. The ratio (3-6')/large dropped from 3.5 for 1977 to 1.9 for 1986. This System with its rearing stockyards in Prince Frederick Harbor is functioning as predicted and is well on the road to recovery. Its recovery is akin to that for the Adelaide System shown in Tables 1 and 2.

Similar remarks apply to the excellent Prince Regent System which is close in size to the Adelaide System. Though the density of non-hatchling crocodiles sighted doubled between 1978

and 1986, it is still only 1.2/km and it must double again to approach the Adelaide for non-hatchling numbers. On the other hand, the size composition of the crocodiles is such that the (3-6')/large ratio fell from 1.2 to 0.7 between 1978 and 1986, whereas on the Adelaide this ratio was only down to 1.2 in July 1984. A few decades hence should see excellent numbers of large crocodiles on the Prince Regent System.

The remarks we made on page 154 of Monograph 18 for the tidal systems in the northern Arnhem Land coast apply with equal force for the tidal systems of the Kimberley. We remarked that a major sustained increase in the number of (3-6') and large crocodiles, and the change in population structure from a dominance in the number of (3-6') to a major dominance in the number of large animals present is inherently a slow and very long term process. During this period, there is an exceedingly severe sorting out process resulting in only a small fraction of highly successful animals surviving. Results for the "OVERALL KIMBERLEY--RESURVEYED SYSTEMS ONLY" support this view. Over an interval of 8 to 9 years, the density of the animals sighted increased from 1.2/km to 1.6/km only and the (3-6')/large ratio decreased from 2.7 to 1.3. It has been satisfying to note how successful our population dynamics model for *C. porosus* has been in helping to analyse the survey results for the Kimberley. It has allowed us to discuss meaningfully what has been observed, even though many 'why' questions still remain. One of the important ones relates to the paucity of hatchlings and (2-3') crocodiles sighted on the Kimberley System during the 1986 surveys. The matter is perhaps best summarized by our discussion of this matter for the Prince Frederick System in Monograph 20:

Our 1986 survey of the Prince Frederick Harbor System yielded a strange picture in relation to the number of hatchlings and (2-3') animals sighted. Nine hatchlings were observed on the Hunter River and only one on the remainder of the Prince Frederick Harbor System. A total of only 12(2-3') animals were observed. What happened? As shall be seen later in this Monograph, this observation parallels our survey results for the other tidal waterways which we surveyed in the Kimberley in July-August, 1986—a paucity of hatchlings and (2-3') animals on each of the major systems surveyed. Could this be related to the observation, which we shall discuss shortly, that the number of large animals sighted had increased considerably since 1977? Is it possible that hatchling recruitment was in fact much higher, but that the hatchling and (2-3') animals were cannibalized by the increasing number of large animals? Or, for some reason, had the two previous wet seasons on the Roe-Hunter Systems been poor nesting seasons? Some indirect support for this latter view may be provided by the 47(3-4') animals sighted (see Table 20.6.30). These animals would have resulted from nesting during the 1983-1984 wet season. However, note that the nesting success on the Hunter appears to have been about the same in 1986 as it was in 1977. Furthermore the wet season of 1985-1986 was "dry" until the very heavy rainfall at the end of January. This caused widespread and heavy flooding in the Kimberley. Most nests laid down in January were not likely to have survived. However, nests laid down after that should have been successful. The wet season of 1984-1985 was relatively dry and there was little flooding in the tidal waterways of the Kimberley. It should have been a very successful nesting season with little or no loss of nests due to flooding. Then why so few (2-3') animals sighted in 1986? Thus the overall mystery remains!

The results in Tables 1 and 1 demonstrate that when we first surveyed the tidal river systems in the Kimberley, during 1977 and 1978, we were dealing with badly depleted populations. In Western Australia hunting pressure on *C. porosus* was particularly high during the early 1960's and by 1969 the species had become rare. *C. porosus* was not protected until April 1970, by which time

commercial hunting had become uneconomic. Protection followed in the Northern Territory in 1972 and a total export-import ban on crocodile products was declared by the Commonwealth Government later the same year. It was this ban that effectively stopped hunting throughout Australia. The species has now had some 16 years to recover, but as we have seen, this recovery is now still only in its early phase and complete protection must continue to be accorded to the species.

In 1978, in Report 34, we gave as estimate for the number of non-hatchling *C. porosus* population in Western Australia is between 2,300 and 2,488 animals.

On page 433, Monograph 1 we also made estimates for the number of non-hatchling crocodiles remaining in the Kimberley in 1978. We stated the following:

"We believe that we examined more than half of the better *C. porosus* habitat in the Kimberley. In the 527.3 km surveyed, 898 crocodiles were sighted of which 227 were hatchlings. The 671 non-hatchling yield a density of 1.3/km and the estimate for the actual number of non-hatchlings present, at the 95% confidence level, is 1,048-1,152. Assuming that the number of non-hatchlings which would be sighted in the areas not surveyed is also 671 we obtain lower limits of 2,127-2,275 for the number of non-hatchlings remaining in the Kimberley as of July 1978. One can extend this estimate (of say 2,500) almost without limit if one cares to make what we feel would be unreasonable assumptions."

It is obvious that we were overly generous with this estimate of 2,500 and that the figure of 2,000 we gave in Report 34 was closer to the correct figure for 1978. The figure of 2,500 non-hatchling crocodiles is the figure for 1986. It is to be compared with the some 3,000 animals reportedly taken for their skins around the Admiralty Gulf area alone, during the period 1963-1965 (pers. comm. Father Sanz, formerly of Kalumburu Mission).

#### ACKNOWLEDGEMENTS

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#### MONOGRAPH SERIES

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A series of monographs covering the navigable portions of the tidal rivers and creeks of northern Australia. Published by Pergamon Press, Sydney, Australia, 1979-1987.

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20. Tidal Waterways of the Kimberley Surveyed during 1977, 1978 and 1986. Messel, H.; Burbidge, A.A.; Vorlicek, G.C.; Wells, A.G.; Green, W.J.; Onley, I.C. and Fuller, P.J.

Appearing in the same series and published by the Western Australian Government:

1. The status of the salt-water crocodile in some river systems of the north-west Kimberley, Western Australia. Dept. Fish. Wildl., West, Aust. Rept. No. 24:1-50(1977). Messel, H.; Burbidge, A. A.; Wells, A. G. and Green, W. J.
2. The status of the salt-water crocodile in the Glenelg, Prince Regent and Ord River Systems, Kimberley, Western Australia, Dept. Fish. Wildl. West. Aust. Rept. No. 34:1-38(1979). Burbidge, A. A. and Messel, H.

TABLE 1. Number of *C. porosus* sighted within each size class on the Kimberley tidal waterways shown during night-time spotlight surveys carried out during 1971, 1978 and 1986. The midstream distance surveyed and density of non-hatchling crocodiles sighted on each waterway is shown, as are the 95% confidence limits for the estimate of the actual number of non-hatchlings present. The TYPE classification of each waterway is given also. Results for the Blyth-Cadell and Goomadeer Systems for 1975 and 1983, for the Adelaide for 1977 and 1984 and for the McArthur for 1979 and 1985 are shown for comparison. Also shown are results for the geographical group of waterways of the Adelaide and Alligator Region for 1977 and 1984, and the Maningrida area for 1976 and 1983.

System	Totals	H	2-3	Numbers in size class							km Surveyed	Density	95% Levels	TYPE
				3-4	4-5	5-6	6-7	>7	EO					
CAMBRIDGE GULF EAST ARM - ORD														
July 78	179	14	17	39	50	19	11	8	21	98.8	1.7	245-297	1	
July 86	153	3	1	15	28	25	12	29	40	98.8	1.5	221-271		
WEST ARM														
July 86	128		1	17	15	23	18	21	33	203.0	0.6	187-233	2-3	
EAST-WEST ARM														
July 86	281	3	2	32	43	48	30	50	73	301.8	0.9	422-490	1 to 3	
PORT WARRENDER-LAWLEY														
July 77	38	11	1	3	6	6	2	5	4	34.0	0.8	34- 54	2	
July 77	44	13	1	4	6	8	5	3	4	34.0	0.9	40- 62		
WALMESLY BAY-MITCHELL														
July 77	50	8	1	9	12	8	3	6	3	47.7	0.9	56- 82	1	
PRINCE FREDERICK HARBOR ROE MAINSTREAM AND CREEKS														
July 77	135	37	40	27	11	7	4	4	5	43.8	2.2	141-181	1	
August 86	158	1	9	35	33	27	23	7	23	43.8	3.6	232-282		

TABLE 1. cont.

System	Totals	Numbers in size class							km Surveyed	Density	95% Levels	TYPE	
		H	2-3	3-4	4-5	5-6	6-7	>7					
PRINCE FREDERICK HARBOR CREEKS													
July 77	41	15			11	7	4	2	2	24.8	1.0	33- 53	1 to 3
August 86	56		1	1	15	10	9	12	8	24.8	2.3	77- 107	
ROE SYSTEM													
July 77	176	52	40	27	22	14	8	6	7	68.6	1.8	181- 225	1 to 3
August 86	214	1	10	36	48	37	32	19	31	68.6	3.1	320- 378	
HUNTER SYSTEM													
July 77	47	11	7	5	10	6	4	2	2	35.3	1.0	47- 71	2-3
August 86	59	9	2	11	8	5	7	9	8	35.3	1.4	68- 96	
OVERALL PRINCE FREDERICK SYSTEM													
July 77	223	63	47	32	32	20	12	8	9	103.9	1.5	237- 287	1 to 3
August 86	273	10	12	47	56	42	39	28	39	103.9	2.5	398- 464	
GEORGE WATER SYSTEMS SALE													
July 78	3					1		2		19.0	0.2	3	1
BARLEE IMPEDIMENT													
July 78	15	1		2	4	5	1	2		19.0	0.7	15- 31	2 to 3
August 86	15			2			2	3	8	20.5	0.7	17- 33	
GLENELG-GAIRDNER													
July 78	193	72	33	24	29	12	10	7	6	58.3	2.1	176- 220	1
August 86	124	20		30	24	14	16	8	12	57.5	1.8	151- 191	

TABLE 1. cont.

System	Totals	Numbers in size class							EO	km Surveyed	Density	95% Levels	TYPE
		H	2-3	3-4	4-5	5-6	6-7	>7					
OVERALL GLENELG AND BARLEE													
July 78	208	73	33	26	33	17	11	9	6	77.3	1.7	198-244	1 to 3
PRINCE REGENT MAINSTREAM AND CREEKS													
July 77	74	15	4	25	12	8	5	1	4	58.6	1.0	82-112	1
July 78	92	31	11	17	11	8	6	6	2	68.2	0.9	84-116	
August 86	87		3	19	12	8	16	20	9	68.2	1.3	124-162	
NORTH ARM													
July 77	39	6	1		8	7	9	8		36.8	0.9	42-66	2 to 3
July 78	62	20	2	1	11	8	7	10	3	63.5	0.7	56-82	
August 86	85	5	3	6	9	11	18	19	14	63.5	1.3	113-149	
SOUTH ARM													
July 77	33	4		2	9	4	6	5	3	39.6	0.7	37-59	2 to 3
July 78	35	5	1		2	4	7	15	1	74.3	0.4	38-60	
August 86	75		6	1	8	10	21	23	6	74.3	1.0	106-140	
OVERALL SYSTEM													
July 77	146	25	5	27	29	19	20	14	7	135.0	0.9	176-220	1 to 3
July 78	189	56	14	18	24	20	20	31	6	206.0	0.6	195-241	
August 86	247	5	12	26	29	29	55	62	29	206.0	1.2	366-428	
OVERALL KIMBERLEY-LATEST SURVEY													
77 or 78 & 76	1037	59	28	150	170	150	150	162	168	790.4	1.2	1541-1667	1 to 3

TABLE 1. cont.

System	Totals	Numbers in size class							EO	km Surveyed	Density	95% Levels	TYPE
		H	2-3	3-4	4-5	5-6	6-7	>7					
OVERALL KIMBERLEY-RESURVEYED SYSTEMS ONLY													
77 or 78	799	206	111	115	139	76	54	56	42	486.0	1.2	924-1022	1 to 3
1986	812	38	25	120	137	110	124	130	128	486.7	1.6	1213-1325	
BLYTH-CADELL - Monographs 1 and 18													
Nov. 75	353	50	106	81	72	23	4	2	15	94.9	3.2	462- 532	1
Oct. 83	354	73	95	69	45	24	11	10	27	92.8	3.0	427- 495	
GOOMADEER - Monographs 1, 5 and 18													
August 75	46		27	7	5	4			3	45.3	1.0	61- 89	1
June 83	63	24	5	6	8	3	3	4	10	45.3	0.9	53- 79	
ADELAIDE - Monographs 3 and 19													
July 77	417	48	24	88	116	47	35	33	26	226.3	1.6	566- 644	1
July 84	602	60	36	105	79	64	78	120	60	231.6	2.3	842- 936	
McARTHUR - Monographs 13 and 19													
May 79	28			2	3	6	4	5	8	232.6	0.1	35- 57	1
Sept. 85	48	2	14	1	3	1	5	9	13	232.6	0.2	61- 89	
ADELAIDE + ALLIGATOR REGION EXCL. WILDMAN - Monograph 19													
July & Oct. 77	1055	111	45	159	244	140	116	126	114	543.1	1.7	1486-1610	1
July 84	1648	145	121	288	181	152	200	340	221	552.6	2.7	2387-2543	
MANINGRIDA AREA - BLYTH TO GOOMADEER - Monographs 1 and 18													
July-Sept. 76	651	121	107	174	83	29	14	12	111	339.9	1.6	823- 915	1
June-July 83	1045	340	189	141	122	77	42	28	106	333.1	2.1	1103-1209	

TABLE 2. This Table was prepared using the results given in Table 1 and groups the crocodiles sighted into the important size classes shown. 50% of the EO size classes were distributed to the (3-6' size classes and the remaining 50% to the  $\geq 6'$ ) size classes. This weights the distribution heavily in favor of larger crocodiles, which are known to normally be the most wary. When the EO is an odd number, the bias is also given to the ( $\geq 6'$ ) size classes.

Survey	Totals	H	(2-3')	(3-6')	Large ( $>6'$ )	(3-6') Large
CAMBRIDGE GULF EAST ARM - ORD						
July 78	179	14	17	118	30	3.9
July 86	153	3	1	88	61	1.4
WEST ARM						
July 86	128		1	71	56	1.3
EAST-WEST ARM						
July 86	281	3	2	159	117	1.4
PORT WARRENDER-LAWLEY						
July 77	38	11	1	17	9	1.9
July 77	44	13	1	20	10	2.0
WALMESLY BAY-MITCHELL						
July 77	50	8	1	30	11	2.7
PRINCE FREDERICK HARBOR ROE MAINSTREAM AND CREEKS						
July 77	135	37	40	47	11	4.3
August 86	158	1	9	106	42	2.5
PRINCE FREDERICK HARBOR CREEKS						
July 77	41	15		19	7	2.7
August 86	56		1	30	25	1.2
ROE SYSTEM						
July 77	176	52	40	66	18	3.7
August 86	214	1	10	136	67	2.0
HUNTER SYSTEM						
July 77	47	11	7	22	7	3.1
August 86	59	9	2	28	20	1.4

TABLE 2. cont.

Survey	Totals	H	(2-3')	(3-6')	Large (>6')	(3-6') Large
OVERALL PRINCE FREDERICK SYSTEM						
July 77	223	63	47	88	25	3.5
August 86	273	10	12	164	87	1.9
GEORGE WATER SYSTEMS SALE						
July 78	3			1	2	0.5
BARLEE IMPEDIMENT						
July 78	15	1		11	3	3.7
August 86	15			6	9	0.7
GLENELG-GAIRDNER						
July 78	193	72	33	68	20	3.4
August 86	124	20		74	30	2.5
OVERALL GLENELG AND BARLEE						
July 78	208	73	33	79	23	3.4
August 86	139	20		80	39	2.1
PRINCE REGENT SYSTEM MAINSTREAM AND CREEKS						
July 77	74	15	4	47	8	5.9
July 78	92	31	11	37	13	2.8
August 86	87		3	43	41	1.0
NORTH ARM						
July 77	39	6	1	15	17	0.9
July 78	62	20	2	21	19	1.1
August 86	85	5	3	33	44	0.8
SOUTH ARM						
July 77	33	4		16	13	1.2
July 78	35	5	1	6	23	0.3
August 86	75		6	22	47	0.5
OVERALL SYSTEM						
July 77	146	25	5	78	38	2.1
July 78	189	56	14	65	54	1.2
August 86	247	5	12	98	132	0.7

TABLE 2. cont.

Survey	Totals	H	(2-3')	(3-6')	Large (>6')	(3-6') Large
OVERALL KIMBERLEY - LATEST SURVEY						
77 or 78 & 86	1037	59	28	554	396	1.4
OVERALL KIMBERLEY - RESURVEYED SYSTEMS ONLY						
77 or 78	799	206	111	351	131	2.7
1986	812	38	25	430	319	1.3
BLYTH - CADELL - Monographs 1 and 18						
November 75	353	50	106	183	14	13.1
October 83	354	73	95	151	35	4.3
GOOMADEER - Monographs 1, 5 and 18						
August 75	46		27	17	2	8.5
June 83	63	24	5	22	12	1.8
ADELAIDE - Monographs 3 and 9						
July 77	417	48	24	264	81	3.3
July 84	602	60	36	278	228	1.2
McARTHUR - Monographs 13 and 19						
May 79	28			15	13	1.2
September 85	48	2	14	11	21	0.5
ADELAIDE + ALLGATOR REGION EXCL. WILDMAN - Monograph 19						
July & Oct. 77	1055	111	45	600	299	2.0
July 84	1648	145	121	731	651	1.1
MANINGRIDA AREA - BLYTH TO GOOMADEER - Monographs 1 and 18						
July-Sept. 76	651	121	107	341	82	4.2
June-July 83	1045	340	189	393	123	3.2



**CROCODILES**  
**THEIR ECOLOGY, MANAGEMENT, AND CONSERVATION**

**A Special Publication of the Crocodile Specialist Group  
of the Species Survival Commission of the International Union for  
Conservation of Nature and Natural Resources**

**International Union for Conservation of Nature and Natural Resources**

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1989

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## FOREWORD

This volume is a special publication of the IUCN/SSC Crocodile Specialist Group. The papers in this volume originally were prepared as chapters in a volume on crocodilians which was to be commercially published. The members of the CSG first committed to producing the commercial volume at the 7th Working Meeting in Caracas, Venezuela, in 1984. That commitment was renewed at the 8th Working Meeting in Quito, Ecuador, in 1986. Unfortunately, conflicting responsibilities prevented many of the authors from meeting their obligations to the publisher on schedule and the project had to be abandoned. Rather than scrap publication of the chapters that were turned in on time, most of the authors agreed to have their papers published in this special volume in the CSG Proceedings series.

Publication of this volume was supported by contributions from Professor Harry Messel and the University Foundation for Physics, University of Sydney, Australia; the Nixon Griffis Wildlife Conservation Fund of the University of Florida Foundation, Gainesville, U.S.A.; and Jacques Lewkowicz of Société Nouvelle France Croco, Paris. The opinions expressed herein are those of the individuals identified and are not the opinions of the International Union for Conservation of Nature and Natural Resources or its Species Survival Commission. Phil Hall was scientific editor and managing editor, Rhoda Bryant was copy and style editor.

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The International Union for Conservation of Nature and Natural Resources (IUCN) was founded in 1948, and has its headquarters in Gland, Switzerland; it is an independent international body whose membership comprises states, irrespective of their political and social systems, government departments, and private institutions as well as international organizations. It represents those who are concerned at man's modification of the natural environment through the rapidity of urban and industrial development and the excessive exploitation of the earth's natural resources, upon which rest the foundations of his survival. IUCN's main purpose is to promote or support action which will ensure the perpetuation of wild nature and natural resources on a world-wide basis, not only for their intrinsic cultural or scientific values but also for the long-term economic and social welfare of mankind.

This objective can be achieved through active conservation programs for the wise use of natural resources in areas where the flora and fauna are of particular importance and where the landscape is especially beautiful or striking, or of historical, cultural, or scientific significance. IUCN believes that its aims can be achieved most effectively by international effort in cooperation with other international agencies, such as UNESCO, FAO, and UNEP, and international organizations, such as World Wild Fund for Nature (WWF).

The mission of IUCN's Species Survival Commission (SSC) is to prevent the extinction of species, subspecies, and discrete populations of fauna and flora, thereby maintaining the genetic diversity of the living resources of the planet. To carry out its mission, the SSC relies on a network of over 2,000 volunteer professionals working through 100 Specialist Groups and a large number of affiliate organizations, regional representatives, and consultants, scattered through nearly every country in the world.

# POPULATION DYNAMICS OF THE AMERICAN ALLIGATOR

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Vanity of vanities, saith the Preacher, vanity of vanities, all is vanity.

Ecclesiastics I:2.

## INTRODUCTION

The necessary title of this chapter suggests more vanity than I would prefer to confess. To begin with, I am not familiar with "the American Alligator". Indeed, modern research indicates that despite relative genetic homogeneity (Adams et al. 1980), the beast varies in demographically important ways from place to place--and perhaps from year to year. That is to say, alligators strongly reinforce the natural historian's fear of generalizations. To make matter worse, I am not particularly confident even about any single-frame "snapshot" of an alligator population at time  $t$ ; therefore, to project a dynamic "movie" over  $t$ ,  $t+1$ , ...,  $t+n$  seems indeed the height of vanity. In other words, most of what I personally know about alligators focuses rather narrowly on Florida animals. And I admit that even for these populations I cannot offer decent life tables, much less expressions of density dependence. Nevertheless, scientific ignorance about alligators is not unbounded. Some facts are known quite well enough, and these facts necessarily entail general demographic consequences. I shall review these facts, and I shall even venture in some instances to speculate beyond the confines of available data. Still, I hate to promise more than I can deliver, and in an age of longer titles, I would have called this chapter "Alligator Life History: Meditations from a Demographic Perspective." Thus my general strategy is rather simple. I shall examine the alligator literature for relevant life-history data. Supplementing this information with observations recently conducted in Florida, I shall attempt to establish broad ranges for values of several important demographic parameters. This will permit semi-informed guesses about what manner of demographic beast the alligator must be. In other words, my essay's objective is to employ what is known about alligators while speculating on matters which are not yet understood. In particular, I have in the back of my mind three presently unanswered questions, all of considerable scientific and managerial significance: What are alligator survival rates? How do alligators respond to alterations in density? And how are alligator populations affected by demographic catastrophes? Again I admit at the outset that I can do little more than merely raise these interesting questions. But I want to start you readers thinking about them because you all will be the folks eventually to work out the solid answers.

Actually I would have been unwilling to attempt even this modest task without considerable assistance, but, fortunately, alligator biologists have been very willing to share their time and insights. Colleagues that come readily to mind are Tommy Hines, Terri Jacobsen, Mike Jennings, Wayne King, Wendell Neal, Jim Nichols, Jane Packard, Franklin Percival, David Scott, Dave Taylor, Phil Wilkinson, and Allan Woodward. The most creative advice came, of course, from Paul Moler--when he could tear himself away from his eternal pursuit of the noble *Pseudobranchius*. The writing of this essay was partially supported by a faculty research grant from Wofford College. And, finally, I need publicly to thank the Spartanburg, South Carolina, K-Mart for selling a word processor that even I could afford.

### DEFINING RANGES OF DEMOGRAPHIC PARAMETERS

The traditional first cut at alligator population dynamics has been to establish a population size structure and to interpret that structure by way of growth rates into a life table (Nichols et al. 1976b). In Florida we have been deterred from that approach by two basic difficulties. It is, to begin with, exceedingly hard to determine a population's size structure. The general problems in night-light counts are well known (Woodward 1978, Magnusson 1983, Wood et al. 1983), and even if those problems were entirely solved, the counts could provide no information on the demographically crucial sex ratios. Understandably leary of night counts, alligator managers have focused instead on harvest structures. Unfortunately, however, harvests are generally biased against some size classes (Hines 1979, Taylor and Neal 1984). Furthermore, Florida observations suggest that harvest is also seriously biased by sex, a point amplified by Ferguson and Joanen (1983).

The saddest note is, of course, that determining a size structure is the easier half of the life-table battle. Within the next few years histological techniques for alligator age determine will probably be developed, but presently it is no fun at all to figure growth rates. In Florida, for example, we have learned that growth rates vary from area to area. Within a given area, they vary from year to year. Within a single area-year, they vary from microhabitat to microhabitat. And when all obvious space, time, and habitat variables are controlled, growth rates appear to vary stochastically from gator to gator!

All of this reinforces my reluctance to inflict an empirical growth curve upon an observed population structure (though you really should take a look at Taylor and Neal [1984]). Nevertheless, there is a very real sense in which limited, certain knowledge about growth tells us a great deal concerning the demographic nature of alligators. A newly-hatched alligator is approximately 25 cm in length and weighs about 50 g. If it is a male, a hatchling can eventually grow to be over 4 m long and may increase its weight by 7,000%. Females are significantly smaller; nevertheless, they seldom attain reproductive maturity at much less than 2 m (about 35 kg). This extraordinary increase from hatchling to adult size, a well-known fact, provides a reasonably firm jumping-off point for an analysis of alligator demography.

Let us consider a hypothetical alligator from north-central Florida, where climate dictates a 6.5-month (about 200 day) growing season. Investigations in Florida indicate that age at maturity is not necessarily constant across a given population, and it certainly is not the same throughout the alligators entire range. McIlhenny (1935) speculated that females might mature in 6-7 years. Although a specially fed captive gator was observed to lay eggs at under 5 years of age (Whitworth 1971), I am reluctant to believe that wild animals successfully nest at ages less than the 9-10 years suggested by Chabreck and Joanen (1979). At the other extreme is the 18-plus years given by Fuller (1981) for North Carolina animals, a figure echoed by Jacobsen (pers. comm.) for alligators

in nutritionally impoverished portions of the Florida Everglades. I shall eventually return to this age-at-maturity question, but for now let us simply assume that a hypothetical female alligator in north-central Florida has, at around age 12 (length about 1.9 m), just reached reproductive adulthood. If we grant her membership in a numerically stationary population, then she can do her part in maintaining the population's stationary size if she produces in her lifetime exactly one daughter that lives long enough to begin her own reproductive career. To see how she might do this, let us consider a simple model of our newly matured female's lifetime production. If  $D$  is the expected number of daughters that will survive to begin their own reproductive careers, then

$$(1) \quad D = (Y)(N)(P),$$

where  $Y$  is the expected number of years before our newly-matured female dies or becomes reproductively senile;  $N$  is the expected number of hatchling daughters our female will produce annually across all  $Y$  year; and  $P$  is the probability that a given hatchling daughter will survive to begin her own reproductive career. (Demographers will note that what I call  $D$  would in conventional notation be  $R[0]$ , the net reproductive rate, calculated in terms of new reproductive-age females rather than hatchling females. Furthermore, I have chosen the nonstandard approach of analyzing the net reproductive rate rather than the finite rate of increase, because the former is calculable in a more easily explained manner from the alligator data we possess).

Each factor in this simplistic equation is actually a combination of many demographic parameters. Let us therefore dissect Equation (1) and indicate apparently reasonable ranges for parameters values.

#### Y: Expected Years between Maturity and Senescence or Death

Let  $L$  represent the probability that a reproductively mature female lives from one year to the next. (Technically the demographer would prefer to talk about  $L[t]$ , which would represent age-specific survivorship between age  $t$  and age  $t+1$ . Fortunately, such precision is probably not practically important. Gibbons and Semlitsch (1982) have demonstrated that mortality in large emydid turtles remains approximately constant over time, and examination of Florida harvest size-class ratios suggests that the same may be true female alligators, at least over the first 10-15 years of maturity. In any case, the current alligator literature does not suggest important deviations from constant adult survivorship, so I shall simplify the demographic equations and replace  $L[t]$  with the single parameter  $L$ ). Convincing estimates for  $L$  do not abound. Nichols et al. (1976a, b) suggest an approximate value of 0.89. Taylor and Neal (1984) believe that survivorship among adult male gators is about 0.775; these authors recognize that female mortality would be lower. Informal observations on radio-telemetered animals suggest to Wilkinson (pers. comm.) that adult female survivorship may be in the neighborhood of 0.95. Given this admittedly sketchy information, it may not be unreasonable to assume initially that adult survivorship is in the 0.85- 0.95 range among female alligators.

To calculate an alligator's potential reproductive years, one must consider not only mortality but also senescence. The time of onset doubtless varies across individuals, and in any case senescent effects are not necessarily sudden (Ferguson and Joanen 1983). Webb et al. (1983b) suggest that female alligator senescence occurs between 40 and 50 years of age. Table 1 gives expected reproductive lifetimes ( $Y$  in the equation above) for newly matured female alligators with various fixed survivorship, ages to maturity, and ages at senescence. From this table it is clear that unless annual survivorship is very high, the number of years between expected maturity and expected senescence is relatively much less important than mortality in determining  $Y$ . Furthermore, it also appears that  $Y$  is likely to lie between about 6 and 18 years.

Table 1. Expected Reproductive Lifetimes

Annual survivorship	Age at maturity	Age at senescence	Expected years as adult (Y)
0.85	16	40	6.03
0.85	12	45	6.12
0.85	9	50	6.15
0.85	--	infinity	6.15
0.90	16	40	8.73
0.90	12	45	9.20
0.90	9	50	9.36
0.90	--	infinity	9.49
0.95	16	40	13.80
0.95	12	45	15.91
0.95	9	50	17.21
0.95	--	infinity	19.50

N: Expected Annual Production of Hatchling Daughters per Mature Female

To avoid getting fancy, I shall express the complex parameter N as

$$(2) \quad N = (R) (E) (H) (F),$$

where the various equation components are as defined below.

R: Annual Nesting Probability. R expresses the probability that a reproductive-aged female nests in any given year. Field research in Louisiana suggests values ranging between 0.48 and 0.68 (Chabreck 1966, Joanen and McNease 1971, 1973, 1975, 1976). Working with animals in a thermally altered reservoir (Par Pond, South Carolina), Murphy (1981) believed the proportion of females nesting was less than 34%. Wilkinson (1983) reports about 27.5% for the South Carolina coastal plain. All these values are considerably lower than estimates reported for *Crocodylus niloticus* (87.6%; Graham 1968) and *C. johnstoni* (90%; Webb et al. 1983a). Perhaps this interspecific variation is a function of differing energy budgets and of more rigorous metabolic requirements in the alligator's temperate range. In that connection it would be particularly interesting to ascertain the percent of adult female gators that nest in certain subtropical Florida habitats. But for the present let us simply agree that, for alligators in general, the proportion of adult females nesting is probably between 0.2 and 0.7.

E: Probability of Nest Success. E is the probability that any given nest escapes predation, flooding, etc. and hatches. Again, field research presents a bewildering array of values. Metzen (1977) reports nest success of 10%. This occurred, however, in area of heavy black bear infestation and is probably about as unusual as the 90% success which can be observed some places, some



years, in Florida. Presumably more typical are the 48.3% and 74.2% success rates reported by Ruckel and Steele (1984) for two Georgia locations. Dietz and Hines (1980) give 67.9% for Orange Lake, Florida. The rate at Rockefeller Refuge, Louisiana, is about 68.3% (Joanen 1969), in South Carolina it is approximately 70% (Wilkinson 1983; this source reports the proportion of nests from which at least one egg hatched). Discounting the somewhat aberrant findings of Metzen (1977), one might conclude that values for E typically lie between 0.3 and 0.7.

H: Hatchlings per Nest. H is the expected number of living young that a nest will produce, given that the nest is not destroyed. Over the years, a great deal of information has been collected on alligator clutch size and fertility. Representative data on these factors are reported in Table 2 below. Where possible, information from geographically proximate areas was combined; I had to calculate some of the figures below from other types of statistics presented in the cited works.

Even in "successful" nests, there are various reasons that not all fertile eggs hatch, and therefore calculations based on percent fertility overestimate the number of actual hatchlings. On the other hand, difficulties in field observation usually mean that reports of hatchlings actually seen tend to underestimate production. I shall largely neglect these factors and assume that H, production per successful nest, is somewhere between 20 and 40.

F: Proportion of Hatch Female. F is the proportion of living hatchlings that are female. Most information on alligator sex ratios seems to focus on animals beyond the hatchling stage (Forbes 1940, Chabreck 1966, Nichols and Chabreck 1980, Murphy 1981, Murphy and Wilkinson 1982, Wilkinson 1983). Earlier, Ferguson and Joanen (1983) reported a reasonable sample of Louisiana marsh hatchling production as 80% female. On the other hand, Taylor (pers. comm.) believed the sex ratio in a north Louisiana system was close to 50-50. In Florida we have observed individual pods with nearly all imaginable sex ratios. My subjective evaluation is that our population-wide hatchling cohorts are no more than 60% female--and may be significantly less. Since alligator gender is determined by early incubation temperatures, it is entirely possible that hatchling sex ratios may differ substantially by geographical area. Nevertheless, by microhabitat nest-site selection, laying females can exercise some "choice" over the gender of their offspring, and arguments have been presented (Ferguson and Joanen 1983) for the likelihood of female-skewed hatchling production in numerous habitats. Therefore, despite field suggestions that gender ratios may not be so definitely skewed, I shall bow to Ferguson's greater expertise and state that F probably lies between 0.6 and 0.8.

P: Probability that a hatchling Daughter Survives to Reproductive Age.

Even in simplest form, this parameter must involve the growth and survival rates of immature animals. We shall model it as

$$(3) \quad P = S^*M$$

where the equation components are as defined below.

M: Time of Maturity. M is the expected number of years between hatchling and attainment of reproductive maturity by female alligators. This parameter has already been briefly discussed above; indications are that in most alligators it lies between 8 and 16 years.

S: Average Immature Survival. S is the "average" (geometric mean) annual survival probability for immature female alligators between ages 0 and M years. (Recall that the geometric mean is necessarily equal to or less than the arithmetic mean.) Our field work in central Florida suggests that appropriate values probably lie between 0.55 and 0.70. This very rough range

Table 2. Nest Production.

Location	Number of nests	Average clutch size	Percent fertile	Percent Reported hatched per successful nest	Estimated Production (clutch size times % fertile, or % hatch)	Source
North Carolina	--	35.3 (minimum)				Fuller, 1981
South Carolina	--	40.6				Bara, 1972
South Carolina	203	44.2	93.85%		41.5	Wilkinson, 1983
Georgia (2 areas)	60	39.4	84.6%		33.3	Rockland Steele, 1984
Okefenokee Georgia	55	30		70%	21.0	Metzen, 1977
N. Central Florida (2 areas)	67	37.5		67.9%	25.5	Deitz and Hines, 1980
N. Central Florida (2 areas)	21	34.6	87.6%		30.3	Woodward, pers. comm.
Central Florida (2 areas)	78	45.7	89.5%		40.9	pers. obs.
Lk. Apopka, FL	20	44.8	45.8%		20.5	pers. obs.
Okeechobee Florida	63	43.6	77.9%		34.0	Woodward pers. comm.
Rockfeller Ref., LA	--	39.5		58.2%	23.0	Joanen, 1969

matches reasonably well with the S-value of 0.61-0.62 derivable from the alligator population model of Nichols et al. (1976b). One should note that S incorporates hatchling-year survival, which under some circumstances may be extremely low.

#### Summary of Suggested Parameter Values.

At this point we can express D, the expected lifetime production of daughters that reach reproductive age, as a function of the 7 parameters defined above:

$$(4) \quad D = (Y) (R) (E) (H) (F) (S^{**}M).$$

If we restrict our analysis to a stationary population (in which D is 1.0 by definition), then we can fix any 6 parameters and observe what value the seventh, "free" parameter, must take. In Table 3 I list previously suggested ranges and range midpoints for all parameters. I also indicate the value each parameter would take if it were left free and all other parameters were fixed at their mid-range values.

### GROWTH AND SURVIVAL: THE DEMOGRAPHIC POWER OF PARTICULAR PARAMETERS

We should note that when "freed", all parameter values fall outside suggested ranges. Some (e.g., Y and H) seem biologically unrealistic, and others (R, E, F) are logically impossible. This indicates that we have in a sense "underestimated" the dynamics of a stable alligator population: the varmits survive better, mature faster, lay more eggs, or produce more females than we had thought. But our simple model tells us more than this: it can also point out which parameters are demographically most important. To address this matter of importance, we should inquire how each parameter affects the value of D when all other parameters are held constant. We can see from Equation (4) that the effects of Y, R, E, H, and F are linear: changes in the values of these parameters will produce only proportional changes in D. Table 3 (above) clearly shows that none of these parameters, considered alone, can be realistically expected to have a value high enough to offset the values estimated for other parameters--and thereby maintain a viable alligator population. Furthermore, even when all these parameters are taken together, the situation is not greatly improved. For example, hold S and M at their suggested mid-range values, but allow Y, R, E, H, and F simultaneously to assume their maximum values suggested as plausible by Table 3. D is then calculated to be 1.00. This means, of course, that the expected lifetime production of maturing daughters has just reached the bare maintenance level. Furthermore, in real gator populations, it is certainly not sufficient to run during normal years at mere maintenance! As we shall eventually discover, demographic catastrophes (such as complete one-year nesting wipeouts) are not uncommon. Therefore (since years with surplus production high enough to balance such catastrophes appear to be very rare and perhaps physiologically impossible), long-term demographic success would require D to stand at a cushioned level substantially above 1.0 during typical years.

Now, for contrast, set all the linear parameters (Y, R, E, H, and F) at midrange and alter only S and M, the nonlinear parameters, to their most favorable suggested values. D is then calculated to be 3.27, a figure greatly exceeding the production required for population maintenance.

The major demographic point of this tedious exercise concerns growth and survival. If female alligators indeed require a substantial number of years of mature (evidence is strong that they do), then in a stable or increasing population, the average survival of even the immature age classes

Table 3. Parameter Ranges.

Parameter and Abbreviated definition	Suggested range	Mid-range value	Value if left free
Y, expected repro. lifetime	6-18	12	60
R, probability of nesting	0.2-0.7	0.45	2.23
E, probability nest hatches	0.3-0.7	0.50	2.48
H, number of hatchlings	20-40	30	124
F, proportion of hatch female	0.6-0.8	0.7	2.61
S, average immature survival	0.55-0.70	0.625	0.723
M, years to reach maturity	8-16	12	7.6

must be quite high (Woodward et al. 1987). Furthermore, this requirement for high survival cannot be obviated by increases in clutch size, nest survival, or percent female: these parameters simply do not have the "punch" to make up the alligator demographic deficit.

#### ALLIGATOR INSTARS: FURTHER RAMIFICATIONS OF GROWTH AND SIZE

Knowledge about alligator size and growth rates has thus led us indirectly to the conclusion that survival, even among juveniles, must be rather high. Furthermore, there is another demographic lesson to be learned from this matter of size. A newly hatched alligator is one of the smaller vertebrate predators in a Florida wetlands system; after it matures, it will be the largest. Thus it may be unreasonable to represent alligators of all sizes by one simplistic demographic model. Consider, for example, the question of population response to changes in density. Simple patterns of density-dependent population growth have often been modeled by the familiar Verhulst-Pearl logistic curve:

$$(5) \quad dN/dt = N(1 - N/K)$$

According to this equation, the rate of per capita population increase decreases linearly as density approaches a "carrying capacity"; the operative mechanism is usually assumed to be some form of intraspecific competition. Even the intro wildlife textbooks admit that the model will require a few minor patches before it can be applied to any actual population. But with gators the problems are more than cosmetic: one might in fact ask whether it makes sense to use this model at all when talking about alligators. How, for example, should one express the density of a natural alligator population? Number of animals per hectare? Meters of animals per hectare? Kilograms of animals per hectare? All of these suggestions sound rather foolish, since it is not realistic to think that hatchlings and adults compete directly for any important, limiting resource.

Of course it is possible to rework Equation (5) for alligators. One would begin by redefining density (and thereby the units of  $K$ ) as some sort of effective size-structured competition density (call it ED):

$$(6) \text{ ED} = \frac{\text{BIG old gator size}}{\text{hatchling size}} \frac{\text{BIG old gator size}}{\text{hatchling size}} a(x,y) f(x) dx dy,$$

where ED is that weird effective density,  $a(x,y)$  is the effect of an animal of size  $x$  on an animal of size  $y$ , and  $f(x)$  is the density of animals of size  $x$ . Unfortunately, Equation (6) is mostly a play-like-you-know-calculus expression, largely useless for at least two reasons. First, the purist gator biologists will demand integration over at least one more variable since effects doubtless differ by sex. And second, realists will point out that we do not have any idea about what numbers to plug into the relatively simple equation already offered.

Nevertheless, practical problems and pseudo-mathematics aside, there is a point, of sorts, to Equation (6). It reminds us that alligators of different sizes have different eco-demographic effects upon--and are differently affected by--other alligators of various different sizes: as alligators grow, they change their ecological status. Fortunately, there is a stylistically elegant (and calculus-free) way to state all this. As some of the old-time Florida crackers say, "At some point they got to stop being big lizards and start being little gators." The simplicity of this expression is appealing, and I believe the basic idea is not inaccurate. Growth rates of young Orange Lake alligators decline until the animals are about 3.5 year old and 85 cm long. Then there occurs a noticeable, statistically significant upturn in growth once more. Webb et al. (1978) discovered a similar situation in young estuarine crocodiles (*Crocodylus porosus*), and it is tempting to speculate on the life-history significance of these upturns. Many predators exploit prey of basically constant size throughout their lives. On the other hand, general isometry of head-to-body length ratios in crocodilians suggests that they are adapted to take increasingly large prey as they themselves grow longer (Dodson 1975). Such adaptations could have at least two consequences. First, as an alligator matures, it becomes able to exploit new food resources unavailable to one-time competitors. Perhaps this is the case with our Orange Lake gators. As youngsters they may compete to some degree with fish, otters, herons, watersnakes, etc. But when the gators get big enough (perhaps this begins around the growth flex point of 85 cm), the former competitors are no longer so important--except perhaps as occasional sources of food!

Second, the exploitation of different sized prey by different sized alligators presumably serves to partition food resources. While we need not agree with Murphy (1981) that such partitioning is the factor which directly permits high alligator densities, we should at least recognize that intraspecific gator competition is structured to a degree by size. Consequently, the next section of this essay will consider the relationship between structured competition and demographic events such as the more or less complete loss of a year's hatchling production.

### ONE-YEAR NESTING WIPEOUTS

My discussion of alligator density dependence will necessarily begin by considering what (if anything) happens when the density of young animals is altered. I talk about juvenile gators because in some Florida systems we have been able to count accurately the number of nests constructed; thus we have a decent idea about the size of a hatchling cohort. I do not think we can

do as well with adult animals; rather, I believe that study populations are likely to contain far more alligators than conventional night-count investigations may indicate. For example, experimental harvest on Orange Lake, Florida, has removed substantially more 3-m plus animals than we believed were present--and has not appreciably altered the night-count structure. Therefore, let us descend ever so briefly from the rarefied heights of speculation and consider nests and hatchlings, subjects we actually know something about. Authorities agree, for example, that flooding can be a very real problem (Hines et al. 1968, Joanen 1969, Joanen et al. 1977). At construction time, the center of the egg chamber in Florida gator nests is characteristically less than 70 cm above the water level. The incubation period (about 65 days) runs very approximately from 1 July through 31 August. Thus a 1-m rise in water levels during these months (some of Florida's rainiest) can drown most of the year's egg production in a given wetlands system. Nesting effort has been carefully monitored on lakes Jessup (central Florida; a comparatively unmanaged water system) and Okeechobee, a few floating nests and levee nests hatched, but most of the year's production was destroyed. On Lake Jessup (where 50-150 nests are usually constructed) absolutely no hatchlings were produced. Furthermore, high water is not the gator's only potential weather problem, for in some years, in certain habitats, extremely dry conditions may also cause the near-entire loss of a hatchling cohort (Hines et al. 1968, Hines pers. comm.). Like floods, droughts appear particularly to affect the younger age classes.

We do not know how often flood, drought, or other population-extrinsic factors induce such catastrophic mortality, but examination of Florida weather data suggests that one-year wipeouts are not extremely uncommon. Thus we may wonder how an alligator population might respond to such events. To begin with, we must admit that it is largely metaphorical to talk about "population response"--as if the population per se possessed a homeostatic adjustment mechanism independent of the biology of its individual members. Rather, we should inquire how a particular hypothetical alligator might be affected by the absence of, say, a year's hatchling cohort. Recall my statement above that some resources are partitioned by alligator size. To the degree that this position is strictly valid, the absence of one cohort size class should exert relatively little effect upon animals of other sizes--and the population would not respond in any dramatic way to a one-year wipeout.

Of course any statement of absolute size-class independence would be simplistic, and I can imagine two (by no means mutually exclusive) ways in which alligators might respond to a one-year wipeout. First, it is possible that nest failure in year  $t$  leaves mature females more capable of reproduction in year  $t+1$ . This could occur for many reasons. If, for example, all nesting sites are flooded before laying begins, it is possible that a female might resorb her eggs. Furthermore, even if completed nests were destroyed, females would expend less energy in nest attendance and hatchling protection. Presently I have no evidence that these phenomena actually occur; it is uncertain that energy savings would be very significant, and in any case it is reasonably clear that clutch size (at least) does not increase in Florida wetland systems in the year following a wipeout. But there is also another possibility. A given female might be on a "physiological schedule" to nest in year  $t$  and to be quiescent the next year. In that case, energy recouped--because of nest failure in year  $t$  might increase the probability that the female would reproduce in year  $t+1$ . Indeed it does appear that the percentage of females nesting increases somewhat after a year of catastrophic nest mortality. But I do not have the data to test this possibility statistically.

A second possible response to catastrophic mortality would be increased growth rates among animals in age classes adjacent to the one that was destroyed. Let me simplify just a little. Suppose that no alligators were hatched in year  $t$ . Then hatchlings produced in year  $t+1$  would enter a system vacant of yearlings that might have competed with them for scarce resources. Thus they might grow faster, and some could attain reproductive size ahead of "schedule".

Five rather sticky comments should be offered about this second proposed scenario. First, if compensatory growth actually occurs, it would probably affect most directly those animals hatched the year after the wipeout. However, one would expect the "benefits" to be passed in diluted quantity on down (and possibly up) the age pyramid.

Second, if he/she were not careful, a systems theorist might look at our compensatory scenario and say, "The number of animals was reduced at year  $t$ . Even if you mature the  $t+1$  hatchlings a whole year faster than normal, you still won't get any compensatory reproduction for at least 10 to 12 years. For technical reasons, feedback delayed that long (proportional to generation time) doesn't do you much good; it is highly likely to destabilize the system". This catchy little objection is defeated by the simple fact that feedback is not delayed very much at all. Consider the population's reproductive capacity. The first impact (on the total number of breeding-size females) of a year- $t$  wipeout might be expected at, say, year  $t+12$ . However, that is just about the same time that one might expect fast-growing  $t+1$  animals to begin their accelerated reproductive years.

Third, although considerable time and money have been expended in Florida to test experimentally the possibility of compensatory growth among wild hatchlings, the results have been inconclusive (Hines and Abercrombie 1987). This is not surprising. For one thing, it is extremely difficult in Florida wetlands systems to achieve reasonable control over environmental variation: extraneous variables eat up one's degrees of freedom! More important, the growth experiment may not have run long enough yet. Most of the Florida gator folks believe that compensatory growth (if it occurs) would be least important in the first years after hatchling. Animals hatched in year "wipeout + 1" would always have a "vacant" size class just above them--unless they grew into it! (Here for sake of argument we neglect intra-cohort growth-rate variability, which renders the idea of precisely separate size classes something of an abstraction.) That asset would not be particularly valuable to small alligators, which compete for food with fish, watersnakes, and what have you. Rather it would become significant after the young alligators had grown to the size at which their only important competitors would be other gators. In other words, there are sound ecological reasons to suspect that most compensatory growth would be delayed beyond the first year or two of an alligator's life.

Fourth, you will note that I have dealt exclusively with compensatory growth and have not mentioned compensatory survival. That is because I believe that direct compensatory survival is unlikely to occur in any important degree (and see Webb et al. 1983b). This is not because field research has failed to demonstrate compensatory survival (of course it has failed, but given the difficulties in estimating wild crocodilian survival rates, who would have expected otherwise?). Instead, it is because at this point I cannot even guess how the presence or absence of year- $t$  hatchlings would directly affect the survival probability of other alligators. For young alligators in typical Florida habitats, food is the only demonstrably important resource that is mediated by density (note that some authorities--Thorbjarnarson, pers. comm.--would deny that even food resources are meaningfully related to wild alligator densities). The absence of an otherwise adjacent year-class might allow more food--but how many young alligators would die of causes related to lack of food in any case? It is my opinion (admittedly subjective, but based on some experience with wild and captive animals) that the response of young crocodilians to moderate food deprivation is stunting, not starvation or even ill health. Furthermore, it seems to me that the chief response to more severe food deprivation is--more stunting. Of course it is important to note that compensatory growth has demographic effects on reproduction somewhat similar to those caused by compensatory survival. Suppose a set of animals grows rapidly and attains reproductive maturity in  $M - 1$  years instead of the usual  $M$  years. Then the population receives reproductive benefit from those animals expected to die between  $M - 1$  and  $M$  years. Considering the problem a bit more expansively, we might say that the effective reproductive lifetime is

extended by one year. (At this particular point, demographers might question my easy decision to examine "D" rather than . If the above speculations are correct, then one effect of a nesting wipe-out might be the temporary reduction of generation-time. The population-wide consequences of this would extend somewhat beyond the addition of one reproductive year to a cohort of females.)

Fifth, I would like to point out that all my speculation on compensatory growth is basically unencumbered by statistically valid data (Hines and Abercrombie 1987). And I could also be bad wrong about the survival business.

#### CONTINUING, MORE BLATANT, SPECULATIONS ON DENSITY DEPENDENCE

Since I have already stretched the available gator data painfully thin, there seems little reason why at this point I should not openly break entirely the fetters of real information and just plain guess about alligators. First, I do not believe that growth or survival is significantly dependent on density for animals much under 1 meter (Webb et al. 1983b; however, density alterations that concentrate mixed size classes into close proximity may result in cannibalism [Delaney and Abercrombie 1986]). Nor am I convinced that density alterations (at levels induced by moderate harvest or routinely observed under natural conditions in the field) affect large adult alligators in any important way (Hines and Abercrombie 1987). For animals of intermediate size, however, the situation may be very different: in a long-term stable population, there may be a survival and/or growth bottleneck for older juveniles and subadults. I have reported the growth slowdown above. And, furthermore, preliminary Florida studies (Delaney and Abercrombie 1986) indicate that (Nichols et al. 1976b notwithstanding) this may be the size class most severely affected by cannibalism.

I do not know how such a subadult bottleneck might impact male alligators. On the one hand, it is possible to argue that any effects would be demographically irrelevant. Research has indicated that some individual males may have very long reproductive lifespans (Ferguson and Joanen 1983). If, year after year, one or two of these long-lived males can breed a large number of females, then the presence of many males will not be critical to population maintenance. Thus, if even a few subadult males occasionally make the transition to maturity, that could be sufficient; or at least such is the assumption of male reproductive value under which we in Florida have generally operated. On the other hand, the proportion of successfully maturing males could be more important than our Florida research has usually assumed. Alligator precopulatory pairing behavior is often quite protracted. Since in certain climates there is only a restricted time period during which ovulation and spermatogenesis coincide, a single male may be able to breed only a very limited number of females; thus a shortage of adult males could result in reduced reproduction (Wilkinson, pers. comm.).

Whatever the reproductive importance of males, the fate of maturing females is certainly a significant demographic question. I believe that near-adult females may be limited from breeding by the presence of dense age/size cohorts above them--and that the removal of older females may increase the percentage of the younger animals that nest. For example, over four years, 122 female alligators larger than 1.8 m were removed from Orange Lake (about 5000 ha; north-central Florida). Although this number exceeds by about 25% the maximum number of nests observed in any pre-test year (and nest observation is known to approach 100%), to date absolutely no decrease in number of nests has occurred (Hines and Abercrombie 1987, Woodward, pers. comm.). Florida researchers are uncertain at this point how density alterations may have affected nesting, though we are reasonably sure that the limiting factor is not physical nesting sites



(Woodward et al. 1984). Perhaps density reduction breaks the growth bottleneck and allows pre-adult females to reach mature size more rapidly. Could such a mechanism operate fast enough to explain the maintenance of nesting effort throughout the Orange Lake experimental harvest? Intuitively, at least, this seems unlikely. Perhaps, then it is possible that removal of large females frees up some sort of "social space", thereby allowing smaller animals to breed and nest (see Ferguson and Joanen 1983). If this latter scenario were correct, then while nesting *per se* might be maintained, actual hatchling production would be expected to decrease. After all, Ferguson and Joanen (1983) show that younger alligators often produce only small numbers of eggs; these authors also state that smaller females may not even be reproductively synchronized with the males' sperm production. On Orange Lake case neither mean clutch size nor fertility showed any decline following 1981, 1982, or 1983 harvests (over which a total of 93 adult females were taken). However, in the summer of 1985 (after the 1984 harvest), very modest reductions in clutch size and percent fertility were noted.

All these observations tempt one to believe that the initial response to reduced female density is an increase in the breeding percentage of large adults. Continued removal of fully mature females may eventually result in early recruitment of smaller animals to the reproductive ranks. At the present time, however, I would counsel against uncritical acceptance of such assumptions since the Orange Lake experiment is far from complete. Furthermore, the 1985 data should be received with particular caution since they were gathered after a siege of very dry spring weather--which may have affected clutch size and fertility quite independently of density or harvest. In other words, it's all hard to figure. And like other bits of information on alligator density dependence, the Orange Lake insight must remain for now just one more tantalizing clue that something must be going on.

## CONCLUSION

From McIlhenny (1935) into the sixties, zoologists seemed confident that they knew about the biology of the alligator. But, as additional hard data were collected, the realization of ignorance grew. Despite much valuable research (particularly the field observations of Joanen and the laboratory studies of Ferguson), alligator population dynamics remains a mystery, very partially unraveled. Furthermore, it is highly probable that over the coming decades, alligators (like other crocodilians) will be subjected to increasing commercial exploitation. This will present both problems and opportunities. Even in our ignorance we know that alligators are slow-maturing, long-lived animals. As such, they cannot be expected to recover rapidly from serious overharvest like white-tail deer (or possibly fast-maturing spectacled caiman [Staton and Dixon 1977, Rebelo and Magnusson 1983]), and gator exploitation should therefore be conducted with considerable caution. On the other hand, some relatively safe harvest strategies have been suggested, and revenues generated by these harvests can help finance long-term, if modest, research (Hines and Abercrombie 1987). In the present essay I have tried to indicate areas in which investigation would be especially important. Particularly, I believe we need to know more about the growth and survival of female alligators between 1 and 2 meters. We should also determine more about the percentages of various sized females that successfully nest, and we need to discover how all these factors vary with density. Except for one or two potential technological breakthroughs (such as a precise histological technique for age determination), these next steps will be slow and expensive. Fortunately--and on this, I believe virtually all alligator researchers will agree--the work will also be fun.

## LITERATURE CITED

- Adams, S., M. Smith, and R. Baccus. 1980. Biochemical variation in the American alligator. *Herpetologica* 36:289-296.
- Bara, M. 1972. Alligator research project. Ann. Prog. Report. South Carolina Wildl. Marine Res. Dept., Columbia.
- Chabreck, R. H. 1966. Methods of determining the size and composition of alligator populations in Louisiana. *Proc. Ann. Conf. S.E. Assoc. Fish and Wildl. Agencies* 20:105-112.
- \_\_\_\_\_, and T. Joanen. 1979. Growth rates of American alligators in Louisiana. *Herpetologica* 35:51-57.
- Delaney, M. F., and C. L. Abercrombie. 1986. American alligator food habits in northcentral Florida. *J. Wildl. Manage.* 50:348-352.
- Dietz, D., and T. Hines. 1980. Alligator nesting in north-central Florida. *Copeia* 1980:249-258.
- Dodson, P. 1975. Functional and ecological significance of relative growth in *Alligator*. *J. Zool.* 175:315-355.
- Ferguson, M., and T. Joanen. 1983. Temperature-dependent sex determination in *Alligator mississippiensis*. *J. Zool.* 200:143-177.
- Forbes, T. 1940. A note on reptilian sex ratios. *Copeia* 1940:132.
- Fuller, M. 1981. Characteristics of an American alligator (*Alligator mississippiensis*) population in the vicinity of Lake Ellis Simon, North Carolina. M.S. Thesis, North Carolina State Univ., Raleigh.
- Gibbons, W., and R. Semlitsch. 1982. Survivorship and longevity of a long-lived vertebrate species: How long do turtles live? *J. Anim. Ecol.* 51:523-527.
- Graham, A. 1968. The Lake Rudolf crocodile (*Crocodylus niloticus* Laurenti) population. Wildl. Serv. Ltd. Mimeogr. Rept. to Kenya Game Department.
- Hines, T. C. 1979. The past and present status of the alligator in Florida. *Proc. Ann. Conf. S.E. Assoc. Fish and Wildl. Agencies* 33:224-232.
- \_\_\_\_\_, and C. L. Abercrombie III. 1987. The management of alligators in Florida, U.S.A. Pp. 43-47 in G. J. W. Webb, S. C. Manolis, and P. J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- \_\_\_\_\_, M. Fogarty, and L. Chappell. 1968. Alligator research in Florida: A progress report. *Proc. Ann. Conf. S.E. Assoc. Fish and Wildl.* 22:166-180.
- Joanen, T. 1969. Nesting ecology of alligators in Louisiana. *Proc. Ann. Conf. S.E. Assoc. Fish and Wildl. Agencies.* 23:141-151.

- \_\_\_\_\_, and L. McNease. 1971. Propagation of the American alligator in captivity. Proc. Ann. Conf. S.E. Assoc. Fish and Wildl. Agencies. 25:106-116.
- \_\_\_\_\_, and \_\_\_\_\_. 1973. Developments in alligator research in Louisiana since 1968. Presented at a symposium of the American Alligator Council, Winter Park, FL.
- \_\_\_\_\_, and \_\_\_\_\_. 1976. Notes on the reproductive biology and captive propagation of the American alligator. Proc. Ann. Conf. S.E. Assoc. Fish and Wildl. Agencies 29:407-415.
- \_\_\_\_\_, \_\_\_\_\_, and G. Perry. 1977. Effects of simulated flooding on alligator eggs. Proc. Ann. Conf. S.E. Assoc. Fish and Wildl. Agencies 31:33-35.
- Magnusson, W. E. 1983. Size estimates of crocodilians. J. Herp. 17:86-89.
- Metzen, W. 1977. Nesting ecology of alligators on the Okefenokee National Wildlife Refuge. Proc. Ann. Conf. S.E. Assoc. Fish and Wildl. Agencies 31:29-32.
- McIlhenny, E. L. 1935. The Alligator's Life History. Christopher Publ. House, Boston.
- Murphy, T. M. 1981. The population status of the American alligator on the Savannah River Plant, South Carolina. Published by Savannah River National Environmental Research Park, Aiken, South Carolina.
- \_\_\_\_\_, and P. M. Wilkinson. 1982. American alligator investigations: Management recommendations and current research—1982. Published by South Carolina Wildl. Mar. Res. Dept., Columbia.
- Nichols, J. D., and R. H. Chabreck. 1980. On the variability of alligator sex ratios. Am. Nat. 116:125-137.
- \_\_\_\_\_, \_\_\_\_\_, and W. Conley. 1976a. The use of restocking quotas in crocodilian harvest management. Michigan Agri. Exp. Sta. J., No. 7579.
- \_\_\_\_\_, L. Viehman, R. Chabreck, and B. Fenderson. 1976b. Simulation of a Commercially Harvested Alligator Population in Louisiana. Louisiana State Univ. Agri. Expt. Sta. Bull. No. 691.
- Rebelo, G., and W. E. Magnusson. 1983. An analysis of the effect of hunting on *Caiman crocodilus* and *Melanosuchus niger* based on the sizes of confiscated skins. Biol. Conserv. 26:95-104.
- Ruckel, S. W., and G. W. Steele. 1984. Alligator nesting ecology in two habitats in southern Georgia. Ann. Conf. S.E. Assoc. Fish and Wildl. Agencies 38:212-221.
- Staton, M. A., and J. D. Dixon. 1977. Breeding biology of the spectacled caiman, *Caiman crocodilus crocodilus* in the Venezuelan Llanos. U.S. Fish and Wildl. Serv. Res. Rept. No. 5.
- Taylor, D., and W. Neal. 1984. Management implications of size-class frequency distributions in Louisiana alligator populations. Wildl. Soc. Bull. 12:312-319.

- Webb, G. J. W., H. Messel, J. Crawford, and M. Yerbury. 1978. Growth rates of *Crocodylus porosus* (Reptilia: Crocodilia) from Arnhem Land, Northern Australia. *Aust. Wildl. Res.* 5:385-399.
- \_\_\_\_\_, R. Buckworth, and S. C. Manolis. 1983a. *Crocodylus johnstoni* in the McKinlay River, N.T. IV. Nesting Biology. *Aust. Wildl. Res.* 10:607-637.
- \_\_\_\_\_, \_\_\_\_\_, and \_\_\_\_\_. 1983b. *Crocodylus johnstoni* in the McKinlay River area, N.T. III: Growth, movement and the population age structure. *Aust. Wildl. Res.* 10:383-401.
- Whitworth, J. 1971. Notes on the growth and mating of American alligators *Alligators mississippiensis* at the Cannon Aquarium, Manchester Museum. *Int. Zoo Yearb.* 11:144.
- Wilkinson, P. M. 1983. Nesting ecology of the American alligator in coastal South Carolina. Published by South Carolina Wildl. Mar. Res. Dept., Columbia.
- Wood, J., and S. Humphrey. 1983. Analysis of Florida alligator transect data. Technical Report No. 5, School Forest Res. Cons., IFAS, Univ. Florida, Gainesville.
- Woodward, A. R. 1978. An evaluation of factors affecting night-counts of alligators. M.S. Thesis, Univ. Florida, Gainesville.
- \_\_\_\_\_, T. C. Hines, C. L. Abercrombie, and C. Hope. 1984. Spacing patterns in alligator nests. *J. Herp.* 18:8-12.
- \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_, and J. D. Nichols. 1987. Survival of young American alligators on a Florida lake. *J. Wildl. Manage.* 51:931-937.

# THE FORENSIC IDENTIFICATION OF CROCODILIAN HIDES AND PRODUCTS

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## INTRODUCTION

The conservation and management of wildlife, including crocodilians, is usually based upon an assessment of the status of endemic populations and those factors which have impact upon the survival of the species. Adverse factors may often be negated by manipulating the habitat or the makeup of the species populations, or by protecting the species from outside or unnatural pressures which may be detrimental in themselves or may amplify the effect of other negative factors. The latter may be achieved by the enactment of local, national or international laws which limit or prohibit the taking or utilization of the species for personal or commercial purposes.

While biologists and other scientists may define the ecological or environmental problems, legislators may be called upon to enact the legal solutions, while law enforcement authorities are charged with enforcing and judicating compliance. The effectiveness of wildlife conservation and management programs is contingent upon the integrated workings of all three. The ability of the forensic scientist, in applying scientific fact to the legal problems which arise, is often an important catalyst.

Crocodilians pose unique problems in conservation, management, and wildlife law enforcement (Brazaitis 1984), and to the forensic herpetologist. Of the 21 traditionally recognized species found throughout the tropical and sub-tropical regions of the world, 15 or more forms may be exploited commercially. They provide a major source of raw material and a significant economic basis for the world exotic leather industry. The trade is estimated to utilize about 1.5 million skins annually, three quarters of which include skins of South American species. A large number are taken illegally in violation of national wildlife regulations (Hemley and Caldwell 1986). Harvest quotas, size limits, or regional protections (Fuller and Swift 1984, Groombridge 1982) may frequently be disregarded. These constitute the major types of violations in addition to the contraband trade in endangered species.

The international trade in crocodilians is regulated under the Convention on the International Trade in Endangered Species of Wild Flora and Fauna (CITES) promulgated in 1973, and in the United States, trade is regulated under the Lacey Act of 1900 (amended 1981) and the U.S. Endangered Species Act which was revised in 1973 to implement CITES regulations. Under U.S. law, violations may result in simple seizure of goods for improper documentation, denial of

importation, forfeiture of goods, civil penalties or prosecution under felony charges. Lacey Act violations may result in penalties of up to U.S. \$20,000 and up to five years imprisonment for each count charged.

The amount of illegal trade, if we consider all types of violations as constituting an illegal transaction, appears to be inconsistent with the extensive amount of national and international regulation. This may, in part, be due to the fact that most skins are taken from wild populations endemic to poor or developing countries, which may be under enormous economic pressures. Such countries may be least able to afford extensive management or law enforcement programs. Second, hides and products may be shipped and re-shipped through many ports and countries before arriving at final destinations and markets. Third, closely related species from different origins may be difficult to distinguish from each other in their processed form. Whole skins or cut up pieces of skin from different species or races of different origins may be mixed in tanning, shipping, or ultimately during their manufacture into products. Last, wildlife authorities often find it difficult to trace individual skins or the skins combined on products back to their native sources as nearly all such skins lack identifying marks or tags. Authorities may need to rely on export or re-export documents which list numbers of skins of designated species. Only skins of the American alligator bear individual identifying tags which must remain affixed to the hide through the tanning process and up to the time the hide is manufactured into a product.

The problems are exacerbated when wildlife authorities, confronted with the unpopular task of having to enforce foreign wildlife regulations, are beset by pressures from those who view the strict application of regulations which affect commercial trade as obstacles to free enterprise. The national debt, deficits in foreign trade and weakening national economies all may be given priority. Wildlife law enforcement budgets may be the first to suffer for lack of financial support. The extent to which forensic techniques are applied in developing prosecutions may become particularly restricted.

Few published manuals exist which deal with the identification of crocodilians, their hides and products (King and Brazaitis 1971b, Brazaitis 1973, Brazaitis and King 1984, Fuchs 1974, Wermuth and Fuchs 1978, 1983); yet, the availability of biologically accurate manuals is most important for the training of wildlife officers who must apply this information in day to day field investigations involving a wide assortment of skins and products, each with its own peculiar problems in species identification. Some commercially sponsored manuals have only served to compound the problems of enforcement by presenting taxa based on commercial material, often of unknown specific origins (Fuchs 1974, Wermuth and Fuchs 1978, 1983) rather than scientifically accredited study material. A number of taxonomic citations which have been included without broad scientific peer review have drawn considerable criticism from the scientific community (Frair and Behler 1983, Brazaitis and King 1984, Ross and Mayer, pers. comm.).

Standard taxa providing the basis for the identification of crocodilians, their hides and products, and the basis for U.S. law enforcement efforts, are presented in Brazaitis (1973b, Groombridge (1982), King and Brazaitis (1971), Medem (1981, 1983), Wermuth (1953) and Wermuth and Mertens 1961).

Common names, local native names, and the commercial nomenclature for crocodilians are given in Fuchs (1974), Fuchs and Wermuth (1978), Groombridge (1982), King and Brazaitis (1971), Brazaitis (1973b) and Medem (1981, 1983).

Current status of wild populations and distributions are presented in Groombridge (1982), the Proceedings of the IUCN Crocodile Specialist Group and the Bulletins and Newsletters of TRAFFIC, the Wildlife Trade Monitoring Unit of IUCN.

Legal protections are given in Fuller and Swift (1984) for Latin American countries, Groombridge (1982), TRAFFIC bulletins and newsletters and in the U.S. are published regularly in the Federal Register by the U.S. Fish and Wildlife Service. The Federal Register also regularly publishes changes in foreign wildlife regulations as well as changes in enforcement policies.

An overview of tanning techniques and hide processing is presented by Fuchs (undated) and in Wilson (1928, 1929).

### **The Forensic Examination of Wildlife Products**

Wildlife and wildlife products generally enter or leave the United States through certain designated ports which are staffed with agents and inspectors of the U.S. Fish and Wildlife Service. Invoices, manifests and customs declarations pertaining to wildlife shipments are referred to wildlife inspectors who may elect to make a personal inspection of the shipment. Inadequate documentation, discrepancies between the country of origin and the known distribution of the species listed or the presence of a species which is grossly similar to a prohibited endangered form, may result in the shipment being refused entry into the country or it may be detained for further examination. A random sampling of the contents of the shipment may then be taken for forensic examination. The examination may be made by trained agents or inspectors within the service, or items may be presented to an independent forensic examiner. Given the thousands of dollars often involved in shipments of wildlife products, unnecessary delays and damage to the detained items are avoided.

In the interest of objectivity, forensic examiners should be deprived of all knowledge of the origins and species citations invoiced for the items, the names of the companies or owners involved and generally the extent of the investigation. Identifications must be made solely on the basis of the physical evidence presented. The examiner should bear in mind that his or her conclusions must reflect only those facts which have been physically determined and which can be substantiated and presented without reservation in any future court proceeding. Thus, although the examiner may believe the characteristics displayed on a pair of shoes suggest a particular race or subspecies, his examination must be definitive and rely only on positive characteristics. There is little room for subjective interpretation. If, based on the examiner's report, a violation is confirmed, the examiner may then be called upon to make a comprehensive inspection of the shipment and ancillary documents, and may later be called upon to testify as to his findings. Common, commercial and scientific names invoiced, skin sizes relative to the lengths commonly attained by the species in life, origins cited and actual distributions for the species involved, types of tannage, stamps and other markings, all may be scrutinized and compared to known standards for possible additional supporting evidence. The role of the forensic examiner is to provide the unbiased scientific facts, which he has determined to the best of his ability, that will elucidate the legal contentions (Brazaitis 1986b).

### **Categories of Commercial Skins in Trade**

The manner in which raw crocodilian skins are prepared prior to processing is determined by the amount and body location of usable skin on the particular species involved, the use to which it will be put in the manufacture of products, the preferences of the market for which the product is intended and, in some instances, the customs of the hunter who procures the skin from the animal.

In the United States, various state laws mandate that American alligators be skinned and shipped with different small portions of skin left attached to help distinguish the harvest year in which the skin was taken. A number of countries are adopting similar skinning variations into management protocols.

Most crocodilians are utilized as whole belly skins which are sold by the piece or by the belly width. They are skinned in the traditional manner, discarding the hard bony scales of the back, dorsal neck and tail, and feet. The remaining commercially desirable portion includes the skin of the lower jaw and throat, belly, complete with as much flank skin on each side as possible and as much of the ventral and lateral portions of the tail as possible (Fig. 1 A).

An alternate method of skinning produces a "hornback." By this method, the animal is skinned via a longitudinal mid-ventral incision which preserves the neck, back and anterior dorsal tail scalation (Fig. 2). Native crafts from West Africa and Latin America as well as moderate quality products produced or marketed in Japan and southeast Asia utilize hornback skins.

Although *Melanosuchus niger* is skinned in the traditional manner, the tanned and finished skins may often be cut up into sections and sold as throats, chests, bellies, girdles and tails, as well as whole skins, by the piece or square measure (Fig. 1 D).

The various races of spectacled caiman *Caiman crocodilus* may either be skinned in the traditional manner, or only the flank regions may be taken (Fig. 1 B). Flanks include the softer, less ossified skin between the front and rear limbs and the dorsal and ventral scales. Occasionally, the two flanks are left joined by the skin of the gular and pelvic regions. The tail is cut off immediately posterior to the vent and is discarded, along with the mid-ventral belly region. More often, each flank is shipped as independent pieces packed in bundles. Half tanned crusts as well as tanned and finished caiman flanks may be shipped directly from South American tanneries to manufacturers around the world. Flanks may be invoiced and sold by the piece or by the square measure.

Total maximum and average lengths for crocodilians are given in Brazaitis (1973b), King and Brazaitis (1971), and Groombridge (1982). The length of the flank skin, from axilla to groin (Fig. 3F), may be used as an index in determining the approximate size of the animal from which the flank was taken, and may help to distinguish the flank skins of large species from those achieving only small to moderate lengths. For caiman, this straight line measurement from axilla to axilla approximates 22 % of the total length of the animal. Thus, a flank length of 40 cm would indicate it was taken from an animal about 182 cm in total length. Comparable flank proportions may be used to approximate lengths for races of *C. crocodilus*, *M. niger*, and *Alligator mississippiensis* (Brazaitis, in prep.). Hide grading by quality, skinning methods, proportional amounts of usable skin for different types of crocodilians and methods of measuring commercial skins are given in Fuchs (undated) and Van Jaarsveldt (unpubl.).

Scraps and trimmings are small pieces of skin from any species, which may remain after whole skins, flanks, etc. are cut up in the manufacture of products. Scraps may be in the form of crust or completely tanned and finished skin. Scraps are often sold by weight (Fig. 1 C).

### The Species Identification of Crocodilian Skins

The identification of crocodilian hides and products relies largely on the determination of gross morphological characteristics, although more sophisticated biochemical methods of



identification are currently under investigation. Figure 4 shows the regions of body scalation referred to in the following identification procedures and keys. Figure 3 shows the scale configurations and patterns at various body regions. Numbers of scale rows, scale inclusions in certain body regions and the shape and arrangement of scales may be definitive in themselves or in conjunction with other characters.

There are two basic characteristics which serve as fundamental criteria in the identification of crocodilians in life, as skins or hides, or as manufactured products. These are the presence or absence of integumentary sense organs (ISOs) on the body scalation (Fig. 5A, B), and the presence, composition, degree, or lack of bony plates or osteoderms in the ventral body scalation (Fig. 6).

Only members of the families *Crocodylidae* and *Gavialidae* have integumentary sense organs. All members of the family *Alligatoridae* lack ISOs on body scales. However, all crocodilians bear ISOs on various portions of the head. While having a single ISO on each scale is the general rule, as many as two to five may be found on ventral scales. When present, ISOs can be found on the anterior middle portion of the body scales in living animals, and in all forms of processed skins and products.

Osteoderms (Fig. 6) are body plates which occur in parts of the body scalation of all crocodilians. However, as a diagnostic tool, we only consider those osteoderms which occur in the ventral regions of the throat, pectoral and belly scalation. There are two types: composite osteoderms, which are made up of two or three sutured plates (Fig. 6A) such as those found in the genera *Caiman*, *Melanosuchus* and *Paleosuchus*, and single bone osteoderms such as those found in the genera *Alligator*, *Crocodylus* and *Osteolaemus* (Fig. 6C, D). Shaving and processing enhances the ability to determine the presence and type of ventral osteoderms in hides and products. While processing may change the texture and thickness of the skin and scalation, the form of the scales and their relationship to each other remains the same. Appendix I gives a key for the identification of commercial crocodilian hides and skins based on body scalation. Although the key focuses on whole belly skins, the scale morphology may be applied in the identification of flanks, cut pieces of skin and manufactured products presented in commercial trade. In doing so, it is of utmost importance to determine the specific body region from which the skin represented on the product has been taken (Fig. 3). The key is adapted from (Brazaitis 1973a, b), King and Brazaitis (1973) and Ross and Ross (1974). The morphology presented in this paper reflects the classic identifying characteristics of the species involved.

### Types of Crocodilian Products in Trade

Crocodilian products commonly found in trade include dried, salted, or raw untanned whole skins or skin parts; partially tanned skins termed "crusts" (Fig. 12 C); fully tanned and finished whole hides, portions of hides and trimmings from manufacturing procedures; manufactured products; trophy skins and skulls; novelty items and curios. Manufactured products and tanned skins may be of moderate or high quality commercial manufacture, which are widely exported, or of poor quality native craft. Novelty items, curios and trophy skins are usually of native craft and are largely directed at the local consumer or tourist, although in recent years such items have found a sales market in low income shops and street vendors in the U.S. and Europe.

Manufactured products include handbags, shoes, wallets, belts, attache cases and small pieces of luggage, watchbands, key cases and billfolds. These make up the bulk of and economic basis for the crocodile leather trade. Quality commercially tanned and processed hides and products are

generally characterized by their soft supple leathers, uniform coloration and texture, and careful workmanship combined with polished metal fittings.

Quality handbags and other items are fabricated from matched panels of selected belly skins while gussets and hide panels are matched with sections of tail, neck or selected leg skin (Figs. 3, and 7). France, Italy, Switzerland and West Germany are the centers of quality fabricating and tanning of crocodilian skin. In general, highest quality or "classic" skins are used in the manufacture of the highest priced products. These are from species which lack or have poorly developed bony plates or osteoderms in the ventral areas. They produce soft supple leather and have scale patterns which are aesthetically pleasing when processed. Highly desirable classic species include the American alligator *A. mississippiensis*, Nile crocodile *Crocodylus niloticus*, salt-water crocodile *Crocodylus porosus*, New Guinea crocodile *Crocodylus novaeguineae novaeguineae*, Morelet's crocodile *Crocodylus moreleti*, the Siamese crocodile *Crocodylus siamensis*, and frequently the black caiman *M. niger* and the broad-snouted caiman *Caiman latirostris*.

Shoes are usually made from young crocodilians with small scales. Scraps or trimmings are often used for toes, heels and straps, although entire shoes are commonly composed of pieces of flank skins of caiman *C. crocodilus* (Fig. 1B and C). Most quality caiman shoes are manufactured in Italy from the wide flanks of Yacare caiman *Caiman crocodilus yacare*. Tanned and finished Yacare flanks may be shipped from Bolivia, which have frequently been taken from animals often killed illegally in Brazil (Hemley and Caldwell 1986).

Quality billfolds, wallets, desk sets, etc. are made from neck, throat flank and tail sections of black caiman (Fig. 1D), American alligator and caiman. Two to four belly skins of juvenile dusky caiman *Caiman crocodilus fuscus*, often shipped from Colombia in disregard of minimum size limitations, may be used in the manufacture of a single wallet and are sewn side by side on a wallet or billfold.

Most belts are composed of small scraps of skin (Fig. 1C), usually caiman, carefully matched to conceal the seams and backed with steer leather. The seams between pieces in quality belts are well matched. The forensic examiner must have a thorough knowledge of scale configurations from crocodilian body regions, and must carefully scrutinize the product if a species identification is going to be possible on such items.

Watchbands are generally composed of scraps or trimmings (Fig. 1C) of nearly any species, but primarily of caiman *C. crocodilus*.

In recent years, softer body portions of the heavily ossified members of the species *C. crocodilus* have increasingly been used in the manufacture of better quality products. South American skins are shipped to South Africa, Japan and Southeast Asia and are often documented as endemic true crocodile species after manufacture into products. Many are misleadingly sold to visiting tourists as well, under the name of the familiar endemic species.

Figure 2 shows the typical "hornback" look of products manufactured in Southeast Asia and Japan. These are not truly native crafts, although they do not reflect quality commercial manufacture. The skins are not well tanned and tend to be hard and somewhat inflexible. Rather than displaying the ventral portions of the crocodilian as the focal point of front and rear panels, the coarse back scalation of an animal skinned through the belly is the prominent feature. The bony keeled dorsal scales preclude burnishing and finishing, thus the back scales are left dull while the remainder of the skin is finished to a high gloss. Species most often used include caiman *C. crocodilus*, the salt-water crocodile *C. porosus*, Johnston's crocodile *Crocodylus johnsoni*, the Siamese crocodile *C. siamensis* and infrequently, the Malayan false gaviel *Tomistoma schlegelii*.

Native crafts reflect the opposite traits of quality products. Native crafts generally utilize local tanning materials and can be identified by their uneven "hardness" due to hand processing and inconsistent times spent at various steps in the tanning process. Many skins and products are left in bleached-out neutral tones. The uneven suppleness and thickness of the leather, combined with disregard for controlled tanning chemistry, preclude the uniform absorption of dyes. The effect when dyed is a blotchy uneven appearance. Linings may be of similar poor quality domestic leathers while borders and seams may be wrapped with leather thongs. Latches and fasteners are usually of leather as well. Holes in skins may simply be plugged with a glued-on patch. A number of reptile species may be combined with crocodilians; favorites include python (Boidae), monitor lizard (Varanidae) and sea turtle (Cheloniidae). While nearly any species of crocodilian may be utilized in native crafts and sold locally, African species and products from western Africa have the widest sales distribution and are often presented to the forensic examiner for identification. These include the west African dwarf crocodile *Osteolaemus tetraspis*, west African slender-snouted crocodile *Crocodylus cataphractus*, and the Nile crocodile *Crocodylus niloticus*.

#### Characteristics of Frequently Utilized Species As They Commonly Appear on Manufactured Products

The dwarf crocodile *Osteolaemus tetraspis* of west Africa is often used in the production of poor quality native crafts, such as handbags and carrying cases. Its flanks are distinctive and are often prominently displayed on products. The species has ISOs, and in addition, has large keeled scales arranged in a random fashion in a field of creased skin (Fig. 3F<sup>2</sup>). The characteristic nuchal cluster on the back of the neck (Fig. 8C) is made up of a group of four scales arranged in a square. Ventral scales are arranged in 18 to 22 transverse rows. The belly skin is extensively ossified, containing single osteoderms (Fig. 6C) and is not easily dyed, shaved thin or decalcified in tanning. Products are stiff, often bleached in color and frequently are left in neutral tones or sometimes dyed black or red.

The Nile crocodile, *C. niloticus*, and the west African slender-snouted crocodile, *C. cataphractus*, both occur in trade and bear ISOs. While some populations of Nile crocodiles do not bear osteoderms in the ventral scalation, others do. These latter animals contain poorly developed but diagnostic small elliptical osteoderms in the gular or pectoral regions of the skin (Fig. 6D). In contrast, *C. cataphractus* has extensive round osteoderms in nearly all of the ventral scales. These osteoderms can be clearly seen as flattened hard reflections under the surface of the glossy smooth scales in tanned skins and manufactured products (Fig. 6C and D) and as larger hard bony plates in native crafts.

Base plates and gusset portions of handbags may contain tail portions which display mid-ventral rows of irregular scales extending caudad from the cloaca (Fig. 9D), characteristic of the Siamese crocodile *C. siamensis*. The species lacks ventral osteoderms but has ISOs.

Inclusions of extra scales between the rows of scales on the ventral anterior portion of the tail are diagnostic for other species of crocodilians as well, and are often found under careful scrutiny on shoes as well as larger items. Transverse ventral inclusions with ISOs (Fig. 9A) identify the sub-caudal tail skin of Morelet's crocodile *C. moreleti*.

The tail skin of *Crocodylus acutus*, the American crocodile, can be identified if the inclusions are restricted to the lateral portions of the tail as in Fig. 9C (Ross and Ross, 1974).

The tail skin of black caiman *M. niger* is equally identifiable. Although the inclusions are similar to those of the Morelet's crocodile, the black caiman lacks ISOs.

Irregular swirling trails found on the ventral scales, including the tail scales of many crocodilians throughout the world, were once thought to be characteristic of the Orinoco crocodile, *Crocodylus intermedius* (Fig. 5C). They are, however, produced by a parasitic nematode of the genus *Capillaria* (H.I. Jones, pers. comm.) and are not diagnostic.

Nuchal scalation (Fig. 4A) may also be diagnostic for certain species. Nuchals are often prominently displayed on native crafted as well as poorly manufactured hornback products (Fig. 2) and hornback skins. The square block like nuchal formation (Fig. 8C) of *O. tetraspis*, the west African dwarf crocodile, is unique, and combined with the presence of ventral osteoderms, ISOs and flanks composed of randomly arranged keeled scales in a field of soft creased skin (Fig. 3F<sup>2</sup>) is diagnostic.

A typical *Crocodylus* nuchal cluster (Fig. 8A), combined with connective scales so as to form a continuation of the dorsal scales (Fig. 8E) identifies *C. johnsoni*, the Johnston's crocodile. The flanks are composed of uniform rows of round scales similar to those in Fig. 3F<sup>1</sup>. ISOs are present as are well developed ventral osteoderms.

The nuchal formations of the west African slender-snouted crocodile (Fig. 8F) and the Malayan false gavia *T. schlegeli* (Fig. 8D) are similar, however, the former species has ventral osteoderms while the latter does not.

Although the Indian gavia *Gavialis gangeticus* has not entered trade in many years, perhaps it should be noted that it does have a nuchal formation similar to *Tomistoma* and *C. cataphractus*, however it differs in having uniform rows of square or hexagonal flank scales as opposed to round or oval flank scales.

The saltwater crocodile, *C. porosus*, which has a typical *Crocodylus* nuchal formation (Fig. 8A) may sometimes be identified by the lack of post occipital scalation (Fig. 4A). In addition, the species lacks ventral osteoderms and has flank scalation arranged in uniform length rows similar to Fig. 3F<sup>1</sup>. There are 30 to 35 transverse ventral rows of scales. The skin of this species produces the finest of crocodilian leathers.

The nuchal clusters of members of the genus *Caiman* and *Melanosuchus*, as well as *A. mississippiensis* are distinctive (Fig. 8B). However, the family Alligatoridae displays other characteristics as well.

Members of the family Alligatoridae may be separated from other crocodilians by their total lack of body ISOs. ISOs are restricted to the head only. Although most alligatorids have ventral osteoderms, the American alligator usually has only poorly developed single osteoderms in the pectoral and midventral regions, if at all (Fig. 6C and D). The surface of the skin assumes a smooth finish when tanned. The scar remaining from the umbilicus in this species remains throughout life as a fine network of creases (Fig. 7), and can usually be seen near the top of at least one face panel on larger purses and handbags.

The black caiman, *M. niger*, differs in having a composite square osteoderm in nearly all of the ventral scales (Fig. 6A). The surface of the ventral skin is highly polished, smooth, unpitted and somewhat inflexible. Like all alligatorids, it lacks body ISOs. The inclusions between the ventral scale rows under the anterior tail are definitive (Fig. 9B). The flanks are composed of six to eight rows of large, round, poorly keeled scales, alternating with rows of small scales (Figs. 10C

and D). Manufactured items include handbags, wallets, billfolds, men's shoes, attache cases and desk top accessories. The skin of the species is often too valuable to be sold in small pieces (Fig. 1D). Most skins originate from Bolivia but they are taken from neighboring countries.

*Caiman* also lack body ISOs and have large, square, composite bony osteoderms in the ventral scales as do the black caiman, but differ in that when tanned, the belly scales display deep surface pitting (Fig. 6B) in typical glossy finishes. Caiman may be tanned to a high gloss finish or as suede like sauvage finishes. Osteoderms are clearly visible on the inside and outside surfaces of the skin (Fig. 6A and B). Bombe finishes usually produce a wrinkling effect surrounding a raised "button" on the outer surface of ventral scales.

The ventral scales of *C. latirostris*, the broad-snouted caiman, show extensive surface pitting (Fig. 6B) when tanned. The trunk is wide, and is often used as a whole belly skin. The flank scales are composed of a single row of rectangular large keeled scales, followed by one or two alternating rows of large rectangular and small bead-like scales (Fig. 10A and B). There are no tail inclusions. The composite ventral osteoderms take processing well. Unlike products from other members of the caiman group, products may feel soft and more compressible to the touch.

The most commonly utilized crocodilians are the races of *C. crocodilus* of South America, except for the Rio Apaporis caiman, *Caiman c. apaporiensis*. These animals are closely related and widely distributed. The skins are collected throughout South America from a multitude of regions. Skins are mixed during tanning and are shipped as mixed species to consuming and manufacturing countries. Raw skins are also shipped to tanneries in Italy and France, where they again are mixed and re-exported to other countries. Most skins are unmarked and are often taken in violation of national wildlife regulations which often include harvest limits and size limitations.

While it is relatively easy to distinguish the dark raw skins of the yacare caiman, *C. c. yacare*, from the yellow green skins of the common caiman, *C. c. crocodilus*, or the dusky unicolor skin of *C. c. fuscus*, tanned but unfinished bleached skins, and tanned and finished hides may be difficult to separate on a subspecific level. All lack sensory organs, all have surface pitting (Fig. 6B), all have extensive composite square ventral osteoderms (Fig. 6A) and none have ventral tail inclusions is such as those found in the black caiman.

They do differ in flank scalation. While black caiman has six to eight rows of alternating small and large round unkeeled scales (Fig. 10B and C), the yacare caiman has flanks composed of three to five rows of round nearly unkeeled scales separated by "chain-like" interscales (Fig. 11). The rows are largely uniform in longitudinal arrangement.

*C. c. crocodilus*, the common caiman, usually bears a row of enlarged strongly keeled oval flank scales, followed by one or two series of oval keeled scales separated from each other in a field of soft skin creases containing small round scales (Fig. 12).

We do not include the Rio Apaporis caiman *C. c. apaporiensis* in this discussion as the species has already been largely extirpated by commercialized hunting and is no longer found in international trade.

The dusky caiman, *C. c. fuscus*, is similar to the common caiman, except the flank rows tend to be uniform in arrangement and are separated from each other by a series of small bead-like scales (Fig. 13). Juvenile dusky caimans are frequently taken from Colombia under the 1.2 m size limit and are tanned into wallets. As many as four belly skins may be used in a single men's wallet. Many are sold as curios and novelties and originate in Mexico, Colombia and Panama.

The wide flanks of the yacare caiman *C. c. yacare* are the most often utilized. Flank scalation is usually composed of four rows of round or oval poorly keeled scales separated by a chain like pattern of creased skin and small scales (Fig. 13). Single shipments of two to three thousand whole flanks are not uncommon, and are not difficult to identify. However, when caiman skin scraps are pieced together and fastened to steer leather, only the deeply pitted surface of the underlying ventral osteoderms is available to make a determination. In this case, the only identification which may be made is that it is a member of the family Alligatoridae and of the genus *Caiman*.

The genus *Paleosuchus* rarely is found in any appreciable numbers in commercial trade, and then only as stuffed curios. Belly scales are the most extensively boned, with composite osteoderms that overlap successive scales to form an impervious armor, which makes commercial processing uneconomical. Ventral scales are in 18 to 24 transverse rows.

### Crocodilian Skin Reproductions

With the rising cost of quality crocodilian skin, a number of techniques have been developed for reproducing genuine crocodilian skin patterns on domestic leathers and plastics. The results have been moderately successful in that, in some cases, the species from which the type was taken is readily identifiable on the artificially manufactured product. To the untrained examiner, artificial skin may be mistaken for the genuine product. Chemical or spectroscopic analysis may be used to determine the presence of plastic components. However, artificial products are relatively easy to separate from their genuine counterparts if a few basic principles are kept in mind.

Domestic leathers which are embossed with crocodilian prints are done so from prepared stamps or molds. Thus, the scale patterns are repetitive, and body regions are often displayed with body regions they are not associated with in life. Creases between scales and junctures lack the ultra-fine detail, uniqueness and individuality of different living animals. Bony scales, expected to be hard and unyielding, such as dorsal and nuchal scales, are often as soft as surrounding scales. Examination with a hand lens often reveals pock marks and blistering on the surface of the product as a result of high temperature molding processes. Turning small pieces of surface material may result in an odor of burning hydrocarbons, indicating plastic, rather than the odor of burning keratin such as hair or feather.

### The Identification of Crocodilian Skins by Biochemical Techniques

The biochemical identification of wildlife is in its infancy. However, systematics investigations into the molecular identification of crocodilians have been carried out on blood (Densmore 1983) and meat and blood (Joanen, pers. comm). Forensic biochemical investigations are underway under the joint auspices of the New York Zoological Society, Long Island University and World Wildlife Fund (USA). An overview of the application of current biochemical techniques is presented in Brazaitis (1986a). A bibliography of the applications of forensic science in wildlife law enforcement is given in Wilson, 1978).

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## LITERATURE CITED

- Brazaitis, P. 1973a. The identification of *Crocodylus siamensis* Schneider. *Zoologica* 58:43-45.
- \_\_\_\_\_. 1973b. The identification of living crocodilians. *Zoologica* 58:59-101.
- \_\_\_\_\_. 1984. Problems in the identification of commercial crocodilian hides and products, and the effect on law enforcement. Pp. 110-116 *In* Crocodiles. Proc. 6th Working Meeting IUCN/SSC Crocodile Specialist Group. IUCN. Gland, Switzerland.
- \_\_\_\_\_. 1986a. Biochemical techniques: new tools for the forensic identification of crocodilian hides and products. Pp. 384-388 *In* Crocodiles. Proc. 7th Working Meeting IUCN/SSC Crocodile Specialist Group. IUCN. Gland, Switzerland.
- \_\_\_\_\_. 1986b. Reptile leather trade: the forensic examiner's role in litigation and wildlife law enforcement. *J. Forensic Sci.* 31:621-629.
- \_\_\_\_\_, and F.W. King. 1984. A guide to the identification and forensic examination of the common caiman *Caiman crocodilus crocodilus* and the Yacare caiman *Caiman crocodilus yacare*. U.S. Fish and Wildlife Service and Florida State Museum Presentation (Xerox).
- Densmore, L.D., III. 1983. Biochemical and immunological systematics of the Order Crocodylia. Pp. 397-465 *In* M.K. Hecht, B. Wallace and G.T. Prance (eds.), *Evolutionary Biology*, Vol. 16.
- Frair, W., and J.L. Behler. 1983. Book review: *Liste der Rezenten Amphibien und Reptilien. Testudines, Crocodylia, Rhynchocephalia* by H. Wermuth and R. Mertens. 1977. *Herpetological Rev.* 14:23-25.
- Fuchs, K. 1974. *Die Krokodilhaut*. Eduard Roether Verlag, Darmstadt. 183 pp.
- \_\_\_\_\_. Undated. The chemistry and technology of novelty leather. Food and Agriculture Org., Rome, Italy. 201 pp.
- Fuller, K.S., and B. Swift. 1984. *Latin American Wildlife Trade Laws*. World Wildlife Fund-U.S., Washington, D.C. 354 pp.

- Groombridge, B., ed. 1982. The IUCN Amphibia-Reptilia Red Data Book, Part I, Testudines, Crocodylia, Rhynchocephalia. IUCN, Gland, Switzerland.
- Hemley, G., and J. Caldwell. 1986. The crocodile skin trade since 1979. Pp. 398-412 *In* Crocodiles. Proc. 7th Working Meet. IUCN/SSC Crocodile Specialist Group. IUCN, Gland, Switzerland.
- King, F. W., and P. Brazaitis. 1971. Species identification of commercial crocodilian skins. *Zoologica* 56:15-70.
- Medem, F. 1981. Los Crocodylia de Sur America. Volumen 1. Los Crocodylia de Colombia. Colciencias, Bogota. 354 pp.
- \_\_\_\_\_. 1983. Los Crocodylia de Sur America. Volumen 2. Colciencias, Bogota. 270 pp.
- Ross, C.A., and F.D. Ross. 1974. Caudal scalation of Central American *Crocodylus*. *Proc. Biol. Soc. Washington* 87:231-234.
- van Jaarsveldt, K.R. Unpubl. Standard methods of flaying, curing and measurement of crocodile skins as used by the Crocodile Farmers Association of Zimbabwe. Presented at 6th Working Meeting IUCN/SSC Crocodile Specialist Group, Victoria Falls, Zimbabwe, Sept. 19-30, 1982. (Mimeo.)
- Wermuth, H. 1953. Systematik der Rezenten Krokodile. *Mitt. Zool. Museum Berlin* 29:375-514.
- \_\_\_\_\_, and K. Fuchs. 1978. Bestimmen von Krokodilen und ihrer Haute. Gustav Fischer Verlag, Stuttgart, 100 pp.
- \_\_\_\_\_, and \_\_\_\_\_. 1983. CITES Crocodile Skin ID Manual.
- \_\_\_\_\_, and R. Mertens. 1961. Schildkroten, Krokodile, Bruckenechsen. Gustav Fischer Verl., Jena. 422 pp.
- Wilson, J.A. 1928. The Chemistry of Leather Manufacture, 2nd Ed., Vol. 1. The Chemical Catalog Co., Inc., New York. pp. 1- 495.
- \_\_\_\_\_. 1929. The Chemistry of Leather Manufacture, 2nd Ed., Vol. 2. The Chemical Catalog Co., Inc., New York. pp. 497- 1181.
- Wilson, M., ed. 1978. Bibliography of Forensic Science in Wildlife Law Enforcement. Suppl. to Proc. Forensic Sciences Symp., Calgary, Alberta, April 13-15, 1977. Alberta Recreation, Parks and Wildlife, Fish and Wildlife Div. 171 pp.





10. a) No osteoderms present in belly scales, or an osteoderm composed of a single bone (Fig. 6C, D) ..... 11
- b) Osteoderms present in belly scales as a composite bone made up of at least two sections (Fig. 6A) ..... 12
11. a) Umbilical scar present in all sizes, appearing as a network of fine creases (Fig. 7); ventral scales in 29 or more transverse rows ..... *Alligator mississippiensis*
- b) Umbilical scar absent, ventral scales in 28 or fewer rows ..... *Alligator sinensis*
12. a) Ventral scales lack surface pitting ..... 13
- b) Surface pitting present (Fig. 6B) ..... 14
13. a) Subcaudal tail inclusions present (Fig. 9B); flank scales as in Fig. 10B, C; ventrals in 25 or more rows ..... *Melanosuchus niger*
- b) Subcaudal tail inclusions absent, belly scales in 24 or less rows .....  
         ..... *Paleosuchus palpebrosus*,  
         ..... *Paleosuchus trigonatus*
14. a) Ventral collar scales (Fig. 4) not noticeably enlarged, composed of a double row of scales; belly scales in 26-30 transverse rows; flank scalation as in Fig. 10A,B .....  
         ..... *Caiman latirostris*
- b) Ventral collar scales greatly enlarged, especially mid-ventrally, composed of a single row of scales, belly scales in 20-27 transverse rows ..... 15
15. a) Flank scalation as in Figure 11 ..... *Caiman crocodilus yacare*
- b) Flank scalation as in Figure 12 ..... *Caiman crocodilus crocodilus*
- c) Flank scalation as in Figure 13 ..... *Caiman crocodilus fuscus*

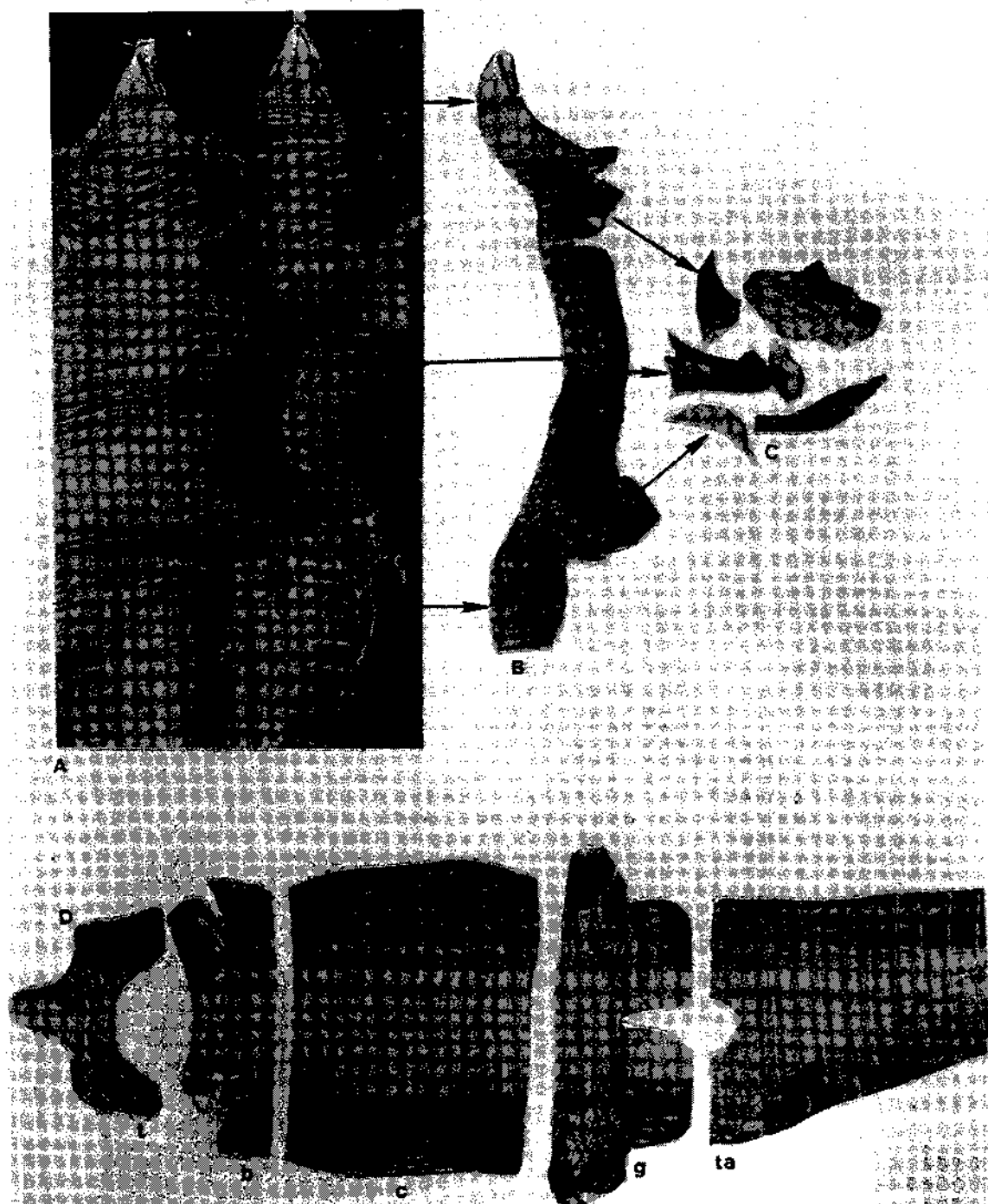


Figure 1. A. Full belly "crust" tanned skins of *Caiman crocodilus*. Crusts are partially tanned and are unfinished. The leather at this point is bleached white or tan and is softened. B. Flank skins are cut from the sides of crocodilians, usually caiman, and include portions of the upper front and rear legs, as well as the base of the tail and part of the lower jaw. C. Scraps or trimmings are pieces of finished or crust skin which remain after flanks or whole skins are cut up for manufacture into products. D. Black caiman skins are often cut up and sold as throats (t), bellies (c), girdles (g), and tails (ta).

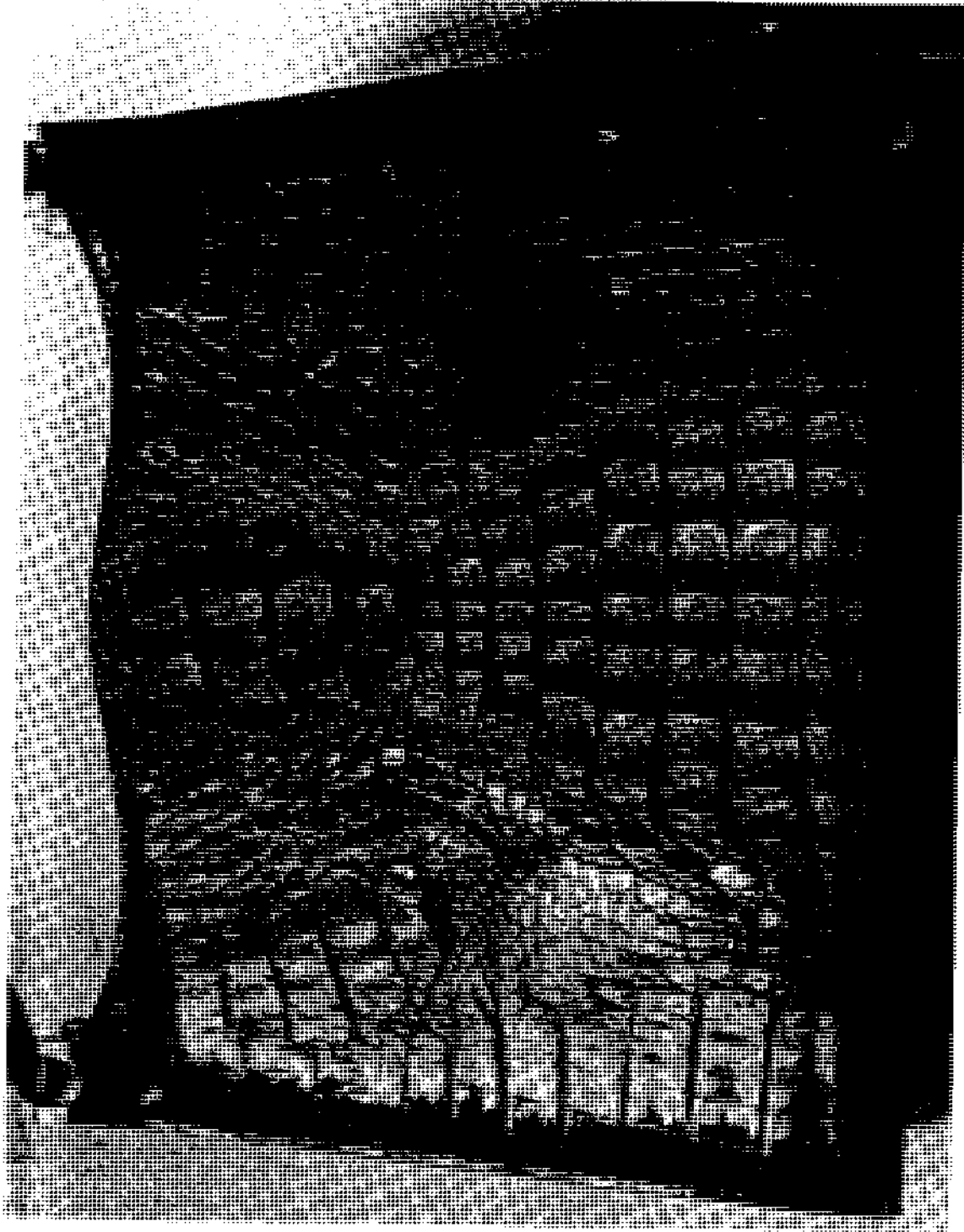


Figure 2. This is a "hornback" handbag manufactured in Thailand from *Caiman c. fuscus* skins shipped from South America, and exported or sold to tourists as native crocodile. The nuchal cluster (N), dorsal scales (D), pitted ventral scales (V), and flank (F) regions are shown.



Figure 3. Characteristic scale shapes which are found on different body regions. D - Rectangular to square heavily ossified and strongly keeled dorsal scales. LC - Posteriorly rounded, ossified, keeled rectangular scales from the lateral tail regions. N - Round neck scales. SC - Rectangular unkeeled ventral scales. V - Unkeeled ventral scales. L - Diamond shaped scales on the dorsal regions of the legs. F - Arrows separated by the dotted line indicate the extent of the flank region from axilla to groin used to calculate approximate flank length relationship to total body length. Random large scales are shown in a field of smaller round scales. F<sup>1</sup> shows flank scales arranged in uniform rows. F<sup>2</sup> shows random scales in a field of soft creased skin.

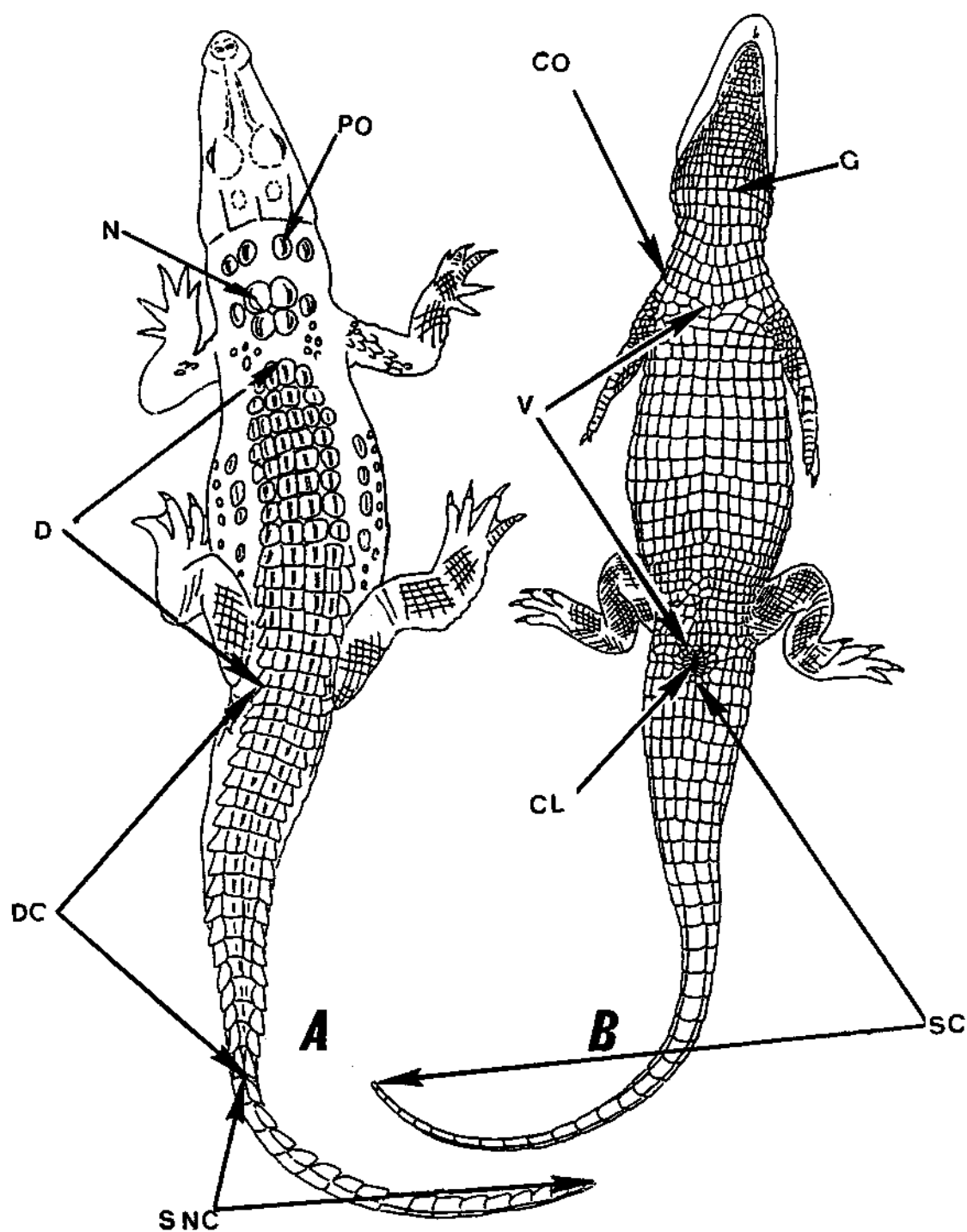


Figure 4. Body regions of crocodilians. A. SNC - single caudal verticils; DC - double caudal verticils; D - dorsal scales; N - nuchal scales; PO - post occipital scales.  
B. SC - sub-caudal scales; CL - anal opening or vent; V - ventral scales; CO - collar; G - gular region.

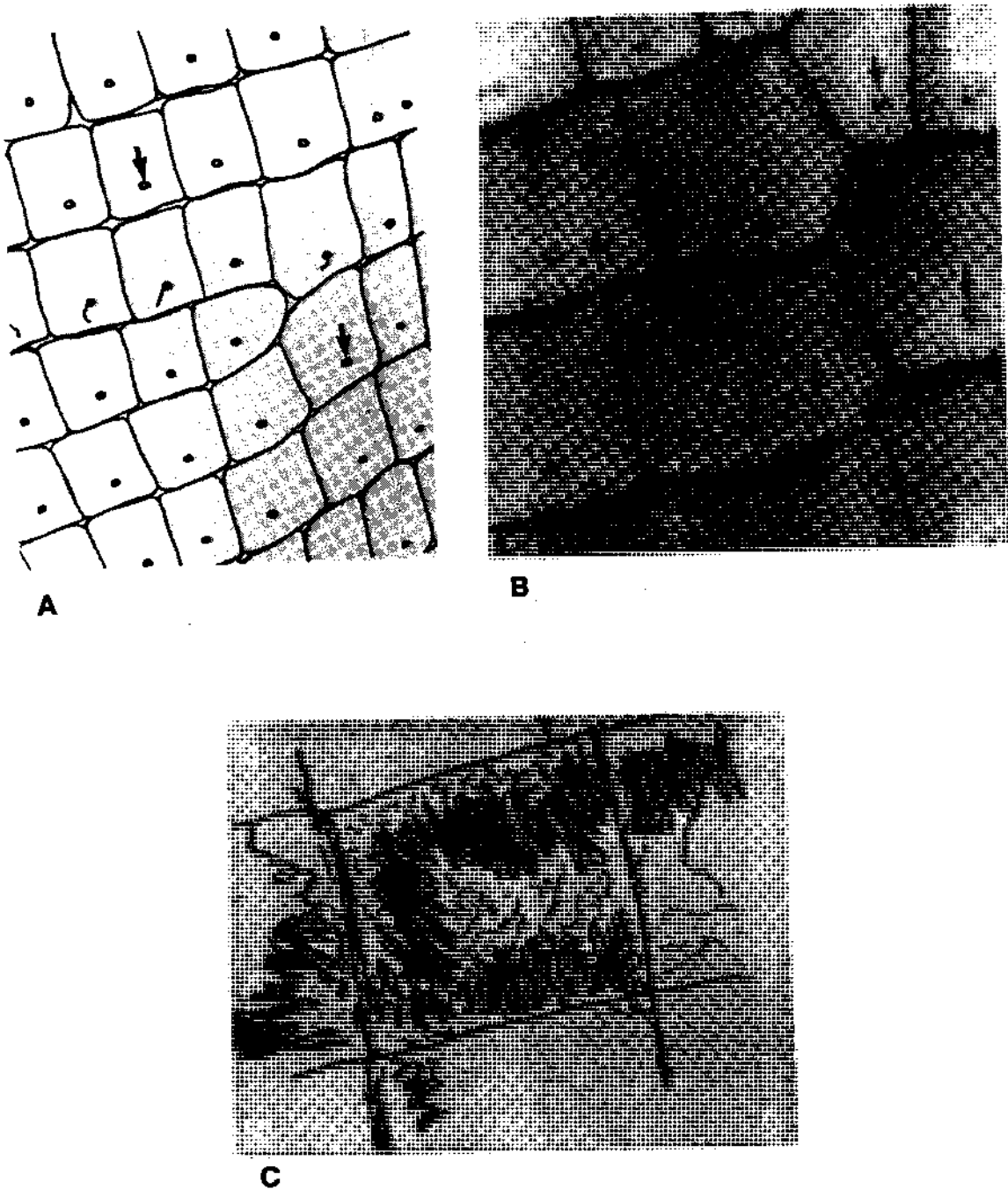


Figure 5. A. Arrows show integumentary sense organs (ISOs) found on the body scalation of members of the families *Crocodylidae* and *Gavialidae*. Ventral or belly scales are depicted diagrammatically. B. ISOs as seen in life and on hides and products. Multiple ISOs on ventral scales are not uncommon. Multiple ISOs are not diagnostic for any specific species. C. Undulating worm trail produced by the boring of a parasitic nematode (*cappilaria*) which may be seen on the ventral scales of many crocodilians from round the world.

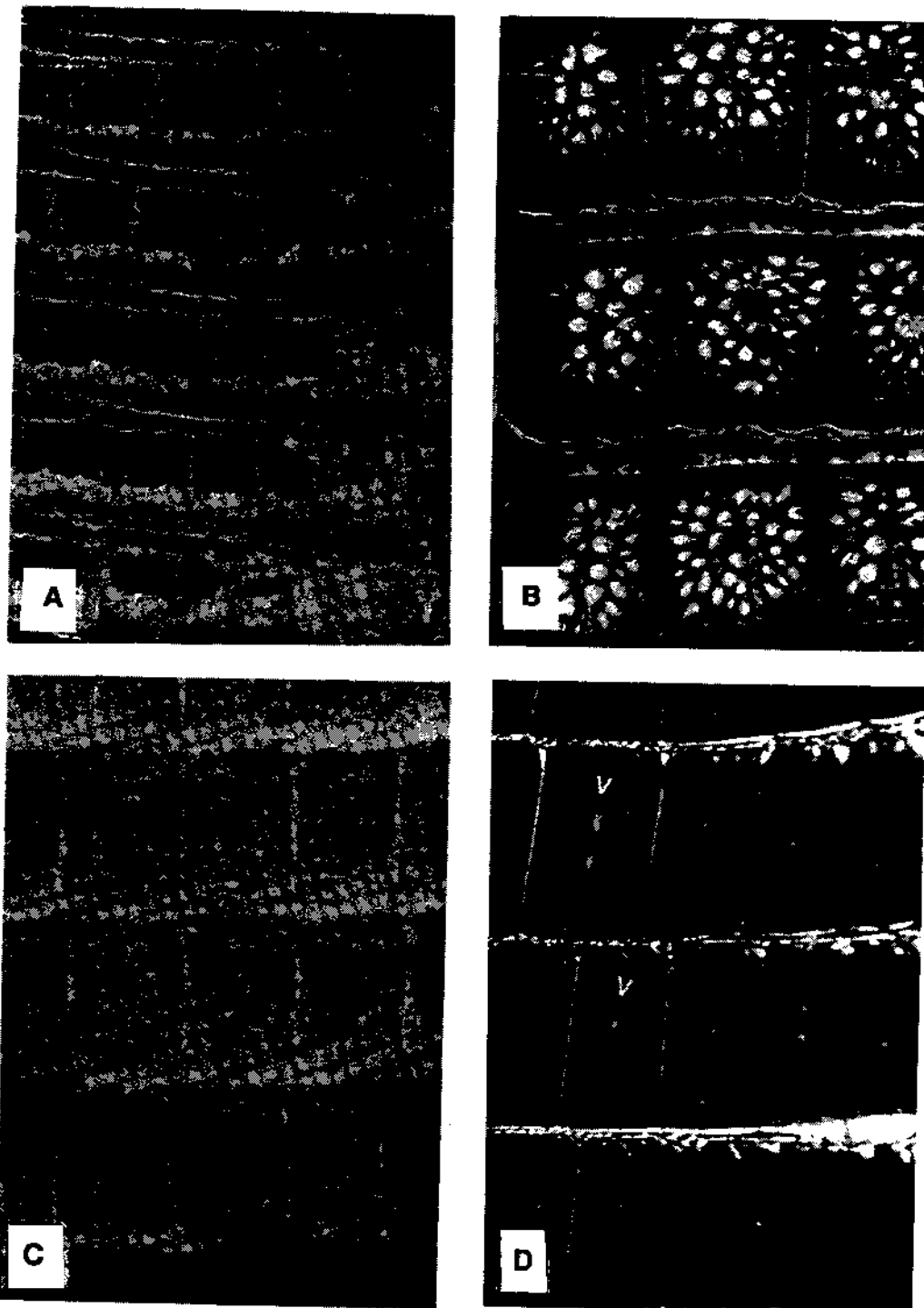


Figure 6. A. Arrows indicate composite two part ventral osteoderms typical for *Caiman* and *Melanosuchus* is viewed from the flesh side of a finished skin. B. Two part ventral osteoderms of *Caiman*. Arrows indicate surface pitting in the finished skin. C. Arrows indicate the large round osteoderms found in the belly scales of *Crocodylus cataphractus* as viewed from the flesh side of the finished skin. D. Large arrows indicate small elliptical belly osteoderms of *Crocodylus niloticus* as seen from the skin surface.



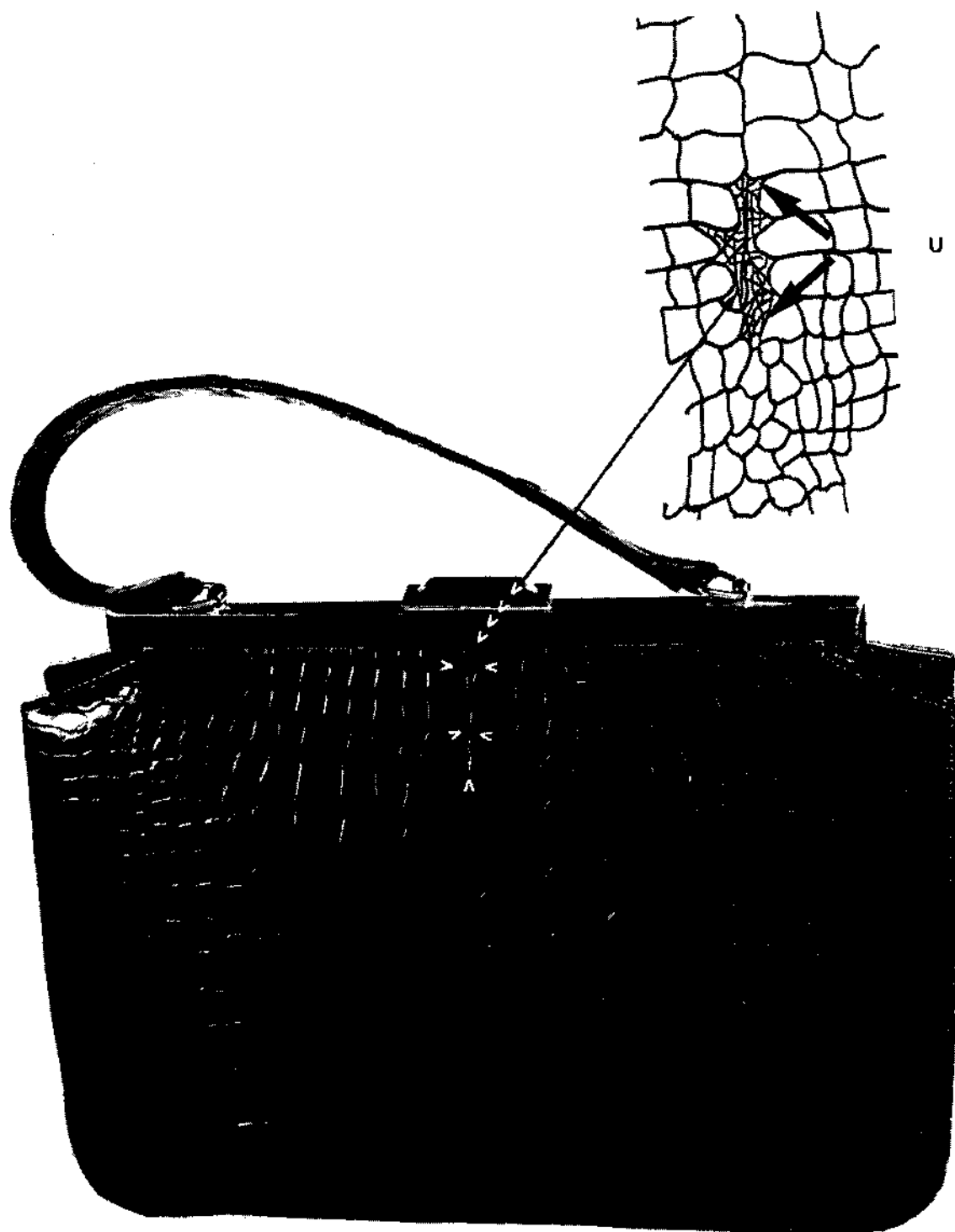


Figure 7. Arrows indicate the network of fine creases which remains as an umbilical scar (U) throughout the life of *Alligator mississippiensis*. The scar is usually seen near the top of the front panel of quality handbags made from this species. It is diagnostic in conjunction with the absence of ISOs.



Figure 8. A. Nuchal cluster (See also Fig. 3.) typical for most *Crocodylus*. B. Nuchal cluster typical of *Caiman* and *Melanosuchus*. C. Nuchal group typical for *Osteolaemus tetraspis*. D. Nuchal group typical for *Tomistoma*. E. Nuchal group typical for *Crocodylus johnsoni*. Note the similarity of the anterior scales in the nuchal group to those in A; however, they are continuous with the dorsal scales and are tightly sutured together to form what appears to be one contiguous mass. F. Nuchal group typical of *Crocodylus cataphractus*.

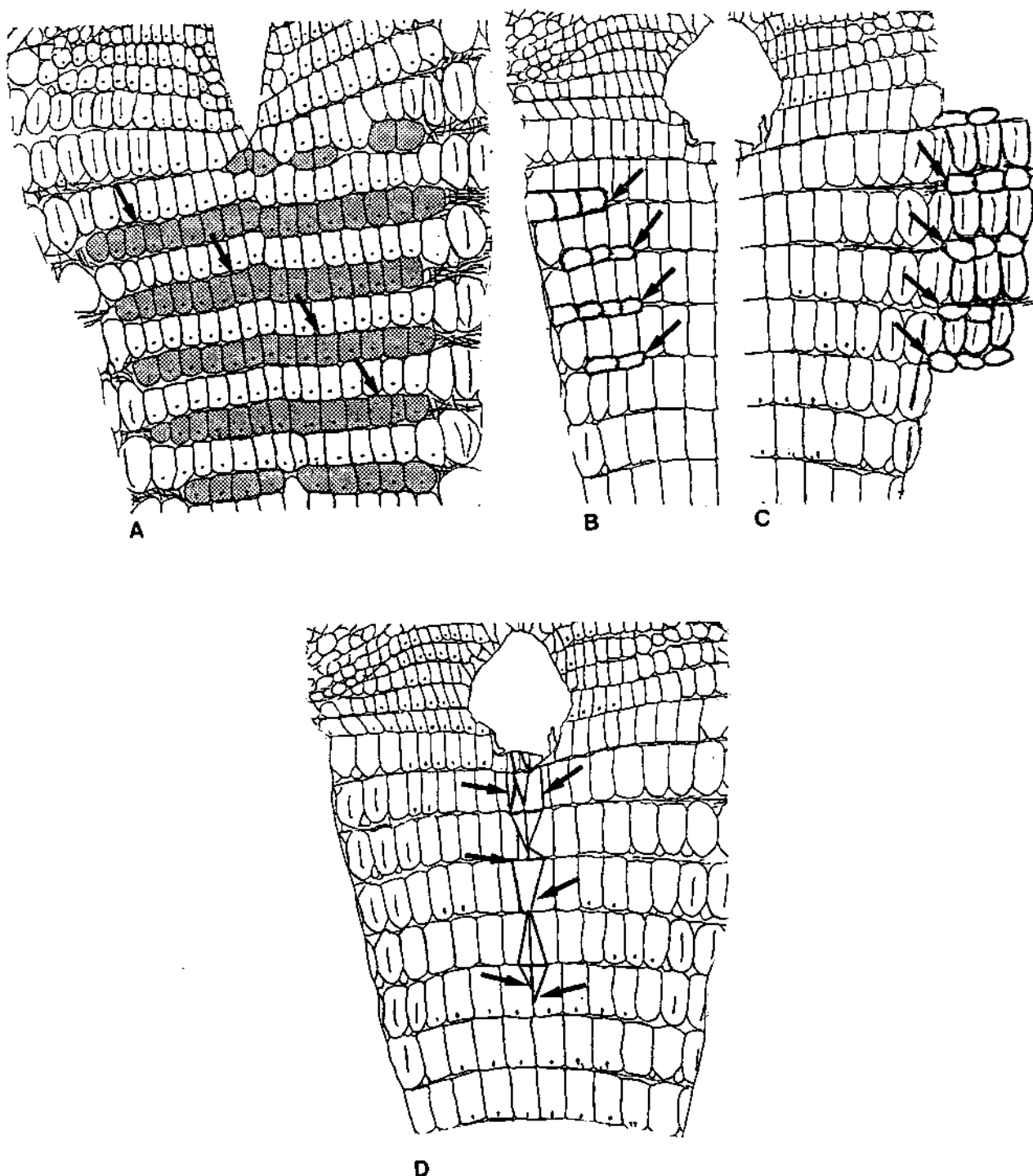
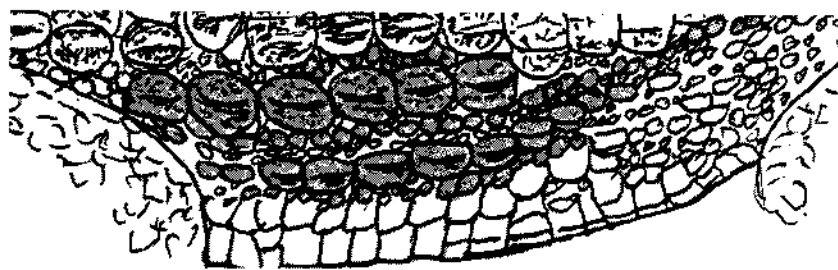


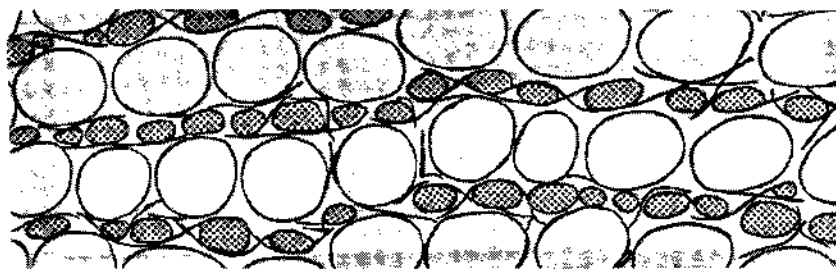
Figure 9. Subcaudal tail section immediately posterior to the vent showing inclusions of scales. A. In conjunction with ISOs, subcaudal tail inclusions are shown occupying the lateral and ventral portions of the anterior tail which is characteristic of *Crocodylus moreleti*. B. Tail inclusions typical for *Melanosuchus niger* which lacks ISOs. C. Inclusions which are confined to the lateral tail regions, typical for *Crocodylus acutus*. D. Midventral series of inclusions extending from the vent through the first several rows of scales are typical for *Crocodylus siamensis*.



A



B



C



D

Figure 10. A and B. Flank scalation typical for *Caiman latirostris*: A. Illustrated. B. In life. C and D. Flank scalation typical for *Melanosuchus niger*, composed of at least five rows of alternating small and large round, poorly keeled scales. C. Note alternating rows of large and small scales illustrated. D. In life.

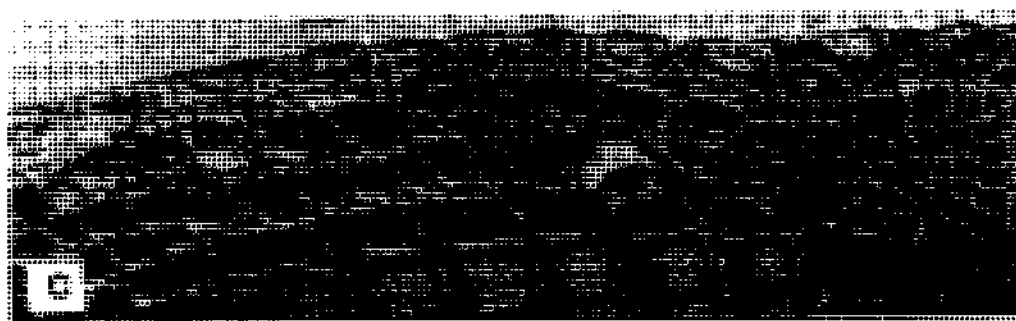
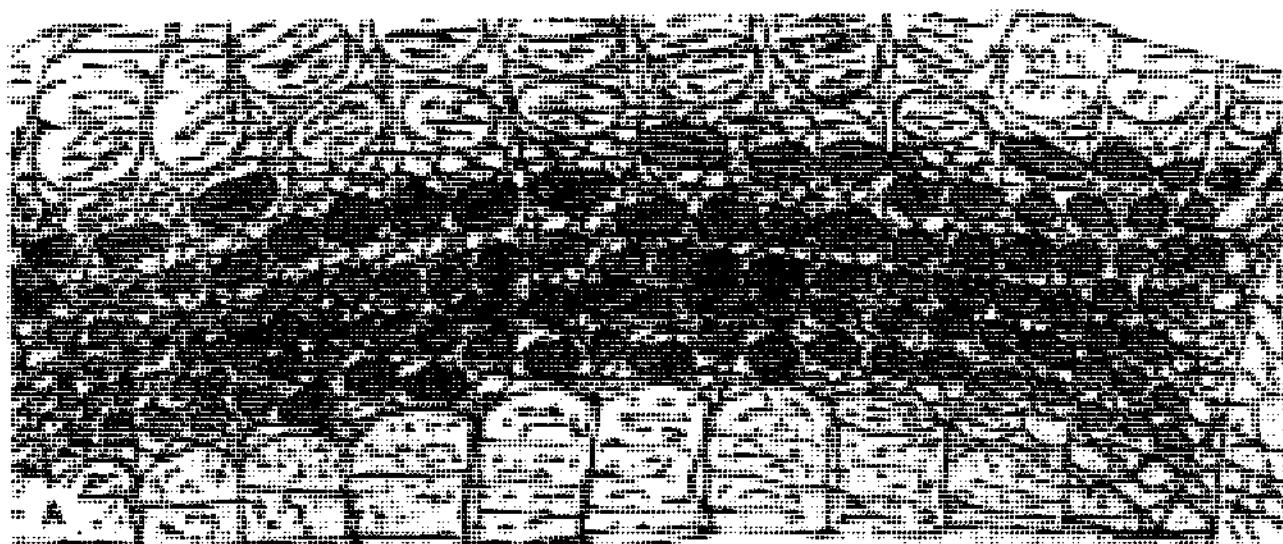


Figure 11. Flank scalation typical for *C. crocodilus yacare*. A. Diagrammatic. B. Raw dried skin. C. Tanned and finished skin. D. In life (juvenile).

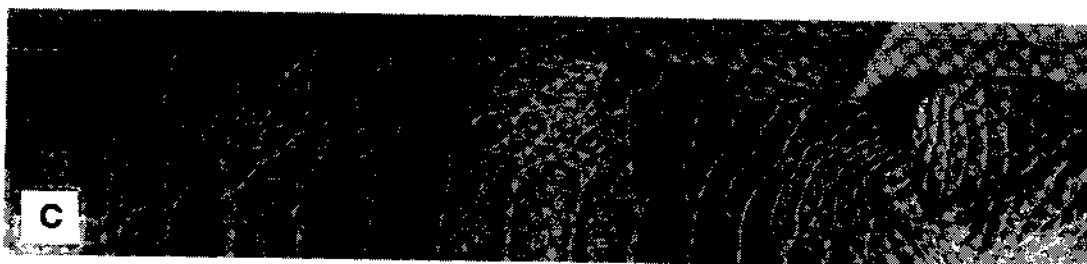
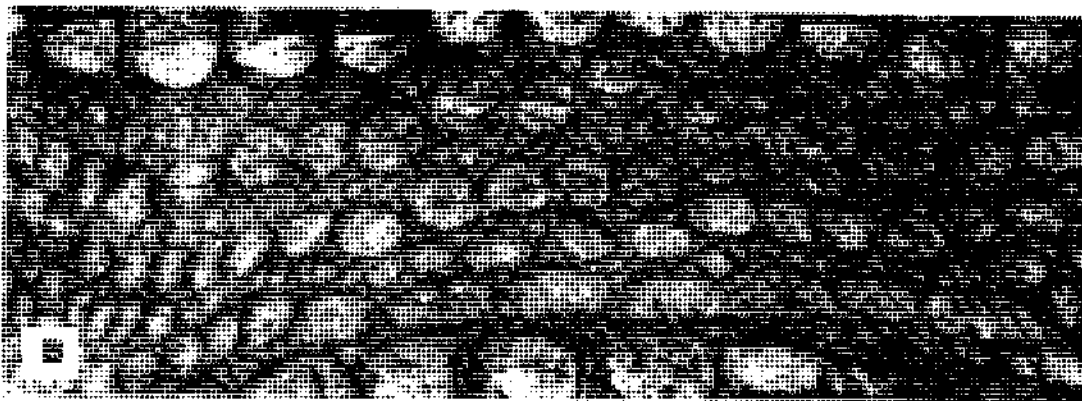
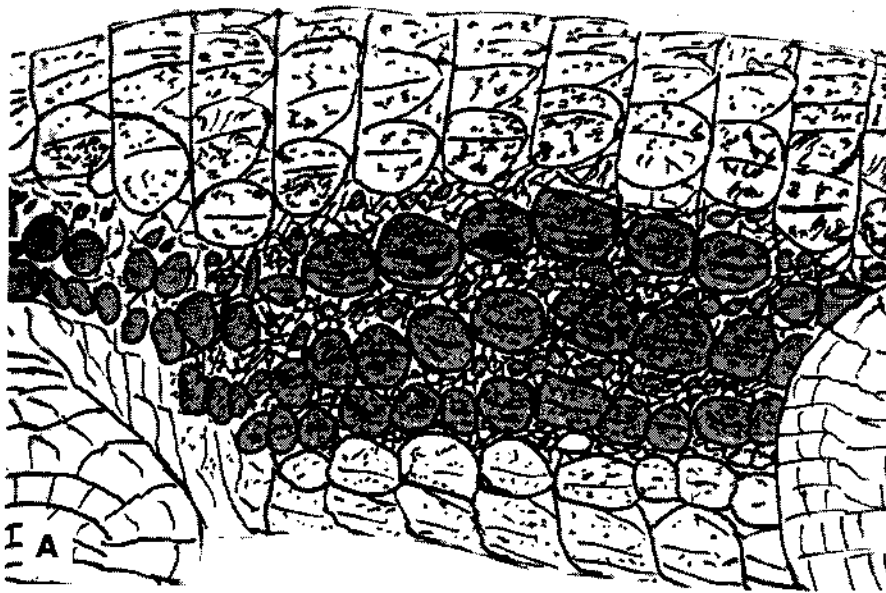


Figure 12. Flank sculation typical for *C. crocodilus crocodilus*. A. Diagrammatic. B. Raw dried skin. C. Crust tanned skin.

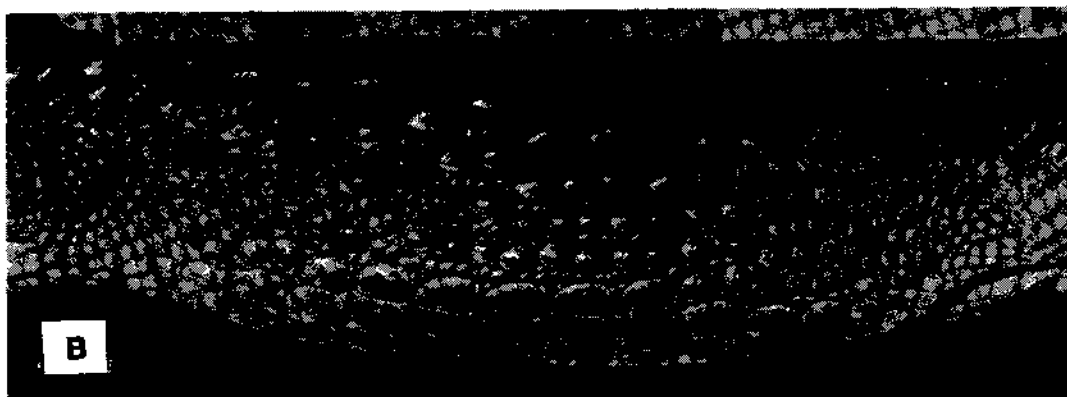


Figure 13. Flank scalation typical for *C. crocodilus fuscus*. A. Diagrammatic. B. As in life.

## THE COMMON CAIMAN

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### INTRODUCTION

The common or spectacled caiman is a species complex whose taxonomy is in a confused state. Primarily for management and conservation considerations, rather than for nomenclatorial justification, we follow in this chapter the terminology of the Red Data Book (IUCN 1982), using the binomial *Caiman crocodilus* with four nominal subspecies (*C. c. apaporiensis*, *C. c. crocodilus*, *C. c. fuscus*, and *C. c. yacare* (King and Brazaitis 1971; Brazaitis 1973)). Medem (1981) discussed the validity of this usage and argued that *Caiman sclerops* should be applied to this taxon. Likewise he recognized *C. c. fuscus* as two distinct subspecies (*fuscus* and *chiapasius*), and gave full species status to *C. c. yacare* (Medem 1983). Two additional subspecies *C. c. mattogrossiensis* and *C. c. paraguayensis* have been included in another checklist (Wermuth and Mertens 1977). However, the original descriptions were based on commercial hides (Fuchs 1974) and the use of those names should be suppressed (Frair and Behler 1983).

Numerous works on *C. crocodilus* have been 'published' in Latin America as internal manuscripts of government organizations and as theses of universities. Due to the difficulty in obtaining such material we have been selective and have cited only those that we consider contain data or concepts of particular worth. Given Medem's (1981, 1983) extensive treatment of South American crocodilians and their literature, we have restricted our review in general to publications of the last two decades.

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## GEOGRAPHICAL DISTRIBUTION

The common caiman occurs from about latitude 16° 20' N in Central America to latitude 34° 00' S in South America. Off of the mainland it occurs naturally on the island of Trinidad and Tobago. Feral populations are established in the Lanier Swamp in the southwest of the Isla de Pinos (Cuba; Varona 1976), and in the State of Florida (USA) as far north as latitude 26° 40' (King and Krakauer 1966, Ellis 1980). In the accounts of subspecies we list them in order of occurrence from north to south.

*C. c. fuscus* ranges from the Pacific drainage of the states of Oaxaca and Chiapas in southern Mexico (Alvarez del Toro 1974), through Central America into northwestern South America. In Nicaragua, Costa Rica and Panama it is found in both Pacific and Caribbean lowlands (Budowski and Vaihnan 1976, Dixon and Staton 1983). In northwestern South America it occurs to the west of the Andes as far south as Machala in the Gulf of Guayaquil in Ecuador (Medem 1983). The subspecies extends east through the Caribbean drainage of Colombia, in the Cauca and Magdalena basins, into the Maracaibo basin of northwestern Venezuela (Medem 1981, 1983), and along the Caribbean coast as far as the Rio Yaracuy (Medem 1983). The taxonomic relationships of the most eastern population with *C. crocodilus* along the rest of the Venezuelan Caribbean coast is not clear (Seijas 1986).

*C. c. crocodilus* is the most widespread subspecies and may well be a composite. Medem recognize the existence of various demes in this subspecies and discusses the unpublished revision that was begun by the late K. P. Schmidt of the Chicago Natural History Museum. The subspecies occurs to the east of the Andes into northern South America in Venezuela, Guyana, Surinam, French Guiana, Colombia, Ecuador, Peru, the Amazon basin in Brazil, and the islands of Trinidad and Tobago (IUCN 1982; Medem 1983).

*C. c. apaporiensis* is known only from southeastern Colombia along a 200 km stretch of the Rio Apaporis (Medem 1981, IUCN 1982).

*C. c. yacare*, which is regarded as a full species by Medem (1983), occurs in the Llanos de Mojós region in the southeastern tributaries of the Amazon in Bolivia (rivers Beni, Mamore and Madre de Dios), in the adjacent Mato Grosso region of Brazil, and southward through the Paraguay (Parana) River basin of Paraguay and northern Argentina (IUCN 1982, Medem 1983).

## HABITAT

*C. crocodilus* is found in a wide range of aquatic habitats from sea level up to about 500 m, representing the 24° to 27° isotherm (Chirivi-Gallego 1973), and exceptionally up to 800 m (Gorzula and Paolillo 1986).

*C. c. apaporiensis*

This subspecies is found in quiet waters and lagoons of the upper and middle Rio Apaporis. Medem (1983) notes that the water temperature of the lagoons where they occur is warmer (25 to 28° C) than that of the adjacent bodies of water (21° to 22° C) occupied by *Paleosuchus palpebrosus*.

*C. c. crocodilus*

General descriptions of the habitat of this subspecies have been given for numerous authors (Medem 1981; Ramos et al. 1981, IUCN 1982, Gorzula and Paolillo 1986). Habitat types have been described as: permanent and temporary lagoons, ponds, lakes, reservoirs, hydroelectric dams, oxbow lakes, flood plains, quiet water, bodies of water in flat lands with sandy beaches without plants, borrow pits, flooded savannas, savannas modulated with dikes, moriche and palm swamps, swamps, marshes, brackish waters in mangrove swamps, the lower areas of forest streams, flooded forest, rivers, river meanders, mudbanks at the bend of rivers, the mouth of branch creeks, shallow waters with a gradually sloping shore and many inlets, drainage ditches, canals, and sometimes in rivers near to falls and rapids.

Climatic data have been reported for some areas (Ramos et al. 1981, Ouboter and Nanhoe 1984) and indicate that the habitat of *C. c. crocodilus* in Venezuela is characterized by a marked dry season for the first few months of the year. Ramos et al. (1981) provide limnological data for one site in the Venezuelan Llanos showing water temperatures from 26 to 30° C, pH from 5.7 to 7.5, and low concentration of minerals and nutrients, especially calcium, magnesium, carbonates, phosphorus and nitrogen. Limnological data for 15 *C. c. crocodilus* localities and 7 *Paleosuchus trigonatus* localities indicated that *Caiman* inhabits waters that are less oligotrophic than those where *P. trigonatus* occurs (Gorzula et al. 1989). The mean temperature (°C), conductivities (MHOS) and total cations (eq/l) were 26.1/22.4, 48.5/29.1, and 125.6/32.4 respectively. The range of values for conductivity, sodium, potassium and total cations fell into two distinct groupings. The ranges of values for temperature, pH, calcium and magnesium overlapped only slightly.

*C. c. crocodilus* is occasionally sympatric with other species of crocodilians, but this may be a seasonal phenomenon (Vanzolini and Gomes 1979, Medem 1981, 1983; Magnusson 1982, 1985; Gorzula and Paolillo 1986). Its present day distribution may be in part due to its expansion to places where larger crocodilian species are extinct or severely depleted due to commercial hunting (Dixon and Sioni 1977, Medem 1983). Human intervention, through the creation of reservoirs, dams and canals has favored the expansion of this subspecies by the creation of new habitats (Dixon and Sioni 1977, Magnusson 1985, Gorzula and Paolillo 1986).

*C. c. fuscus*

Compared to the previous subspecies *C. c. fuscus* is more coastal, extending only up some large rivers in Colombia and Ecuador into the low lying alluvial plains. Its habitat has been described as: quiet waters, swamps, lagoons, dams, meanders of large rivers, small streams and creeks, stormtide inner beaches, lowlands, brackish water mangrove swamps, saltwater, and ponds on offshore islands (Chirivi-Gallego 1971, 1973; Alvarez del Toro 1974, Medem 1981, 1983; IUCN 1982, Seijas 1986). Chirivi-Gallego (1971) notes that the specimens collected in saltwater habitats show flaking of the dorsal scutes. Where sympatric with *Crocodylus acutus*, this subspecies occurs in low numbers (Seijas 1986). In areas where *C. acutus* has been hunted out *C. c. fuscus* has invaded the former's niche (Medem 1981, 1983; Seijas 1986).

*C. c. yacare*

This subspecies has been described as inhabiting open waters, marshy savanna, lakes, lagoons, roadside borrow pits, and rivers (IUCN 1982, Schaller and Crawshaw 1982, Medem 1983). It avoids salt or brackish waters (IUCN 1982). Although the general habitat is similar to that of the Venezuelan Llanos with a distinct dry season in the latter half of the year, there is also a marked cool period from June to September during which the air temperature may fall to 0° C (Schaller and Crawshaw 1982).

Although this subspecies occurs in two separate river basins, the watershed is low (about 400 m above sea level). Medem's (1983) geographical generalities indicated that the flooded relatively open plains of the Llanos de Mojos, the Mato Grosso and the Pantanal form a continuum of habitat that is occupied by this subspecies. This habitat is distinct from the lowland forest habitat of *C. c. crocodilus* in the adjacent Amazon region. *C. c. yacare* is the largest subspecies attaining lengths of between 2.5 to 3.0 m. It is interesting to note that the deme of *C. c. crocodilus* which inhabits the llanos of Venezuela and Colombia, and which the late K. P. Schmidt had intended to describe as a distinct subspecies, *C. c. humboldtii* (Medem 1983), also attains large sizes (up to 2.5 m), whereas *C. c. crocodilus* in southern Venezuela are significantly smaller (Gorzula 1987).

## POPULATION DENSITIES

Problems related to the censusing of caimans have been discussed by Magnusson (1982, 1984) and others (Gorzula 1984, 1987; Gorzula and Paolillo 1986). These authors have proposed techniques for estimating size during such surveys (Magnusson 1983, Gorzula 1984). In most surveys, with the exception of the Venezuelan Llanos where caimans concentrate into well defined bodies of water during the dry season, it is not known whether the populations are partially or totally migratory. The planning of surveys with regards to factors such as tide, weather and phases of the moon is based on the individual experience of the researcher. It is not known what proportion of the true population has been counted. The surveys are frequently not repeated and densities are expressed as number per unit area of general habitat, but do not take into account within habitat preferences of the caiman. Additionally, few workers report the age- or size-structure of the population. In spite of these problems, the surveys conducted over the past ten years or so indicate that *C. crocodilus* is still a common species in many areas.

The majority of surveys have been of *C. c. crocodilus*. In riverine habitats observed densities in different countries are surprisingly uniform. In Peru, densities of 6.6 caiman/km of shore have been reported for the Rio Mairia (Morley and Sanchez 1982) and 9.02 caiman/km of shore for the Pacaya-Samiria National Reserve (Verdi et al. 1980). In the Coesewijne River in Surinam Glastra (1983) observed densities from 0.7 to 19.0 caiman/km of river, the densities being higher near the mouths of large side creeks and on sections of the river bordered by large open swamps. Mean observed densities were 3.3 caiman/km of river during the wet season and 6.41 caiman/km of river during the dry season. In the same area the overall density has been estimated at 5.3 caiman/ha of habitat (Ouboter and Nanhoe 1984). In the Venezuelan Guayana for riverine habitat and lake shore a mean density of 2.52 caiman/km has been reported (Gorzula and Paolillo 1986). In the Venezuelan Llanos Staton and Dixon (1975) calculated densities of 130 caiman/ha of lagoon during the dry season, Ayarzagüena (1983) reported 80 to 150 caiman/ha of lagoon for similar conditions and Marcellini (1979) observed a mean value of 63.5 caiman/ha of lagoon. Caimans in this area disperse over the flooded savannas during the wet season and population densities for gross habitat (including dry land) have been reported as 0.17 caiman/ha for a 78,000 ha ranch

(Ayarzagüena 1983), 0.21 for the same ranch (D'Andria 1980), 0.19 for a series of ranches covering a total area of 233,800 ha (Seijas 1986), and 1.11/ha for a 75,000 ha ranch (Woodward and David 1985). In modulated savannas in the same area dry season densities were 3.1 caiman/ha of water surface, dropping to 1.6 caiman/ha in the wet season (Ramos et al. 1981). For the Venezuelan Guayana one study (Gorzula 1978) estimated densities of 100 caiman/ha of lagoon during the dry season and 10 caiman/ha of lagoon during the wet season. Subsequent results for this region (Gorzula and Paolillo 1986) estimate an overall density of 6.64 caiman/ha of lagoon or 23.4 caiman/km of lagoon shoreline.

Populations of *C. c. fuscus* along the northern coast of Venezuela have been surveyed by Seijas (1986). In lacustrine habitats a mean density of 5.8 caiman/km of shoreline was reported for 144 km of lake shore where *C. c. fuscus* occurs alone, but only 2.5 caiman/km (in 45.3 km of lake shore) where they were sympatric with *Crocodylus acutus*. Likewise, in riverine habitat densities were higher (7.1 caiman/km along 143 km of river) in habitats where *C. acutus* was absent than where they were sympatric (1.5 caiman/km along 86.9 km of river).

In the pantanal area of Brazil Schaller and Crawshaw (1982) counted a total of 2,368 *C. c. yacare* in borrow pits along a 14 km stretch of the Transpantanal Highway. They estimated that this figure represented 75% of the total population.

### POPULATION STRUCTURE

The studies that have been made to date of the population structure of the spectacled caiman have been of size structure, rather than age structure, of populations of this species. Results of ten such studies are shown in Figure 1. Since certain authors did not include hatchlings in their analysis, we have eliminated data for hatchlings from those reports that did so. It should also be noted that, due to the high mortality that may occur in hatchlings, these percentages may vary greatly within a given population in a short period of time. Likewise, authors varied in which parameter was used to express size, using either the snout-vent length or the total length of the animals. In order to facilitate a direct comparison between the use of both parameters two scales have been given, one for the snout-vent length in mm and the other for the total length in m. Staton and Dixon's (1975) regression of  $Y = 2.3997 + 1.8548X$  was applied in order to calibrate the two scales.

As a broad generality, yearlings of this species reach a snout-vent length of approximately 200 mm (Chirivi-Gallegos 1971, Blohm 1973, Rivero-Blanco 1974, Staton and Dixon 1975, 1977; Gorzula 1978, Verdi et al. 1980, Medem 1981, Ayarzagüena 1983). Females reach sexual maturity as, or slightly before, they attain a snout-vent length of 600 mm. With the exception of certain cases reported by Medem (1981) for *C. c. apaporiensis*, females do not grow larger than a snout-vent length of 900 mm. Males possible reach maturity at a larger size than females do, but attain substantially greater maximum sizes. Thus for the size frequency histograms of the Venezuelan Llanos population (Fig 1: A, B, C, D and E) the first size class shown (class II individuals) represent the non-hatchling immature portion of the population, the second size class shown (class III) represent all of the sexually mature females of the population and the smaller mature males, and the third size class (class IV) represents adult males. All of these populations have suffered no significant hunting pressure for at least ten years. In spite of different methodologies being employed they show reasonably similar size structures, especially with respect to the class IV portion. The Brazilian Pantanal population of *C. c. yacare* studied by Schaller and Crawshaw (1982; Fig. 1: F) is shown with four size classes. The first two represent non-hatchling subadults (class II), the third represent adult females and subadults males (class III), and the fourth are the

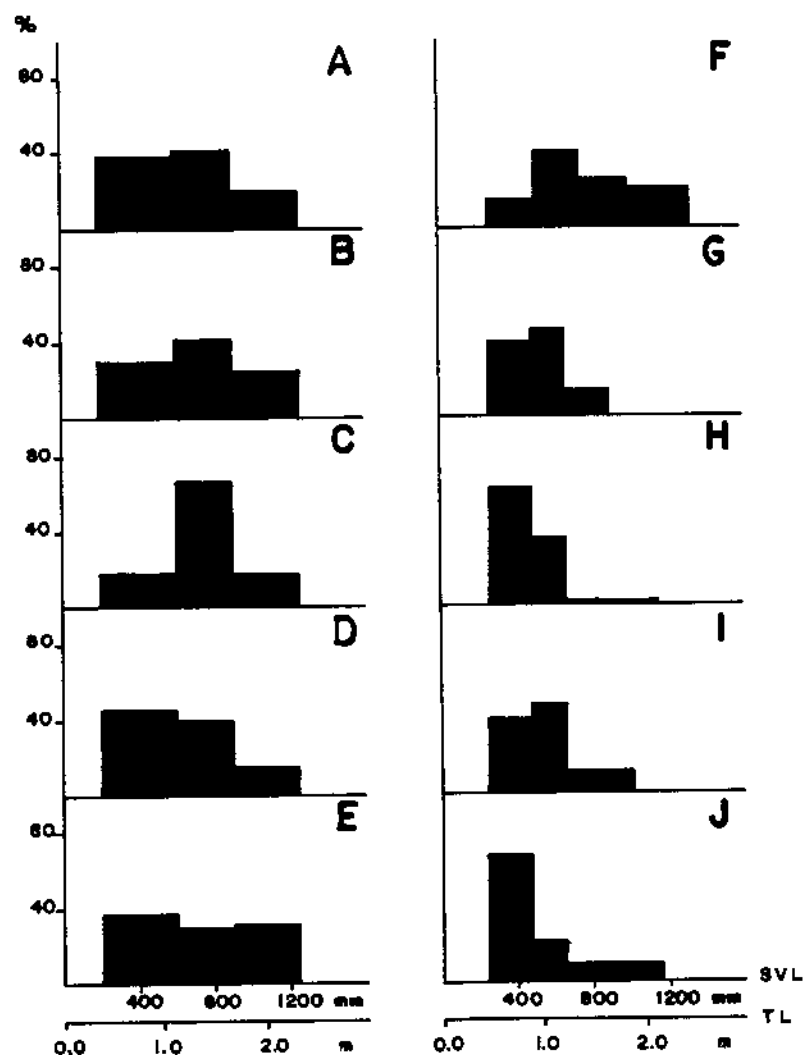


Figure 1. The size structure of nine populations of *Caiman crocodilus* - A: Venezuelan Llanos, captures, N = 219 (Ayarzagüena 1980); B: Venezuelan Llanos, visual size estimates, N = 296 (Ayarzagüena 1980); C: Venezuelan Llanos, visual size estimates, N = 13,185 (Seijas 1984); D: Venezuelan Llanos, captures, N = 174 (Staton and Dixon 1975) E: Venezuelan Llanos, visual size estimates, N = 4,570 (Woodward and David 1985); F = Brazilian Pantanal, visual size estimates, N = 637 (Schaller and Crawshaw 1982); G = Venezuelan Guayana, captures, N = 119 (Gorzula 1978); H = Brazilian Amazonas, visual size estimates, N = 112 (Magnusson 1982); I = Surinam, visual size estimates, N = 213 (Glastra 1983); J = Surinam, captures, N = 337 (Ouboter and Nanhoë 1984). SVL = snout-vent length in mm. TL = total length in m.

adults males (class IV). It has been already pointed out that *C. c. yacare* shares certain characteristics of its general ecology with the Venezuelan Llanos deme of *C. c. crocodilus*. It is thus an additional curiosity that the yacare caiman population studied, which was probably under moderate if not intense hunting pressure, should show a population size structure with a marked similarity to those of the Venezuelan Llanos populations.

The populations of *C. c. crocodilus* studied in the Venezuelan Guayana, Brazil and Surinam (Fig. 1: G, H, I, J) are markedly different in size frequency distribution from those of the Llanos or Pantanal, but again fairly similar between themselves. In these cases the three sizes classes shown were arbitrarily chosen to illustrate the general trend of the population structure, and do not correspond to the classes II, III and VI. All four populations were reported to be, or have been recently, under slight to heavy commercial hunting pressure. However, Gorzula's unpublished follow-up of the El Manteco population for some fourteen years after a total hunting ban was enforced suggest that this size structure is normal of *C. c. crocodilus*, at least in the Venezuelan Guayana.

### REPRODUCTION

Authors have generally concluded that the sex ratio of *C. crocodilus* populations is 1:1, although in some data it seems that this might not necessarily be so (Gorzula 1978, Ouboter and Nanho 1984). The fact that males attain larger sizes results in marked differences in sex ratio within certain size classes (Staton and Dixon 1975, Schaller and Crawshaw 1982, Ayarzagüena 1983). External sexual dimorphism has been examined by Ayarzagüena (1983) who showed that female *C. crocodilus* have proportionally larger and more rounded eyes. In general females start breeding when they have reached a total length of 1.14 m. However, Chiviri-Gallego (1971) reported a breeding female *C. c. fuscus* of 1.08 m. The basic breeding strategy of this species is that of a mound builder that nests during the mid wet season, producing young at the beginning of the dry season.

**Courtship and mating** - In the Llanos and Pantanal at the end of the respective dry seasons caimans are concentrated in small permanent bodies of water. Although these aggregations are of a passive nature due to environmental factors, there is evidence that *C. crocodilus* does make active breeding aggregations (Schaller and Crawshaw 1982, Ouboter and Nanho 1984). Breeding behavior has been observed in the llanos from March to August (Staton and Dixon 1977) and in the Pantanal from July to December (Schaller and Crawshaw 1982). Courtship involves jumping, a horizontal tail display, a vertical tail display, head slapping and tail slapping (Alvarez del Toro 1974, Staton and Dixon 1977, Ayarzagüena 1983). Vocalizations play little or no part in the courtship of Llanos caiman (Staton and Dixon 1977). Nibbling by the female of the male's lower mandible and mutual neck rubbing have been observed during pre-coitus (Alvarez del Toro 1974, Staton and Dixon 1977). Copulatory position may vary according to the depth of water where it is carried out. The male is usually on top of the female but one case was observed where the female was on top of the male (Staton and Dixon 1977). Copulation lasts from four minutes to half an hour (Alvarez del Toro 1974, Staton and Dixon 1977).

**Nesting** - Nesting in *C. crocodilus* has been reported from August to October in the Llanos (Staton and Dixon 1977) and in the mouth of the Amazon during May and June (Best 1984). *C. c. fuscus* breeds all year round in Colombia, but with a peak of nesting activity from January to March (Medem 1981, IUCN 1982). *C. c. yacare* nests between December and April (Crawshaw and Schaller 1980). Caimans used the material closest to the nest site for construction (Alvarez del Toro 1974). In the Llanos nests constructed in open savanna were of *Paspalum fasciculatum*, and those in

or near to gallery forest were made of leaves, twigs and soil (Staton and Dixon 1977). Nest sizes of *C. c. crocodilus* in the Llanos have been reported as a mean diameter of between 80 and 110 cm with a height of 40 to 50 cm (Rivero-Blanco 1974), and as a mean length of 117 cm, a mean width of 104.5 cm and with a mean height of 44.5 cm (Staton and Dixon 1977). Nests of *C. c. yacare* average 134 x 117 cm and 40.5 cm height (Crawshaw and Schaller 1980). A single nest of *C. c. apaporiensis* with ten eggs has been found (Medem 1981). Clutch sizes in *C. c. crocodilus* vary from 14 to 40 eggs with a mean about 29 (Rivero-Blanco 1974, Staton and Dixon 1977). In *C. c. fuscus* smaller clutch size from 12 to 32 eggs have been reported (Alvarez del Toro 1974, Medem 1981, IUCN 1982). *C. c. yacare* produces larger clutch sizes of 21 to 38 in Brazil (Crawshaw and Schaller 1980, Schaller and Crawshaw 1982) and 23 to 41 in Bolivia (mean 33.6; IUCN 1982). Clutch size may depend in part on the size of the female. Eggs are elliptical to round, white, hard shelled and rugose. Eggs of *C. c. apaporiensis* measured 66 x 63 mm (Medem 1981). Those of *C. c. crocodilus* in the Llanos averaged 64 x 41 mm and weighed 60 g (Rivero-Blanco 1974; Staton and Dixon 1977). Eggs of this subspecies in Surinam are more elongate (Ouboter and Nanhoe 1984). *C. c. fuscus* eggs have been reported as being from 63 to 70 mm long, 38 to 41 mm wide and weighing 40 to 45 g (Medem 1981). Nest temperatures has been measured from 25 to 32 °C with a mean temperature in the order of 29 to 30° C (Blohm 1973, Staton and Dixon 1977, Crawshaw and Schaller 1980, Medem 1981). Incubation periods are from 70 to 90 days in *C. c. crocodilus* (Staton and Dixon 1977) and 75 to 80 days in *C. c. fuscus* (Alvarez del Toro 1974). Several authors have observed that the female regularly attends and guards the nest site during the incubation period (Blohm 1973, Crawshaw and Schaller 1980, Ayarzagüena 1983) and Alvarez del Toro (1974) also observed nest attendance by the male. Hatching is accompanied by vocalization of the young (Staton and Dixon 1977, Gorzula 1978). The female, sometimes with the help of the male, opens the nest and escorts the young to the water (Alvarez del Toro 1974; Staton and Dixon 1977; Crawshaw and Schaller 1980). The female may carry the young in her mouth (Alvarez del Toro 1974), and there is evidence that she may also assist hatching by cracking eggs open in her mouth (Crawshaw and Schaller 1980). Hatching in the Venezuelan Llanos occurs from October to December with a peak in November (Staton and Dixon 1977). Peak hatching in the Brazilian Pantanal takes place in March (Crawshaw and Schaller 1980).

**Postnesting period** - After hatching the young stay together in discrete pods (Alvarez del Toro 1974, Staton and Dixon 1977, Gorzula 1978, Medem 1981, Ayarzagüena 1983, Romero 1983, Ouboter and Nanhoe 1984, Gorzula 1986). Single sex pods have been reported (Ouboter and Nanhoe 1984), and pods of mixed ages have also been observed (Gorzula 1985). Adult caimans defend pods in response to distress calls (Staton and Dixon 1977, Gorzula 1978, Staton 1978, Romero 1983, Ayarzagüena 1983, Ouboter and Nanhoe 1984, Gorzula 1986). Defensive behavior by the adults ranges from displaying to outright attack. The defending adult is not necessarily a parent (Gorzula 1978; Gorzula and Paolillo 1986). Although the pods generally stay near the nest site, pods with a female in attendance have been observed undergoing migration (Ayarzagüena 1983, Ouboter and Nanhoe 1984). Pods may stay together for a year and a half before dispersing, resulting in the female breeding during alternate years (Gorzula 1978, Ouboter and Nanhoe 1984).

## GROWTH

The few studies on growth rate in wild populations have been of *C. c. crocodilus* (Fig. 2). Gorzula (1978) used mark-recapture data to produce a growth curve for a population of spectacled caimans inhabiting the savanna lagoons in the Venezuelan Guayana. It was estimated that caimans reach a total length of slightly less than one meter in six years. It was also shown that caimans less than two years old grew steadily during the whole year, but thereafter the growth rate slowed during the dry seasons. In an exceptionally dry year there was no growth registered in five caimans with total lengths of between 0.90 and 1.20 m, whereas during a wet year two caimans within this

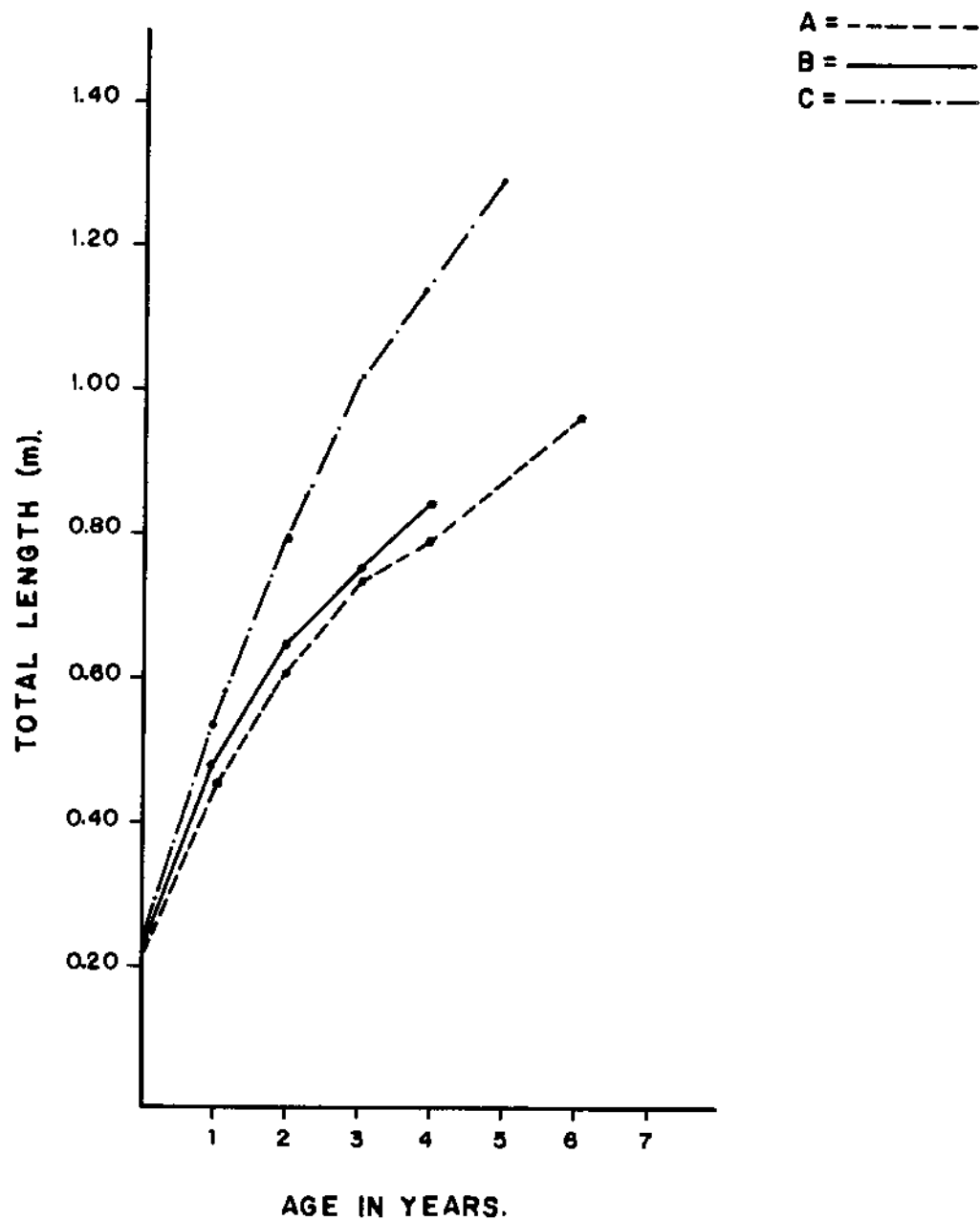


Figure 2. Growth rates of *Caiman crocodilus* in three populations - A: the Venezuelan Guayana (Gorzula 1978); B: the Venezuelan Llanos (Ayarzagüena 1980); Surinam (Ouboter and Nanhoe 1984).



size range grew some ten centimeters each. Ayarzagüena (1983) using size frequency histogram analyses produced a similar growth curve for caimans in the Venezuelan Llanos. Ouboter and Nanhoe (1984) using mark-recapture data for a population of spectacled caimans in Surinam, demonstrated significantly faster growth rates. Caimans were estimated to reach a total length of nearly 1.30 m in five years. They suggest that the differences in growth rate, compared to that of caimans in the Venezuelan Guayana, were due to food availability.

The three studies of growth rate in wild populations show growth rates of between 2.0 and 2.6 cm/month during the first year of life. These results are similar to the growth rates of hatchlings kept under captive conditions (Rivero-Blanco 1974, Rodriguez-Arvelo and Robinson 1986). However, Rivero-Blanco (1974) reported some exceptional growth rates for hatchlings that reached lengths of between 55 and 60 cm in ten months.

### FOOD AND FEEDING

Although over much of the range of *C. crocodilus* there have been no detailed studies of diet and feeding strategies, it may be said that this species diet, as in other crocodilians, is very varied and depends upon the size of the individuals, the season of the year and the specific characteristics of the habitat where they live. Hatchlings and juveniles feed mainly on invertebrates, insects (principally Coleoptera) being the major food items. Juveniles and adults also feed on snails, shrimps and crabs (Donoso-Barros 1965, Chirivi-Gallegos 1971, 1973; Alvarez del Toro 1974, Staton and Dixon 1975, Castroviejo et al. 1976, Gorzula 1978, Vanzolini and Gomes 1979, Seijas and Ramos 1980, Verdi et al. 1980, Medem 1981, Ouboter and Nanhoe 1984). In subadults and adults vertebrates progressively acquire more importance, including not only fishes and other aquatic vertebrates, but also terrestrial species (Medem 1981; Alvarez del Toro 1974). Cannibalism has also been reported (Staton and Dixon 1975; Schaller and Crawshaw 1982) and feeding on carrion (Staton and Dixon 1975).

The variations in diet that have been demonstrated by different studies, including those carried out in localities that are relatively near to each other (Castroviejo et al. 1976, Seijas and Ramos 1980, Ayarzagüena 1983), may be interpreted as being due to differences in faunal composition between localities, rather than due to the food preferences of specific populations of caimans. The importance of each food item, therefore, depends principally upon the relative abundance with which it occurs in the locality. For example, the commonest fish found in the stomach contents of caiman in a Venezuelan Llanos locality (Seijas and Ramos 1980), correspond precisely to the most abundant species that inhabit those waters (Ramos et al. 1981). Gorzula (1978) indicated the importance of anurans in the diet of caimans in the Venezuelan Guayana during the rainy season, when these anurans are abundant. Snails and crabs are important in caiman diets in areas where these invertebrates are very common (Alvarez del Toro 1974, Medem 1981, Ayarzagüena 1983).

Feeding strategies and feeding behavior have received little attention in the literature. Our observations and the literature suggest, as a broad generality, that the common caiman exploits shallow waters and the narrow littoral fringes of extensive bodies of water. Some types of feeding behavior have been described in the literature. Ayarzagüena (Ayarzagüena 1983) distinguished the following feeding strategies: lying in ambush for terrestrial prey; localization of prey by the sounds that the prey species produce; lying in wait for prey, principally fishes, that arrive by chance at the site where the caiman is. Schaller and Crawshaw (Schaller and Crawshaw 1982) describe additional strategies, among which there is one where the caimans "drive", using their body and tail, fish towards the shore or into shallow waters where capture is easier. Ambushing and actively

hunting of prey on dry land has also been observed (Medem 1981; Alvarez del Toro 1974; Ayarzagüena 1983).

### PREDATION

Numerous animals have been indicated as natural enemies of *C. crocodilus* (Table 1). The stages of life in which the spectacled caiman is most susceptible to predation are the eggs and the hatchlings. The golden tegu lizard, *Tupinambis nigropunctatus*, is implicated as the most serious predator of eggs in the Venezuelan Llanos (Rivero-Blanco 1974, Ayarzagüena 1983). Here and in other localities other real or potential predators of eggs include the crested caracara (*Polyborus plancus*), the crab-eating fox (*Cerdocyon thous*), and the raccoon (*Procyon* sp.; Leitao de Carvahlo 1951, Alvarez del Toro 1974, Rivero-Blanco 1974, Gorzula 1978, Ayarzagüena 1983).

Among the predators of hatchlings and juveniles are some species of fish (Alvarez del Toro 1974) and aquatic birds such as the maguari stork (*Euxenura maguari*), the American wood stork (*Mycteria americana*), the jabiru stork (*Jabiru mycteria*) and the white necked heron (*Ardea cocoi*). Captive animals have been observed to eat hatchling *C. crocodilus* (Gorzula 1978, Medem 1981), which suggests that many animals would be predators of hatchling caimans if given the opportunity.

Predators of adult caiman such as the Orinoco crocodile (*Crocodylus intermedius*), the American crocodile (*C. acutus*), the black caiman (*Melanosuchus niger*), and the jaguar (*Panthera onca*), have been exterminated over much of their former ranges. Perhaps the most important predator of large spectacled caiman (apart from man) in the present day is the anaconda (*Eunectes murinus*; Staton and Dixon 1975, Medem 1981, 1983; Ayarzagüena 1983, Lopez-Corcuera 1984). Medem (1981) cites the case of a 2.05 m long spectacled caiman found in the stomach content of an anaconda, and Lopez-Corcuera (1984) published an old photograph of a similar case.

### ACTIVITY AND BEHAVIOR

**Annual activity cycles** - In the Venezuelan Llanos (Staton and Dixon 1975, Ayarzagüena 1983), the Venezuelan Guayana (Gorzula 1978), Surinam (Ouboter and Nanhoe 1984), and the Brazilian Pantanal (Schaller and Crawshaw 1982) the population ethology of *C. crocodilus* is characterized by dry season concentrations and dispersal in the rainy season. It has been described above how reproduction is linked to this cycle. In some areas or in exceptionally dry years caiman may aestivate by burrowing into the mud of drying lagoons (Staton and Dixon 1975, Dixon and Sioni 1977, Medem 1981). In other areas the dry season concentrations of fish are a significant food resource that is exploited by the caimans, and the dry season is thus a period of activity and growth (Schaller and Crawshaw 1982, Ouboter and Nanhoe 1984). Staton and Dixon (1975) observed that in the Venezuelan Llanos dry season concentration commenced in January and ended in July, with peak concentrations in March. Caimans frequently returned to the same dry season refuge lagoon in consecutive years in the Brazilian Pantanal (Schaller and Crawshaw 1982), but in some instances males move to lagoons up to 9.4 km away. In general, females moved less than expected and subadults moved more than expected. In Surinam (Ouboter and Nanhoe 1984) dry season home ranges from 11 to 35 ha were observed in telemetry studies. Caimans in Surinam displaced up to 3 km in the rainy season. In the Venezuelan Guayana (Gorzula 1978) caimans migrate to temporary lagoons during the rainy season. These lagoons were used by the same caimans on successive years. Single night foraging migrations to small pools for frogs were also observed during the rainy

Table 1: Predators of the common caiman, *Caiman crocodilus*.

Scientific name	Common name	Life stage	Source
<b>PISCES</b>			
<i>Hoplias macrophthalmus</i>	Catfish	Hatchlings	Medem 1983.
<i>Serrasalmus</i> sp.	Piranha	Hatchlings	Ayarzagüena 1980; Blohm 1973.
<i>Lepidosteus tropius</i>		Hatchlings	Alvarez del Toro 1974.
<b>REPTILIA</b>			
<i>Tupinambis nigropunctatus</i>	Golden tegu	Eggs	Ayarzagüena 1980; Rivero-Blanco 1974; Staton and Dixon 1977.
<i>Drymarchon corais</i>	Indigo snake	Hatchlings	Alvarez del Toro 1974.
<i>Eunectes murinus</i>	Anaconda	Adults	Medem 1983; Ayarzagüena 1980; Staton and Dixon 1975; Lopez-Corcuera 1984.
<i>Chelus fimbriatus</i>	Matamata	Hatchlings	Medem 1981.
<i>Phrynops geoffroanus</i>	Side-neck turtle	Hatchlings	Medem 1981.
<i>Melanosuchus niger</i>	Black caiman	Adults	Medem 1981.
<i>Crocodylus acutus</i>	Caribbean crocodile	Adults	Medem 1981.
<i>Crocodylus intermedius</i>	Orinoco crocodile	Adults	Medem 1981.
<b>AVES</b>			
<i>Ardea cocoi</i>	White-necked heron	Juveniles	Gorzula 1978.
<i>Heterocnus mexicanus</i>	Tiger-bittern	Hatchlings	Alvarez del Toro 1974.
<i>Nycticorax nycticorax</i>	Black-crowned night heron	Hatchlings	Ayarzagüena 1980.
<i>Mycteria americana</i>	American wood stork	Juveniles	Gorzula 1978.
<i>Euxenura maguari</i>	Maguari stork	Juveniles	Staton and Dixon 1977.
<i>Jabiru mycteria</i>	Jabiru stork	Juveniles	Gorzula 1978; Romero 1983.
<i>Buteogallus urubitinga</i>	Great black hawk	Hatchlings	Ayarzagüena 1980.
<i>Polyborus plancus</i>	Crested caracara	Eggs	Ayarzagüena 1980; Rivero-Blanco 1974.
<b>MAMMALIA</b>			
<i>Cerdocyon thous</i>	Crab-eating fox	Hatchlings	Ayarzagüena 1980; Gorzula 1978;
<i>Procyon</i> spp.	Raccoon	Eggs	Leitao de Carvahlo 1951. Medem 1983;
<i>Nasua nasua</i>	Coatimundi	Eggs	Alvarez del Toro 1974. Crawshaw and Schaller 1980;
<i>Felis pardalis</i>	Ocelot	Juveniles	Leitao de Carvahlo 1951.
<i>Panthera onca</i>	Jaguar	Adults	Alvarez del Toro 1974.
<i>Sus scrofa</i>	Domestic pig	Hatchlings	Medem 1983.
<i>Cebus</i> sp.	Capuchin monkey	Eggs	Gorzula 1978. Crawshaw and Schaller 1980.

season in this area. In addition to seasonal migrations "forced migrations" by caimans from areas under heavy hunting pressure by man have been registered in Colombia (Medem 1981).

**Diel activity cycles** - In the Venezuelan Guayana and Surinam, *C. crocodilus* is essentially a nocturnal species and basking during the day has been observed only infrequently (Gorzula 1978, Ouboter and Nanhoe 1984). However, in many other areas basking is a normal part of the daily activity pattern of this species (Alvarez del Toro 1974, Staton and Dixon 1975, Maness 1976, Marcellini 1979, Schaller and Crawshaw 1982, Ayarzagüena 1983, Seijas 1986). In the Venezuelan Llanos a bimodal cycle of basking has been reported by several authors. The two modes correspond with the morning rise and the late afternoon drop in air temperature. This behavior is assumed to be thermoregulatory. Maness (1976) observed early morning basking followed by a second period between 1700 and 1800 hours. Marcellini (cited in Medem 1981) recorded peak morning basking activity at 0900 hours followed by even greater basking activity from 1600 to 1800 hours. The proportion of caimans basking at any one time did not exceed 36% of the highest number counted during night surveys. Staton and Dixon (1975) showed that the marked bimodal basking activity observed in April had virtually ceased by May. Ayarzagüena (1983), however, observed that bimodal basking activity did occur during the wet season on sunny days during periods of several days without rain, but was absent on rainy or cloudy days. The basking behavior of individual animals has not been followed.

Gorzula (1978) recorded mean cloacal temperature of 27.27° C (sd = 0.88) for caimans in savanna lagoons in the Venezuelan Guayana. Staton and Dixon (1975) found that body temperature of caimans during the dry season in the Venezuelan Llanos ranged from 25.5 to 33.0° C (mean 30° C), with the highest temperatures occurring during late afternoon. Diefenbach (1975) showed that preferred body temperatures in laboratory experiments ranged from 28.5 to 36.2° C and were size dependent. Ouboter and Nanhoe (1984) demonstrated a similar phenomenon in wild caught caimans in Surinam.

Spectacled caiman often dive in response to a predator such as man and may stay under the water up to 80 min (Gorzula 1978). Such diving is accompanied by bradycardia (Gaunt and Gans 1969, Garrick and Saiff 1974).

**Social behavior** - *C. crocodilus* is a territorial species. The incidence of stub-tailed individuals increases with size in populations in the Venezuelan Llanos, the Venezuelan Guayana, and Surinam and is presumably the result of intraspecific fighting (Staton and Dixon 1975, Gorzula 1978, Ouboter and Nanhoe 1984). However in the Brazilian Amazon region there was no correlation between incidence of damage and the size class of the individuals (Magnusson 1985). Territorial behavior has been observed in the Venezuelan Llanos (Staton and Dixon 1975). The resident caiman displays to the intruder by tail-flagging. Infrequently the intruder may reply with a similar display. Usually such interactions result in the intruder fleeing or being chased out by the resident. Territoriality has been demonstrated indirectly by Gorzula (1978) who displaced marked caimans into similar lagoons that contained caimans. In 15 of 18 such trials caimans returned to the original lagoon where they were first captured. In three instances the caiman remained in the lagoon where they had been displaced. Homing up to 2.4 km was recorded. On one occasion a caiman was recaptured while homing, and it was concluded that the caiman had waited until the first rainy night to effect its return.

*C. crocodilus* has paired throat and cloacal musk glands. Caiman often release musk upon being captured (Gorzula 1978). Musk squeezed from the throat glands of a hatchling and mixed in the water elicited a strange swimming response in the mixed pod from which it had been captured (Gorzula 1986). Musk is not always present in these glands, but no correlation between or other factors has yet been described, nor has any function for musk yet been proposed.

Ayarzagüena (1983) produced an ethogram for *C. crocodilus*. He also listed three non-vocal and eight vocal sounds as part of the repertoire of auditory signals of this species. He considered the three non-vocal sounds (palmada de cabeza, gelser nasal and chasquido) to have territorial and threat functions. Six of the vocal sounds (bramido, ronquido, pujido grave, pujido agudo, pujido atenuado and aviso de peligro) were produced exclusively by adult caimans. The two remaining sounds were the "distress" and "contact" calls of hatchlings.

Territoriality and social hierarchy in the spectacled caiman are undoubtedly maintained by a very complex series of visual, auditory and chemical signals. However, most observations of caiman behavior have to date been either limited to special situations, such as daytime observation of dry season concentration of caimans, or have involved human/caiman interaction, such as capturing hatchlings and observing the response of adults. These brief insights into the behavior of the spectacled caiman are far from providing a comprehensive understanding of the complex intraspecific communication of a caiman community.

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#### LITERATURE CITED

- Alvarez del Toro, M. 1974. Los Crocodylia de Mexico, México, D.F.: Instituto Mexicano de Recursos Naturales Renovables, A.C.
- Ayarzagüena, J. 1980. Ecología del Caiman de anteojos o baba (*Caiman crocodilus*) en los Llanos de Apure, Venezuela. Unpubl. Ph.D. thesis of the Faculty of Biological Sciences, Universidad Complutense de Madrid. Madrid, Spain. 216 pp.
- Best, R.C. 1984. Pp. 371-412 in H. Sioli, ed. The Amazon. Limnology and landscape ecology of a mighty tropical river and its basin. W. Junk Publishers, Netherlands.
- Blohm, T. 1973. Conveniencia de criar crocodilídeos en Venezuela con fines económicos y para prevenir su extinción. Unpubl. rept. presented at the Simposio Internacional Fauna Silvestre, Pesca fluvial y lacustre Amazónica in Manaus, Brasil, November 1973. 32 pp.
- Brazaitis, P. 1973. The identification of living crocodilians. Zoologica 58:59-101.
- Budowski, G., and C. Vaihan. 1976. Información sobre *Caiman crocodilus* e *Hydrochoerus hydrochoeris*. II Seminario sobre Chigüires y Babas. Programa y Resúmenes, Maracay, Venezuela: CONICIT.
- Castroviejo, J., C. Ibañez, and F. Braza. 1976. Datos sobre la alimentación del babo o caiman chico (*Caiman sclerops*). II Seminario sobre Chigüires y Babas, Programa y Resúmenes, Maracay, Venezuela: CONICIT.
- Chirivi-Gallego, H. 1971. Notas sobre la problemática en el manejo de los Crocodylia en Colombia, con especial referencia a la habilla, (*Caiman crocodilus*), y la factibilidad de su cría

- en cautividad. Instituto de Desarrollo de los Recursos Naturales Renovables (INDERENA):1-142.
- \_\_\_\_\_. 1973. Contribucion al conocimiento de la babilla o yacare-tinga (*Caiman crocodilus*) con notas acerca de su manejo y de otras especies de Crocodylia neotropicales. Instituto de Desarrollo de los Recursos Naturales Renovables (INDERENA):1-126.
- Crawshaw, P., and G. Schaller. 1980. Nesting of Paraguayan caiman (*Caiman yacare*) in Brasil. Papéis Avulsos Zool., S.Paulo 33:283-292.
- D'Andria, B.M. 1980. Estructuración de un modelo matematico sobre la dinamica poblacional de la baba (*Caiman crocodilus*) con miras a su posible explotación comercial. Unpubl. B.S. thesis of the Universidad Simón Bolívar. Sartenejas, Venezuela. 144 pp.
- Diefenbach, C.O. da C. 1975. Thermal preferences and thermoregulation in *Caiman crocodilus*. Copeia 1975:530-540.
- Dixon, J.R., and P. Soini. 1977. The reptiles of the upper Amazon basin, Iquitos region, Peru II. crocodilians, turtles and snakes. Milwaukee Publ. Mus. Contrib. Biol. Geol. 12:1-91.
- \_\_\_\_\_, and M.A. Staton. 1983. In D.H. Janzen, ed. Costa Rican Natural History. Univ. Chicago Press, Chicago.
- Donoso-Barros, R. 1965. Contribución al conocimiento de los cocodrilos de Venezuela. Physis 25:387-400.
- Ellis, T.M. 1980. *Caiman crocodilus*: an established exotic in south Florida. Copeia 1980:152-154.
- Frair, W., and J.L. Behler. 1983. Book Review of: Liste der Rezenten Amphibien und Reptilien. Testudines, Crocodylia, Rhynchocephalia by H. Wermuth and R. Mertens. Herpetological Review 14:23-25.
- Fuchs, K.H. 1974. Die Krokodilhaut. Edward Roether Verlag, Darmstadt.
- Garrick, L.D., and E.I. Saiff. 1974. Observations on submergence reflexes of *Caiman sclerops*. J. Herpetol. 8:231-235.
- Gaunt, A.S., and C. Gans. 1969. Diving bradycardia and withdrawal bradycardia in *Caiman crocodilus*. Nature 223:207-208.
- Glastra, R. 1983. Notes on a population of *Caiman crocodilus crocodilus* depleted by hide hunting in Surinam. Biological Conservation 26:149-162.
- Gorzula, S.J. 1978. An ecological study of *Caiman crocodilus crocodilus* inhabiting savanna lagoons in the Venezuelan Guayana. Oecologia (Berl.) 35:21-34.
- \_\_\_\_\_. 1984a. Request for interchange of ideas on standardization of terminology used to express densities of crocodilians. IUCN/SSC Crocodile Specialist Group Newsletter 3:23.
- \_\_\_\_\_. 1984b. Proposal for a photographic method for size estimates of crocodilians. Herpetological Review 15:38-39.

- \_\_\_\_\_. 1987. The management of crocodilians in Venezuela. Pp. 91-101 in G.J.W. Webb, S.C. Manolis, and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty & Sons. Chipping Norton, Australia.
- \_\_\_\_\_. 1985. Are Caimans Always in Distress? *Biotropica* 17:343-344.
- \_\_\_\_\_, and A. Paolillo. 1986. La Ecología y el estado actual de los aligatódidos de la Guayana Venezolana. Pp. 37-54 in *Crocodiles. Proceedings of the 7th Working Meeting of the Crocodile Specialist Group*. IUCN, Gland, Switzerland.
- \_\_\_\_\_, A. Paolillo, and J.B. Thorbjarnarson. 1989. Applications of limnology and hydrology to crocodilian conservation and management. Pp. 169-182 in *Crocodiles. Proceedings of the 8th Working Meeting of the Crocodile Specialist Group*. IUCN, Gland, Switzerland.
- Hofmann, R. 1967. Informe sobre la visita al distrito del Rio Samiria y el Rio Pacaya. Unpubl. Rept. of FAO Project No. 116. Lima, Peru. 7 pp.
- IUCN. 1982. The IUCN Amphibia-Reptilia Red Data Book Part 1 Testudines, Crocodylia, Rhynchocephalia. IUCN. Gland, Switzerland.
- King, F.W., and P. Brazaitis. 1971. Species identification of commercial crocodilian skins. *Zoologica* 56:15-70.
- \_\_\_\_\_, and T. Krakauer. 1966. The exotic herpetofauna of southeast Florida. *Quart. Jour. Fla. Acad. Sci.* 29:144-154.
- Leitao de Carvahlo, A. 1951. Os Jacares do Brasil. *Arq. Mus. Nac.* 42:127-150.
- Lopez-Corcuera, G. 1984. Fauna Legendaria, Rayas, Tembladores, Caimanes y Culebras de Agua, Colección Fauna de los Llanos de Venezuela, Caracas Venezuela, Editorial Arte, Fundación Fluvial Científica de los Llanos.
- Magnusson, W.E. 1982a. Biological aspects of the conservation of amazonian crocodilians in Brasil. Pp. 108-116 in *Crocodiles: Proceedings of the 5th Working Meeting of the Crocodile Specialist Group*. IUCN. Gland, Switzerland.
- \_\_\_\_\_. 1982b. Techniques of surveying for crocodilians. Pp. 387-401 in *Crocodiles: Proceedings of the 5th Working Meeting of the Crocodile Specialist Group*. IUCN. Gland, Switzerland.
- \_\_\_\_\_. 1983. Size estimates of crocodilians. *J. Herpetol.* 17:86-88.
- \_\_\_\_\_. 1984. Response to request for exchange of ideas on standardization of terminology on crocodilian densities. *IUCN/SSC Crocodile Specialist Group Newsletter* 3:14-15.
- \_\_\_\_\_. 1985. Habitat selection, parasites and injuries in Amazonian crocodilians. *Amazoniana* 9:193-204.
- Maness, S.J. 1976. Contribución al conocimiento del ciclo de vida del *Caiman crocodilus*. Parte I: Epoca de sequia. II Seminario de Chigüires y Babas, Programa y Resúmenes, Maracay, Venezuela: CONICIT.

- Marcellini, D.L. 1979. Pp. 263-271 in J.F. Eisenberg, ed. *Vertebrate Ecology in the Northern Neotropics*. Smithsonian Institution Press, Washington, D.C.
- Medem, F. 1981. *Los Crocodylia de Sur America. Volumen I. Los Crocodylia de Colombia*. Colciencias. Bogota, Colombia.
- \_\_\_\_\_. 1983. *Los Crocodylia de Sur America. Volumen II*. Colciencias. Bogota, Colombia.
- Morley, S., and S. Sanchez. 1982. Censo preliminar de la fauna ribereña en el bajo Urubamba. Unpubl. rept. to the Universidad Nacional Agraria, Lima, Peru. 18 pp.
- Ouboter, P.E., and L.M.R. Nanhoe. 1984. An ecological study of *Caiman crocodilus* in Northern Surinam. Unpubl. rept. of the Department of Animal Ecology, Catholic University of Nijmegen. Nijmegen, Netherlands. 65 pp.
- Ramos, S., S. Daniellewski, and G. Colomine. 1981. Contribución a la ecología de los vertebrados acuáticos en esteros y bajíos de sabanas inundables. *Bol. Soc. Ven. Cienc. Nat.* 36:79-103.
- Rivero-Blanco, C. 1974. Hábitos reproductivos de la baba en los Llanos de Venezuela. *Natura* 52:24-29.
- Rodriguez-Arvelo, G., and M.D. Robinson. 1986. Estudio del crecimiento en cautiverio de la baba, *Caiman crocodilus*, durante sus primeros meses de vida. Pp. 62-79 in *Crocodiles: Proceedings of the 7th Working Meeting of the Crocodile Specialist Group*. IUCN. Gland, Switzerland.
- Romero, G.A. 1983. Distress call saves a *Caiman c. crocodilus* hatchling in the Venezuelan Llanos. *Biotropica* 15:71.
- Schaller, G.B., and P.G. Crawshaw, Jr. 1982. Fishing behavior of Paraguayan caiman (*Caiman crocodilus*). *Copeia* 1982:66-72.
- Seijas, A.E. 1984. Estimaciones poblacionales de babas (*Caiman crocodilus*) en los Llanos occidentales de Venezuela. Ministerio del Ambiente y de los Recursos Naturales Renovables (MARNR)(PT) Serie Informes Técnicos DGSIA/IT/165. Caracas, Venezuela. 23 pp.
- \_\_\_\_\_. 1986. Situación actual de las poblaciones de babas y babillas (*Caiman crocodilus*) en la región norte-costera de Venezuela. Pp. 28-36 in *Crocodiles: Proceedings of the 7th Working Meeting of the Crocodile Specialist Group*. IUCN. Gland, Switzerland.
- \_\_\_\_\_, and S. Ramos. 1980. Características de la dieta de la baba (*Caiman crocodilus*) durante la estación seca en las sabanas moduladas del Estado Apure, Venezuela. *Acta Biol. Venez.* 10:373-389.
- Staton, M.A. 1978. "Distress calls" of crocodilians--Whom do they benefit? *Amer. Natur.* 112:327-332.
- \_\_\_\_\_, and J.R. Dixon. 1975. Studies on the dry season biology of *Caiman crocodilus crocodilus* from the Venezuelan Llanos. *Mem. Soc. Cienc. Nat. La Salle* 35:237-265.
- \_\_\_\_\_, and \_\_\_\_\_. 1977. Breeding biology of the Spectacled Caiman, *Caiman crocodilus crocodilus*, in the Venezuelan Llanos. *Fish and Wildlife Service Report* 5:1-21.



- Vanzolini, P.E., and N. Gomes. 1979. Notes on the ecology and growth of amazonian caimans (Crocodylia, Alligatoridae). *Papéis Avulsos Zool.*, S. Paulo 32:205-216.
- Verdi, L., L. Moya, and R. Pezo. 1980. Observaciones preliminares sobre la bio-ecología del lagarto blanco *Caiman crocodilus* (Linnaeus, 1758) (Alligatoridae) en la cuenca del Río Samiria, Loreto, Perú. Unpubl. rept. presented at the Seminario sobre los Proyectos de Investigación Ecológica para el Manejo de los Recursos Naturales Renovables del Bosque Húmedo Tropical in Peru 12 to 18 October 1980. 37 pp.
- Wermuth, H., and R. Mertens. 1977. Liste Der Rezenten Amphibien Und Reptilien. Testudines. Crocodylia, Rhynchocephalia. *Das Tierreich*, New York.
- Woodward, A., and D. David. 1985. A study of the baba (*Caiman crocodilus crocodilus*) population on the Hato Piñero in Venezuela. Unpubl. rept. of the Florida Game and Fresh Water Fish Commission. 17 pp.

## CROCODILE MANAGEMENT IN ZIMBABWE

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### INTRODUCTION

The Nile Crocodile *Crocodylus niloticus* Laurenti, 1768, is the only crocodile native to Zimbabwe. Though within the tropics, Zimbabwe's climate, and as a result the distribution of crocodiles, is strongly influenced by altitude (Hutton 1984). Prior to 1900 the range of the crocodile in Zimbabwe was not documented, but the animal probably occurred along all perennial and many annual rivers below 1800 m, with reliable breeding below 900 m. Despite a high level of crocodile/human conflict, this range has not been greatly affected by Zimbabwe's burgeoning population. Numbers were markedly reduced in the 1950s, but have recovered and although there has been some loss of habitat, crocodiles have benefitted from the proliferation of dams. In particular, the construction of Lake Kariba created particularly favorable conditions for crocodiles at the time when their numbers were poised to recover as a result of new conservation policies.

The Department of National Parks and Wild Life Management of Zimbabwe (hereafter, the Department) recognizes wildlife as a renewable natural resource and considers that conservation is encouraged when the resource is used for the benefit of the people who live with it. It is impractical to attempt to safeguard a species through legislation and law enforcement unless people are at least tolerant towards it. This is especially true of a large predator like the Nile crocodile which seriously competes with legitimate human interests. Although non-consumptive uses may be preferred, there is not always a choice and benefits can often only be realized through the marketing of animals or their products. This philosophy towards the conservation and use of wildlife is well illustrated by the sustained-yield utilization of *C. niloticus* in which, for 20 years, eggs have been collected from the wild and hatchlings raised for their skins on licensed rearing stations.

Unfortunately, in Zimbabwe and elsewhere, management of the Nile crocodile along these lines has been hammered by politics. *C. niloticus* is classified by the IUCN as "vulnerable" (Groombridge 1982). Trade in its products was restricted when *C. niloticus* was placed on Appendix I of CITES prior to the acceptance of the "Berne Criteria" (CITES Conf 1.1, 1.2 and 1.3, 1976) for listing, delisting or transferring species between appendices. Many African Parties to the Convention questioned this classification and at least four, including Zimbabwe, entered a reservation against it. An inability to trade in the species would have represented a major setback for its conservation, with every likelihood of irresistible demands for the extermination of crocodiles outside protected areas. The success of Zimbabwe's policy of conservation through utilization led to the country's *C. niloticus* population being acknowledged as "out of danger" and transferred from Appendix I to Appendix II of CITES in 1983 (CITES 1984). This was followed, in 1985, by its downlisting in 9 other countries, each agreeing to an annual export quota.

This chapter describes the conservation of *C. niloticus* in Zimbabwe and for completeness includes information on the animal's biology, its conflict with humans and the history of its exploitation, its present utilization (together with associated legislation and technology) and, perhaps most importantly, the present status of the wild population and its response to exploitation.

### LIFE HISTORY

The life history of *C. niloticus* is markedly affected by the environment. In Zimbabwe, hatchlings measure about 0.3 m total length (TL) and grow at a rate largely dependent on temperature. Puberty is more influenced by size than age. Females mature at approximately 2.6 m TL which has been recorded as taking from 8-30 years (Hutton 1984). Females rarely exceed 3.2 m TL, but males longer than 4 m TL are common and individuals greater than 5 m TL have been recorded from the Zambezi River in recent years (M. Ellerment pers. comm.).

Courtship and mating occur in July and early August (cool-dry season). Nest chambers are excavated and most clutches laid in late September (hot-dry season).

Both clutch and egg size increase with the increasing age and size of the female (Hutton 1984). The average clutch size of the Lake Kariba population is 45 (Blake and Loveridge 1975). Although dependent on temperature, the incubation period is about 90 days, during which most females remain in nest attendance. Incubation temperatures also determine the sex of embryos (males at high temperatures) and as a result, the sex ratio of the population (Hutton 1987b).

The extent and causes of nest failure vary between localities, but losses can be as high as 77% where incubation temperatures are sub-optimum. In warm areas predation is usually the largest single factor accounting for losses. At Ngezi predation averaged 40% over 10 years (Hutton 1984). The main natural predator is the Nile monitor *Varanus niloticus*.

Hatching usually takes place in December (hot-wet season) and is invariably assisted by the female.

Juveniles are highly susceptible to predation until they reach 1.2 m TL which can take from 3 to 8 years. In cool localities, where growth is slow, juvenile mortality becomes a bottle-neck to population growth (Hutton 1984). In warmer localities, where nest success and juvenile survivorship are high, the reproductive potential of the species begs some form of density-dependent regulation. Though there are few data from the wild, the intra-specific predation of one size class by another is implicated in the regulatory process. Cannibalism is common in captivity and ecological separation of size classes has been recorded in some wild populations. The home ranges of adults and their offspring (<1.2 m TL) coincide, but are completely separate from those of larger juveniles and subadults (Hutton 1984).

As a result of the various environmental factors which affect life history processes, crocodiles are demographically most successful in areas of Zimbabwe below 600 m (Fig. 1).

Nile crocodiles are opportunistic predators though their prey target size increases with body size (Cott 1961, Hutton 1987a). Large mammals comprise the main diet of crocodiles larger than 2.5 m TL and in populated areas this may lead to the death of people and their livestock.

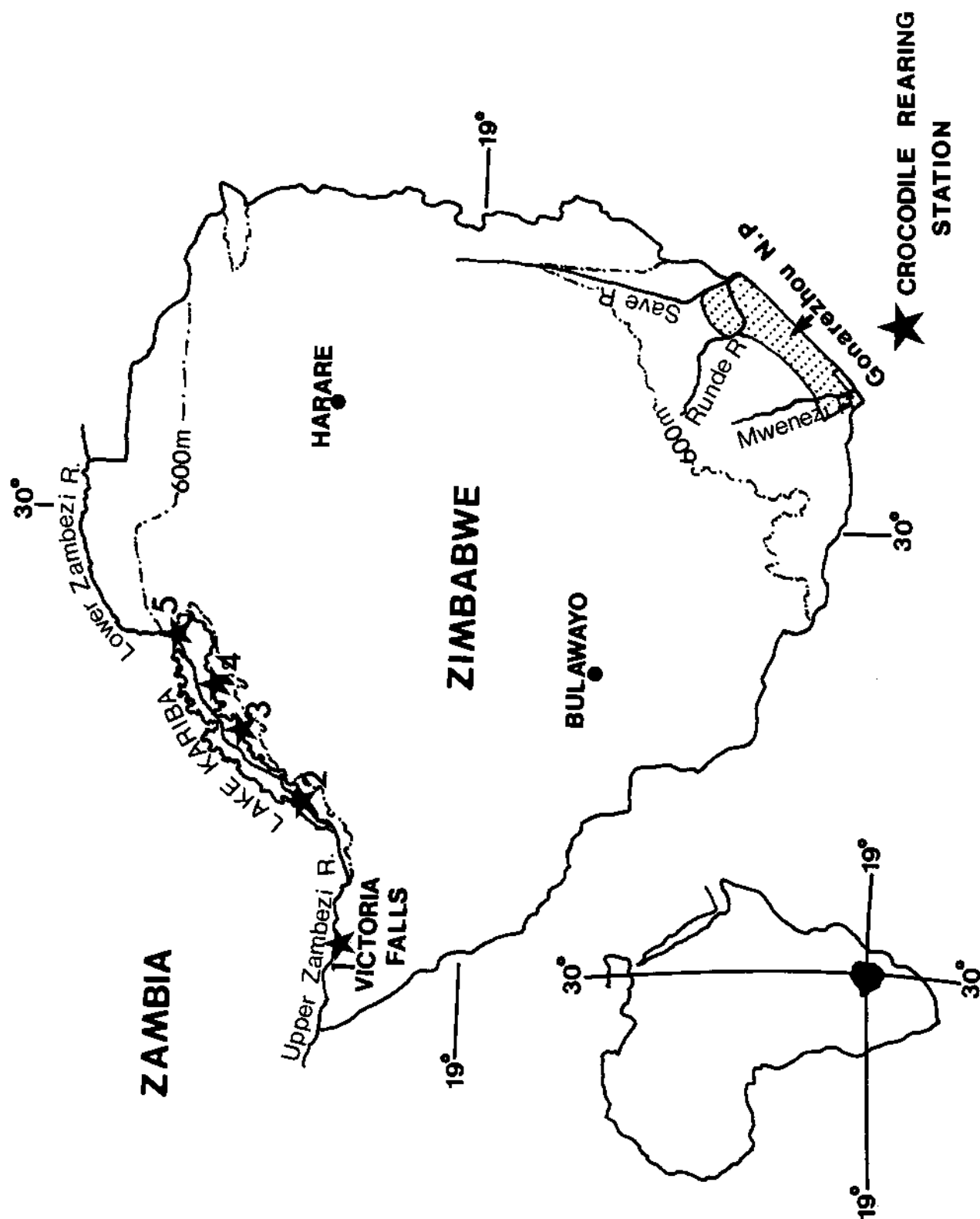


Figure 1. Zimbabwe, showing major rivers with crocodiles in areas below 600 m and the five crocodile rearing stations which currently have egg collection permits.

## MANAGEMENT

**Perspective** - There has always been conflict between crocodiles and rural people dependent on natural water supplies for their domestic and livestock needs, but this has intensified since the 1940s when human numbers entered a phase of exponential increase. Zimbabwe has no tradition of crocodiles or their eggs being used as food, but their destruction has always been viewed as a service to the community. Originally this hunting probably had little effect on either crocodile numbers or distribution. However, soon after the Second World War the commercial hide hunting of *C. niloticus* commenced. This peaked in the 1950s, bringing many accessible populations to the point of extinction (G. Hall pers. comm.). At that time, Zimbabwe's crocodiles were only protected within National Parks which covered less than 5% of the country and contained little habitat suitable for the animal. Unprotected populations were affected badly by uncontrolled exploitation. For example, few large crocodiles survived along those reaches of the middle Zambezi which are now submerged by Lake Kariba (G. Child unpubl. data).

As a result of the Wild Life Conservation Act, crocodiles first received a measure of legal protection throughout Zimbabwe in 1961. At the same time the foundations were laid of the present Parks and Wild Life Estate which recognizes six classes of protected area, includes 12.7% of Zimbabwe and has substantial prime crocodile habitat. Mainly due to the control of skin hunting, crocodile numbers responded immediately.

Although crocodiles occur virtually throughout Zimbabwe, the country is divided by a central watershed which separates the two main river basins with crocodile habitat below 600 m. It is therefore convenient to consider that the recovery took place in two distinct populations, one in the northern Zambezi basin, the other in the southern Save/Limpopo basin - better known as the lowveld (Fig. 1). There are important physical and developmental differences between the two. The Zambezi valley has poor agricultural potential and is poorly developed. The Zambezi River is perennial and a 300 km section was flooded by the construction of the Kariba dam in the late 1950s. The resultant lake and most of the remaining river are part of the Parks and Wild Life Estate. By contrast, the region of the Save and associated rivers supports a dense human population. Large areas are irrigated and virtually the only undisturbed crocodile habitat occurs as relatively short stretches of the Save, Runde and Mwenezi Rivers in the Gonarezhou National Park (Fig. 1). All rivers in the area are annual and although they previously had large perennial pools, many of these, especially in the east, have been modified by impoundments, irrigation and resultant siltation. The crocodile population in this area is restricted by its dry season water requirements and may have always been much smaller than that of the Zambezi. Unfortunately, although most undesirable interactions between humans and crocodiles occur in the lowveld, the Zambezi population has the greater harvesting potential.

As recorded by Zimbabwe's newspapers, at least twenty persons were killed by crocodiles during the period 1982 until 1986 (Hutton 1986). In addition, many deprivations on livestock were reported to the Department's problem animal control units which respond to all serious crocodile problems by capturing or, occasionally, destroying the offending animals.

**Rationale** - The Parks and Wild Life Act of 1975 broke with traditional wildlife legislation in Africa and, in addition to consolidating the present system of protected areas, it effectively conferred ownership of most wildlife onto the landholder. Mechanisms exist to prevent abuse, but in general, landowners have the discretion of using their wildlife as they deem best and all benefits from such use accrue to them as there are no state hunting licenses or country-wide hunting seasons (Child 1977). The rationale behind this legislation is that the people best able to conserve wildlife are

those on whose land it occurs and that their motivation for doing so is increased with an economic incentive.

The possibility of a sustained-yield harvest of *C. niloticus* in Zimbabwe was first considered in the early 1960s, when crocodile populations were beginning to recover and calls for their control were becoming difficult to resist. The first permits allowing crocodile rearing stations to exploit the Lake Kariba population were issued in 1965.

It was argued that crocodile rearing stations would provide and make conspicuous an economic incentive to maintain Zimbabwe's wild crocodile populations and this has proved to be the case at the policy-making level. In 1985 hide and live sales earned Zimbabwe the equivalent of almost Z\$1 million in foreign exchange, while Spencer's Creek Crocodile Ranch (one of the two stations which has visitor facilities) entertained approximately 40,000 tourists. As a result, crocodile welfare is a consideration when new development is planned. If this was not the case, many prime crocodile breeding sites would have disappeared by default already.

Unfortunately, despite its benefit to the national and local economies, the industry offers little direct advantage to the people of the Zambezi who have crocodile neighbors, and none to people in the lowveld. Every year numerous crocodiles and their eggs are destroyed in the lowveld, while in 1984 humans destroyed over 38 crocodile nests along the upper Zambezi River (R. Gee pers. comm.). Although little information is available, it appears that the Zambezi nests were destroyed by fishing communities (usually fishing illegally) in retaliation for net damage. Perhaps more serious for the crocodile population in this area is the entanglement and death of adult crocodiles in nets, though inadequate data are available on the magnitude of this problem.

Clearly, rural communities should be involved in Zimbabwe's conservation policy, but providing them with a tangible benefit is not simple. Crocodile eggs are delicate and their collection by largely uneducated rural people has been allowed, but has proved unsatisfactory. Suggestions that stations should pay for eggs have been resisted where the crocodile resource is on land with communal tenure because the benefits would not directly accrue to those most involved. In 1985 a number of people along the worst affected stretches of the Zambezi River were employed by stations to act as "wardens," locating and protecting nests for their collectors and this scheme shows promise. To tackle the problem in the lowveld, two new rearing stations are planned, one of which is to be run as a co-operative in a poor Communal Area (former Tribal Trust area in which all land is communally owned) with a high population of crocodiles and other wildlife.

Magnusson (1984) made a number of observations regarding the captive propagation of crocodilians and concluded that, for species with poorly valued commercial hide, such as *Caiman crocodilus*, neither farming (where adults are kept for the production of eggs) nor ranching (where eggs are collected from the wild) is likely to be economically viable. Unfortunately, the impression was given that the value of crocodile farming and ranching is dubious in all circumstances. In fact, with species which produce high quality "classic" hides, rearing is usually preferable to the hunting of wild animals.

Commercial rearing stations in Africa are privately funded and impinge little on limited government wildlife budgets. Capital investment in rearing facilities creates a commitment to sustained-yield harvesting, perennial employment and honesty in trade. If correctly managed, a harvest of eggs will yield many more skins than a harvest of live animals (mortality of wild eggs and juveniles can exceed 95% and the killing of adults erodes reproductive capital) and any mistake in the level of exploitation is less dangerous where eggs are being utilized. Hide size and quality can

be controlled on rearing stations and, where skins are "stored" as live animals, advantage can be taken of short-term market fluctuations.

The importance of rearing stations in displaying the economic value of crocodile conservation must again be stressed.

Mechanics - The mechanics of utilization are simple. Wild crocodiles and their eggs are protected throughout Zimbabwe by a special Statutory Instrument which makes it illegal to "injure, willfully disturb or remove the egg of any crocodile; or hunt or remove any crocodile" except by special permit available from the Department (Hutton 1986).

Egg collection permits are currently issued to only five commercial rearing stations. These produce skins from a mixture of ranching and farming. As noted above, two new stations are planned to utilize the lowveld population.

Permits for wild eggs are issued annually on the basis of each station's rearing success in the previous year. Overall egg quotas are set by the Department using data from monitoring of the wild population, but the Crocodile Farmers Association of Zimbabwe (CFAZ), in a self-regulatory role, recommends individual quotas for its members. These are subject to the Department's veto, but are usually accepted.

It is not intended that captive production should replace the wild harvest. Only from biological necessity, based on population monitoring, would wild quotas be reduced. However, farming allows stations to expand beyond the limit imposed by quotas.

Permits carry a number of standard conditions which include the requirement that stations submit monthly stock returns and cards as well as maps recording egg collection information (Hutton and Brennan 1985). Stations also have to make available to the Department, for restocking purposes, a number of juveniles of 1.2 m TL equivalent to 5% of the eggs collected (juveniles of this size appear to be free of interspecific predation). In reality, for a number of years the Department has taken only a few of these crocodiles, mostly for research. The wild population is large (Taylor, Loveridge, and Blake unpubl. data), making restocking an unnecessary (and unpopular) option. Nevertheless, the "5% requirement" is retained.

The sport hunting of a limited number of large crocodiles, especially on private land, is considered to have a conservation value and is permitted.

In accordance with Zimbabwe's obligations to CITES arising from its successful 1983 proposal to downlist the species, all crocodiles and their derivatives which enter international trade are marked with unique tags identifying their country of origin and their legality.

## REARING INDUSTRY

Some technical aspects of crocodile production have been presented (Blake 1974, 1982), but ideas and technology are in a continual state of flux, being as much influenced by personalities as science. The following summarizes the rearing process as it stands today.

Egg collection - Blake (1974, 1982) has described egg collection where nests are found with a probe and the eggs recovered with great care. A similar system continues, but aircraft are used increasingly to locate nesting females.

Eggs are usually collected after 50 days because, though never rigorously tested, experienced collectors hold that the probability of embryonic mortality is highest in eggs lifted during the first few weeks after laying. However, although late collection has the advantage of allowing inviable eggs to be distinguished, by the time of collection a large proportion of nests have been lost to predation. Early collection would allow these eggs to be utilized. In addition, there is mounting evidence that incubation conditions strongly influence the subsequent growth and survival of hatchlings (Hutton 1987b). Under these circumstances, early collection would have advantages. Some stations, anticipating this possibility, are already lifting the eggs of captive stock shortly after oviposition (before the embryo has attached to the shell membranes) and artificially incubating them for the full period of development.

Because of the vast area over which wild eggs are collected it will never be possible to obtain them within a few hours of laying, but this may not be as critical as commonly believed. Although flooding of Zambia's Luangwa River necessitates that eggs are collected early, within a few weeks of laying, in 1985 hatching success was 85% (C. Beukes pers. comm.). Further investigation may show that earlier collection is practical in Zimbabwe and, if so, it will be encouraged.

Until 1985 the quota of eggs given to any station never exceeded 2500 and was commonly less. However, inviable eggs did not count against quotas (Hutton and Brennan 1985). From 1985 all eggs counted against permits and to compensate for this quotas were increased by 10%. As a result, the mean percentage of eggs rejected as inviable, which had risen to 14.5% by 1984, immediately fell to 7.4%. Incubation success did not decline (88.8% in 1984 and 90.5% in 1985) and thus it appears that eggs were more efficiently selected.

**Incubation** - Broadly similar incubation technology has evolved on each station. Eggs are packed in moistened vermiculite or sand within styrofoam boxes (Blake 1982). These are stacked, approximately 30 cm apart, on wooden shelves in a room in which, by various means, the temperature is maintained between 28° and 34° C. Experience has shown that heating is easier and more accurately controlled than cooling.

With the exception of one or two notably poor seasons, since 1979 the rearing stations have regularly achieved 80-90% success when hatching wild eggs (Fig. 2). The average hatch over the period 1981-85 was 89%. While eggs are spending most of their incubation under natural conditions it is unlikely that better success can be achieved. Under the present system, precise temperature control is difficult and short term extremes are prevented by the vermiculite or sand used as packing. One station, planning to artificially incubate eggs for their full term to influence hatchling survival, has built a simple, inexpensive, but more efficient incubator in which hatching success has been better than 90% (R. Lowe pers. comm.). This incubator comprises a small (10m<sup>2</sup>), well insulated room which is plastered and enamel-painted for hygiene. The eggs are stacked, without packing medium, in shallow plastic trays. A high humidity may be maintained either by a continuous flow of, or standing, water. Temperatures are maintained within 0.5°C by a fan heater with a sensitive thermostat. It seems likely that all stations will eventually switch to a similar design and opt for early collection.

**Hatching** - When wild eggs are collected it is common for the embryos within a single clutch to be at different stages of development (Pooley 1969, Hutton 1984) and hatchlings, if allowed to emerge undisturbed, may do so over a period of several days or even weeks. Blake (1974) considered that the "croaking" of emerging hatchlings stimulated neighboring embryos to hatch, but Magnusson (1980) disagreed. Some stations prudently isolate boxes of "croakers" to avoid premature hatching, others leave them amongst developing clutches.



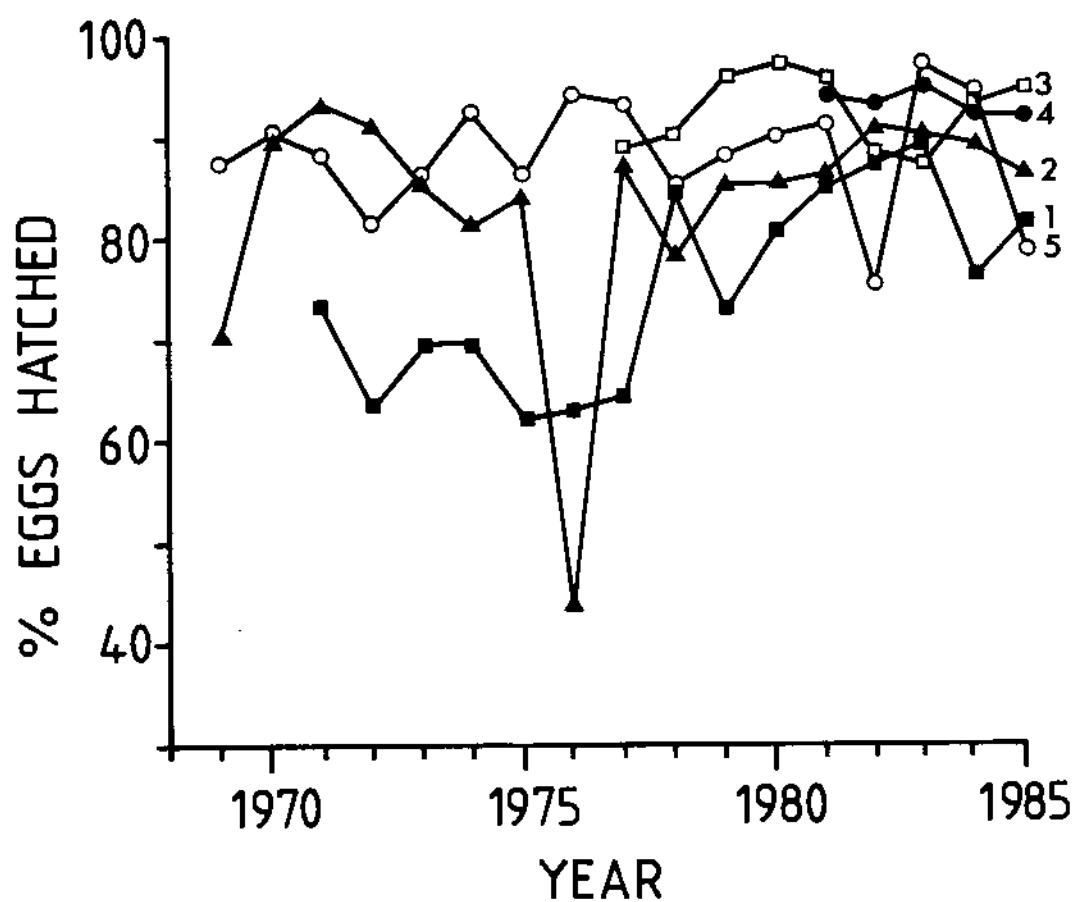


Figure 2. Hatching success of wild eggs on each of the five rearing stations from the first issue of their permits (station 1 since 1971; station 2, 1967; station 3, 1977; station 4, 1981; station 5, 1965).

Ideally, hatchlings which emerge unaided are washed and toe clipped in a clutch specific sequence. Each clutch is placed in a dry concrete pen or plastic tray of approximately 1 m<sup>2</sup>, within a hygienic, well ventilated room where hatchlings are allowed to "harden-off" for 24-48 hours at 34°C.

Assisted hatching is done under strict hygienic conditions. Premature hatchlings with poorly resorbed yolk may require extended "hardening-off". They are kept dry except for a short daily swim in clean, shallow water dosed with tetracycline at 20 mg/l. The holding area is disinfected daily.

Care of hatchlings - The quantity and quality of crocodiles surviving to the end of their first year has shown great variation both between and within stations; mortality on the most successful station has ranged from 5 to 55% in consecutive years while on the poorest station it has been consistently greater than 30% and was 100% in one year (Fig. 3). The average from all stations during the period 1981-85 was 28.2%.

Hatchling crocodiles are very susceptible to handling and other stresses as Garnett (1983) clearly demonstrated with *Crocodylus porosus*. Though unquantified, the following are considered to cause stress, contributing to mortality on Zimbabwe's stations: unsuitable temperatures, poor hygiene, overcrowding, rough handling, poor size grading (resulting in a dominance hierarchy), inadequate attention to routine in feeding and cleaning and poor nutrition.

Mortality is clearly temperature related. More hatchlings have died in September, at the end of the cool season, than in February, immediately prior to the cool season, or November when the hot season is well advanced (Hutton and Brennan 1985). Low cool season temperatures suppress appetite, digestion and growth. Heating of ponds can substantially reduce mortality and increase food intake and growth (Blake and Loveridge 1975).

All stations appreciate that they have a temperature problem and have tackled it in some way, some by covering the pens at night, others by pumping water, which never falls below 18°C, direct from Lake Kariba. Unfortunately, it is not certain how effective these efforts have been because stations have usually underestimated the optimum temperature for growth (Hutton and Brennan 1985). The only hatchling rearing system with precise temperature control is that at Spencer's Creek, the most temperate station, which has pens incorporating thermostatically controlled coal-fired heating.

Extremely high temperatures also stress crocodiles, and death is recorded as occurring at temperatures approaching 40°C (Hutton and Brennan 1985).

It is clear that, although the ultimate cause of death is usually disease, temperature or other stress is commonly the predisposing factor and a great number of deaths could be avoided with appropriate management.

Enclosure design is by no means standardized on stations, but small, outdoor, concrete pens, approximately 3m<sup>2</sup>, each with a saucer-shaped pond holding 50 hatchlings are currently preferred to larger pens holding 200 to 300 animals at the same density. Temperatures are more easily regulated, hygiene strictly maintained and disease controlled in small enclosures. Insulating the concrete of the pool, and covering pens with black plastic sheeting, when the ambient temperature begins to fall, can maintain high temperatures at night (Siziba 1985). Overheating during the day can be prevented by artificial shade. Feeding and cleaning routines are strictly maintained. Pens are best cleaned and disinfected after every feeding and always refilled with clean borehole or purified water.

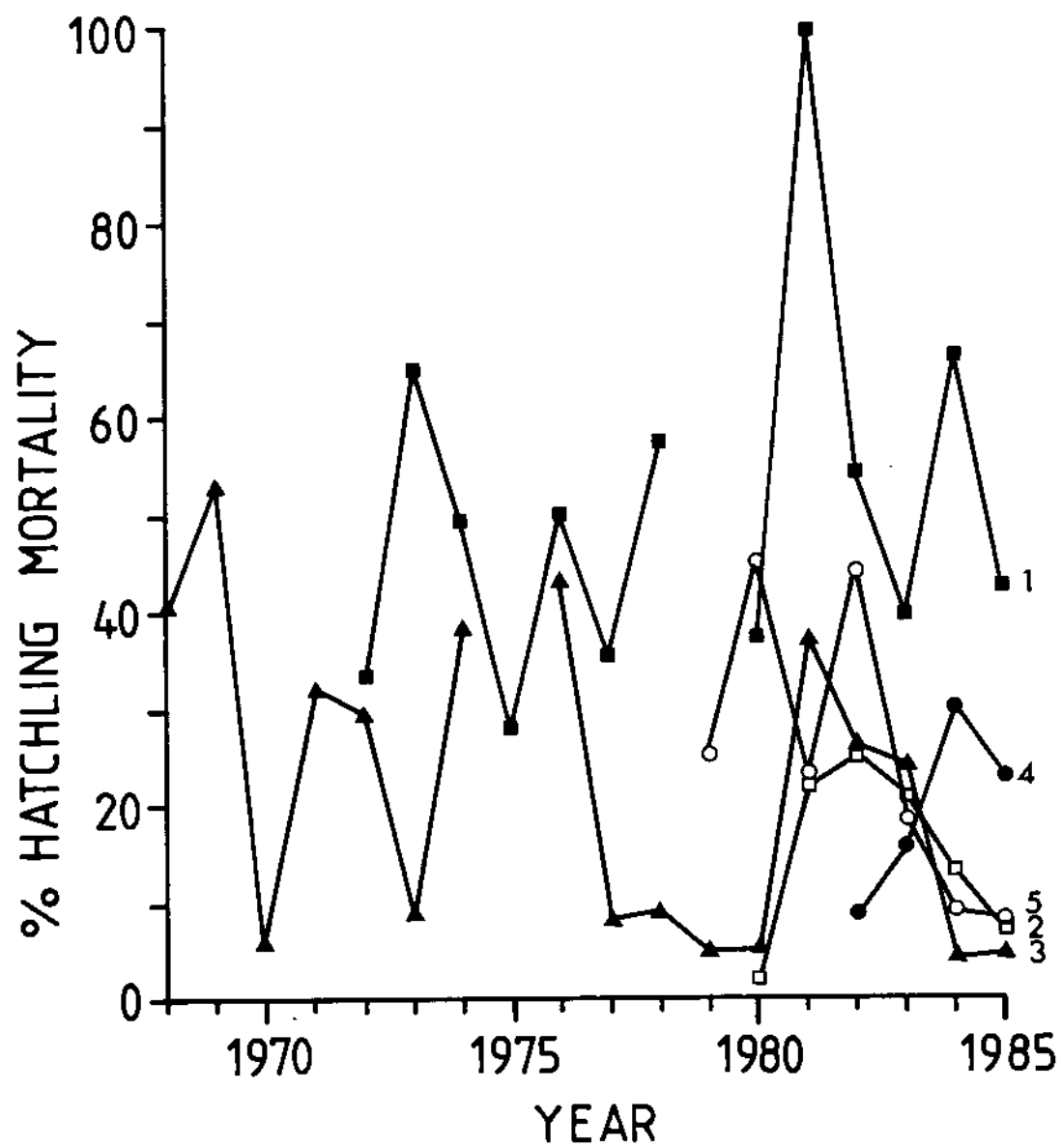


Figure 3. Annual percentage hatching mortality on each station since the issue of their permits.

Hatchlings are moved into these pens in early January after the "hardening-off" period. They are graded in March/April before the onset of the cool season, and again in October, when the new hot season is well advanced and before they are moved to new accommodation. Pens are then sterilized with formalin and sun-baked for as long as possible before the next season's hatchlings are introduced.

Environmental chambers, of a similar kind to those successfully used with *Alligator mississippiensis* in Louisiana (Joanen and McNease 1974) are currently being tested at temperatures of 34°C by a member of the CFAZ and the preliminary results are more encouraging than those recorded from Australian crocodiles under similar conditions (Webb et al. 1983).

Experience has shown that irrespective of the quality of facilities, information and extension services, the raising of crocodiles requires stringent management.

Care of rearing stock - On four stations, mortality among rearing stock (yearlings and older) commonly has been below 5% per annum. On the coolest station, however, rearing stock mortality has been as high as amongst hatchlings (Fig. 4). The overall mean mortality in the period 1981-85 was 3.3%.

Blake (1974) described the variety of pens used for rearing stock. Each design has proved adequate, but a double concrete pond results in an equal distribution of animals and a minimum of stress during cleaning. Adjacent ponds are drained, cleaned and refilled on alternate days and the crocodiles are thus never denied access to water. Corners and vertical sides are avoided, oval ponds with a saucer-shaped profile are considered most effective. As with hatchling pens, a mosaic of shade is provided. Separate feeding platforms are being built on some stations. These allow the crocodile to retreat into a trough of shallow water with their food, preventing contamination of the main pond. At least one station has completely concreted the area around ponds, others maintain a surround of closely cropped grass.

Some stations have earth "finishing" ponds, but the belief that these promote better growth than concrete pens has still to be verified. However, earth ponds are inexpensive and when properly managed do not appear to be less successful than those of concrete. If management is inadequate, efficient cropping is difficult and problems of hygiene, burrowing and escape may be encountered.

Feeding - Blake (1982) noted that the diet of captive crocodiles in Zimbabwe is virtually restricted to kapenta (*Limnothrissa miodon*), a sardine-like fish, and game meat (particularly elephant) from controlled hunting and on-going population reduction exercises.

On most stations, fresh kapenta is favored for hatchlings. Where only red meat is fed, deficiency syndromes soon appear and a supplement of vitamins, calcium, trace elements etc. is always added, often in the form of dried kapenta. Continual monitoring of food quality is encouraged, and some stations even supplement kapenta with calcium, trace elements and vitamins.

As noted by Magnusson (1984), the political climate of Zimbabwe has changed and the human population is rapidly growing. Although the financial justification is unlikely to change, social pressures against the continued feeding of crocodiles with game meat are anticipated and alternative sources of protein are being examined. One established station is diversifying into

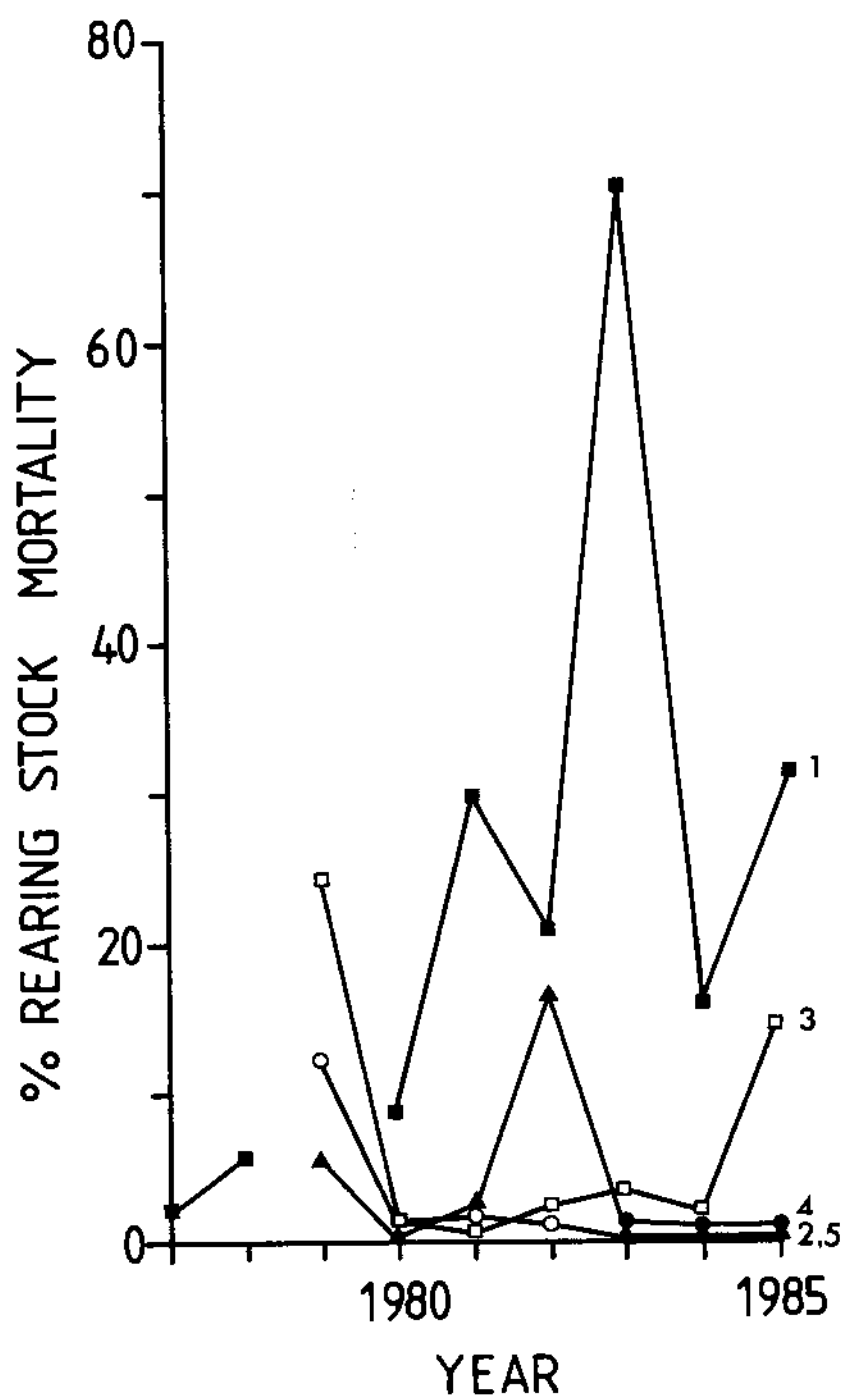


Figure 4. Annual percentage rearing stock mortality on each station since the issue of their permits.

ostrich production for hides (for the luxury leather trade) and meat to maintain crocodile production, another is experimenting with the large-scale production of bream fry (*Tilapia* spp.) in tanks.

Additional stations will only be allowed if, in addition to other requirements, they can show that they have access to an adequate and reliable source of food.

Disease - Disease has affected seriously the viability of crocodile farming in Zimbabwe and there are ethical objections to a system of conservation and management in which large numbers of animals succumb to disease (Foggin 1987). The fact that there is considerable variation in the occurrence and severity of disease between farms depending on climate, management, egg incubation, diet and housing suggest that these factors play a major role in the development of disease and that severe losses are a secondary manifestation of poor husbandry.

The main causes of death are major infectious disease syndromes including bacterial septicemia (*Aeromonas* and *Salmonella* species), viral hepatitis and coccidiosis. Runting, the causes of which are unknown, usually leads to death and is a severe problem on some stations.

Less important syndromes have been caused by pox virus and fungal infections, parasites, over-feeding and dietary deficiencies.

While disease prevention through improved husbandry is being encouraged, disease treatment remains important and although considerable work on this subject has already been done on rearing stations (Foggin 1987) more research is required and planned.

Cropping, flaying and curing - Zimbabwe crocodile hide is marketed in commercial units based on the width of the belly and by tradition animals have been slaughtered when about 1.5 m TL and 30-35 cm belly width (BW). However, the optimum size for cropping depends on a combination of production and marketing factors and has been as low as 25 cm BW. All stations crop by shooting the required animals in the head with a .22 short bullet. To ensure quality control, the CFAZ encourages a standardized skin preparation based on international practices. After washing, the backskin is removed ahead of that on the belly and each is thoroughly cleaned before curing in wet salt. Skins are then graded, measured and tagged before being rolled and stored in a cold room prior to export (Van Jaarsveldt 1987).

Efficiency - The proportion of incubated eggs which result in saleable hides has varied greatly between stations and on some has been consistently low. As an example of the efficiency of the industry in recent years, it is notable that of the average total of 9,600 eggs available to four stations in each of the years 1978 until 1982 only 3,360 (35%) were successfully hatched and raised to cropping size, and of these 43% were on one station. In order to improve this performance, in 1985 the Department and the CFAZ together adopted minimum standards for each stage of the rearing process and any station which does not consistently achieve these standards may be penalized by having its quota of wild eggs reduced. An immediate improvement was recorded in the ensuing 1985-86 season with only one station falling short of requirements. By 1987 an efficiency of 65% is anticipated and by 1990, with more eggs from captive stock, the five existing stations should be producing 15,000 hides per annum.

All crocodiles and their derivatives are marketed to best effect under the auspices of the CFAZ.

Research and extension - The industry is provided with extension services by the Department (which has a full-time crocodile specialist) and the Department of Veterinary Services. However,

recommendations are often based on experience rather than research. Research has been hampered by a shortage of funds, a lack of experimental facilities, the remoteness of stations and a lack of scientific expertise on the part of station management. Recently, the CFAZ has provided central experimental facilities, including eight heated pens for hatchlings, and two stations presently have managers with scientific training. Critical problems have been identified and an extensive research program is underway. This includes investigations into the effect of incubation on subsequent growth and survival, the effect of stress on growth and susceptibility to disease, pathogenicity to disease, nutrition and the design and thermal dynamics of enclosures.

### EFFECTIVENESS OF MANAGEMENT

Response of wild populations - The most heavily exploited populations are those of Lake Kariba and the upper Zambezi River between the lake and the Victoria Falls, but the brunt of increased egg collection in recent years has been borne by the Kariba population from which a total of 11,273 eggs were removed in 1985 (Fig. 5). As a result, survey and monitoring has focused on this population. Only about 8% of the Zambezi below the lake is exploited and there are virtually no census data for this stretch of water.

From virtual extinction in the 1950s, crocodiles in the upper Zambezi increased until, by 1971, they bred in sufficient numbers to support the collection of about 2,000 eggs each year. This was not necessarily the maximum number of eggs that could have been removed, but reflected the ceiling of one station's quota. From a peak of 1,974 in 1975, the number of eggs recovered had fallen by 40% to 1,305 (of which 275 had been destroyed by humans) by 1985 despite intensive searching. The decline is due to the uncontrolled expansion of settlement and fishing on the Zambian side of the river. The Department has accepted that, with the exception of a few small colonies within major tributaries, this population is severely threatened and some of the remaining animals are being captured and moved to rearing stations.

Very little is known about crocodiles along the Zambian shore-line of Lake Kariba, but on the Zimbabwe side only those in the extreme western headwaters are seriously affected by pressures from fishing and settlement. Most of the remaining shore-line has well protected crocodile habitat and controlled fishing. Annual aerial and spotlight surveys conducted since 1975 suggest that the population numbers some 30,000 animals, 5,000 of which are adults (Taylor, Loveridge and Blake unpublished data). In its present state, monitoring does not give any indication of trends, mainly because there is no good correction factor for the effect of fluctuations in lake level on the number of animals seen. However, it is clear that the population has risen to its present level in the 25 years since the lake filled, while being exploited for most of this period.

Aerial surveys are rapid and simple, but only give an index of the number of large crocodiles in an area. Correction factors for the size structure of a population are established from spotlight counts, the accuracy of which is commonly considered dubious (Hutton 1984). As a consequence, any demographic response to utilization may not be detected for several years, until they are reflected as changes in the numbers of large juvenile and adults. Because the present system of monitoring does not show trends, some concern has been expressed about the doubling, since 1980, of the number of eggs collected from the lake and the fact that all areas outside Matusadona National Park are now regularly exploited (Hutton and Brennan 1985). However, as only about 300 nests are being raided for eggs each year, while census data indicate that there are 5,000 adult crocodiles, it has also been suggested that the population may still be under-exploited and the quota

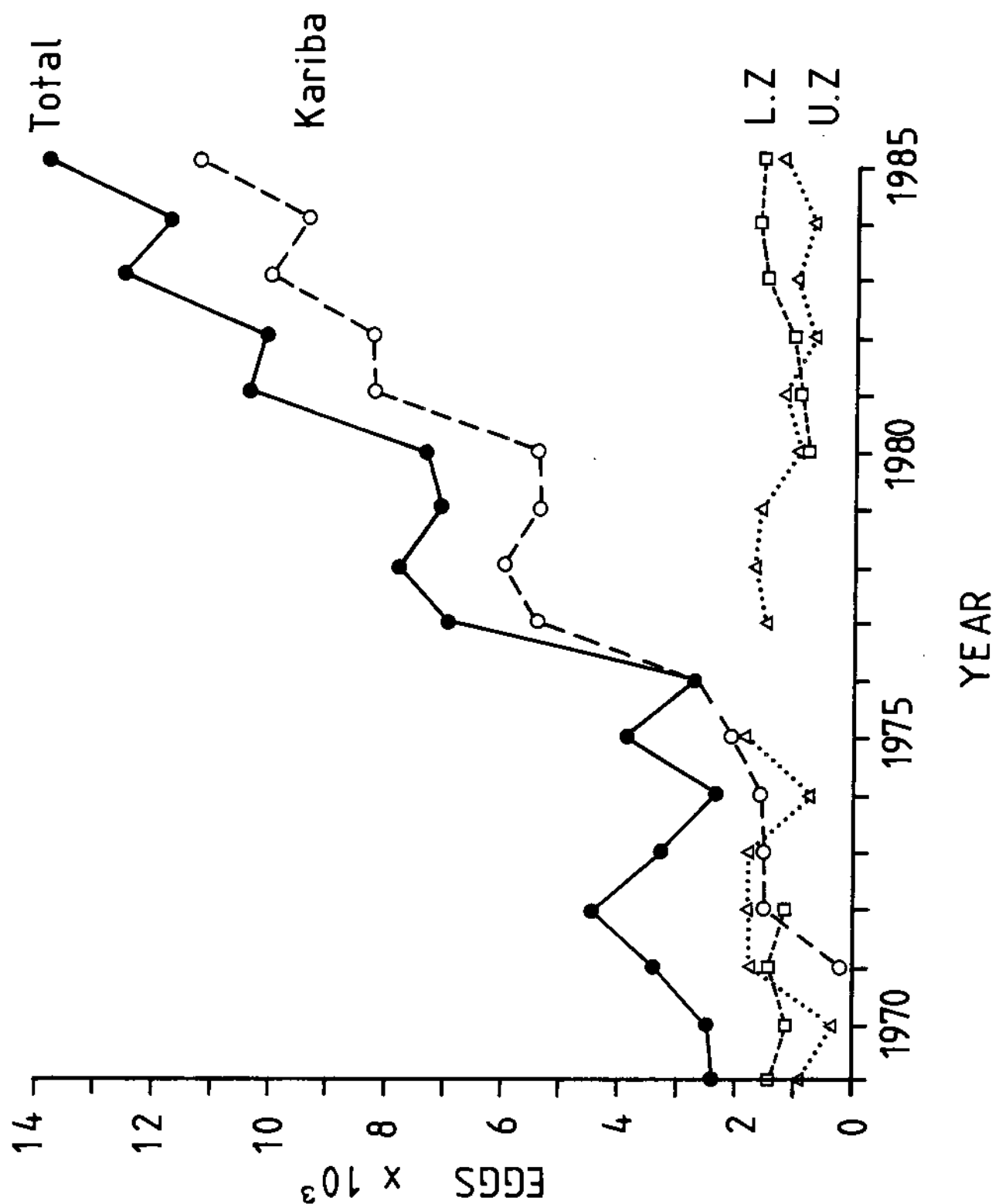


Figure 5. Total number of eggs removed from nests in each of the three main collecting localities in the Zambezi valley since the first issue of egg collecting permits. U.Z = Upper Zambezi River, L.Z = Lower Zambezi River, Kariba = Lake Kariba (see Fig. 1).



set by the Department too conservative. As detailed below, the information necessary for modeling, prediction and improved management is being sought as a matter of priority.

Monitoring and research - As part of the Department's monitoring efforts, stations have been required to submit information on the fate of every clutch collected since 1969. Unfortunately, although there is some important information of clutch size and the number of nests in broad localities, these records allow no measure of natural predation and collecting efficiency, nor do they give the exact locality of nests. In 1985, after analysis of all the available data, the system of returns was altered and stations are now helping gather this information.

It has already been noted that direct census and monitoring of population numbers has also been of limited value. As a result, census and survey techniques are being researched. In order to gain enough information to measure and monitor the size structure of the population, radiotelemetry is to be used to establish movement and dispersion patterns and capture-recapture experiments are planned to provide correction factors which can be applied to eliminate bias inherent in different forms of survey.

Recent research into the dynamics of a Nile crocodile population has identified the critical data required before exploited populations can be modeled and the demographic effects of different exploitation regimes predicted (Hutton 1984). Together with the University of Zimbabwe, the Department is now directing research towards obtaining information such as growth rates, size and age at maturity, sex ratio, proportion of females breeding each year, reproductive success and size-specific mortality from Lake Kariba crocodiles.

## CONCLUSIONS

Crocodile management in Zimbabwe is based on the pragmatic philosophy that, particularly with species which conflict with man, utilization can lead to conservation. This has proved to be the case. Crocodile numbers have climbed since the end of uncontrolled hunting in the early 1960s and it is now estimated that there are more than 30,000 crocodiles in Lake Kariba alone. The economic benefits of utilization have proved particularly important where emotive conservation and development issues have been argued.

As a result of recent research into the dynamics of crocodile populations, it has been possible to make some predictions as to the level of exploitation which would be sustainable in a population of a given size and age structure. Unfortunately, despite considerable expenditure of resources, accurate measurement of these parameters for larger populations has proved elusive, thus requiring that management remain both conservative and adaptive. More research is being focused on census techniques, particularly with respect to factors which affect apparent age structures, such as size-specific dispersion.

Even with utilization, Zimbabwe's burgeoning population threatens to deplete the crocodile resource unless more obvious benefits are made available to rural communities which coexist with the animals. More emphasis is being placed on this aspect of management and in one scheme cooperative rearing stations are planned.

The industry has been largely dependent on inexpensive meat from game cropping. While the use of game meat is likely to remain economically justifiable, social pressure against its use is anticipated and alternative food sources are being investigated. To allow rearing stations to expand and to buffer them from unfavorable egg quota decisions, the keeping of limited captive

breeding stock is being encouraged and it is expected that food, rather than the availability of eggs, will limit the size of the industry.

#### ACKNOWLEDGMENTS

Our wild crocodiles wish to express their gratitude to all those in the Department, the CFAZ and elsewhere who have ensured their survival through the success of sustainable utilization.

#### LITERATURE CITED

- Blake, D.K. 1974. The rearing of crocodiles for commercial and conservation purposes in Rhodesia. *Rhod. Sci. News* 8:315-324.
- \_\_\_\_\_. 1982. Crocodile ranching in Zimbabwe. *Zimb. Sci. News* 6:208-209.
- \_\_\_\_\_. and J.P. Loveridge. 1975. The role of commercial crocodile farms in crocodile conservation. *Biol. Cons.* 8:261-272.
- Child, G.F.T. 1977. Problems and progress in Nature Conservation in Rhodesia. *Koedoe* 20 (supplement):116-137.
- CITES. 1984. First Meeting of the Technical Committee, Brussels (Belgium), 25-30th June 1984, CITES Secretariat, Gland (Mimeographed).
- Cott, H.B. 1961. Scientific results of an enquiry into the ecology and economic status of the Nile crocodile (*Crocodylus niloticus*) in Uganda and Northern Rhodesia. *Trans. Zool. Soc. Lond.* 29:211-356.
- Foggin, C.M. 1987. Disease and disease control on crocodile farms in Zimbabwe. Pp. 351-362 in G.J.W. Webb, S.C. Manolis, and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons. Chipping Norton, Australia.
- Garnett, S.T. 1983. Nutrition and farm husbandry of the green sea turtle (*Chelonia mydas*) and the estuarine crocodile (*Crocodylus porosus*), Ph.D thesis, James Cook University of North Queensland, Australia.
- Groombridge, B. 1982. *Amphibia-Reptilia Red Data Book, Part I, crocodilians and chelonians*. IUCN. Gland, Switzerland.
- Hutton, J.M. 1984. The population ecology of the Nile crocodile, *Crocodylus niloticus* Laurenti, 1768, at Ngezi, Zimbabwe. D.Phil thesis, University of Zimbabwe.
- \_\_\_\_\_. 1986. Cashing in on crocs. *Zimbabwe Wildlife*, March 1986:27-29.
- \_\_\_\_\_. 1987a. Growth and feeding ecology of the Nile crocodile (*Crocodylus niloticus*) at Ngezi, Zimbabwe. *J. Anim. Ecol.* 56:25-38.

- \_\_\_\_\_. 1987b. Incubation temperatures, sex ratios and sex determination in a population of Nile crocodiles (*Crocodylus niloticus*). *J. Zool. (Lond)* 211:143-155.
- \_\_\_\_\_. and S.L. Brennan. 1985. An analysis of records of the crocodile rearing industry in Zimbabwe, Branch of Terrestrial Ecology Internal Report, Department of National Parks and Wild Life Management, Zimbabwe.
- Joanen, T. and L. McNease. 1974. Propagation of immature American alligators in controlled environmental chambers. *Proc. Am. Assoc. Zoo, Parks Aquar. Reg. Conf.*:262-268.
- Magnusson, W.E. 1980. Hatching and creche formation by *Crocodylus porosus*. *Copeia* 1980:359-362.
- \_\_\_\_\_. 1984. Economics, developing countries and the captive propagation of crocodiles. *Wild. Soc. Bull.* 12:194-197.
- Pooley, A.C. 1969. Preliminary studies on the breeding of the Nile crocodile (*Crocodylus niloticus*) in Zululand. *Lammergeyer* 10:22-44.
- Siziba, C. 1985. Design of pens for hatchling crocodiles, B.Sc. Honours thesis, University of Zimbabwe.
- Van Jaarsveldt, K.R. 1987. Flaying, curing, and measuring crocodile skins. Pp. 387-392 in G.J.W. Webb, S.C. Manolis, and P.J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons. Chipping Norton, Australia.
- Webb, G.J.W., R. Buckworth, and S.C. Manolis. 1983. *Crocodylus porosus* in a controlled-environmental chamber: a raising trial. *Aust. Wildl. Res.* 10:421-432.

**EDITOR'S NOTE:** Since this manuscript was received, substantial changes have been made to the management system in Zimbabwe. Anyone interested in obtaining further information should contact the senior author.

## **CROCODILIANS AND THE LAW\***

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### **FOREWORD**

Background data for this paper have been derived from the IUCN Environmental Law Centre's "Index to Species Mentioned in Legislation". This Index which has been maintained since 1978, forms a part of IUCN's Environmental Law Information System. Its purpose is to assist in ascertaining the legal status of species and higher taxa mentioned in international agreements or national legislation. To date, over 1,500 international and national law instruments have been analyzed for inclusion in the Index.

Considerable efforts are made by IUCN to obtain on a regular basis copies of legislation from countries throughout the world. Nonetheless it is recognized that gaps still exist in the collection. As the field of conservation legislation is rapidly evolving it is difficult to track rapidly changes in legislative provisions. Therefore, although extensive, the data cited in this paper are not totally comprehensive. Rather the authors intend to provide an illustrative overview of national and international law which concern crocodilians.

### **1) BACKGROUND**

Legal protection for crocodiles is a recent phenomenon. It has come only after the realization that wide scale exploitation of crocodiles for profit was resulting in the extermination of a valuable renewable resource. In the past, crocodiles were almost everywhere either simply ignored by national law or listed as pest or vermin species whose destruction was encouraged at all times and by any means. In other words, the taking of crocodiles was completely unrestricted.

Crocodiles were also ignored by the earliest international wildlife conventions. For example, the London Convention of 1933 (Convention Relative to the Preservation of Fauna and Flora in Their Natural State) did not include crocodiles in its Annex of protected species. Nor were they listed in the proposed amendments to that Annex which was put forward at a Conference in Bukavu in 1959. Furthermore, none of the lists of species to be protected established in pursuance of the Western Hemisphere Convention of 1940 (Convention on Nature Protection and Wildlife

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\* Note: The views expressed in this paper are those of the authors and do not necessarily represent those of IUCN.

Preservation in the Western Hemisphere) mention any species of Crocodilia. In fact, the only reference to crocodiles in early international law can be seen in the African Convention of 1900 (Convention for the Preservation of Wild Animals, Birds and Fish in Africa) which was never ratified and, therefore, never came into force, and which urged Parties to destroy the eggs of crocodiles.

During the 1960's it became evident that the current rates of exploitation could well result in, at least, the commercial extinction of several species. This realization came only after several decades of unfettered exploitation of crocodilians in Latin America and one to two decades of such exploitation in Africa and Australia.

Protective legislation followed which applied mostly to commercial hunting, it generally provided for the licencing of crocodile hunters, the establishment of closed seasons and the determination of a minimum size under which crocodiles could not be taken or their hides sold.

Significantly, the African Convention of 1968 (African Convention on the Conservation of Nature and Natural Resources), listed crocodiles for the first time in an international instrument as species the taking of which was to be regulated by the Contracting Parties.

Since then, the almost universal legislative trend has been towards increased protection for crocodilians. In many countries, since mere exploitation regulations were seen to be clearly insufficient to prevent a further decline in populations, complete protection became the rule. As this was still not sufficient, domestic and international trade prohibitions were introduced through national legislation. Finally a comprehensive international system for the control of trade in wildlife and wildlife products covering, inter alia, all species of crocodilians was established when the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) was adopted in 1973.

Another convention, the 1979 Migratory Species Convention (Convention on the Conservation of Migratory Species of Wild Animals) lists the gharial (*Gavialis gangeticus*) as a fully protected endangered species and the estuarine crocodile (*Crocodylus porosus*) as a species requiring international cooperation for its conservation and management.

Consequently, unrestricted commercial exploitation of wild populations of crocodiles now belongs to the past. Poaching, however, remains rife in many areas and gaps in enforcement of national and international legislation continues to pose problems. As controls tighten, however, several countries with remaining relatively healthy crocodile populations are now turning to "ranching" as a more rational form of exploitation. That is to say the rearing in a controlled environment of hatchlings collected from the wild or obtained from eggs so collected. Examples of such ranching schemes can be found in Papua New Guinea and Zimbabwe. In order to meet conservation concerns these operations require prohibition or strict control of taking of adults in the wild, regulation of taking of eggs or young, and a system to ensure that only ranched specimen may enter trade.

This paper provides an overview of legislation currently in force for the conservation of crocodiles, with major sections devoted to enactments covering the prohibition or restriction of taking and trade in these species since modern legal provisions are almost entirely limited to these two approaches. Habitat protection for the specific purpose of preserving crocodiles is rarely a legal requirement, and a final section of this paper is devoted to a review of the few existing legal provisions available for the conservation of crocodile habitat. This is certainly an area in conservation legislation which requires further development.

## II) TAKING

Crocodiles are no longer ignored in legislation. In almost all countries of their range, crocodiles are either fully protected, or partially protected, i.e. they may only be taken under a permit or license system. They are hardly ever still listed in legislation as vermin, although this is still the case in Madagascar, for example, pursuant to the terms of a 1961 decree which remains in force.

### A) General Overview

#### 1) Full Protection

In many jurisdictions, crocodilian species enjoy full protection with legal prohibitions against the taking of crocodiles for commercial or sport purposes. Indeed, there is a reasonable match between those crocodilian species considered "endangered" in the IUCN Red Data Book and those which are given full protection.

However, full protection is never absolute. It is usual for exceptions to be included within legislation allowing taking for scientific research or education purposes and for self-defense or defense of property. For example, it is standard in African legislation to provide for exceptions in the case of protection of livestock. Since crocodiles pose obvious safety problems, it is clear that legislative provisions will exist for the destruction of nuisance individuals. This applies even to endangered species such as (*C. porosus*) as is provided for in the 1984 amendments to full protection legislation in Queensland, Australia. Finally, although the effectiveness of full protection from taking varies from jurisdiction to jurisdiction, it has been universally recognized that this protection must be reinforced by trade controls if efforts to improve the conservation status of crocodiles are to succeed.

#### 2) Partial Protection

In certain jurisdictions a system of partial protection for crocodilian species has been established by law. One example may be seen in limited exceptions for sport hunting, such as for *Crocodylus niloticus* in Ethiopia or for *C. porosus* or *Crocodylus palustris* in Sri Lanka.

Another example may be seen in the institution of open and closed seasons for commercial exploitation, or for minimum size limitations for such exploitation. In Nicaragua, commercial licenses are required and there are size limits for taking, e.g. minimum length of four feet. In other jurisdictions, minimum belly width has been established as a condition for taking. This was the case as early as in 1958 in the legislation of Oubangui-chari (at the time a French possession, now the Central African Republic) where a limit of 25 cm was set. Current examples include a limit of 25 cm in the Ivory Coast and Zaire with 1.5 m for *C. niloticus* and *Crocodylus cataphractus*, and 50 cm for *Osteolaemus tetraspis*.

In a small number of cases instead of setting a minimum size to protect juveniles, legislation establishes a maximum size to safeguard the breeding potential of mature individuals. An example can be seen in the 1972 legislation of the Solomon Islands where the export of crocodiles and

crocodile skins, the belly-width of which exceeds 50 cm, is prohibited except for the skins of crocodiles reared in a crocodile farm. Papua New Guinea's legislation also provides for the prohibition or restriction of taking, possession, disposal or exportation of crocodiles below a set size. Pursuant to this legislation a maximum width of 51 cm was imposed in 1969 for specimens in trade. Although in these two cases the actual taking of oversized specimens does not seem to be prohibited, the fact that such specimens cannot be sold or exported provides a lack of incentive for such taking.

The tendency to set size limits received the support of African delegations at the Fifth Conference of the Parties to the CITES Convention in Buenos Aires (April 1985) as the submission presented by Malawi for the transfer of *C. niloticus* from Appendix I to Appendix II made it clear that young and breeding crocodiles would not be hunted, with controls being instituted in regard to the length of the crocodiles allowed to be harvested.

## B) Specific Examples

In the following paragraphs, an indication is provided of the coverage of current national legislation in Africa, tropical America and in Asia and the Pacific concerned with the taking of crocodiles.

### 1) Africa

The legal status of all three species of African crocodiles - *C. cataphractus*, *C. niloticus* and *O. tetraspis* is the same whenever more than one species occurs in a particular country. Although there are exceptions, full protection is usually given to crocodiles in countries where populations have been seriously depleted.

#### a) Examples of Full Protection Legislation

Angola	: Hunting Regulations of 1957.
Benin	: Ordonnance portant reglementation de la protection de la nature et de l'exercice de la chasse, 1980.
Burkina Faso	: Loi portant interdiction de la chasse a l'elephant, a l'hippopotame et au crocodile, 1979.
Burundi	: Reglementation de la chasse et de la protection des especes animales, 1971.
Central African Rep.	: Ordonnance portant protection de la faune sauvage et reglementant l'exercice de la chasse, 1984.
Egypt	: Decree 1059 of 1984.
Ethiopia	: Wildlife Conservation Regulations, 1972 (Note, however, that specimens may be taken under a supplementary game license).
Gambia	: Wildlife Conservation Act, 1977.
Ghana	: Wildlife Conservation Regulations, 1971.
Liberia	: Decision of the President, 1978.
Nigeria	: Endangered Species Decree, 1985.

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|--------------|---|
| Senegal      | : Decret portant code de la chasse et de la protection de la faune, 1967.   |
| South Africa | : In the two provinces where <i>C. niloticus</i> (the only crocodilian species in South Africa) still occurs, Natal and the Transvaal, full protection is provided by provincial legislation (Natal Nature Conservation Ordinance, 1974, Transvaal Nature Conservation Ordinance 1983). There is no relevant federal legislation. |
| Tanzania     | : Wildlife Conservation (National Game) Order, 1974.  |

#### b) Examples of Partial Protection Legislation

In several African jurisdictions, legislation exists which allows for crocodiles to be taken under a game or commercial license. Although such hunting laws are still in force, in several of these countries hunting bans have been instituted pursuant to regulations under the legislation. Several examples follow.

Ivory Coast: Commercial taking is regulated by the Arrête reglement la chasse des crocodiles et varans dans un but commercial, 1967, with minimum width set at 25 cm. However, an overall hunting ban was established by order in 1974 and another 1974 order required that hunting rifles and hunting licenses must be deposited at local district offices.

Kenya: *C. niloticus* is listed as a game species which may only be taken under license (Wildlife Conservation and Management Act of 1976). However, Legal Notice No. 120 of 1977 banned all hunting until further notice and cancelled all hunting licenses.

Mali: Pursuant to the Ordonnance portant institution d'un code de la chasse, 1969, crocodiles were classified as game species that may only be taken by holders of hunting licenses, with a bag limit of 3 animals per year and per licence holder. However, recently an overall hunting ban was established by Decree 325 PGRM (date unavailable).

Niger: Crocodiles were listed as pest species by the Loi fixant le regime de la chasse, 1962. An overall hunting ban was, however, instituted in 1964 for a period of two years. This ban was subsequently extended several times until a permanent hunting ban was established by decree in 1972. In addition, on the occasion of a future revision of the Hunting Act it is intended to upgrade the Nile crocodile to fully protected status (letter of the relevant authorities in Niger to the Environmental Law Centre of IUCN, dated 19 September 1985).

Somalia: Under the Fauna (Hunting) and Forest Conservation Act of 1969, the Nile crocodile could only be taken by holders of supplementary game licenses. There was a maximum bag limit of two specimens. However, a complete ban on the hunting of all wildlife was established by Act No. 65 of 1977.

In other African countries the taking of crocodiles is authorized under licence. Examples include:

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|------------|---|
| Botswana   | : Fauna Conservation Act, 1961.   |
| Cameroon   | : Arrête fixant la liste des animaux des classes A, B, et C, 1983.                                |
| Congo      | : Arrête determinant les animaux integrelement et partiellement proteges prevus par la loi, 1983. |
| Malawi     | : Crocodile Act, 1968.  |
| Mozambique | : Modalidades de Caca, 1978.  |



Rwanda	: Ordonnance-loi portant creation de l'office Rwandais du tourisme et des parcs nationaux, 1973.
Sierra Leone	: Wildlife Conservation Act, 1972.
Sudan	: Preservation of Wild Animals Act, 1936.
Togo	: Ordonnance reglementant la protection de la faune et l'exercice de la chasse, 1968. Under terms of this law, all three species of crocodiles are listed as predatory species. They may be killed at all times in inhabited and farming areas. The use of firearms to kill crocodiles in such areas is limited, however, to holders of valid hunting licenses (Decree No. 79-139 of 1979). In game management areas crocodiles are game species and may only be taken by holders of special licenses.
Uganda	: Fish and Crocodiles Act, 1951.
Zaire	: Loi portant reglementation de la chasse, 1982.
Zambia	: National Parks and Wildlife Act, 3.12.1968.
Zimbabwe	: In Zimbabwe crocodiles are protected along the Zambeze River and its tributaries up to 20 km upstream of their confluence (Statutory instrument 718 of 1980). They may be killed elsewhere by holders of game licenses. Rearing stations have been established for the purpose of commercial exploitation. The harvesting of wild laid eggs to supply these stations is to be strictly controlled on the basis of a quota system for the conservation and management of crocodiles.

#### c) Examples of Crocodiles Listed as Pest Species

Madagascar	: Decret repartissant en trois categories les oiseaux et animaux sauvages vivants, 1961.
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#### d) Incomplete Information

The IUCN Environmental Law Centre does not hold legislation materials concerning crocodiles from Chad, Namibia or Swaziland. In addition, in a few other countries, based on information available, the legal situation for crocodiles is unclear. For example, in Gabon, crocodiles were not mentioned in the Wildlife Act of 1960. A new Wildlife Act was adopted in 1982, but its implementing regulations have yet to be approved. A temporary ban on all hunting was proclaimed by a Decree in 1981. This was rescinded for small game (unspecified) by decree in 1982. In Guinea Bissau under the Regulamento de caca, 1980, the taking of crocodiles by sport hunters is prohibited, but it is apparently the case that commercial hunting is authorized. Finally, in Mauritania, the Hunting Act of 1975 prohibits commercial hunting of all species but other taking is not covered.

## **2) Tropical America**

Within Tropical America, many countries have now instituted overall or commercial hunting bans which provide conservation benefits to crocodilians. Information is provided in the following section about the jurisdictions which have instituted such bans and thereafter a treatment of the legal status of particular tropical American crocodilian species is provided.

#### a) Overall Hunting Ban

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|----------|---|--|
| Colombia | : | Decreto 1608 of 1978 provides for only subsistence hunting, pending official listing of game species.  |
| Paraguay | : | Decreto No. 18796, 1975, prohibits all hunting of indigenous wildlife.   |
| Peru     | : | Decreto Supremo No. 934-73-AG, 1973, prohibits for an indefinite period of time all non-subsistence hunting in the region of La Selva (i.e. the Amazonian lowlands).   |
| Uruguay  | : | All vertebrates except fish have been protected from hunting as from as early as 1953 pursuant to Government Order under Ley No. 9.481 of 1935. There is, however, a very short list of excepted game species which are specified in annual hunting orders. No crocodilians have been listed as excepted game species. |

#### b) Commercial Hunting Bans

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|------------|---|---|
| Brazil     | : | Act No. 5197, 1967.   |
| Costa Rica | : | Act No. 6919 of 1983 and Decreto No. 15273A of 1984.                        |
| Ecuador    | : | Decreto No. 487 of 1980 which prohibits commercial hunting of all reptiles. |
| Mexico     | : | Ley de Caza, 1951.  |
| Nicaragua  | : | Decreto No. 625 of 1977.  |

#### c) Species by Species Analysis in Tropical America

##### *Alligator mississippiensis*

This species was initially classified as endangered throughout its range in the United States and its taking was prohibited under the Endangered Species Act of 1973. It has now recovered in many parts of its range as a result of Federal and State protection. Special rules were developed as a consequence to allow controlled exploitation in those states where populations had sufficiently recovered: Louisiana, Texas and, most recently (1985), in Florida (50 CFR, 17.42).

The species is also protected by State legislation. The legislation of Florida (Florida Wildlife Code Title 39) is particularly interesting. Statute 372-66 indicates that a license is required for dealing in or buying alligator skins. Statute 372-6645 provides that the retail sale of alligators requires a permit and that the sale of stuffed baby alligator is prohibited. Statute 39-25-07 regulates the operation of alligator farms and the harvest and sale of alligators from such farms. It also regulates the sale of alligator meat. Statute 39-25-03 controls the taking and disposal of nuisance alligators. This may be done only by a designated agent trapper of the Florida Game and Fresh Water Commission. The qualifications and selection of the trappers and the rules governing these operations are laid down in regulation. Finally, Florida legislation provides that alligators lawfully obtained outside the state may only be imported into Florida under permit. The taking, possession, buying or selling of any alligator, crocodile, black caiman or their nests or eggs or any parts thereof requires a permit and is subject to regulation.

*Caiman crocodilus**C. c. crocodilus* and *C. c. fuscus*

These are fully protected in:

- |            |   |                        |
|------------|---|------------------------|
| Costa Rica | : | Decreto 15273A of 1984 |
| Panama     | : | Resolucion 2-80, 1980. |

The species also benefits from protection in those countries where overall or commercial hunting bans are in force (Brazil, Ecuador, Mexico and Peru).

In other jurisdictions it is listed as a game species which may be hunted under license and according to certain size restrictions.

- |                   |   |   |
|-------------------|---|---|
| Colombia          | : | Resolucion por la cual se reglamenta la caza de la babilla en todo el territorio nacional, 1973.  |
| Guyana            | : | Fisheries Regulations of 1966.  |
| Trinidad & Tobago | : | Conservation of Wildlife Act, 1958.   |
| Guatemala         | : | Reglamento sobre la caza de largartos, 1955 (which also provides for closed seasons).   |
| Nicaragua         | : | By Administrative Decision of IRENA, the Wildlife Agency, minimum size four feet in length.   |
| Venezuela         | : | Resolucion por la cual tengase como oficial la lista de animales de caza que en ella se indica, 1970. In addition, Resolucion No. 445 of 1982 established an experimental programme for the management of the species in certain regions. |
| Belize            | : | Wildlife Protection Act, 1981.  |

No protective legislation exists in Suriname and French Guyana, finally no information is available from El Salvador or Honduras.

*C. crocodilus apaporiensis* is fully protected in:

- |          |   |  |
|----------|---|--|
| Colombia | : | Resolucion por la cual se reglamenta la caza de la babilla en todo el territorio nacional, 1973. |
|----------|---|--|

*C. crocodilus yacare* is fully protected in:

- |          |   |                                |
|----------|---|--------------------------------|
| Bolivia  | : | Decreto Supremo 16606 of 1979. |
| Paraguay | : | General hunting ban.           |

In Argentina this subspecies is protected by federal law. This law, however, only applies to inter-provincial and international commerce (Act No. 22,421 of 1981 and implementing regulations, in particular, Decreto No. 691/81 of 1981 and Resolucion No. 144 of 1983). In Argentina, the right to regulate taking is constitutionally vested in the provinces that may, if they so wish, adhere to the Federal law. To date none of the provinces in the range of this species have chosen to do so. Thus, in Argentina, the protection of *C. c. yacare* remains governed by provincial legislation for which no information is presently available to IUCN.

In Brazil the species also receives protection under the commercial hunting ban noted above.

*Caiman latirostris*

This species is fully protected in:

Bolivia	: Decreto Supremo No. 16605 of 20.6.1979.
Brazil	: Portaria of 13.5.1973 listing protected endangered species.
Paraguay	: Under the overall hunting ban.
Uruguay	: Under annual hunting orders since 1958.

In Argentina the situation is the same as for *C. crocodilus yacare*.

*Melanosuchus niger*

This species is fully protected in:

Bolivia	: Decreto Supremo No. 16606 of 1979.
Colombia	: Resolucion por la cual se establece la veda para la caza de algunas especies de caimanes, 1969.
French Guyana	: Arrete fixant pour le Departement de la Guyane la liste des especes animales proteges 1975.

It is protected from commercial hunting in Ecuador and Brazil and is fully protected in the Selva region of Peru. It may be taken under license in Guyana pursuant to the Fisheries Regulations of 1966.

*Paleosuchus palpebrosus* and *Paleosuchus trigonatus*

These species are fully protected in:

Bolivia	: Decreto Supremo 16606 of 1979.
Colombia	: Resolucion por la cual se vede la caza y el comercio de los productos de dos especies de la fauna silvestre, 1970.
Suriname	: Game Resolution, 1970.
Venezuela	: Resolucion no. 95, 1979.

It also benefits from protection in Brazil and Ecuador under commercial hunting bans and in Peru in the Selva region. They may be taken under license in Guyana pursuant to the Fisheries Regulation of 1966 and are unprotected in French Guyana.

*Crocodylus acutus*

The species has full protection in:

Belize	: Wildlife Protection Act, 1981.
Colombia	: Resolucion por la cual se establece la veda para la caza de algunos especies de caimanes, 1969.
Costa Rica	: Decreto 15273A of 1984.
Dominican Republic	: Decreto de Veda, 1978.
Jamaica	: The Wildlife Protection Act, 1945.
Nicaragua	: Acuerdo No. 2, 1983 (IRENA).
Panama	: Resolucion 2-80, 1980.

USA	: Endangered Species Act, 1973.
USA-Florida	: Florida Wildlife Code, Chapter 39-27
Venezuela	: Resolucion por la cual tengase como official la lista de animales de caza que en ella se indica, 1970.

In addition, *C. acutus* enjoys protective status in Mexico since commercial hunting is prohibited by the overall commercial hunting ban and it is exempt from sport hunting under current annual hunting regulations. In Peru the species was listed as a protected endangered species by Ministerial Resolution in 1977 and benefits from the hunting ban in the La Selva region. *C. acutus* remains listed as a game species in Guatemala, although a closed season has been declared. It is probably unprotected in El Salvador, Haiti, Honduras and Cuba, from where no recent information has been made available to IUCN.

*Crocodylus intermedius*

This species is fully protected in the two countries where it naturally occurs:

Colombia	: Resolucion por la cual se establece la veda para la caza de algunas especies de caimanes, 1969.
Venezuela	: Resolucion No. 95, 1979.

*Crocodylus moreletii*

This species is fully protected in:

Belize	: Wildlife Protection Act, 1981.
Guatemala	: Ley General de Caza, 1970.

In Mexico, it is also protected pursuant to the general commercial hunting ban and under annual hunting regulations for sport hunting. The species is considered to be unprotected in Honduras.

*Crocodylus rhombifer*

No information is available from its only range state, Cuba.

### 3) Asia and the Pacific

For this region it is more convenient to provide a species by species analyses of relevant legal provisions.

*Alligator sinensis*

This species is fully protected in:

China	: Order Strictly Protecting Certain Wild Animals, 1983.
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*Crocodylus johnsoni*

The species is protected in all three Australian jurisdictions where it occurs.

- Northern Territory : Under the Wildlife Conservation Ordinance, 1962, superseded by the Territory, Parks and Wildlife Conservation Ordinance, 1976.
- Queensland : Fauna Order in Council, 1974.
- Western Australia : Under the Fauna Conservation Act, 1950.

*Crocodylus novaeguineae mindorensis*

No information is available from the only country in its range, the Philippines and the sub-species is presumably unprotected.

*Crocodylus novaeguineae novaeguineae*

This sub-species is protected in Indonesia under the Fauna Regulations of 1978 (1978/327). However, it may be taken under license in Papua New Guinea under the Crocodile Trade (Protection) Act, 1974.

*Crocodylus palustris*

This species is protected in:

- Bangladesh : Wildlife Preservation Act, 1973.
- India : Wildlife Protection Act, 1972.
- Iran : As noted in a survey of game laws and regulations in Iran published by the Department of the Environment - undated.
- Nepal : National Parks and Wildlife Protection Rules, 1974. Taking of some species authorized under license. It may be, however, that the species has been given full protection since that date.
- Pakistan : Hunting comes under State jurisdiction. All States and the Islamabad Capital Territory give full protection to the species.
- Islamabad : Wildlife Protection, Preservation, Conservation and Management Ordinance, 1979.
- Baluchistan : Wildlife Protection Act, 1974.
- Azad Jammu and Kashmir : Azad Jammu and Kashmir Protection Act, 1975.
- North-West Frontier Province : Wildlife (Protection, Preservation and Management) Act, 1975.
- Punjab : Punjab Wildlife (Protection, Preservation, Conservation and Management) Act 1974.
- Sind : Sind Wildlife Protection Ordinance, 1972.
- Sri Lanka : Fauna and Flora Protection Ordinance, 1938. (But it may be hunted under a special license).

*Crocodylus porosus*

This species is protected in:

Australia

- Northern Territory : Protected since 1971 under the Wildlife Conservation and Control Ordinance 1962-1974, replaced in 1976 by the Territory Parks and Wildlife Conservation Ordinance.
- Queensland : Protected since 1974 under the Fauna Conservation Regulations, 1974 and the Fauna Order in Council of 29.8.1974. The degree of protection was slightly relaxed recently as a result of an 1984 amendment to the Fauna Conservation Act, 1974. Pursuant to this amendment, a person is no longer guilty of an offence when he kills an estuarine crocodile in the belief, on reasonable grounds, that the animal has caused, is causing, or is likely to cause injury to a person.
- Western Australia : Protected under the Fauna Conservation Act, 1950, although initially listed as unprotected. The species became protected by notice in 1970.
- Bangladesh : Wildlife Protection Act, 1973.
- India : Wildlife Protection Act, 1972.
- Indonesia : Fauna Regulations, 1980 (1980/716).
- Pakistan : Protected in Baluchistan under the Baluchistan Wildlife Protection Act, 1974.
- Sri Lanka : Fauna and Flora Protection Ordinance, L3.1938. Single specimens may, however, be taken by holders of special licenses.

The species may be taken under license in Malaysia (Protection of Wildlife Act, 1972), Papua New Guinea and the Solomon Islands.

It appears to be unprotected in Brunei, the Philippines, Thailand, Vanuatu and Vietnam, where no information has been made available. In Burma the species is unprotected but the issuance of hunting licenses for all species of game has been officially suspended since 1958.

*Crocodylus siamensis*

The species is protected in Indonesia under the Fauna Regulations of 1978 (1978/327). It is unprotected in Thailand and no information is available for Democratic Kampuchea, Laos and Vietnam.

*Tomistoma schlegelii*

The species is protected in:

- Indonesia : Fauna Regulation of 1978.
- Thailand : Ministerial Regulation of 1982.

It is listed as game species in West Malaysia (Protection of Wildlife Act, 1972) and is apparently unprotected in Sarawak and Brunei. No information is available for Sabah.

*Gavialis gangeticus*

This species is protected in Bangladesh under the Wildlife Preservation Act, 1973, in India, Wildlife Protection Act, 1972, and Pakistan in all the provinces where it could occur, Azad Jammu

and Kashmir, Baluchistan, Punjab and Sind. (The relevant texts are the same as for *C. palustris*). Most probably protected in Nepal but no recent information available.

### III) TRADE

#### A) Background

As noted above, it has become evident in the past several years that trade controls are needed to supplement restrictions on taking to help conserve crocodilian species. However, even the best legislation controlling trade is difficult to enforce when the commercial value of wildlife products is high. To prevent poaching, the most effective procedure has proven to be the control of possession and trade in protected species and their parts and derivatives.

The great majority, if not all, legal texts protecting crocodiles prohibit or otherwise regulate the sale and export of hides. Where commercial hunting has been banned, domestic trade and exports are also prohibited. Brazil, Costa Rica, Ecuador, Mexico, Nicaragua, Paraguay, Uruguay, all prohibit such trade and exports (one exception, Nicaragua, allows limited domestic trade in *C. crocodilus* products). Other examples can be seen with India and Pakistan which have prohibited almost entirely commercial exports of wildlife and wildlife products, including crocodilians. These prohibitions are often relatively recent having been made necessary by the continued deterioration of the conservation status of the species concerned.

An evolution in legal protection can be seen in the Indian example. The Exports (Control) Order, 1962, allowed the export of crocodile hides on an ad hoc basis within limited ceilings. This was followed by the Export Trade (Control) Order, 1968 which banned, inter alia, the export of crocodile skins but allowed the export of live crocodiles. Finally the Export Trade (Control) Order 1979 has prohibited the export of all wildlife and wildlife products with extremely limited exceptions.

Enforcement is, in principle, easier when all trade and exports are prohibited than when some limited trade remains authorized. In the latter case there is a need to ensure that hides entering trade were obtained from legally taken specimens. This usually requires fairly sophisticated enforcement techniques.

Trade restrictions are becoming more common in legislation and may concern the minimum, or maximum, size of specimens that are allowed to enter trade. Undersized or oversized skins may then be seized and confiscated at all stages of the trading operation including possession, transport, tanning, sale and export.

Another system, called the "register", is broadly used in Africa. Holders of game licenses or commercial hunting permits must maintain a register on which the characteristics of the animals that have been taken must be recorded, e.g. size, as well as the date and place of the taking. A certificate of lawful possession is delivered to the licensee upon presentation of his register for each specimen so recorded. The certificate must accompany the specimen through every transaction up to the stage of final processing or export. Export permits may only be delivered to holders of such certificates. The possession of specimens without a certificate establishes a presumption of unlawful possession, prosecution and confiscation may, therefore, follow.

The most sophisticated trade control system is the tagging system. Perhaps it is because it is so sophisticated that it has been little used to date. An example may be seen in the Central African Republic under the Ordonnance reglementant la chasse aux crocodiles et la collecte des



peaux de crocodiles, 1969, pursuant to which crocodile hides cannot be transported or exported without a tag.

But the most interesting and effective example is that of the United States with regard to trade in hides of the American alligator (*A. mississippiensis*; 50 CFR 17.42).

In those U.S. states where the taking of alligators is authorized under federal law, hides must be tagged by the State where the taking has occurred with a non-corrodible, serially numbered tag. The tag number, length of skin and date and place of taking are recorded by the State. Tags cannot be removed without destroying the tag and damaging the hide. In addition, all persons engaged in transactions in crocodile skins must hold federal permits, this applies to sellers, buyers, tanners, processors and exporters. This system ensures that only legally taken specimens enter trade. It seems to have worked well and will be used as a model by CITES which will soon control trade in hides of *C. niloticus* and *C. porosus* under a quota system.

The control of the export of protected species and their products albeit essential is, however, insufficient to curb illegal traffic as long as controls are not applied by importing countries. Indeed, it has proven to be the case that unlawfully obtained hides could be easily smuggled out of countries of origin and may then be imported lawfully into countries of destination.

The problem was recognized first in international law in 1968 by the African Convention which made it mandatory for Parties to exercise import controls on endangered wildlife. This was, however, limited to Africa and could not involve the major importing countries. There remained, therefore, the need for importing countries to develop legal and institutional mechanisms to control the lawfulness of the export of the goods they were importing.

This extremely innovative approach in international law was spear-headed by the United States through its Lacey Act which was originally adopted early in this century. Under that Act, it is illegal to import into the United States specimens taken or exported in violation of the legislation of their country of origin. The Act initially only applied to mammals and birds. It was extended to cover, inter alia, reptiles in 1969. In addition, the US Federal Endangered Species Act of 1973 provides for the listing of endangered species, both domestic and foreign, the import or export of which is totally prohibited.

It was felt, however, that a comprehensive control of world trade in wildlife could not be achieved without an international convention.

## **B) International Cooperation Through CITES**

### **1) Background to CITES**

As early as in 1963, the need for a global treaty to control international trade in endangered species had been recognized. That year at the IUCN General Assembly in Nairobi a resolution was adopted calling for the conclusion of "an international convention on the regulation of export, transit and import of rare or threatened wildlife species or their skins and trophies" (Resolution no. 5, 8th IUCN General Assembly, Nairobi, September, 1963).

Almost ten years later, on March 3, 1973, the text of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) was officially adopted at a diplomatic conference in Washington. By December 1985 there were some 91 Contracting Parties to the

Convention from all regions of the World. The objective of the Convention is the protection, through international cooperation, of certain species of flora and fauna against over-exploitation through international trade.

The Convention contains no restrictions as to the taxonomic groups which can be made subject to its rules. Any animal species, whether vertebrate or invertebrate and any plant species may, therefore, be listed provided it meets the necessary criteria. The species, or higher taxa, to which the Convention applies are listed in three appendices. Listing criteria and trade controls vary from one appendix to the other. All crocodilian species have been made subject to the terms of the Convention.

The most important provisions of the Convention are those which institute strict trade controls for listed species. The system is based on cooperation between exporting and importing countries as a means to ensure, through strict controls exercised by importing countries, that specimens from exporting countries have not been illegally exported. For that purpose the Convention provides for the designation by each Party of a Management Authority to issue export or import permits and of a Scientific Authority to advise the Management Authority on the scientific soundness of proposed exports and imports.

CITES also governs relations between parties and non-party states since the convention requires that import permits be issued for the import of Appendix I species from non-parties and that no imports of specimens from non-parties be accepted by parties if they are not accompanied by documents equivalent to CITES export permits.

Appendix I to the Convention lists species threatened with extinction which are or may be affected by trade. No export of specimens of such species may take place until an export permit has been granted by the relevant authority of the State of export. No such permit may be issued unless:

- A Scientific Authority of the state of export has advised that such export will not be detrimental to the survival of that species,
- A Management Authority of the state of exports is satisfied that the specimen was not obtained in contravention of the laws of that state, and
- An import permit has been granted for the specimen by the relevant authority of the state of import.

In addition, no import of specimens of Appendix I species may take place until an import permit has been granted, and no such permit may be issued unless:

- A Scientific Authority of the state of import has advised that the import will be for purposes which are not detrimental to the survival of the species concerned, and
- A Management Authority of the state of import is satisfied that the specimen is not to be used primarily for commercial purposes (Articles II.1 and III of the Convention).

A general exception is provided for specimens of Appendix I species that have been bred in captivity for commercial purposes. Such specimens are, for the purpose of the convention, deemed to be specimens of species included in Appendix II and the provision regulating trade in such specimens described below are therefore applicable to them (Art. VII.4). The Conference of the Parties to the Convention has interpreted the expression "bred in captivity" in a restrictive sense.

Specimens bred in captivity must be borne from parents already in a controlled environment at the time when their offspring were conceived. (Res. Conf. 2.12, 2nd Meeting of the Conference of the Parties, San Jose, Costa Rica, March 1979). Thus specimens borne from eggs collected from the wild could not qualify as "bred in captivity".

As a result of these requirements, no commercial imports or exports of Appendix I specimens may be authorized by the Parties. As to specimens which may still be traded (e.g. for scientific or education purposes) a system of international cooperation has now been established as importing states can no longer accept specimens without export permits from their country of origin and exporting states cannot issue export permits if an import permit has not been granted beforehand by the importing state.

Appendix II to the Convention lists species "which although not necessarily now threatened with extinction may become so unless trade in specimens of such species is subject to strict regulation in order to avoid utilization incompatible with their survival" (Article II.2(a)). It may also list species which, because of their similarity of appearance with listed species, need to be brought under effective control. This provision is designed to prevent illegal trade in specimens of listed species under the name of unlisted species which they may superficially resemble (Article II.2(b)).

The export of specimens of Appendix II species requires the prior issuance of an export permit. Export permits may only be granted if a Scientific Authority of the state of export has advised that such export will not be detrimental to the survival of the species and if a Management Authority of that state is satisfied that the specimen was not unlawfully obtained. (Art. IV.2). In addition, the import of a Appendix II specimen requires the prior presentation of an export permit (Art. IV.4).

The main function of Appendix II is, therefore, to ensure that only lawfully obtained specimens are exported and subsequently imported. Here again, because of the requirement for importing countries not to import specimens that are not accompanied by an export permit, the obligations of the parties concerned are mutually reinforcing.

Appendix II listing has, in addition, another important function: Article IV.3 of the Convention requires exporting parties to monitor export permits and actual exports of Appendix II specimens. Whenever, as a result of such monitoring, a Scientific Authority determines that the export of specimens of a species should be limited in order to maintain that species at a level consistent with its role in the ecosystems in which it occurs and well above the level at which that species might become eligible for inclusion in Appendix I, the Scientific Authority must advise the appropriate Management Authority of suitable measures to be taken to limit the grant of export permits for specimens of that species.

Finally, Appendix III lists species not included in the other two appendices, which have been listed by individual parties to ensure that no specimens of these species will be imported by other parties if they are not accompanied with valid export permits from their countries of origin.

Appendices I and II may be amended at biannual meetings of the Conference of the Parties, or between meetings by postal vote, by a two-thirds majority of Parties present and voting. Amendments to these appendices enter into force 90 days after the date of their adoption. Amendments to Appendix III are made unilaterally by the Party concerned by simple notification to the Secretariat. When the amendment to Appendices I and II comes into force it takes effect for all Parties including those who may have voted against it except for those Parties that have entered a reservation within 90 days of the adoption date. Reservations may only be made at the time of

adhesion to the Convention or at the time when a new species is listed on an Appendix to the Convention. Parties that have made reservations in respect of the listing of a species are deemed to be non-parties in relation to trade in the species concerned. Reservations may be withdrawn at the discretion of the Parties that have entered them. Once a reservation had been withdrawn it cannot be reinstated.

The Conference of the Parties also makes recommendations for improving the effectiveness of the Convention. Recommendations of the Conference, although not binding in law have played a very important role in the implementation of the Convention as they are generally readily put into effect in the Parties. Recommendations have so far addressed a wide range of subjects from an agreed interpretation of certain provisions of the Convention such as the term "breeding in captivity" noted above to the development of criteria, including "ranching" criteria, to the use of standardized CITES permit forms. They provide a means to give guidance to Parties on many aspects of the implementation of the Convention, to fill gaps in the Convention and to develop gradually a common Convention implementation policy.

Mention should also be made of the Convention Secretariat which plays an essential role as a watchdog for infractions and as a link between Parties. The Secretariat, inter alia, services meetings, prepares reports, sends notifications to Parties on matters relating to the implementation of the Convention and advises the Conference of the Parties on the listing and delisting of species.

#### Coverage of Crocodilians Under CITES

The following species or sub-species of crocodilians were listed on Appendix I to CITES at the Washington Conference in 1973:

*Alligator mississippiensis*  
*A. sinensis*  
*Caiman crocodilus apaporiensis*  
*C. latirostris*  
*Melanosuchus niger*  
*Crocodylus cataphractus*  
*C. intermedius*  
*C. moreletii*  
*C. niloticus*  
*C. novaeguineae mindorensis*  
*C. palustris*  
*Osteolaemus tetraspis*  
*Tomistoma schlegeli*  
*Gavialis gangeticus*

All other species or sub-species were listed on Appendix II where they appear as "Crocodylia spp."

Following the entry into force of the Convention in 1975 the Conference of the Parties adopted several changes in the list of crocodilians. Two species were uplisted from Appendix II to Appendix I: *Crocodylus acutus* and *Crocodylus porosus*.

*C. acutus* was transferred to Appendix I in two stages. First, the population of this species in the United States was moved to that appendix at the second meeting of the Conference of the Parties (San Jose, Costa Rica, 1979). Subsequently, the third meeting of the Conference (New Delhi, India 1981) decided to transfer to Appendix I all other populations of the species.

*C. porosus* was also transferred to Appendix I at the second meeting of the Conference of the Parties. This change affected all populations of the species except the population in Papua New Guinea which remained listed on Appendix II.

Several species or populations have also been downlisted.

*A. mississippiensis* was transferred from Appendix I to Appendix II at the second meeting of the Conference as a result of the recovery of this species in the United States.

The Zimbabwe population of *C. niloticus* was transferred to Appendix II by the fourth meeting of the Conference (Gaborone, Botswana, 1983). However, this transfer only applies to ranched specimens. At the fifth Meeting of the Conference (Buenos Aires, 1985) several African States requested the Conference to agree to the transfer to Appendix II of their populations of Nile crocodiles. The Conference agreed to these transfer subject to annual export quotas. The quotas adopted by the Conference are as follows:

Cameroon	20
Congo	1000
Kenya	150
Madagascar	1000
Malawi	500
Mozambique	1000
Sudan	5000
United Rep. of Tanzania	1000
Zambia	2000

To implement this decision a tagging system, similar to the one used in the United States for *A. mississippiensis*, has now been developed by the CITES Secretariat. The parties concerned receive from the Secretariat a number of plastic tags corresponding to their quota. The tags are marked with the word CITES, the letters NIL to identify the species, a two-letter country code, a two-digit reference to the year and a serial number. A tag must be affixed on each hide entering trade. Furthermore, importing and exporting countries are requested to mention trade in all specimens so tagged in their annual reports to the CITES Secretariat. This system was scheduled to become operational at the end of 1985.

As noted above, *C. porosus* was transferred from Appendix II to Appendix I in 1979, except for the Papua New Guinea population. The fifth meeting of the Conference in 1985 decided to re-transfer to Appendix II the Australian and Indonesian populations of the species. The decision regarding the Australian population was taken on the basis of a ranching scheme which is being developed in that country. The decision relating to the Indonesia population was made subject to an export quota of 2,000 hides per year. A tagging system identical to the one applicable to the Nile crocodile will be used except that specimens will be identified by the letters POR instead of NIL.

It should also be mentioned that certain of the Contracting Parties have entered formal reservations to the listing of crocodiles in the CITES Appendices and hence were able to avoid the provisions of the Convention for trade in those species. Many of these reservations were subsequently withdrawn, but some still remain:

- A general reservation was entered by the United Kingdom on behalf of Hong Kong in regard to all reptile species. It was subsequently withdrawn.

- *C. cataphractus*

Zambia and Austria (which announced it would treat the species as an Appendix II and not Appendix I species), France and Italy, (both subsequently withdrawn).

- *C. niloticus*

Botswana, Sudan and Zambia and Zimbabwe, France and Italy, (both subsequently withdrawn).

- *C. porosus*

Japan, France, Italy, Fed. Rep. of Germany and Switzerland (all four subsequently withdrawn).

Austria which had indicated that it will treat the species as being on Appendix II and not Appendix I to the Convention.

- *C. siamensis*

Thailand.

## 2) Stricter National Implementation Measures Under CITES

### a) International Trade

CITES provides for a detailed permit system to control trade in endangered wildlife. In addition, however, the right for individual Parties to take stricter national measures is also provided for in the Convention (Art. XIV.I). Several countries with important markets had already taken stricter measures before the time the Convention entered into force, others have availed themselves of this possibility subsequently. The United States as mentioned above have enacted legislation (Endangered Species Act of 1973) which provides stricter measures for some species. For example, *C. crocodilus yacare* is on CITES Appendix II which allows for controlled commercial trade. However, it is listed as "endangered" under the US legislation which prohibits trade in species so designated.

Another further example can be seen in the law of Australia (The Wildlife Protection [Regulation of Imports and Exports] Act, 1982). Section 37 of the Act requires import permits for trade in CITES Appendix II species, which goes beyond the requirements of the Convention. Import permits shall not be granted if an export permit had not been issued by a relevant authority of the country of export. In addition, the specimen in trade must have been taken in accordance with an approved management program, that is to say a programme approved by the Australian relevant Minister. In other words, Australia will refuse imports if it does not approve a management programme for the species in an exporting country. A management programme is defined by the Act as meaning a programme for the protection, conservation or management of animals.

Finally, it is useful to consider the situation for the implementation of CITES within the European Economic Community (EEC). For the Member States of the EEC the implementation

of CITES is governed by an EEC Regulation (No. 3626/82 of 1982) which forms an integral part of their domestic legislation.

The purpose of the regulation is to ensure that all Member States apply the same rules as regards trade in CITES specimens with third countries. Trade between member states is unrestricted for CITES Appendix II specimens.

The regulation contains a number of measures that are stricter than those provided for by the Convention.

- There is a general requirement for import permits for Appendix II species. Issuance of the permit prior to the granting of an export permit, as would be the case for Appendix I specimens is, however, not necessary. Import permits may, for instance, be issued on the condition that valid export documents are presented together with the import permit at the time of import.
- Certain Appendix II species are treated as Appendix I species. They cannot, as a result be imported for primarily commercial purposes. No crocodilians belong to this category.
- Certain other Appendix II species, including all Appendix II crocodilians are made subject to stricter controls. The issuance of import permits is in this case subject to conditions which may go beyond the provisions of the Convention. This enables management authorities in the community to take due account of the actual conservation status of the species or population concerned and, for instance, to decline to grant an import permit for Appendix II specimens from an endangered or depleted species or population.

#### b) Domestic Trade in CITES Specimens

CITES only deals with the control of imports and exports. It is clear, however, that a prohibition of domestic trade in Appendix I specimens, since they cannot be imported for primarily commercial purposes may considerably strengthen the enforcement of the Convention.

Yet there are still few examples of legislation which specifically apply domestic trade prohibitions to CITES specimens. Once again an example can be seen in the US Endangered Species Act which prohibits the sale, offer for sale, or transport in view of a commercial activity of endangered wildlife. But although the US Endangered Species list contains many of the species listed under Appendix I to CITES, the two lists far from coincide.

The only legislation known to completely prohibit domestic trade in CITES Appendix I is the 1982 EEC Regulation. Under Article 6 of this instrument trade in CITES Appendix I specimens, and in specimens of species which have been given by the Regulation the same status as Appendix I species, is prohibited throughout the Community. In addition, the same restriction applies to species listed on the other CITES Appendices when they have been introduced into the Community in violation of the Regulation.

#### IV) HABITAT CONSERVATION

As has been noted in the introduction to this paper, specific habitat protection measures for crocodiles are rare. Of course, crocodile habitat is preserved incidentally by means of national legislation for the establishment of national parks and other protected areas. At international level crocodile habitat may be protected through designations for protected areas under Conventions such as the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramaar, 1971), the Convention for the Preservation of the World's Cultural and Natrual Heritage (Paris, 1972) or under protected areas protocols to the UNEP Regional Seas Conventions. However, in all these cases conservation benefits for crocodilians are incidental rather than direct.

The only regulation known to be particularly focused upon the conservation of crocodile habitat pertains to *Crocodylus acutus* in the United States. Under the US Endangered Species Act an area of "critical habitat" has been designated for this species (see 50 CFR 17.95). The area is for the most part included within the Everglades National Park. Pursuant to Section 7 of the Act, all Federal Agencies must ensure that action which they authorize, fund or carry out does not result in the destruction or modification of this critical habitat of the endangered species as determined by the Secretary of the Interior.

The critical habitat concept represents a major innovation in conservation legislation which should be promoted for application elsewhere.

#### V) CONCLUSIONS

There has been an evolution in recent years in the treatment of crocodiles under national and international law. This overview has shown a steady movement in legislation from indifference or hostility to the species to partial protection and then more recently to full protection for crocodiles.

Although there are exceptions, it is rare to find jurisdictions which still consider crocodiles to be pest species under law or which fail to regulate at all the taking of crocodiles. In all regions where crocodiles occur, stringent protection measures are now the rule, in recognition of the precarious conservation status of many species and in light of the value of crocodiles as a resource. The overview has, however, shown that anomalies in legislative provisions still exist from jurisdiction to jurisdiction.

Nevertheless, experience has shown that even stringent protection is not enough given the incentives for poaching and hence the most significant legal development for the conservation of crocodiles has been the international trade controls implemented by the 1973 Convention on Trade in Endangered Species (CITES). The success of the CITES system for crocodiles may be seen in the development of ranching operations for these species. Ranching schemes if properly managed may be seen to provide for sustainable utilization of a renewable resource in accordance with one of the main objectives of the World Conservation Strategy. In practice there have been difficulties with ranching operations, but certainly the concept can be seen to be a step in the right direction for the long-term conservation of crocodilians and other species.

Finally, it has been noted that little effort has been made to provide in legislation for the conservation of crocodile habitat. This would appear to be the next area for attention in the evolution of protection measures for crocodile species as ultimately the survival of crocodiles and other wild species will depend upon the maintenance through law of their habitat areas.



## *Paleosuchus*

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In 1950 Federico Medem arrived in Colombia and set about studying the crocodilians of that country. By the time of his death in 1984 Fred Medem had contributed significantly to studies of all species of South American crocodilians (Medem 1981a, 1983). However, he will probably be best remembered for his pioneering work on the genus *Paleosuchus*. When I started studying *Paleosuchus* in 1979 the ground work had been laid and any basic information I could not find in his publications Fred provided in correspondence. This paper is largely a review of the literature, most of which was written by Federico Medem. It is unfortunate that Fred could not write it himself. I am also grateful to Andy Ross who provided much literature not available in Brasil. The work was financed by the Instituto Nacional de Pesquisas da Amazonia and by grant number 40.5055/83 from the Brazilian Conselho Nacional de Desenvolvimento Científico e Tecnológico to W. E. Magnusson.

### NOMENCLATURE

Biochemical analyses (Densmore 1983) support the status of *Paleosuchus* as a distinct genus within the Alligatorinae. The problems associated with *Paleosuchus* nomenclature are complex and have been detailed by Mook and Mook (1940). However, since Medem's (1958) revision there has been almost universal acceptance of the names *Paleosuchus trigonatus* and *P. palpebrosus* for the two South American species of dwarf caimans. The only modern point of contention is the allocation of *Jacaretinga moschifer* Spix to synonymy with one of the species of *Paleosuchus*. The type specimen of *J. moschifer* was destroyed during World War II. However, the description of *J. moschifer* is accompanied by a figure of a crocodilian with a snout shape similar to that of *P. trigonatus*. Vaillant (1898) considered *J. moschifer* to be synonymous with *P. palpebrosus* based on the description which specifically mentions four rows of dorsal scutes between the hind legs. Medem (1958) considered *J. moschifer* to be a composite, the description based on *P. palpebrosus* and the figure based on a *P. trigonatus*, and so synonymized *J. moschifer* with *P. trigonatus*. The synonymy would not be important except that *J. moschifer* was described from Bahia, an area which has several confirmed reports of *P. trigonatus* (Magnusson 1987). For zoogeographic reasons I agree with Vaillant (1898) that *J. moschifer* is a synonym for *P. palpebrosus*. Also, Muller (1923), a specialist familiar with the species of *Paleosuchus*, identified and catalogued the type specimen as *P. palpebrosus*.

Medem (1983) considered Seba's plate 105, Figs. 3 and 4, of the specimen on which Schneider based his description of *P. trigonatus*, to represent the species we now call *P. palpebrosus* but did not suggest that the names of the two species be switched. In the interest of nomenclatural stability it may be necessary to designate a neotype for Schneider's *Crocodylus trigonatus*.

## MORPHOLOGY

Species in the genus *Paleosuchus* are among the smallest of the Crocodylia. Medem (1981a) encountered male *P. trigonatus* up to 136 cm snout-vent length (SVL), however most adult males are in the size range 75-90 cm SVL. Females reach about 75 cm SVL. Few data are available for *P. palpebrosus* but it is generally considered that they mature at smaller sizes than *P. trigonatus*. Medem (1981a) records male *P. palpebrosus* up to 90 cm SVL and females up to 68 cm SVL. *Paleosuchus* tend to have short tails, at least in comparison to *Caiman crocodilus* (Vanzolin and Gomes 1979).

Distinctive features of the skull are the lack of distinct supratemporal fossae (small fossae are present in juvenile *P. trigonatus*), 8 teeth in the premaxilla, and the lack of an interorbital ridge. Three bones form a plate over the orbit and almost obscure it when the skull is viewed from above. The shape of the skull of *P. trigonatus* is that of a generalized crocodilian, but *P. palpebrosus* has a high smooth "dog-like" skull (Medem 1958, 1981a). Some individuals have body characteristics of *P. palpebrosus* but head shape and color of *P. trigonatus*. Medem (1970, 1981a) considered these to be hybrids. The best feature to distinguish between skulls of the two species is the relative size of the external mandibular foramen. In *P. trigonatus* the maximum width of the foramen (measured perpendicular to the long axis) is equal to or greater than the distance from the foramen to the inferior edge of the angular. The width of the external mandibular foramen is less than the distance from the foramen to the inferior edge of the angular in *P. palpebrosus*.

The skins of both species of *Paleosuchus* are heavily ossified, the bony osteoderms of the venter, dorsum and tail being so closely juxtaposed that the animal almost appears to be enclosed in a shell. Algae adhere to the skins of both species in captivity, and in some natural habitats (Medem 1958), giving the animals a green color. Medem (1981a) gives the sizes and meristics of individuals of each species collected in Colombia.

The eyes of *Paleosuchus* are a rich brown color. Medem (1981a) presents many color plates of each species. Adult *P. palpebrosus* have extensive dark pigment on the ventral surfaces and light-brown heads. Adult *P. trigonatus* have dark heads and generally lack pigment on the ventral surface. The dorsal surface of the head behind the eyes is light yellow in juveniles of each species (color photographs in Medem 1981a). Other aspects of coloration are variable and not very distinctive (Medem 1958).

The only other crocodilian genus with deep-brown eyes, heavily-armoured skin, heavily ossified palpebrals, and small adult size is the African crocodyline *Osteolaemus tetraspis*. Too little is known of the life histories of either genus to warrant speculation on the reasons for this morphological convergence but it may be significant that the distributions of both genera are centered on areas of tropical rainforest.

## DISTRIBUTION

*Paleosuchus trigonatus* occurs throughout the Amazon and Orinoco drainage basins and the coastal rivers of the three Guianas. *P. palpebrosus* occurs over essentially the same range and extends south across the Brazilian shield to the Rio Parana and Rio Paraguay drainage basins. It also occurs in the Rio Sao Francisco drainage basin of the Brazilian states of Bahia and Minas Gerais. Medem (1983) gives detailed locality records. Two records for *P. trigonatus* (Aruana and Bahia) south of the Amazon Basin given by Medem (1983) are probably erroneous (Magnusson and Yamakoshi 1986). In Venezuela *P. trigonatus* is largely restricted to the southern, forested regions whereas *P. palpebrosus* occurs extensively over the northern "llanos" areas of the Rio Orinoco drainage (Gorzula 1987: Figs. 2 and 3).

Despite being sympatric over large areas, the two species of *Paleosuchus* are rarely syntopic. In water bodies in which they are found together one species is usually common and the other rare (Medem 1967, 1971a). The major habitat for *P. trigonatus* appears to be small forest streams (Medem 1967, Dixon et al. 1977, Magnusson 1985) and *P. palpebrosus* rarely occurs in that habitat. In the central Amazon Basin *P. palpebrosus* is found most commonly in inundation forests around the major rivers and lakes (Magnusson 1985). On the Brazilian shield, *P. palpebrosus* occurs in streams lined by gallery forests that run through savanna (Rebello and Louzada 1984). Much of the confusion that surrounds the ecological distributions of the two species stems from the fact that it is difficult to work in small rainforest streams and gallery forest. Most observations (as distinct from occurrences) of *Paleosuchus* are made around large water bodies with easy access by boat. Individuals, especially large males and dispersing juveniles, are often found in such situations but to date there is no evidence that either species normally breeds around large water bodies. Large rivers and lakes are normally the major habitats for *C. crocodilus*, *Melanosuchus niger* and *Crocodylus intermedius*. Medem (1980) suggested that the occurrence of *Paleosuchus* in some habitats in Colombia increased after the larger, commercially more valuable species, had been eliminated by overhunting.

Much more work needs to be done on the ecological distributions of the species of *Paleosuchus*, especially *P. palpebrosus*, but care must be taken to evaluate habitats for the presence of both sexes, nests and juveniles. Spotlight surveys from a boat as are used for most other species of crocodilians are probably of little use for evaluating populations of *Paleosuchus*. Gorzula (1987) suggests that the water bodies in which *P. trigonatus* occurs are chemically distinct from those in which *C. crocodilus* occurs, so limnological variables may be useful for distinguishing habitats.

## FOOD

As with other crocodilians, *Paleosuchus* species eat a variety of vertebrate and invertebrate prey. Medem (1981a) lists the stomach contents of *Paleosuchus* taken in a variety of habitats in Colombia, Vanzolini and Gomes (1979) give stomach contents of *P. trigonatus* taken in Brazil, and Ruesta (1981) describes the stomach contents of 3 *P. trigonatus* from Peru. Large males of both species occasionally eat other crocodilians (Medem 1981a).

In the central Amazon Basin *P. trigonatus* eats more terrestrial vertebrates than other crocodilians of similar size but *P. palpebrosus* eats similar foods (mainly invertebrates and fish) to *C. crocodilus* and *M. niger* in the same size range. Mammals and snakes are taken mainly by large *P. trigonatus* with fixed home ranges (Magnusson et al. 1987). The diet of *P. palpebrosus* in savanna gallery forest has not been studied.

## REPRODUCTION

Medem (1981a), Dixon and Soini (1977), Ruesta (1981, 1982-83) and Magnusson et al. (1985) have described nests of *P. trigonatus*. Ruesta (1982-83) also described the embryos. The nests found by Ruesta and by Dixon and Soini in Peru were located 13 September and 14 August-30 November, respectively. The nest found by Medem in Colombia was located 13 February and had well developed embryos. Magnusson et al. (1985) found nests in the Manaus area between August and January. Egg laying apparently occurs at the end of the dry season and hatching at the beginning of the wet season. In the Manaus area *P. trigonatus* frequently make their nests beside or on top of termite mounds which elevate the temperatures of the eggs above that which they would otherwise attain (Magnusson et al. 1985). Medem (1981a) and Ruesta (1982-83) give egg dimensions. *P. trigonatus* has been bred in the Cincinnati Zoo (Jardine 1981).

Medem (1971b) recorded a nest of *P. palpebrosus* found in gallery forest in Colombia 1 November 1967, which hatched in December. Another nest found in the same area, but in a slightly more exposed site, had recently laid eggs 8 August 1970. That nest had a temperature of 31°C at 22cm depth. A third nest was located among four small trees on an elevated mound of earth formed by dry canals, 3km from a permanent canal, in August 1978 (Medem 1981a). Nest and egg dimensions of the three nests are given by Medem (1981a). Rebelo and Louzada (1984) found hatchlings near a nest in June-July in the Reserva Biologica Aguas Emendadas on the Brazilian Shield but the age of the nest could not be determined. Marc Hero (pers. comm.) encountered hatchling *P. palpebrosus* 13.2 cm and 14.2 cm SVL in the Rio Negro in October 1985, indicating nesting in the early dry season. The limited data coupled with the great climatic and geographical variation within the range of *P. palpebrosus* makes generalizations about its nesting season(s) presently inadvisable.

Medem (1981a) reports in detail the captive reproduction of a female that he considered to be a hybrid between *P. palpebrosus* and *P. trigonatus*. The female was mated by a *P. palpebrosus* and laid her eggs 27 September 1977. *P. palpebrosus* has also been bred in the Rio Grande Zoo, Albuquerque (A. Dale Belcher, pers. comm.).

Medem (1971b, 1981a) gives incubation periods of 90-92 and 147 days for *P. palpebrosus* eggs incubated artificially at variable temperatures. Ruesta (1982-83) reported incomplete incubation of *P. trigonatus* eggs after 3 months but the eggs had been moved and the final incubation temperature was not given. Jardine (1981) reported an incubation period of 114-118 days for eggs of *P. trigonatus* incubated artificially at 29-31°C. The data in Figure 1 indicate that the normal incubation period of *P. trigonatus* in the Manaus area is in excess of 100 days. This is longer than the incubation periods reported for all other alligatorines and most other crocodilians (Magnusson 1979).

## PARASITES, DISEASES AND PREDATORS

Nothing is known of the effects of parasites, diseases and predators on populations of *Paleosuchus*. Magnusson (1985) reports variation in the frequency of parasitism by nematodes and leeches in different habitats in Amazonia and Medem (1981b) lists internal parasites found in

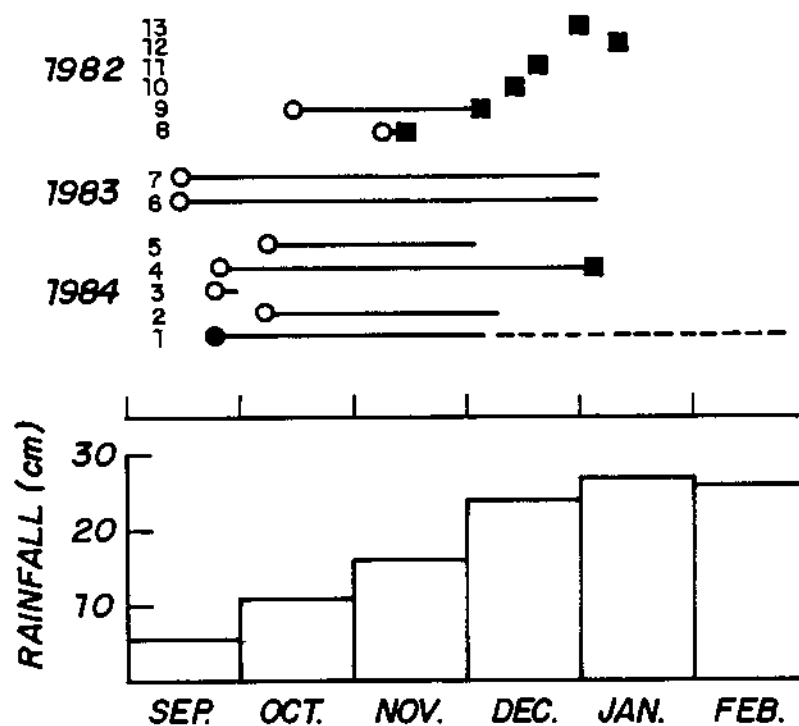


Figure 1. Dates of laying (solid circles), hatching (solid squares), first encountering (open circles), and periods with incubating eggs (lines), for 13 nests in the Manaus area. The dates of death of eggs in nest #1 are not known and the period of uncertainty is indicated by the broken line. Rainfall records are means (1910-1975) for the city of Manaus.

*Paleosuchus* in Colombia. Medem (1981a, 1981b) reports attacks by tabanid flies on animals restrained on shore near the banks of rivers during daylight hours.

There are no reports of diseases in wild *Paleosuchus* and the only confirmed predators of *Paleosuchus* are man, anacondas (*Eunectes murinus*) and other crocodilians (Medem 1983). However, jaguars (*Panthera onca*) regularly eat *C. crocodilus* (Medem 1981a) and other reptiles (Louise Emmons, pers. comm.). There is no reason to believe that they do not also eat *Paleosuchus*. The only large *P. trigonatus* (approx. 65 cm SVL) that I have found dead was eaten by a large cat (*P. onca* or *Felis concolor*). It is likely that the cat killed the *P. trigonatus* as, apart from a conspecific, there are no other predators in the area that are likely to be capable of killing a large *P. trigonatus* close to water.

Most of the nests of *P. trigonatus* I studied in 1983 and 1984 were destroyed by predators. However, I believe the high rate of predation may be related to interference with nests while measuring temperatures. None of the nests studied in 1982, which were all discovered late in incubation, suffered predation. Ruesta (1981) and Medem (1983) list probable nest predators of South American crocodilians but, apart from humans, no predators have been caught in the act of robbing *Paleosuchus* nests.

### BEHAVIOR

Little is known of the behavior of either species of *Paleosuchus* and they are not good candidates for behavioral research as they are much more shy in the presence of humans than most crocodilians. My coworkers and I have caught one female *P. trigonatus* several times in a shallow stream in front of a nest with incubating eggs, and tracks in front of another nest indicate that a female was in attendance. We have never been attacked when opening nests but have noted altered behavior by females associated with hatchlings. Twice females have left their refuges and approached us when we were catching hatchlings near nests and on one occasion a female, which was accompanied by a hatchling group and that had been noosed around the back legs, chased us out of the stream. We have not observed aggressive behavior towards humans by *Paleosuchus* in any other situation. Medem (1981a) describes aggressive behavior by a captive female *Paleosuchus* defending a nest and Gorzula (1984) describes having his inflatable boat sunk by a *P. trigonatus* which responded to human initiations of hatchling *C. crocodilus* calls.

All successful nests in my study area were opened by a crocodilian and females with hatchling groups were found in front of four recently opened nests. One nest, constructed in the home range of an adult male but far from the normal area of activity of any female, was found recently opened and the hatchling group was accompanied by the adult male. No female was found in the area despite intensive searching. A female (64 cm SVL) had been caught at that site the preceding August but no female had been seen there before or after so it seems likely that the male opened the nest and released the young. Eggs in some nests in the Manaus area are encased in hard termite workings by the end of incubation (Magnusson et al. 1985). Nest opening by an adult is probably essential for successful hatching of those eggs. More detailed observations will probably show *Paleosuchus* to have the same range of nest-guarding, nest-opening and hatching-defense behaviors found in other crocodilians.

After heavy rain *P. trigonatus* are often found in rapids or small waterfalls; sitting perpendicular to the current with their mouths open, the lower jaw submerged and the upper jaw above water level. I assume that they are foraging, but I have no evidence of what they catch with this technique.

### SUGGESTIONS FOR FURTHER RESEARCH

Much remains to learn about the ecologies of both species of *Paleosuchus*. It is obvious that the habitats of each differ, and that the habitats of both are different from those of other sympatric crocodilians but just which differences are critical remains conjecture. Reasons for habitat segregation could include competition, predation, and behavioral and physiological adaptations. To differentiate the effects of these factors would require large scale experiments, though areas in which sympatric species have been eliminated by overhunting could serve as unplanned manipulations.

*P. trigonatus* may differ from other crocodilians in its thermal biology because temperatures in its main habitat are moderate, relatively invariant, and opportunities to bask are limited. Zoo animals could serve for the study of the effects of temperature on digestion and metabolic rate.

Field studies will have to focus on populations rather than presence/absence data as has been the pattern in the past. Presence/absence data have raised some interesting questions but to date have been of limited use in providing answers. My as yet unpublished studies indicate that *P. trigonatus* have small home ranges (of the order of 500-1000m small stream) and, if the same proves true for *P. palpebrosus*, long term studies of population dynamics, reproduction and habitat use could be done on marked populations, simply and at low cost. Comparative studies of populations of *P. palpebrosus* living on the high, cold plains of the Brazilian shield, flooded forests of the Amazon system and the lowland floodplains of the Orinoco system would be particularly interesting. Small implanted transmitters could overcome many of the problems associated with difficult habitats and the wariness of the species. Basic data on diet are lacking for *P. palpebrosus* over most of its range and most of the data on the diet of *P. trigonatus* are from a few localities. Stomach contents could be collected by non-destructive means (Taylor et al. 1978) in parallel with other studies.

Schmidt commented in 1928(212) "It is one of the curiosities of zoological collecting that so little is known of the habits and distribution of these species (*Paleosuchus*)". Sixty years later we know only a little more of their distributions and we have advanced very little in studies of their habits. They remain "one of the most interesting problems in South American zoology" (Schmidt 1928:212).

### LITERATURE CITED

- Densmore, L. D. III. 1983. Pages 397-465 in M. K. Hecht, B. Wallace and G. T. Prance, eds. *Evolutionary Biology*. Vol. 16. Plenum Press, New York.
- Dixon, J. R., and P. Soini. 1977. The reptiles of the upper Amazon basin, Iquitos region Peru 2. Crocodilians, turtles and snakes. *Contr. Biol. Geol. Milwaukee Public Mus.* 12:1-19.
- Gorzula, S. 1984. Untitled letter to the editor. *SSC/IUCN Crocodile Spec. Group Newsletter* 3:16.

- \_\_\_\_\_. 1987. The management of crocodilians in Venezuela. Pages 91-101 in G. J. W. Webb, S. C. Manolis, and P. J. Whitehead, eds. *Wildlife Management: Crocodiles and Alligators*. Surrey Beatty and Sons, Chipping Norton, Australia.
- Jardine, D. R. 1981. First successful captive propagation of Schneider's smooth-fronted caiman, *Paleosuchus trigonatus*. *Herp. Review* 12:58-60.
- Magnusson, W. E. 1979. Incubation period of *Crocodylus porosus*. *J. Herpetol.* 13:362-363.
- \_\_\_\_\_. 1985. Habitat selection, parasites and injuries in Amazonian crocodilians. *Amazoniana* 9:193-204.
- \_\_\_\_\_, A. P. Lima, and R. M. Sampaio. 1985. Sources of heat for nests of *Paleosuchus trigonatus* and a review of crocodilian nest temperatures. *J. Herpetol.* 19:199-207.
- \_\_\_\_\_, E. V. da Silva, and A. P. Lima. 1987. Diets of Amazonian crocodilians. *J. Herpetol.* 21:85-95.
- \_\_\_\_\_, and M. Yamakoshi. 1986. Anomalous records of the occurrence of *Paleosuchus trigonatus*. *Herp. Review* 17:84-85.
- Medem, F. J. 1958. The crocodilian genus *Paleosuchus*. *Fieldiana Zool.* 39:227-247.
- \_\_\_\_\_. 1967. El genero *Paleosuchus* en Amazonia. *Atas Simp. Biota Amazonica*. Vol. 3 (Limnologia):141-162.
- \_\_\_\_\_. 1970. Sobre un hibrido inter-especifico del genero *Paleosuchus* (Crocodylia, Alligatoridae). *Rev. Acad. Colombiana Cien. Exat., Fis., Nat.* 13:467-471.
- \_\_\_\_\_. 1971a. Biological isolation of sympatric species of South American crocodilia. Pages 152-158 in Anon., ed. *Crocodiles*. Proc. First Working Meeting Crocodile Specialist Group. Vol. 1. IUCN, Morges, Switzerland.
- \_\_\_\_\_. 1971b. The reproduction of the dwarf caiman *Paleosuchus palpebrosus*. Pages 159-165 in Anon., ed. *Crocodiles*. Proc. First Working Meeting Crocodile Specialist Group. Vol. 1. IUCN, Morges, Switzerland.
- \_\_\_\_\_. 1980. Letter to author dated 4 July.
- \_\_\_\_\_. 1981a. *Los Crocodylia de Sur America*. Vol. 1. *Los Crocodylia de Colombia*. Colciencias, Bogota.
- \_\_\_\_\_. 1981b. Horse flies (Diptera: Tabanidae) as ectoparasites on caimans (Crocodylia: Alligatoridae) in eastern Colombia. *Cespedesia* 10:123-191.
- \_\_\_\_\_. 1983. *Los Crocodylia de Sur America*. Vol. 2. Colciencias, Bogota.
- Mook, C. C., and G. E. Mook. 1940. Some problems in crocodilian nomenclature. *American Mus. Novitates* 1098:1-10.
- Muller, L. 1923. Zur Nomenklatur der sudamerikanischen Kaiman-Arten. *Zool. Anz.* 58:315-320.



- Rebelo, G. H., and D. Louzada. 1984. Os Jacares de aguas emendadas. Resumos XI Congresso Brasileiro de Zoologia:286-288.
- Ruesta, P. V. 1981. Bases Bio-Ecologicos para el Manejo de los Alligatoridae en Jenaro Herrera (Requena Peru). Thesis (Ingeniero Forestal), Universidad Nacional Agraria La Molina, Lima, Peru.
- . 1982-83. Descripcion del desarrollo embrionario de *Paleosuchus trigonatus* Schneider en Requena, Loreto. Rev. Forestal del Peru 11:195-201.
- Schmidt, K. P. 1928. Notes on South American caimans. Field Mus. Nat. Hist. Zool. Ser. 12:205-231.
- Spix, J. B. de. 1825. Animalia Nova sive Species Novae Lacertarum, Munchen: F. S. Hubschmann.
- Taylor, J. A., G. J. W. Webb, and W. E. Magnusson. 1978. Methods of obtaining stomach contents from live crocodilians (Reptilia, Crocodilidae). J. Herpetol. 12:415-417.
- Vaillant, L. 1898. Catalogue raisonne des *Jacaretinga* et *Alligator* de la collection du Museum. Nouv. Arch. Mus. d'Hist. Nat. Paris 10:143-211.
- Vanzolin, P. E., and N. Gomes. 1979. Notes on the ecology and growth of Amazonian caimans (Crocodylia, Alligatoridae). Papeis Avulsos Zool., Sao Paulo 32:205-216.

# GROWTH OF *Crocodylus porosus* IN THE WILD IN NORTHERN AUSTRALIA

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## INTRODUCTION

The main data on growth in the wild of *Crocodylus porosus* in this chapter come from three extended experiments within the former Sydney University-Northern Territory Government Joint Crocodile Research Project. All three have been reported on separately previously, but our aim in this review is to look at the data as a whole, and reanalyze it to obtain the most information possible on aspects of growth of *C. porosus*. The first experiment involved a capture-recapture study of 254 individuals on the Liverpool-Tomkinson River System (Monograph 7); a multiple regression model was fitted to this data (Webb et al. 1978) to derive growth curves and to examine variables affecting growth. Eight animals first captured between 1973 and 1975 were recaptured in 1983; some of them having been captured two times previously. These data also provided valuable information (Chapter 2 Monograph 18). The second experiment was carried out by Magnusson (1978, and several papers) and he studied by capture-recapture techniques the growth of *C. porosus* up to 133 days, again by fitting growth curves. The third experiment (Chapter 8, Monograph 1) involved the capture of hatchlings on the Blyth-Cadell River System (some 30 km to the east of the Liverpool-Tomkinson System) in 1978 and recaptures in following years.

Throughout this chapter we shall be referring to Monograph 1, which is but one of a series of 19 published by Pergamon Press between 1979 and 1986 (Messel et al. 1979-1986) and reporting on the lengthy *C. porosus* studies by Messel and his collaborators. We restrict ourselves to growth of *C. porosus* only. In Chapter 2 of Monograph 18, on which the present chapter is based, we compared these growth rates with those of other crocodilians. In seeking to understand the growth rates presented in this chapter, we are unfortunately lacking quantitative data on an important piece of information--the food availability (or, at least, the relative food availability) on the rivers considered at different times of the year, in different years and on any differences in food availability on different rivers. The ability of crocodilians to survive in a very low growth situation may be illustrated with an example given by Deraniyagala (1939). He quotes the case of two hatchling *C. porosus* (hatching total length around 30 cm), one of which was kept in a tub and the other in a small natural pond (with access to a wild diet). The animal in the tub died after 2 years at a length of only 35 cm, whereas the one in the pond had attained a length of about a meter after only 10 months. An example of the effect of feeding on growth may be taken from our own data. A hatchling captured at SVL 16.4 cm on the downstream Liverpool was recaptured after 3 months on the Tomkinson. Its SVL had changed by only 0.3 cm and weight by only 5 g, which is essentially no growth over the period. This animal had a skewed jaw which presumably interfered considerably with its ability to catch food items; it was very thin on second capture. Other

examples of very low growth over 3 months of the dry season were seen on the upstream Blyth (see Part 1). The differences in growth between Deraniyagala's two animals were probably due to a number of factors, the availability of a proper diet possibly being a major one. However, given that the animals can survive for so long in an essentially no growth situation, it is clear that attempts to interpret variations of growth amongst wild populations are fraught with difficulties, especially when so many necessary data are either unavailable or very difficult to obtain. The results in this Chapter obtained from recaptures over lengthy periods can be suggestive only, and there is need for smaller scale experiments to examine particular points.

To avoid constant repetition, all growth rates referred to in this Chapter are snout-vent length (abbreviated SVL) rates. Units of growth, if not explicitly stated, are cm/day. For conversion between head length (HL) and snout-vent length (SVL), we have used the same equations as used by Webb et al. (1978:388). Other conversions (e.g., SVL to total length, TL) may be obtained from Webb and Messel (1978) who also gave references to other morphometric work on *C. porosus*. All uncertainties quoted are standard deviations ( $n-1$  method). Differences between means are tested by using the  $t$ -test.

## PART 1. EMBRYONIC GROWTH AND POST-HATCHING GROWTH UP TO 133 DAYS

### 1.1 Embryonic Growth

Estimates of growth rates for embryonic *C. porosus* may be obtained from data given by Deraniyagala (1939) for animals in Sri Lanka and by Magnusson and Taylor (1980) for animals in Arnhem Land, northern Australia. The data are inadequate, but we have tried to look at the limited available data in a number of ways. The results are not claimed to be any more than indications of embryonic growth rates. The egg sizes reported by Deraniyagala are consistent with the egg sizes reported by Webb et al. (1977); for 22 nests they report mean egg lengths ranging from 7.2 cm to 8.1 cm, and Deraniyagala's nests I, II, and III have mean egg lengths of 7.4 cm, 7.9 cm, and 8.3 cm. The sizes of hatchlings are also consistent (see Table 1). In fact, the mean HL of 17 animals in Table LVIII of Deraniyagala is  $4.8 \pm 0.2$  cm, to be compared with 4.6 cm (no error limit given) as the mean for 5 nests given by Webb et al. (1978). (However, there can apparently be great variation in egg and hatchling sizes; results from Edward River crocodile farm in north Queensland, Australia, appear to show that small females yield small eggs and small hatchlings (G. Grigg, pers. comm.).

We shall now examine the available data on embryonic growth and derive some estimates for their growth rates. These can only be indications, however, because the length of incubation can vary greatly, from some 80 to 120 days. Nests laid late in the dry season develop more slowly because of the cooler temperatures, and there are indications from field observations that some late nests may not hatch at all. Detailed studies are required for embryonic growth under different temperature regimes in the field.

Deraniyagala gives the following records for embryos from Nest II (days are estimated days after laying, allowing 97 days for incubation; he suggests, however, that the incubation was by no means normal).

Days	37	48	60	97
Total length (cm)	8.1	11.9	17.0	$29.4 \pm 0.5$
	$n = 1$	$n = 1$	$n = 1$	$n = 4$

Table 1. Examples of sizes on hatching of *C. porosus* from Arnhem Land, northern Australia (Liverpool-Tomkinson Rivers System) and Sri Lanka (Deraniyagala 1939).

Nest	Sample	SVL	Length	Weight	Age Processed
Myeeli 1 Removed from nest after hatching 4.3.76	48	14.1 $\pm$ 0.3	30.0 $\pm$ 0.7	83.0 $\pm$ 3.4	~ 2 days
Myeeli 2 Removed from nest after hatching 16.2.76	46	13.6 $\pm$ 0.5	29.6 $\pm$ 0.6	74.5 $\pm$ 4.1	~ 2 days
Myeeli 3 Removed from nest after hatching 18.4.76	50	13.8 $\pm$ 0.3	29.9 $\pm$ 0.5 (49 anmls)	69.6 $\pm$ 3.5	~ 2 days
Liverpool km 47.5 Artificial nest 17.3.76	15	13.7 $\pm$ 0.7 (14 anmls)	29.6 $\pm$ 1.2	81.2 $\pm$ 5.7	~ 2 days
Atlas Creek Artificial nest hatched <sup>1</sup> 15.2.77	26	14.9 $\pm$ 0.3	32.0 $\pm$ 0.7	82.8 $\pm$ 2.7	~ 6 days
Billabong Morngarrie Creek Removed from nest after hatching 13.4.76	11	13.4 $\pm$ 0.5	28.8 $\pm$ 1.1	59.2 $\pm$ 6.0	~ 1 day
Liverpool B22 Artificial nest hatched 30.4.76	26	14.1 $\pm$ 0.4	29.9 $\pm$ 0.6	63.2 $\pm$ 7.6	11-13 days
Tomkinson B48 Artificial nest hatched 30.4.76-10.5.76	8	13.6 $\pm$ 0.3	29.1 $\pm$ 0.5	59.8 $\pm$ 6.5	1-10 days
Tomkinson km 68.5 Artificial nest hatched 19.2.77	9	14.4 $\pm$ 0.3	30.8 $\pm$ 0.7	73.1 $\pm$ 1.5	~ 7 days
T12 Tomkinson km 53.9 between 4-9.6.74	29	14.9 $\pm$ 0.2	31.7 $\pm$ 0.5	92.7 $\pm$ 4.2	~ 7 days
T13 Tomkinson km 59.7 between 4-9.6.74	14	14.0 $\pm$ 0.2	29.9 $\pm$ 0.5	87.4 $\pm$ 4.5	~ 7 days

Table 1. cont.

Nest	Sample	SVL	Length	Weight	Age Processed
T14 Tomkinson km 65.1 between 21-28.6.74	9	14.5 $\pm$ 0.2	31.0 $\pm$ 0.5	82.8 $\pm$ 2.8	~ 7 days
Deraniyagala Nest I Artificial	11	--	30.1 $\pm$ 1.0	90.2 $\pm$ 6.1	0
Deraniyagala Nest II Artificial	4	--	29.4 $\pm$ 0.5	78.8 $\pm$ 6.3	0
Deraniyagala Nest IV Artificial	5	14.6 $\pm$ 0.2	30.4 $\pm$ 0.3	79.4 $\pm$ 3.6	0
Liverpool 1975 hatched May 4 Artificial	23	13.5 $\pm$ 0.6	28.3 $\pm$ 1.4	64.7 $\pm$ 4.8	7 days

<sup>1</sup>. The description "artificial nest" means that the eggs were removed from a natural nest and incubated in an artificial nest.

This shows a TL growth rate for the 37 days before hatching of 0.34 cm/day, which gives an SVL rate of 0.17 cm/day (using an approximate conversion factor of 2); Nest III gives 0.15 cm/day for 37 days before hatching. Deraniyagala states that his animals were incubated at temperatures which fluctuated daily between 27 and 30°C.

From Table 1 of Magnusson and Taylor (1980) we may also obtain some estimates for embryonic growth rates. They give measurements for two series of embryos taken from two different nests; the Series I nest was incubated at a mean 2.5°C lower than that of Series II (28.5°C against 31.0°C). For the Series I animals one obtains, from the 51st to 86th day, an SVL growth rate of 0.15 cm/day and for the Series II animals an SVL growth rate, from the 49th to 86th day, of 0.155 cm/day. To obtain these results we have used a conversion factor of 4.01 between snout-vent and head length rates, since fitting of the four pairs of snout-vent and head length values in their Table I to a straight line gives  $SVL = 4.01 HL - 3.7$ , with coefficient of determination 0.991. If we regress the total length against head length for all the animals in Table LVIII of Deraniyagala, then we obtain  $TL = 8.37 HL - 10.53$  (coefficient of determination 0.97). If we use the conversion factor 0.48 given in Appendix I of Webb and Messel (1978) for converting between the snout-vent length and total length (for their smallest class of animals; they do not consider embryos), then we obtain a conversion factor between snout-vent length growth rate and head length growth rate of 4.02.

When comparing Deraniyagala's results with those of Magnusson and Taylor, one must bear in mind possible variations in incubation period discussed already and differences in temperature.

Magnusson and Taylor give an HL (Series II) of 3.74 cm at 86 days, whereas Deraniyagala (using his ages) has animals of 80 days with HL of 4.2 cm. Plotting of Deraniyagala's head length

measurements against age for Nest II gives a good fit to a straight line between 26 and 81 days (8 points, coefficient of determination = 0.99), with an SVL growth rate of 0.20 cm/day (using 4.01 to convert) compared with 0.155 cm/day for the Series II animals. If the Series I head lengths are plotted against age, a good fit to a straight line is again obtained between 9 and 86 days (8 points, coefficient of determination 0.995; the 28 day value is omitted) with an average SVL growth of 0.17 cm/day. Taking the Nest II and III growths over the last 37 days, one obtains from the head lengths an SVL rate of 0.13 cm/day (somewhat less than that obtained from the total length change), indicating that there may have been a slow-down in growth near hatching time for these two nests (though the data are perhaps too limited to draw such a conclusion). If one looks at Nest I and calculates the average SVL growth over the last 25 days, it is 0.15 cm/day, comparable with the Nest II and Nest III rates over the last 37 days. Thus, an SVL growth rate of between 0.15 and 0.20 cm/day covers the range of results, with the various uncertainties mentioned previously, for the 80 or so days before hatching occurs.

Webb et al. (1983) present some further data on development of *C. porosus* embryos, giving equations relating age to snout-vent length and head length (both expressed as ratios of egg length) for a 30°C incubation. Taking a mean egg length of 8.13 cm as given for their sample, the data in their Table 1 indicates SVL growth rate of 0.18 cm/day (62-82 days) using the SVL coefficients and 0.27 cm/day (36-62 days) using the head length coefficients (and converting as previously).

## 1.2 Hatchling Growth up to 133 Days

Magnusson (1978) carried out a study on hatchling growth up to an age of 133 days by means of capture-recapture methods. He has presented (Magnusson and Taylor 1981) a mean growth rate for these animals during the wet season (months) for their first 80 days, obtaining an SVL rate of 0.09 cm/day. Since each animal in his study was individually marked and some were captured up to five times, much might be learned by examining the individual growth records. This will also allow examination of variations of initial growth between animals from different nests. Nests are identified in Table 1.

In Table 2 we give the individual growth records for the three animals that were captured four or more times; all came from the Myeeli nest. We also present in records A to H, in Table 3, SVL growth records over different periods for animals from various nests. The identification numbers of each crocodile are given so that progress of particular crocodiles can be followed. The best record is for the animals from the Myeeli I swamp (records A, F, G). Comparison of the growth from 0-37 days and from 0-96 days shows little difference in average rate, despite the 0-96 day period, including 40 days of dry season growth (of course, very early in the dry season; there is no sharp transition from wet season to dry season conditions). The 0-65 day average is higher than the shorter and longer period average, as is also shown for the three individuals in Table 2, all of whom show an increased rate of growth from their 37th-65th day. Animal 1403 also shows a slightly higher rate of growth from its 0th-65th day than from 0th-35th day.

The highest rates of growth (record C) are the 0-53 day growths of animals hatched at the base and released at km 23.4 on the Tomkinson River. The average growth rate is  $0.126 \pm 0.021$ , with the highest rate being that of 1415 at 0.158 cm/day, almost double the rate of the slowest growing animal in this group. This high growth occurs at the end of the wet season. Record E shows growth rates for these animals from their 53rd to 82nd day, and the rates for 1404, 1406, and 1407 have dropped considerably. The growth over this period is all in the dry season.

The lowest average rates of growth are from a group of animals that were raised at the base and then released into the Liverpool River at km 47.3. The growth record D is from mid-May to mid-June and so is an all dry season growth rate. These animals may be compared with those in record C, whose wet season growth over a corresponding age span is up to four times higher.

Webb et al. (1977) gave results for three nests (T12, T13, T14) on the Tomkinson River, all of which hatched in June 1974. The initial sizes for the surviving hatchlings from these nests are given in Table 1. (It should be noted that all the standard errors in this reference were calculated incorrectly and are generally too small.) Mean daily SVL growth rates of the hatchlings from these nests were 0.06, 0.05 and 0.05 cm/day, respectively, for periods of 69, 63, and 52 days. These growth rates are all in the dry season (all periods ending mid-August) and may be compared with records, C, D, and F. The dry season growth rate over the same age interval is again considerably less than the wet season one. Magnusson and Taylor (1981) also compared the wet season growth rate of hatchlings with these dry season rates and found that they were significantly higher.

Additional information on early growth may be obtained from data on recaptures of some of the animals from the Liverpool 1975 nest (see Table 1). Five of these animals were recaptured after spending 18-21 days in the wild and their SVL mean growth rate was  $0.086 \pm 0.021$  cm/day (period of growth from 6th to 26th day). Three other animals recaptured after spending from their 6th to 70th day in the field showed an average growth rate of 0.058 cm/day. The growth period for these animals begins in mid-May and so is all dry season growth. The initial growth rates up to the 26th day are comparable with the purely wet season early growth rates.

The growth rates of Record C (mean 0.126 cm/day) are not far below those that we have obtained for embryonic growth rates and perhaps represent an upper limit to the initial growth rate of *C. porosus*.

### 1.3 Blyth-Cadell Hatchling Study

Further information on early growth of *C. porosus* may be obtained from our capture-recapture study on the Blyth-Cadell Rivers System. A large number of hatchlings of various ages were captured in mid-June 1978 and recaptured in late September 1978. The results (Monograph 1, Chapter 8) show that the mean rate of growth of all hatchlings over the 3-month period (all dry season) was  $0.030 \pm 0.013$  cm/day. Because this sample includes hatchlings of various initial ages, care should be exercised when comparing this with the most comparable previous results, those for the Tomkinson T12, T13, and T14 nests of 1974 discussed in the previous section.

Growth rates on the Cadell and Blyth rivers are almost the same during the dry season. Males in September 1978 were bigger than females. There was an indication that male hatchlings grow slightly faster than female hatchlings during the dry season.

Results on hatchling movement suggest that hatchlings move preferably to certain mid-sections of the Blyth River, and hence it was important to check whether hatchlings remaining on particular subsections of the river showed differing BWT gains. If they did, then the movement might be interpreted in terms of the hatchlings seeking a more adequate food supply. One of the problems faced in this consideration is that of small sample number. By examining the rates of new weight to old weight, we found that there were no significant differences between growth on different sections of the river, over a period of nine months which included the wet season. However over 3 months of the dry season the brackish midsection of the Blyth showed significantly higher mean body weight gains than the upstream freshwater sections. The differences are probably related to food supply.

Table 2. Capture histories of three hatchlings from the Liverpool-Tomkinson Rivers System. All hatched from a natural nest on March 4, 1976.

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*Animal 1360*

Age (days)	0	37	65	96
SVL (cm)	13.8	16.5	19.1	21.0
Rate (cm/day)		0.073	0.093	0.061

*Animal 1370*

Age	0	19	37	65	96	131
SVL	14.1	15.3	17.2	20.5	21.9	22.5
Rate		0.063	0.106	0.118	0.045	0.017

*Animal 1394*

Age	0	35	65	94
SVL	14.7	17.5	20.1	21.0
Rate		0.080	0.087	0.031

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In his thesis Magnusson (1978) fits a curve to records of animals up to 133 days old. He found that a parabola gave a better fit to the data than a straight line and that the growth curve also predicted a rate of 0.031 cm/day at 120 days (well into the dry season).

The largest growth rate over the 3-month dry season period on the Blyth was for an animal that went from 19.0 to 24.7 SVL, a rate of 0.061 cm/day. As described in Chapter 8, Monograph 1, growth on the freshwater section of the Blyth was particularly slow. Several animals only gained between 0.4 cm and 0.7 cm in the period, corresponding to growth rates ranging from 0.004 to 0.008 cm/day. Examination of Magnusson's growth records over dry season periods shows that animal 1370 grew only 0.6 cm from mid-June to mid-July (0.017 cm/day).

Record D of Table 3 shows a mean dry season growth rate (0.039 cm/day) for young animals consonant with that found on the Blyth-Cadell System (0.03 cm/day). Animal 1370 shows a mean rate from its 65th to 131st day of 0.030 cm/day and animal 139a has the same rate from its 65th to 94th day.

To examine further the relationship between growth rate and SVL, the change in SVL over the 3-month dry season period was regressed against the initial SVL, for animals (both male and female) that remained on the km20-35 section of the Blyth River (we have selected this section to omit the slow growth freshwater sections). The slope was 0.20 (standard error 0.1), showing a slight upward trend of growth rate with size, but the coefficient of determination was only 0.08 so one should treat the result with care. From Magnusson's results for the wet season one might have expected a clear downward trend in hatchling growth with increasing initial SVL (and hence increasing age), though we did note previously some evidence for an increase in growth with age for some of Magnusson's animals up to 60 days. The possible discrepancy here could perhaps be understandable in the following way. During the wet season food availability is higher than during the dry and is not a restrictive factor on growth. Under the harsher conditions of the dry season,



Table 3. SVL growth rates of animals from some of the nests in Table 1 for various periods measured in days after hatching.

<b>RECORD A</b>	0-(35-37) days Myeeli 1 Nest	<b>RECORD E</b>	53-82 days Liverpool km 47.5 Nest Released on Tomkinson
1360	0.073	1404	0.083
1362	0.071	1406	0.072
1367	0.074	1407	0.041
1370	0.084	1413	0.038
1389	0.083	Mean	0.058 $\pm$ 0.022
1394	0.080	All dry season growth	
1403	0.094		
Mean	0.080 $\pm$ 0.008		
All wet season growth			
<b>RECORD B</b>	0-(37-39) days Myeeli 2 nest	<b>RECORD F</b>	0-96 days Myeeli 1 Nest
1316	0.085	1360	0.075
1344	0.095	1364	0.074
1348	0.122	1370	0.081
Mean	0.100 $\pm$ 0.019	1391	0.083
All wet season growth		1394	0.067
		Mean	0.076 $\pm$ 0.006
<b>RECORD C</b>	0-53 days Liverpool km 47.5 Nest Released on Tomkinson	40 days are dry season	
1404	0.126	<b>RECORD G</b>	0-65 days Myeeli 1 Nest
1405	0.125	1358	0.080
1406	0.132	1360	0.0815
1407	0.109	1370	0.098
1410	0.138	1394	0.083
1414	0.081	1396	0.102
1415	0.158	1403	0.098
1416	0.132	Mean	0.090 $\pm$ 0.010
1418	0.134	Almost all wet season growth	
Mean	0.126 $\pm$ 0.021		
Almost all wet season growth			
<b>RECORD D</b>	13-52 days Liverpool B22 Nest	<b>RECORD H</b>	0-82 days Liverpool km 47.5 Nest Released on Tomkinson
1486	0.029	1404	0.111
1492	0.047	1406	0.111
1506	0.026	1407	0.085
1514	0.028	Mean	0.102 $\pm$ 0.015
1510	0.053	Almost all wet season growth	
1517	0.053		
Mean	0.039 $\pm$ 0.013		
All dry season growth			

Table 4. Examples of growth on the Liverpool-Tomkinson Rivers System over intervals which are mainly in the dry season<sup>a</sup>.

Initial size	Sex	Mean SVL growth (cm/day)	Interval (days)
1. H	F	0.050	146 (17)
2. 2-3'	M	0.054	152 (51)
3. 3-4'	M	0.0355	124 (30)
4. 3-4'	M	0.0357	255 (145)
5. H	F	0.038	124 (30)
6. 2-3'	M	0.028	118 (36)
7. H	M	0.054	263 (49)
8. 2-3'	M	0.032	174 (41)
9. H	M	0.0527	387 (151)
		0.0552	270 (116)
		0.047	117 (35)

a. The number of wet season days in the interval is shown in parentheses.

however, food accessibility may be greater for larger animals. In this way animals that are larger at the start of the dry season may be able to cope better in terms of food sources and so grow faster. Further, an analysis of weights in June of animals that survived to September and those that did not showed that the initial weights of survivors was significantly higher.

## PART 2 COMPARISON OF GROWTH IN THE WET AND DRY SEASON

### 2.1 Introduction

In northern Australia the year is divided into distinct wet and dry seasons (Chapter 3. Monograph 1). As has already been stated by several authors (Magnusson 1978, Chapter 8. Monograph 1, Webb et al. 1978), there are considerable differences between the growth rates of *C. porosus* over the wet season and over the dry season. It is suggested in Section 8.5.4 of Monograph 1 and by Webb et al. (1978) that increased abundance of food sources is the main reason for higher growth during the wet season, in contrast with the view of Magnusson (1978) who suggests that temperature and/or salinity are the major factors involved.

Our purpose here is to review the previous data and present some further data. The discussion is also necessary as a prelude to later sections. In Parts 1.2 and 1.3 we have already mentioned the influence of wet and dry season on early growth of hatchlings. Ideally one would like to have a continuous series of measurements, at say one monthly intervals, for a series of animals living in the wild over a number of years. Unfortunately such data would be very difficult,

if not impossible, to obtain. To work on the rivers during the wet season is very difficult and recapturing animals over successive months would become increasingly difficult due to increasing wariness. For these reasons the main data available comprise capture-recapture records over periods normally involving a mixture of wet and dry season periods.

Another factor to be borne in mind in looking at data which extends over a number of years is that conditions relevant to growth may well vary from year to year. For example, we may have a particularly heavy wet season one year and a particularly dry one the following year. The availability of food could well be different during the two wet seasons and during the following dry seasons. The 1978-1979 wet season was a particularly dry one and growth rates between mid-1978 and mid-1979 obtained on the Blyth-Cadell Rivers System (Chapter 8, Monograph 1) could be less than normal on those rivers. Availability of various food species may also vary over the years and on different rivers in different ways. With all these varying factors affecting interpretation of differences between wet and dry season growth rates of animals in the wild, one must take results on a particular river at a particular period as a guide only. In the following we have attempted to obtain estimates of wet and dry season growth rates by careful examination of capture-recapture records for animals over the period 1973-1980 on the Liverpool-Tomkinson and Blyth-Cadell Rivers Systems. The approach to wet-dry season growth in Webb et al. (1978) has certain flaws which are discussed in detail in Section 2.4, page 39, Monograph 18.

## 2.2 Examples from the Liverpool-Tomkinson System

Examples illustrating dry and wet season growth may be gleaned from the capture-recapture records on the Liverpool-Tomkinson System. They are presented in Table 4 and we shall discuss some of these.

The simplest description of growth over an interval ( $\Delta T$ , days) involving both wet season ( $\Delta T_W$ ) and dry season ( $\Delta T_D$ ) periods is to assume linear growth (at different rates) over the two periods. Let  $a$  (cm/day) and  $b$  (cm/day) be the growth rates over the wet and dry season respectively. The change in SVL ( $\Delta SVL$ , cm) over  $\Delta T$  is given by  $\Delta SVL = a \Delta T_W + b \Delta T_D$ . Such a model has of course a very artificial sharpness in the boundary between the two seasons. Following Webb et al. (1978) we take the wet season as extending from December to April (151 days) and the dry from May to November (214 days). Days 1-120 and 334-365 are wet season and days 121-333 are dry season. The coefficients  $a$  and  $b$  will also depend on the age of the crocodile. To illustrate this approach we take the example of animal 9 in Table 4 that was captured three times on the Liverpool-Tomkinson system over the period of approximately one year. Over a period of 387 days from mid-dry season (day 180) to mid-dry season (day 202) the growth rate was 0.0527 cm/day. From day 85 to day 202 the growth rate was 0.047 cm/day. Use of these results gives  $a = 0.091$  cm/day and  $b = 0.028$  cm/day when substituted into the equation above. This is the only example (besides the animals of Tomkinson nests T12, T13, T14 to be discussed shortly) we have on the Liverpool-Tomkinson System of an animal caught three times within approximately a year and so allowing calculation of  $a$  and  $b$  as above.

If an assumption is made about the magnitude of  $b$  then estimates of  $a$  may be made. These estimates can be a rough guide only, especially when one recalls the artificiality of a sharp boundary between the wet and dry season and that the growth rate probably varies over the wet season and over the dry season. However, by assuming various values for  $b$ , a range of values for  $a$  may be obtained. Consider for example animal 2 from Table 4 and taking  $b = 0.03$ , we obtain  $a = 0.10$ . Any lower value for  $b$  would give a higher value for  $a$  and vice-versa. Taking  $b = 0.05$  gives  $a = 0.06$ . This animal is of 79 cm length initially, in the middle of its second dry season, and a rate of growth of

0.10 cm/day over the initial part of the following wet season would be a rate comparable to that of Magnusson's under 80 day old animals during the wet season (Part 1).

The group of hatchlings from the Tomkinson nests T12, T13, T14 (see Part 1.2) gives rates of growth over approximately 2 months of the dry season and then over the next year (see Part 3.2). These mean rates are both about 0.06 cm/day. This example is out of line with the rest of the data and the reason for this is not clear. Possibly there was a higher food supply on the relevant section of the Tomkinson that year than is usual during the dry season.

### 2.3 The Blyth-Cadell Study

The Blyth-Cadell capture-recapture study initiated in 1978 (Chapter 8, Monograph 1) was specifically designed to throw light on the question of wet and dry season growth rates. Hatchlings were initially captured in June, then again in September (giving a dry season growth rate) and then again in the following June. On the Blyth River the overall average dry season rate was 0.030, from September to the following June it was 0.053, and from June to June 0.048. Calculation of a wet season growth rate as in Part 2.2 gives a rate of 0.073 if we use the June to June rate and 0.070 if we use the September to June rate. Similar calculations for the Cadell results lead to rates of 0.084 in both cases. In this we have assumed, of course, that the average rate over the dry season period outside the June to September interval is also 0.030 in both the first and second year. If it is in fact lower (as appears likely) then the mean rate over the wet season will be larger.

It had been planned to obtain a growth rate over the animals' second dry season by recapturing in October 1979, but extraordinary circumstances (Chapter 8, Monograph 1) meant that only 4 growth records could be obtained for this. The rates over some 4 months of the second dry season were 0.014, 0.015, 0.005 (males) and 0.008 (female) (Table 8.5.8, Monograph 1), with overall mean 0.010. The sample is so small that it is hard to conclude much but we may perhaps take the figure of 0.010 as an estimate of dry season growth rate in the second year, on the Blyth-Cadell Rivers, indicating decreasing growth rate with age (Chapter 8, Monograph 1). This figure is lower than the 0.03 used in the calculations of wet season rates above. If one uses the 0.010 in the above calculation for all dry season days in the second year, one obtains wet season rates of 0.079 on the Blyth and 0.091 on the Cadell. Given that the growth rate probably declines with the progress of the dry season and with age, we may take the wet season growth rate as being in the range 0.07 to 0.10, which again is comparable with the initial wet season growth of Magnusson's hatchlings.

In October 1980, 11 animals were recaptured on the Cadell River. These will be discussed in more detail in Part 4 (Table 11). However, they do throw some further light on differences between wet and dry season growth rates. Nine of the animals were recaptured in June 1979 and so we may calculate for them an average growth rate over a 480-day period which includes 151 days of wet season; all these animals were at least one year old in June 1979. For the 6 males the average growth rate was  $0.0195 \pm 0.0042$  cm/day (range, 0.012-0.023) and for the 3 females it was  $0.0137 \pm 0.0021$  cm/day (0.012-0.016). For the males, if we allow no growth at all over the dry season component of the 480-day interval, we obtain a wet season growth rate of 0.064 cm/day. If we take the figure of 0.010 cm/day that we have just obtained from the June 1979-October 1979 captures, the wet season growth rate becomes 0.042 cm/day. For the females, the same calculations give rates of 0.045 and 0.023 cm/day. The sample size is of course small but the results appear to indicate, especially if we allow a second and third dry season growth rate of 0.01 cm/day, that the growth rate for both males and females over their second complete wet season is considerably less than over their first complete wet season. Further discussion of wet and dry season growth rates

Table 5. Sizes of male and female crocodiles at various ages as predicted by equations (5) and (6) of Webb et al. 1978<sup>1</sup>.

	Ages (years)	HL (cm)	SVL (cm)	TL (cm)	In feet	Annual rate (SVL; cm/day)
MALE	0	4.6	13.2	28.0	11"	
	0.5	8.0	25.3	52.9	1'9"	0.062
	1.0	11.0	36.0	75.0	2'6"	
	1.5	13.7	45.3	94.1	3'1"	0.048
	2.0	16.0	53.6	111.1	3'8"	
	2.5	18.1	60.9	126.1	4'2"	0.038
	3.0	19.9	67.3	139.2	4'7"	
	3.5	21.5	72.9	150.7	4'11"	0.029
	4.0	22.9	77.8	160.7	5'3"	
FEMALE	0	4.6	13.2	28.0	11"	
	0.5	7.8	24.6	51.5	1'8"	0.058
	1.0	10.6	34.5	71.9	2'4"	
	1.5	13.0	43.1	90.0	2'11"	0.044
	2.0	15.2	50.5	104.9	3'5"	
	2.5	17.0	57.0	118.0	3'10"	0.033
	3.0	18.6	62.5	129.0	4'3"	
	3.5	19.9	67.4	138.9	4'7"	0.025
	4.0	21.1	71.6	147.3	4'10"	

<sup>1</sup>. HL denotes head length, SVL denotes snout-vent length and TL denotes total length. The total length was calculated from the snout-vent length using equations from Appendix 2 of Webb and Messel 1978. The annual growth rates are also shown. For consistency with Webb et al. 1978 we have in this Table taken 13.2 cm as the SVL on hatching rather than 13.9 cm which was used in Part 3.4. The figure of 13.2 cm is obtained from HL using the equations on page 388 of Webb et al. 1978, as are all SVLs in this Table.

Table 6. Mean SVL growth rates of hatchlings for the period from June, 1978 to June, 1979 on the Blyth Cadell and Blyth-Cadell Rivers. Abstracted from Table 8.5.7, Monograph 1.

	Blyth		Cadell		Blyth-Cadell	
	Rate	n	Rate	n	Rate	n
All hatchlings	0.0483 $\pm$ 0.0065	46	0.0530 $\pm$ 0.0033	9	0.0484 $\pm$ 0.0063	61
Males	0.0502 $\pm$ 0.0046	33	0.0530 $\pm$ 0.0059	3	0.0495 $\pm$ 0.0052	41
Females	0.0432 $\pm$ 0.0079	13	0.0530 $\pm$ 0.0017	6	0.0461 $\pm$ 0.0079	20

Table 7. Possible SVL (cm) of hatchling hatched on February 1 for two different sets of growth rates (see text, part 3.4).

Day number	Feb. 1 32	Mar. 21 80	Apr. 30 120	Jun. 9 160	Jul. 19 200	Aug. 28 240	Oct. 7 280	Nov. 16 320
Upper Rate	13.9	18.7	22.7	24.7	26.7	28.7	30.7	32.7
Lower Rate	13.9	16.8	19.2	20.4	21.6	22.8	24.0	25.2

Parts 3 and 4. It is interesting to speculate what the growth rates of *C. porosus* in the wild might be in areas such as Papua New Guinea or Borneo where one does not have such a marked dry-wet season difference as in northern Australia. In the absence of a harsh dry season, considerably higher annual growth rates than described here might be expected, especially for smaller animals.

### PART 3 GROWTH OF *C. porosus* OVER THE FIRST YEAR

In order to allow comparison of growth rates on different rivers over the first year of life, we have calculated growth rates for animals that remained on the Liverpool River and those that remained on the Tomkinson River over their first year. This will also allow comparison with the rates (Chapter 8. Monograph 1) already obtained for the Blyth and Cadell rivers. These rates may also be compared with those given by the growth curve (Table 5) and obtained in a much less direct fashion (Webb et al. 1978).

#### 3.1 Liverpool Hatchlings

Twenty-three hatchlings (including 12 males and 11 females) were captured in the mid-dry season of 1973 and recaptured one year later. The overall mean growth rate for these animals was  $0.054 \pm 0.006$  (range 0.043-0.069). For the males it was  $0.056 \pm 0.006$  (range 0.047-0.069), for the females  $0.050 \pm 0.005$  (range 0.043-0.058). Nine hatchlings were similarly recaptured over the 1974-1975 period. The overall average for these animals was  $0.054 \pm 0.008$  (6 males, 3 females). The mean growth rates over the two periods are identical. The largest growth rate for an animal in the later period was for a male whose rate was 0.074, the snout-vent length increasing from 20.1 to 46.4 cm. The lowest growth was for a female, 0.045 cm/day; its snout-vent length changing from 20.5 to 37.3 cm. Taking all 32 animals, the growth rate was  $0.054 \pm 0.007$  cm/day ( $0.056 \pm 0.007$  for males,  $0.050 \pm 0.005$  for females). The interval between recaptures ranged between 340 and 370 days with most being within the range 350-365 days.

To investigate whether there were any differences in growth rates along the river (salinity gradient), the animals were grouped into various intervals between km 20 and km 60 (non-freshwater section). The sample is admittedly small, but there was no indication of any differences in the hatchling mean growth over a year dependent on their position on the brackish section of the river. Most of the animals were caught within a kilometer or so of their first capture positions and one may assume that they spent most of the year along the same stretch of river. These results are consistent with those of Webb et al. (1978), who found position along the brackish sections of the river to be an unimportant variable. The results are also consistent with those obtained for the Blyth River where there appeared to be no difference in growth over the full year between the brackish and freshwater sections (though there was over the three months of dry season growth). Magnusson (1978) and Magnusson and Taylor (1981) also found no dependence of growth on salinity in a somewhat limited salinity regime.

#### 3.2 Tomkinson Hatchlings

In Part 1.2 we referred to the initial growth rates of animals from the three nests T12, T13, T14 on the Tomkinson in June 1974. Twenty-two of these animals were recaptured in July 1975, and their average growth rate over a period of some 340 days from mid-August of 1974 was  $0.060 \pm 0.005$ . This rate is about the same as their initial growth rate over some two months in the 1974 dry season, and does not show the usual decline from the initial growth rate that was observed with

animals that spent their initial growth period in the wet season. Of this sample, 12 were males ( $0.061 \pm 0.005$ ; range 0.054-0.074) and 10 were females ( $0.0585 \pm 0.0040$ ; range 0.052-0.063), and there thus was no significant difference in the male-female growth rates, though the female rate was, as usual, lower. The mean interval between captures was some 340 days. Twenty-one other animals were captured in mid-dry season of 1973 and recaptured some 340 days later in 1974. The average growth rate was  $0.054 \pm 0.009$  cm/day (8 males,  $0.063 \pm 0.0071$ , range 0.052-0.071; 13 females,  $0.049 \pm 0.005$ ; range 0.038-0.056). The female growth rates of the 1973-1974 season are lower than those of the 1974-1975 season. This difference is in fact significant at the 0.01% level. Since the male rates over the same two years are much the same, it is hard to understand this difference.

The growth rates for hatchlings on the Liverpool-Tomkinson system calculated in this direct fashion are in good agreement with those predicted by the growth curve (Table 5).

### 3.3 Growth Over the First Year on Different Rivers

In Chapter 8 of Monograph 1 it was shown that growth over the first year was somewhat higher on the Cadell River than on the Blyth River, into which it runs about 20 km from the mouth of the Blyth. The sample on the Cadell was only small however. The Liverpool-Tomkinson Rivers System lies some 30 km to the west of the Blyth-Cadell Rivers System and the Tomkinson runs into the Liverpool about 20 km from its mouth (Monograph 15). By the end of the dry season the Cadell is slightly brackish at the upstream limit of navigation by survey boat, whereas the Blyth is fresh; likewise the Tomkinson is slightly brackish, whereas the Liverpool is fresh at the upstream level (see Monographs 1 and 7 for full details on the salinity regimes of these rivers). The two river systems are thus somewhat similar, the Blyth corresponding to the Liverpool and the Cadell to the Tomkinson. Now that we have obtained separate growth rates for the Liverpool and Tomkinson we can make some comparisons of growth rates.

Because most of the intervals for the Tomkinson recaptures are about 340 days compared with 350-360 days for the Liverpool and Blyth-Cadell recaptures, there is a slight upward bias (due to a higher percentage of wet season) in the Tomkinson rates. This may be corrected by using the two-rate model discussed in Part 2. Taking a dry season growth rate of 0.030 cm/day, one finds that the Tomkinson rates for 360 days are some 2% lower than the rates over the 340 days given in Part 3.2. It is these corrected rates for the Tomkinson which we use in our comparisons.

Because of the small sample size for the growth over the first year on the Cadell, we shall not include the Cadell in the comparisons here; as we have already said, the rates of growth on the Cadell were higher than on the Blyth. The mean yearly rates on the Blyth were  $0.050 \pm 0.005$  ( $n = 33$ ) for males and  $0.043 \pm 0.008$  ( $n = 13$ ) for females (Table 8.5.7, Monograph 1). The various rates are collected in Table 6.

The male growth rates on the Liverpool and Tomkinson rivers are not significantly different. The female rates are significantly different (at 0.1% level) if we use the 1973-1974 results for the Tomkinson but are not different if we use the 1974-1975 results for the Tomkinson.

Comparisons of the male rates on the Tomkinson with those on the Blyth give results that are highly significant (at 0.0001% level). Comparison of the rates for females on the Blyth and Tomkinson shows that the 1974-1975 rates are highly significantly different (at the 0.01% level), but the 1973-1974 rates are not.



Comparisons of male rates on the Liverpool with those on the Blyth show the difference to be significant at the 0.1% level. The female rates also differ significantly at the 1% level.

The results clearly indicate higher growth in the first year on the Liverpool and Tomkinson rivers than on the Blyth. In fact, the largest growth rate on the Blyth was 0.060 cm/day, for a male, which is about the mean male growth rate on the Tomkinson (the rates on the Liverpool-Tomkinson system are also mostly higher than on the Cadell, though the numbers in the Cadell sample are only small). There is also a strong indication that males grow better on the Tomkinson than on the Liverpool; for females the picture is complicated by the disparity between the 1973-1974 and 1974-1975 growth rates.

### 3.4 Range of Sizes Amongst Hatchling Captures and Ambiguities

Besides the capture-recapture records, we also have available many hundreds of single captures and much may be learned from the size structure of the population at a given time of year. In this section we shall use all available information to consider the range of size that a hatchling may assume during its first dry season. Because of the possibility of errors in measurement, we only take examples of size and growth that are paralleled by at least one other animal. These sizes may then be correlated with the growth rates we have been considering and the possible times of hatching.

Nesting of *C. porosus* in northern Australia (Webb et al. 1977; Magnusson 1978) is stated to take place between November and May, during the wet season. Incubation periods vary between 80 and 100 days. Normally, though during the dry season hatching can take much longer (or as mentioned in Part 1, it may not even occur at all) because the temperature is lower. If a nest is laid on the earliest possible date, say 1 November, then the eggs could be expected to hatch around 1 February. If laid at the end of May they would probably hatch no sooner than 1 September. R. Jenkins (pers. comm.) has found a riverside nest in the Alligator River region which was laid down in August. This is exceptionally early (or late) and we will use the November date in our discussions. It is unknown whether any eggs from such an August nest would hatch.

We first consider animals hatching early in the year. Animal 1406 (record H, Table 3) hatched on 19 March with an SVL of 14.5 cm and by June 9 had an SVL of 23.6 cm. If we assume that an animal with comparably high growth rate had hatched on 1 February with an SVL of 13.9 cm, we may make some calculations of the range of maximum sizes possible over the year. The figure of 13.9 has been adopted for the SVL on hatching, since the mean of the means in Table 1 for hatchlings  $\leq 2$  days old is  $13.9 \pm 0.43$ . Considering first the upper range of growth, we take a mean growth to the end of the wet season (30 April) of 0.1 cm/day. One hatchling, captured on day 205 (24 July) and recaptured on day 351 (17 December), had a mean growth of 0.05 cm/day (the SVL going from 23.0 to 30.3 cm). We may thus take 0.05 cm/day as a possible rate over the dry season, leading to the predicted lengths shown in Table 7. Taking a lower rate for growth during the wet season of 0.06 cm/day and during the dry of 0.03 cm/day we obtain the lower growth rate shown in Table 7.

Examination of our capture-recapture records reveals the following examples. An animal (Blyth River) caught on 22 June (day 173) had an SVL of 25.1 cm. A group of animals was captured on the Blyth River around the end of October (day 300) with SVLs ranging from 29 to 31.5 cm, in agreement with the upper size suggested from an animal born near 1 February. Animals were caught on the Goromuru River in 1975, around day 280, with an SVL of 31.1 and 31.5 cm. In late September (day 269) 1978, an animal was caught on the Cadell River with an SVL

of 28.0 cm; an animal with the same SVL was caught in late August on the Tomkinson River. Another animal with an SVL of 18.5 cm on day 112 (late April) had an SVL of 32.7 cm by day 10 of the next year. If we allow an initial growth rate of 0.1 cm/day, then this animal hatched in early March. With this same sort of growth and a hatching in early February, it seems we could have an animal with an SVL of 33 cm by the end of November. After examining late hatchling growth we shall look again at the question of maximum hatchling sizes late in the dry season.

We now consider the lower size range of hatchlings later in the dry season and attempt to relate this to the latest possible times of hatching. Amongst the Blyth-Cadell captures of late October 1974 (around day 300), there were 3 hatchlings captured on the upstream Blyth River (around km 42) with SVLs of 16.0, 16.5, and 16.5 cm. Some other animals in the range of 17.0-18.5 cm were also captured at this time. During the September 1978 captures on the same river system, the smallest animal caught had an SVL of 17.1 cm. So in 1974 one had animals 1 cm (SVL) shorter one month later. As we have discussed earlier, some very low growth rates occurred over the June-September period on the upstream Blyth in 1978 (see Chapter 8, Monograph 1). If we assume that the mean initial rate of growth of the late October 1974 hatchlings was 0.06 cm/day (i.e., the same as the initial rate for the Tomkinson T12, T13, and T14 nests) and that their initial SVL was 14.0 cm, then a 16.5 cm SVL corresponds to an age of about 40 days, and with a normal incubation period of 90 days we obtain a date of mid-June for the laying of the nest, which would be a late nest. A longer than normal incubation period (as would be highly likely during the colder dry season months) and a lower growth rate would of course push the date further back. Pushing laying back to the end of April (the end of the wet season) and assuming 90 day incubation, we would obtain an age of 90 days for the 16.0 cm hatchling, corresponding to a mean growth rate of 0.02 cm/day, a growth rate that seems possible after examination of the Blyth-Cadell capture-recapture data.

An animal that had an SVL of 16.0 cm in late October and grew at the average rate of 0.05 cm/day over the next year would by the following October have an SVL of 34.3 cm, at a rate of 0.04 cm/day it would have an SVL of 30.6 cm. Thus there could be an overlap in sizes in the late dry season of animals born early that same year or born late in the dry season of the previous year. It is possible that in our assignment of animals to the hatchling class for calculating the Liverpool and Tomkinson growth rates we have erred, in that the animal is actually in its second dry season. Such cases, and there would only be a few, would have the effect of lowering the mean growth rate since growth over the second year of life is slower (see later).

Another way of comparing growth on the two river systems is to compare the sizes of the animals in the second year, in mid-dry season. On the Blyth-Cadell System the largest recapture had an SVL of 42.0 cm, with several others over 40 cm. Examination of the Liverpool-Tomkinson data reveals several animals in mid-July with snout-vent lengths around 46 cm, and numbers between 42 cm and 46 cm. It is also interesting to note that one of the Blyth October 1979 captures, 1753, which had an SVL of 41.8 cm in June, had only 42.5 cm in October. These observations again indicate a higher growth rate on the Liverpool-Tomkinson system.

#### PART 4 GROWTH OF SMALL (3-6', 0.9-1.8 m) *C. porosus*

In this part we re-examine the growth records for animals after their first year on the river and up to the fourth year. This main purpose again is to look for differences between different rivers. For animals larger than 2-3' (0.6- 0.9 m) it is impossible in some cases to be certain of an animal's age, and this uncertainty increases with age. However, amongst the capture-recapture records on the Liverpool-Tomkinson System there are a number of triple captures where animals

were caught in three successive years, and in these cases we know much more about the age of the animal. These triple captures of animals in the wild provide very valuable data, and we have tried to make full use of them.

#### 4.1 Growth from Second to Third Year on the Liverpool-Tomkinson System

The capture-recapture records show 13 animals that spent their second year on the Liverpool River. The SVL growth rates for these initially 2-3' animals from mid-dry season to mid-dry season are:

All animals:  $0.038 \pm 0.007$  ( $n = 13$ , range 0.029-0.050); Males:  $0.039 \pm 0.007$  ( $n = 7$ , range 0.031-0.050); Females:  $0.036 \pm 0.006$  ( $n = 6$ , range 0.029-0.044).

As expected the growth rate for males is higher than that for females, though not significantly.

There were 34 animals that spent their second year on the Tomkinson River from mid-dry season to mid-dry season and were initially 2-3' animals. The growth rates for these animals were:

All animals:  $0.045 \pm 0.006$  ( $n = 34$ , range 0.034-0.059); Males:  $0.045 \pm 0.007$  ( $n = 8$ , range 0.038-0.054); Females:  $0.045 \pm 0.006$  ( $n = 26$ , range 0.034-0.059).

Interestingly, the male and female rates on the Tomkinson are identical. The hatchling growth rates for males and females over the one year period 1974-1975 were also very close.

The average time interval between these Tomkinson recaptures is only 340 days, somewhat short of the average full year interval between the Liverpool recaptures. To enable a comparison of these rates, we may correct the Tomkinson rates by assuming a two rate growth over the year (see Part 2.2). If we assume a rate of growth of 0.02 cm/day (the mean of 0.03 for the first dry season and 0.01 for the second dry season, see Part 2.3) during the dry season component, then we can calculate that the rate 0.045, over 340 days, represents a rate of 0.043 over 365 days. We may take then the corrected Tomkinson annual rates as:

All animals:  $0.043 \pm 0.006$  ( $n=34$ ); Males:  $0.044 \pm 0.007$  ( $n = 8$ ); Females:  $0.043 \pm 0.006$  ( $n = 26$ ).

The male rates are not significantly different between the Liverpool and the Tomkinson; the female rates are significantly different at almost the 1% level. From the equations in the growth paper (see caption of Table 5) we can calculate the mean rate of growth of animals from 1.5 to 2.5 years to compare with the directly calculated rates above, 0.043 (males) and 0.038 (females).

#### 4.2 Growth from the Third to Fourth Year on the Liverpool-Tomkinson System

Examination of the capture-recapture records reveals 21 cases of animals that are likely to be going from their third year to their fourth year (mid-dry season to mid-dry season). Some are definite cases because they are triple captures; in a few cases the initial sizes may be a little large (the two largest animals we have included had SVLs of 58.8 cm and 60 cm). The mean SVL growth rates were:

All animals:  $0.0316 \pm 0.0072$  ( $n = 21$ , range 0.018-0.047); Males:  $0.0337 \pm 0.0049$  ( $n = 5$ , range 0.026-0.038); Females:  $0.0309 \pm 0.0078$  ( $n = 16$ , range 0.018-0.047).

The time Interval for these rates is  $(365 \pm 25)$  days.

Six of the females on the Tomkinson included above are triple captures that we definitely know are going from their third to fourth year. The mean rate for these (over approximately 340 days) is  $0.028 \pm 0.010$  (range 0.018- 0.047). Thus the male growth rate is higher, but not significantly.

Unfortunately the numbers of animals which spent the year on one particular river are insufficient to allow any comparison of the Liverpool and Tomkinson growth rates. The equations from Webb et al. (1978) predict the following values for growth rates from 2.5 to 3.5 years: 0.033 (males) and 0.028 (females).

#### 4.3 Two Year Growth Rates from First to Third Year on the Liverpool-Tomkinson System

By selecting from triple captures and 2 year spaced captures we can obtain a mean SVL rate of growth from the hatchling to the 3-4' (0.9-1.2 m) stage over a 2-year period from mid-dry season to mid-dry season. There are 19 such cases from the whole Liverpool-Tomkinson system, with the interval between recaptures varying between 675 and 740 days. The mean growth rates over the approximately 2-year interval are:

All animals:  $0.044 \pm 0.007$  ( $n = 19$ , range 0.034-0.056); Males:  $0.046 \pm 0.006$  ( $n = 11$ , range 0.034-0.056); Females:  $0.042 \pm 0.007$  ( $n = 8$ , range 0.034-0.052).

These rates may be compared with those calculated using the equations of Webb et al. (1978), calculating from age 0.5- 2.5 years; 0.049 cm/day for males and 0.044 cm/day for females. The rates predicted are in good agreement with the directly calculated rates. In Table 8 we give the individual records of growth of the 11 triple captures included in the above. It will be seen that the growth rate over the second year is on average only 60% of that over the first year.

From the 19 two-year spaced captures we can abstract some information on relative growths on the Liverpool and Tomkinson rivers. The samples are very small unfortunately, but the results are in support of earlier results indicating a higher growth rate on the Tomkinson. For male animals on the Liverpool, the mean growth rate was  $0.0434 \pm 0.0021$  ( $n = 5$ , range 0.041-0.046). On the Tomkinson there were 2 males with mean 0.0528 (0.0499, 0.0557). For females on the Liverpool, the mean rate was  $0.0362 \pm 0.0018$  ( $n = 4$ , range 0.0343-0.0384). On the Tomkinson it was  $0.0489 \pm 0.0026$  ( $n = 3$ , range 0.0473-0.0519). Interpretation of these differences is complicated by the fact that the Liverpool capture intervals ranged from 718 to 739 days, whereas the Tomkinson intervals ranged from 675 to 703 days. As we shall now show, even when this is compensated for, the strong indication is still that the growth rate is higher on the Tomkinson. We again use the simple model from Part 2.2. We take a two year growth, allowing 0.08 over the wet season and 0.02 over the dry season. Over 730 days (302 wet, 428 dry) this gives a mean rate of 0.045. Over 675 days, with 55 fewer dry season days, we get a rate of 0.047, so the shorter interval has little effect on the average rate.

#### 4.4 Growth from Second to Fourth Year on the Liverpool-Tomkinson System

By selecting from triple captures and 2 year spaced captures we can obtain a mean SVL rate of growth from the 2-3' (0.6-0.9 m) stage on the Liverpool-Tomkinson system. The interval between captures varies from 666 days to 730 days, with the majority of intervals being around 680 days. The mean growth rates are:

All animals:  $0.0368 \pm 0.0063$  ( $n = 21$ , range 0.025-0.047). Males:  $0.0380 \pm 0.0076$  ( $n = 9$ , range 0.025-0.047). Females:  $0.0358 \pm 0.0053$  ( $n = 12$ , range 0.028-0.046).

Unfortunately the samples are too small to permit any conclusions about differences between Liverpool and Tomkinson growth rates, the majority of the animals being from the Tomkinson River.

In Table 9 we give the individual histories of the triple captures included in the above animals. The equations in Webb et al. (1978) give rates of 0.038 for males and 0.033 for females for growth from 1.5 to 3.5 years. The male-female differences are not significant, though as usual the male rate is higher.

Table 8. Capture histories of animals caught on the Liverpool-Tomkinson System in their first year and recaptured in their second and third years<sup>1</sup>.

Number	Sex	Initial SVL	1st year rate	SVL	2nd year rate	Final SVL
15	M	25.4	0.047	42.4	0.022	50.7
30	M	25.0	0.059	46.0	0.027	56.1
94	M	23.0	0.062	44.5	0.031	55.9
95	F	21.0	0.054	40.0	0.017	46.2
98	F	24.0	0.043	39.0	0.034	51.6
103	M	22.5	0.053	41.0	0.032	53.0
184	M	23.0	0.059	43.2	0.042	57.7
232	F	20.0	0.053	38.2	0.042	52.7
270	M	22.0	0.061	42.9	0.039	56.3
349	F	29.0	0.056	48.1	0.038	60.9
351	M	21.5	0.070	45.1	0.042	59.1

<sup>1</sup>. The rates of SVL growth are also given (the intervals between captures vary between 337 and 371 days).

#### 4.5 Growth Rates of Animals up to 6' (1.8 m)--Liverpool-Tomkinson System

In Table 10 we present some interesting growth records for animals up to 6' (1.8 m) in length. The ages of most of these animals is uncertain to within a year. We shall now comment on some of these growth records.

Animal 37 exhibits a very high growth rate for a non-hatchling over a 2-year period, going from a total length of 1.0 m to 1.81 m over the period. Because of a toe abnormality noted on both captures, there is no question that this was the same animal both times. Its mean growth rate over 2 years matches that of many hatchlings in their first year. This animal could conceivably be 1.5 years old on first capture and so had reached 1.8 m (6') at age 3.5 years. Animal 291 exhibits a growth rate that is not much lower. The two males 451 and 517 exhibit a mean growth of 0.030 cm/day over what is probably their fourth year of growth (from age 3.5 to 4.5). Animals 124, 176, 177, and 195 have very similar mean growth rates of around 0.036 cm/day over a 2-year period which possibly is from their third to fifth year on the river (age 2.5 to 4.5 years). So at 4.5 years they have an SVL of 80 cm, which is in agreement with the growth curve.

#### 4.6 Blyth October 1980 Recaptures

In October 1980 11 animals (7 males, 4 females) were recaptured of the original animals of 1978; the animals were very difficult to approach and this was all that could be caught in the time available. Summary histories of the animals are given in Table 11. Since all these animals had been captured in September 1978 we can calculate 2 year SVL growth rates. For all animals it is  $0.032 \pm 0.005$  cm/day; for the males,  $0.033 \pm 0.004$  cm/day, and for the females,  $0.029 \pm 0.006$  cm/day. The largest rate was 0.040 cm/day for a male, and the lowest 0.022 cm/day for a female. These rates may be compared with those for animals for which we calculated 2-year growth rates in Section 4.3. The rates are less than those on the Liverpool-Tomkinson system. The male rates differ at the 0.01% level and the female rates at the 1% level.

Though the sample of animals on the Blyth-Cadell is much smaller than for the Liverpool-Tomkinson, it is interesting, by looking at individual examples, to compare the extremes of growth on the Liverpool-Tomkinson and Blyth-Cadell rivers systems. The largest animals captured (1617 and 1817) on the Blyth-Cadell system in October 1980 had an SVL of 50 cm. Within a month or so, their ages may be estimated at 32 months. Two very comparable animals from the Liverpool-Tomkinson system (1 male, 1 female) of similar age had SVLs of around 63 cm, and there are many examples of animals of the same age with SVLs between 57 and 60 cm. The smallest male captured (1631) on the Blyth-Cadell system had an SVL of 43 cm and total length 87 cm, so it has not reached the 3-4' category yet. This animal is at least 28 months old and may be compared with an animal from the T14 1974 Tomkinson Nest which had the same SVL at some 13 months (both animals were hatched around June-July). Again we see that the growth rate, on average, appears to be greater on the Liverpool-Tomkinson system than on the Blyth-Cadell system and that, as we have already discussed, the confident attribution of an age to a given animal more than a year old is impossible, especially if the animals are from different systems. In October 1981 we managed to recapture one of the 1978 hatchlings, a female, and at the age of at least 42 months, its SVL was only 49 cm. Use of the growth curve (Fig. 3) in Webb et al. (1978) would give an SVL of 67 cm at 42 months. Some discussion of these animals recaptured on the Blyth-Cadell in October 1980 has already been given in Part 2.3.

Table 9. Capture histories of animals caught on the Liverpool-Tomkinson System in their second year and recaptured in their third and fourth years<sup>1</sup>.

Number	Sex	Initial SVL	1st year rate	SVL	2nd year rate	Final SVL
35	M	42.5	0.0431	58.7	0.0264	68.2
40	F	39.0	0.0368	52.1	0.0195	59.3
92	F	36.0	0.0429	51.0	0.0249	60.2
262	F	36.0	0.0436	50.9	0.0252	59.4
301	M	39.0	0.0376	52.0	0.0338	63.5
317	F	37.5	0.040	50.9	0.0251	59.2
318	F	36.0	0.0418	50.0	0.0240	58.2
321	F	36.5	0.0445	51.4	0.0466	67.4
322	F	31.0	0.0533	48.9	0.0297	59.0
355	F	36.5	0.0524	54.2	0.0184	60.4

<sup>1</sup>. The rates of SVL growth are also given (the intervals between captures average around 340 days, with 378 the longest interval and 335 the shortest).

Table 10. Growth records for animals up to 6' (1.8m) in length on their final capture. All animals are from the Liverpool-Tomkinson System.

No.	Sex	Initial SVL	Final SVL	Rate	Period (days)
37	M	49.0	87.1	0.0518	736
110	F	52.0	77.5	0.0351	727
124	M	55.0	80.7	0.0365	704
165	M	64.0	77.4	0.0388	345
176	M	58.0	82.8	0.0356	696
177	M	56.0	81.3	0.0364	696
195	M	48.0	74.4	0.0380	695
291	M	46.5	78.6	0.0467	687
451	M	65.0	75.3	0.0300	343
517	M	72.5	82.1	0.0291	330

Table 11. Growth histories for 11 hatchlings first captured in June or September, 1978 and recaptured in October, 1980 on the Blyth-Cadell Rivers System. Rates are cm/day.

	Sex	Capture	SVL	Rate	Capture	SVL	Rate	Capture	SVL
1617	M	June 78	23.1	0.033	Sept 78	26.2	0.048	June 79	38.8
		--	--	0.023	Oct. 80	50.0			
1626	F	June 78	21.0	0.045	Sept. 78	25.2	0.022	Oct. 80	41.5
1631	M	June 78	20.1	0.012	Sept. 78	21.2	0.048	June 79	34.0
		--	--	0.019	Oct. 80	43.0			
1644	M	June 78	17.4	0.006	Sept. 78	18.0	0.072	June 79	37.0
		--	--	0.023	Oct. 80	48.0			
1656	M	June 78	18.7	0.016	Sept. 78	20.2	0.057	June 79	35.4
		--	--	0.022	Oct. 80	46.0			
1687	M	June 78	20.0	0.034	Sept. 78	23.2	0.029	Oct. 80	45.0
1758	F	June 78	19.5	0.024	Sept. 78	21.7	0.066	June 79	39.0
		--	--	0.012	Oct. 80	45.0			
1773	F	June 78	18.4	0.020	Sept. 78	20.3	0.068	June 79	38.2
		--	--	0.016	Oct. 80	46.0			
1816	M	Sept. 78	17.1	0.007	June 79	37.2	0.012	Oct. 80	43.0
1817	M	Sept. 78	26.5	0.057	June 79	41.5	0.018	Oct. 80	50.0
1818	F	Sept. 78	24.8	0.054	June 79	39.0	0.013	Oct. 80	45.0



## PART 5 GROWTH OF LARGE ANIMALS

In October-November of 1980 and 1981 a number of animals caught originally between 1973 and 1976 on the Liverpool-Tomkinson system were recaptured, providing valuable information on the growth of *C. porosus* after the third year, i.e., for the ages where the data were very limited before. In Table 12 we give the capture histories of these animals and also the average rate of SVL growth between first and last capture. In Table 13 we give the size at the end of each year calculated using the growth curves in Webb et al. (1978); for large animals we have used the 65 cm maximum head length curve for males, and the 51 cm maximum head length curve for females; we have also calculated the yearly growth rates.

It may be seen in Table 12 that for males, 0.025 cm/day seems to be about the average growth rate over the first seven or so years of life (491, 382, 454, 1418, 1059). From Table 13 and assuming an initial SVL of 13.9 cm (see Part 3.4), we see that the growth curve of Webb et al. (1978) predicts an average SVL growth rate of 0.037 cm/day over the first seven years; a figure which is too high when compared with the specific examples. Both animals 491 and 454 are from the June 1974 Tomkinson nests and so are known to be 7.2 years old. Use of the growth curve for large males (the 65 cm case) would predict that their SVL should be around 110 cm which is much higher than these two examples and also than that of 382, about a year younger.

Animal 251 merits attention. Between its first two captures, about a year apart, its growth rate was 0.030 cm/day. Over the next six years, between the 1974 and the 1981 captures, it averaged 0.021 cm/day. According to the growth curve, an animal with an SVL of 65 cm should be some 3 years old, and so by October 1981 animal 251 should be some 10 years old, with an SVL of 126 cm (53 cm case) or 131 cm (65 cm) case instead of the 122.0 cm found. The 65 cm case also predicts, between the 4th and 10th year, an average growth rate of 0.024 cm/day, which is fairly close to the observed value of 0.021 cm/day.

The two females recaptured in 1980 and 1981 (438 and 148) also deserve comment. Animal 438 has an SVL of 77.4 cm at an age of some 6.5 years, again somewhat less than that predicted by the growth curves. Animal 148 may be taken as approximately 2.5 years old on first capture (according to the growth curve) and so has an SVL of 110 cm at age approximately 10 years in good agreement with the 51 cm curve for females.

Animal 1418, one of Magnusson's 1976 hatchlings, at 5.5 years, has an SVL of 69 cm, which by the growth curve should be the SVL of a 3 year old. However, as we have seen in Part 4.3, there are examples of animals that show growths up to their third year in line with that predicted by the growth curve.

Animals 176 and 177 (see Table 10) both males from the Liverpool, have SVLs of about 58 cm in July 1973 and about 83 cm in June 1975. It is easily within reason that these animals hatched in June 1971, and thus at the age of 48 months have SVLs slightly larger than that of 491 which is some 88 months old. (One wonders if possibly 1978-1981 was not such a good period for growth. Since we are comparing the Blyth-Cadell and Liverpool-Tomkinson systems for different years, it is possible the years on the Blyth-Cadell were bad ones for growth. However, the comparisons of the Liverpool and the Tomkinson in Parts 3 and 4 are over the same years and there are differences.)

Some other individual growth records for larger animals over the period 1973-1976 may also be examined. One female (359) changed from an SVL of 80.0 to 107.0 cm over a 22 month period, giving the high average rate of 0.040 cm/day (calculation from the head length change gives an

Table 12. Capture histories of animals recaptured on the Liverpool-Tomkinson Rivers System in October, 1980 and October, 1981<sup>1</sup>.

Animal	Sex	Capture Date	SVL (cm)	Capture Date	SVL (cm)	Capture Date	SVL (cm)	Rate (cm/day)
491	M	17.8.74	15.5	26. 7.75	38.3	23.10.81	82.0	0.025
251	M	16.8.74	65.0	25. 7.75	75.3	13.10.81	122.0	0.022
382	M	29.6.74	18.4	21. 5.75	38.8	1.11.80	86.0	0.029
438	F	2.8.74	22.4	1.11.80	77.4	--	--	0.024
454	M	16.8.74	18.9	24. 7.75	39.6	6.10.81	90.9	0.028
1418	M	17.3.76	14.9	11. 5.76	22.0	8.10.81	69.2	0.027
148	F	20.8.73	60.0	27. 8.74	72.1	22.10.81	110.0	0.017
1059	M	23.7.75	20.5	8.10.81	77.5	--	--	0.025

a. The rate shown is that between the initial and final capture.

Table 13. Growth of large crocodiles calculated using the equations of Table 1 of Webb et al. (1)<sup>a</sup>.

	Age (years)	HL (cm)	SVL (cm)	TL (cm)	TL (feet)	Growth rate
MALE	4.0	23.1	78.5	162.2	5'4"	0.028
	5.0	26.0	88.8	183.3	6'0"	0.026
	6.0	28.7	98.4	203.0	6'8"	0.0245
	7.0	31.2	107.3	221.2	7'3"	0.023
	8.0	33.6	115.7	238.4	7'10"	0.021
	9.0	35.8	123.4	254.2	8'4"	0.020
	10.0	37.8	130.6	269.0	8'10"	0.018
	11.0	39.7	137.3	282.7	9'3"	
FEMALE	4.0	21.1	71.6	147.3	4'10"	0.0215
	5.0	23.4	79.5	163.2	5'4"	0.020
	6.0	25.4	86.8	177.9	5'10"	0.018
	7.0	27.3	93.5	191.3	6'3"	0.017
	8.0	29.1	99.7	203.8	6'8"	0.016
	9.0	30.7	105.5	215.5	7'1"	0.015
	10.0	32.2	110.8	226.1	7'5"	0.014
	11.0	33.6	115.8	236.2	7'9"	

a. For males we have taken the 65 cm maximum head length case; for females the 51 cm case. The annual growth rate (SVL, cm/day) is also shown. See Table 5 for symbols.

SVL rate of 0.037 cm/day). This is a very high rate for a large animal, especially a female. Another female (1070) grew from an SVL of 103 to 114 cm (0.024 cm/day) over a 460-day period; another (401) grew from 107 to 114 cm over a year (0.019 cm/day). The growth of two large males (called A and B) has already been detailed in Webb et al. (1978). Another record of a large male is that of 365, which changed in SVL from 149 to 160 cm over a 282-day period, giving a rate of 0.039 cm/day (however calculation from the head length change gives an SVL rate of 0.027 cm/day and shows that care must be taken in interpreting SVLs derived from HLs, especially for big animals).

In Table 14, we show the capture histories of 8 animals recaptured in October 1983, of animals first caught in the period 1973-1975. Since the growth rate slows with age and the growth rates in Table 13 are obtained by averages over a longer period (9-10 years in most cases) than those in Table 12 (7-8 years in most cases), we would expect the rates in Table 13 to be somewhat lower. This appears to be the case, though the sample is of course very small. We shall now comment on some individual cases of particular interest.

Animal 931 was 3.44 m long on initial capture and weighed 163 kg. On recapture some 8 years later its length was 3.54 m and its weight was 154 kg. With such a large animal measurement uncertainty can be large, but it is clear that the animal has hardly grown over the 8-year period. The weight loss is perhaps attributable to the fact that the initial capture was in July, reasonably early in the dry season, whereas the recapture was at the end of October, near the end of the dry season. The food supply appears to be better over the wet season, and one would expect the animal's condition to be lower at the end of the dry season than at the start. A further complicating factor is that the 1981-1982 and 1982-1983 wet seasons were "dry" ones, and there may have been less than the usual supply of food. Generally speaking, it does appear that some large animals appear to stop growing, whereas others continue to grow.

Animals 131 and 318 are both females and show dramatically the variation in growth rates that can occur and that were emphasized. The brands on both these animals were clear and unambiguous. Female 131 was caught as a hatchling in 1973 and recaptured in October 1983 with a length of 2.52 m and a weight of 57.2 kg. Female 318 was caught as a 2-3' animal in 1973; most likely it was a late hatchling in 1972 but it may have been an early hatchling in 1973. On recapture 318 was 1.87 m in length and 19.1 kg in weight; its weight was one-third that of 131. Seeing the two animals side by side it was hard to believe that 318 was the older animal. Female 131 looked in very fine condition, whereas 318 was in poor condition; of course, it is possible 318 was diseased in some way.

Worrell (1964) presents information about a large *C. porosus* kept in a zoo. The animal was approximately 2 m originally and for 6 years grew at an SVL rate of 0.040 cm/day (at apparently a uniform rate) and then slowed, averaging only 0.010 cm/day over the following 16 years. The latter growth rate is hard to interpret as the animal may have stopped growing at some stage. However, the rate of 0.040 cm/day from approximately its fifth to eleventh year is high. The animal of course is in a state of captivity and is presumably always well fed; however, the figure indicates a possible growth rate for a large animal, one that is higher than most of our observations in the wild. At an age of approximately 27 years the animal was about 4.9 m in length. Animal 251 is 2.4 m, with an age of probably 10 years, in comparison with this captive animal which was 3.7 m at about 12 years. We also have the cases A and B of Webb et al. (1978), one of which showed no appreciable growth over 3.3 years and another (B) which averaged 0.011 cm/day over 2.3 years (very similar to Worrell's rate over 16 years). This animal (of total length 4.0 m, 13 feet) was estimated as 20-24 years old.

Table 14. Capture histories of animals recaught on the Liverpool-Tomkinson Rivers System in October, 1983. The growth rate shown is that between the initial and final captures.

Animal	Sex	Capture Date	SVL (cm)	Capture Date	SVL (cm)	Capture Date	SVL (cm)	Rate (cm/day)
184	M	23.8.73	23.0	17. 7.75	57.7	28.10.83	105.0	0.022
Also recaptured 2.8.74 with SVL of 43.2								
331	M	17.9.73	39.0	15. 7.75	62.9	25.10.83	111.0	0.020
517	M	29.8.74	72.5	25. 7.75	82.1	29.10.83	127.5	0.016
931	M	28.5.75	171.0	19.10.83	180.0	--	--	0.003
131	F	19.8.73	27.0	23. 7.75	63.5	25.10.83	126.5	0.027
318	F	16.9.73	36.0	24. 7.75	58.2	24.10.83	93.5	0.016
Also recaptured 17.8.74 with SVL of 50.0								
1049	F	21.7.75	20.5	27.12.75	24.0	20.10.83	90.0	0.023
246	F	4.9.73	23.0	20.10.83	106.0	--	--	0.022

In Webb et al. (1978), there is a discussion of typical maximum sizes reached by *C. porosus* on different rivers. For males, they estimate (from hunters' reports) 4.2-5.0 m and for females, 3.2-3.7 m (though some male specimens are known to exceed 6.0 m). Cott (1961) in discussing the maximum size of *C. niloticus* quotes (also from shooters' reports) 4.0 to 4.6 m as the average for large crocodiles shot in an area in Central Africa, with specimens up to 6 m. In other areas animals up to 6.5 meters have been taken. Webb and Messel (1978) report a reliable measurement of a *C. porosus* specimen of at least 6.15 m, and less reliable reports give lengths over 8 m. The typical maximum size reached by *C. niloticus* and *C. porosus* do not appear to be all that different. From his data, Cott takes it as evident that the maximum size attained by *C. niloticus* differs widely according to locality, in agreement with the general opinion amongst hunters (quoted by Webb et al. 1978) that the typical maximum size of *C. porosus* males varies in different river systems and regions. This would fit in with our results for early growth, which appear to indicate differences between river systems. However in attempting to draw inferences about differences of growth of larger animals on different rivers, one must always remember that the animals can and do move between river systems.

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#### LITERATURE CITED

- Cott, H. B. 1961. Scientific results of an inquiry into the ecology and economic status of the Nile crocodile (*Crocodylus niloticus*) in Uganda and northern Rhodesia. Trans. Zool. Soc. Lond. 29:211-337.
- Deraniyagala, P. E. P. 1939. The tetrapod reptiles of Ceylon. Vol. 1, Testudines and crocodilians. Colombo Museum Natural History Series.
- Magnusson, W. E. 1978. Nesting ecology of *Crocodylus porosus*, Schneider, in Arnhem Land, Australia. Ph.D. thesis submitted to the School of Biological Sciences, University of Sydney.
- \_\_\_\_\_, and J. A. Taylor. 1980. A description of developmental states in *Crocodylus porosus*, for use in aging eggs in the field. Aust. Wildl. Res. 7:479-485.
- \_\_\_\_\_, and \_\_\_\_\_. 1981. Growth of juvenile *Crocodylus porosus* as effected by season of hatching. J. Herp. 15:239-242.
- Messel, H. et al. 1979-1986, Monographs 1-19. Surveys of tidal river systems in the Northern Territory of Australia and their crocodile populations. Pergamon Press Aust.
- Webb, G. J. W., R. Buckworth, G. C. Sack, and S. C. Manolis. 1983. An interim method for estimating the age of *Crocodylus porosus* embryos. Aust. Wildl. Res. 10:563-570.
- \_\_\_\_\_, and H. Messel. 1978. Morphometric analysis of *Crocodylus porosus* from the north coast of Arnhem Land, northern Australia. Aust. J. Zool. 26:1-27.
- \_\_\_\_\_, \_\_\_\_\_, J. Crawford, and M. J. Yerbury. 1978. Growth rates of *Crocodylus porosus* from Arnhem Land, northern Australia. Aust. Wildl. Res. 5:385-399.
- \_\_\_\_\_, \_\_\_\_\_, and W. E. Magnusson. 1977. The nesting of *Crocodylus porosus* in Arnhem Land, northern Australia. Copeia 1977:238-250.
- Worrell, E. 1964. Reptiles of Australia. Angus and Robertson, Sydney.

## STATUS AND CONSERVATION OF *Crocodylus porosus* IN AUSTRALIA

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Following very severe exploitation for the skin trade during the 1950's and 1960's, the Australian population of *Crocodylus porosus* was very severely depleted by the start of the 1970's (Bustard 1970, Messel pers. obs.). A total import-export ban on crocodile skins and products by the Federal Government in 1972 effectively ended the period of intensive exploitation, though this had already happened in many areas due to numbers being too low for economic exploitation.

In 1971 the University of Sydney Crocodile Research Group commenced its study of *C. porosus* in northern Australia. The results of this lengthy and extensive study have appeared in numerous publications covering the physiology, nesting, growth, movement, mortality and population structure and status of *C. porosus* over much of the northern Australian coastline.

An important aspect of this work has been the development of systematic survey methods to enable the numbers of *C. porosus* on the tidal waterways to be estimated and the carrying out of surveys using these methods over a period of years to monitor the changes in the population. (A full description of the survey methods used and of the Project's aims may be found in Chapters 1 and 2, Monograph 1, Messel et al. 1979-1986). In this chapter we only summarize the results of some ten years of night-time crocodile surveys, involving well over 70,000 km of river travel, and discuss the results.

During the period 1975-1979, using a research vessel as a floating base, some 100 tidal systems (Fig. 1, and Figs. 1 to 9, Chapter 9, Monograph 1) were surveyed systematically and many of these were surveyed more than once. In the Northern Territory 3,998 km of tidal waterways were surveyed; in Western Australia 527 km and in Queensland 643 km. The detailed results of the study and the analyses of these results appeared in a series of 19 Monographs (Messel et al. 1979-1986) and 2 Western Australian Reports (Messel et al. 1977, Burbidge and Messel 1979) and a series of specialist papers. Intensive population surveys and studies were continued during 1980, 1981, 1982 and 1983 on some 330 km of tidal waterways centered on the Liverpool-Tomkinson and Blyth-Cadell Rivers Systems in northern Arnhem Land and on some 59.3 km of associated alternative habitat. These relatively undisturbed waterways constituted our population dynamics and status monitoring systems. In addition Ngandada Creek and the Glyde River with its associated Arafura Swamp were resurveyed twice in 1983. During June-July 1984 we resurveyed the 861.2 km of tidal waterways in Van Diemen Gulf which includes the Adelaide and Alligator Region River Systems and the Cobourg Complex. In September-October 1985 the major tidal waterways of the southern Gulf of Carpentaria were resurveyed. All these latter surveys are analyzed in great detail in Monographs 18 and 19 (Messel et al. 1979-1986) and were described in the population dynamics chapter.

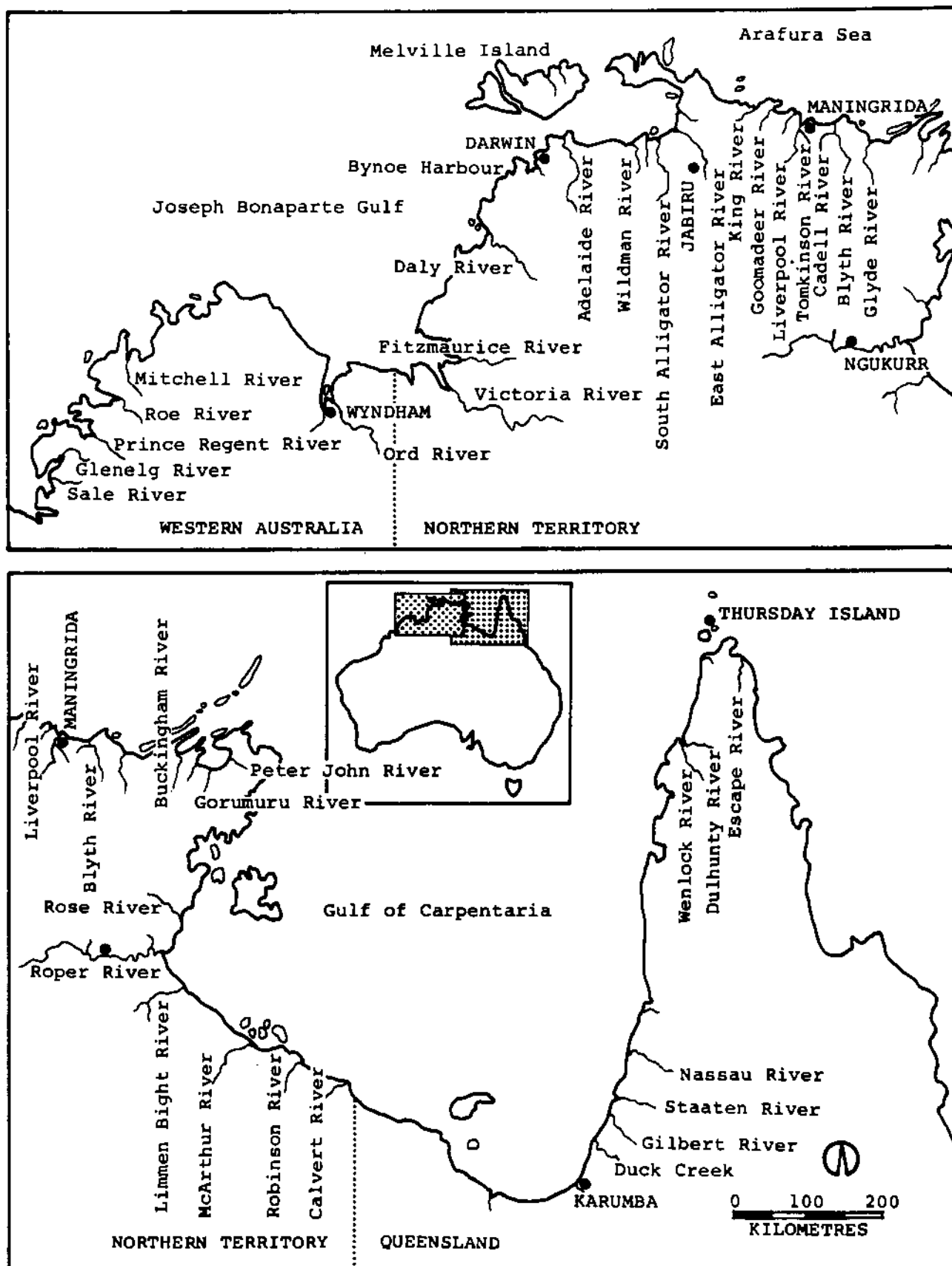


Figure 1. Area map, northern Australia, showing locations of some of the rivers surveyed.

The results of our surveys and studies have allowed a picture of *C. porosus* population dynamics in northern Australia to be developed and this picture was presented in some detail in our chapter on population dynamics. It enables us to account in a consistent fashion for the results of the surveys and to predict results to be expected on future surveys. The results also enable us to make an assessment of the overall status of *C. porosus* in northern Australia, and of the prospects for recovery of the population. Management implications of the results and population model are discussed also. The presentation here is necessarily very much abbreviated and the reader is referred to the 19 Monographs and 2 Reports for a wealth of supportive detail.

## STUDY AREA AND METHODS

**Study Area** - Figures 1 to 9 in Chapter 9, Monograph 1, enable the locations of all waterways surveyed to be ascertained. The approximately 100 waterways surveyed extend from the Sale River (124°36'E, 15°58'S) at the top of Cape York Peninsula in Queensland. The only major area of coastal *C. porosus* habitat inadequately sampled is the eastern coast of Cape York Peninsula. The waterways of the Northern Territory have been most thoroughly surveyed, most of them having been surveyed at least twice. Each of the Monographs (except 15) deals with the waterways of a particular area and, besides the results of crocodile counts, gives details of salinity and temperature profiles, tidal patterns, ranges and delays and fringing riverside vegetation. Color photographs in each Monograph illustrate the nature of the waterways. Detailed river work maps (of all waterways surveyed) with mileages are collated in Monograph 15 and show channels and navigational hazards such as rock bars and sand and mud bars. Figures 1-6 in our Population Dynamics Chapter in the current volume show the monitored area, the Alligator Rivers Region and the Adelaide River in more detail.

**Survey Methods** - The methods used for surveying tidal river systems and their crocodile populations are described by Messel (1977), Messel et al. (1978) (also see for full details, Chapter 2, 4, 5 of Monograph 1). Particularly, it should be noted that these methods do not necessarily apply to non-tidal systems or swamp habitats.

Night-time spotlight counts are normally conducted from two modified 5.5 m work boats, each with three or four staff members. A 3.5 m dinghy with a 9.9 HP motor is used for surveys of upstream areas, billabongs and small coastal creeks. The staff members include a spotter, driver and recorder/navigator.

Crocodiles can be located as the tapetum of their eyes reflects light and appears as a red glow in the beam of the spotlight. Counts can proceed when the tide leaves 60 cm or more of exposed bank (Plate 2.1, 1, Monograph 1) on the sections to be surveyed. This means surveys must normally be carried out within 2-3 hours of low tide, depending upon the tidal pattern. Most crocodiles are spotted in the shallow water at the edge of the river; surveying when  $\geq 60$  cm of bank is exposed assures that a minimal number are missed because of screening by vegetation.

The location ( $\pm 100$  m) of each crocodile spotted is recorded. Whenever possible, the animal is approached to within 6 m and its size is estimated by an experienced observer, who also notes its situation on the bank or in the water. Measurements are also made, at 5 km intervals, of air and water temperatures, salinity and light level.

The survey methods outlined yield a distribution of crocodile numbers and size classes for the tidal system. The question then is: what relation do these numbers have to the actual number of crocodiles on the system? The Blyth River calibration survey study was initiated in 1976 to gain



some insight into this difficult question (Messel 1977 and Monograph 1). Two 10 km calibration sections were surveyed 204 times.

It was shown in Monograph 1 that, providing surveys are made when  $EB \geq 60$  cm, in the manner indicated, there is no statistically significant variation in the fraction of crocodiles counted on surveys made during any time of the night and no significant variation between surveys made on incoming or outgoing tides. It was further shown that there is no consistent statistically significant variation between surveys carried out during different periods of the dry season.

In Monograph 1, it was also shown that the estimate for the actual number of crocodiles present on the river is approximated by the expression  $(aN \pm bN)$ , where  $N$  is the number of crocodiles sighted on a single survey ( $N$  to be  $> 10$ ) and the coefficients 'a' (the inverse of the average fraction of crocodiles counted) and 'b' have different values for the various size classes, and  $b$  includes the confidence level factor. Values of  $a$  and  $b$  are given in the accompanying Table. For instance, for non-hatchlings the implication is that 95% of observations would fall in the interval  $(1.64N \pm 2.01N)$  and 99% of the observations in the interval  $(1.64N \pm 2.64N)$ . For simplicity of interpretation, a difference between two counts will be called significant at the 95% (99%) level if the two counts do not overlap at their 95% (99%) confidence limits. These coefficients were derived on the basis that the counts were well described by the binomial distribution. Full details may be found in Chapter 5 of Monograph 1.

Size Classes	95% Confidence Level		99% Confidence Level	
	a	b	a	b
Hatchlings	1.59	1.89	1.59	2.49
Small (2-6')	1.49	1.68	1.49	2.21
Hatchlings plus small	1.52	1.73	1.52	2.28
Non-hatchlings	1.64	2.01	1.64	2.64
All crocodiles	1.59	1.89	1.59	2.49

## RESULTS

The picture of the dynamics of *C. porosus* that has emerged from our studies and which is presented in our earlier chapter on population dynamics, shows that when discussing population increases or decreases, it is usually essential to consider not only results for individual waterways, but also those for broad groups of tidal waterways. We were able to show in Monographs 1, and 9 to 11, that a decrease in crocodile numbers in a TYPE 1 tidal waterway need not necessarily imply that the population of *C. porosus* is decreasing. The decrease may only imply that a fraction of the sub-adult *C. porosus* has been excluded from the system by breeding adults. Furthermore, the surviving fraction of the excluded sub-adults could give rise to a increase in population numbers in adjacent TYPE 2 and TYPE 3 waterways, and they could in due course return to the TYPE 1 system. Because *C. porosus* is known to travel long distances (Webb and Messel 1978), it is necessary first to consider small geographic subgroups and then larger groupings of tidal waterways covering broader geographic areas, if one is to appreciate the overall changes occurring in the populations of *C. porosus*. The tidal waterways considered in each Monograph normally form a natural geographic subgroup and these often contain a mixture of TYPE 1, TYPE 2 and TYPE 3 systems. For instance those in Arnhem, Buckingham and Castlereagh Bays form such subgroups. In particular it should be realized that repeated surveys of just one part of a waterway can be of very limited value because of

seasonal adjustments that occur in the distribution of animals on a complete waterway, as well as movements in and out of the waterway.

In Table 1 we present the following results up to the end of 1979 for each survey of the tidal waterways of the Northern Territory, Western Australia and Queensland: the number of *C. porosus* sighted within each size class, the midstream distance surveyed, density of non-hatchlings sighted and the 95% confidence level for the estimate of the actual number of non-hatchlings present. Also shown is the broad classification of tidal waterway TYPE as determined by the salinity signature of the waterway. It usually does not include the often differing TYPES of the waterway's sidecreeks; the dominant TYPE only is normally given. All crocodiles whose size class could not be determined positively (the EO, EO > 6' and EO > 6' classes) have been lumped together and shown in the EO size class. When it is necessary to allocate these crocodiles to various size classes, it is probably best to use the scheme outlined in Table 3 in the Population Dynamics Chapter.

Our results for the tidal waterways of the Northern Territory are presented in the same sequence as the Monographs. We then group and sum the results for the latest survey of each waterway, according to TYPE 1 (and waterway whose TYPE has a "1" in it), TYPE 2-3 (any waterway whose TYPE has a "2" but not a "1" in it) and TYPE 3. The summing of these three then yields the overall results for the Northern Territory. The percentage which each size class constitutes of the total number of *C. porosus* sighted is also shown. Next, we present the overall results for subgroups of waterways, grouped according to geographic proximity. Wherever possible, we show results for the 1975 and 1979 surveys so that increases or otherwise in population size for the geographic areas concerned may be examined. Finally the latest surveys (up to the end of 1979) of the tidal waterways of the Northern Territory are gathered and summed for the four large geographic areas:

1. Gulf of Carpentaria, which covers tidal waterways from the Queensland border of Gove (Figs. 5 to 7 Chapter 9, Monograph 1).
2. North Arnhem Land, which covers the tidal systems from the Burungbirinung River in the east to the King River in the west (Fig. 5 Chapter 9, Monograph 1).
3. Darwin eastward to the Cobourg Peninsula including Melville Island waterways (Fig. 4 Chapter 9, Monograph 1).
4. Darwin westward, from Port Darwin to the Victoria River near the Western Australian Border (Figs. 2 and 3 Chapter 9, Monograph 1).

The total number of *C. porosus* sighted, to the end of 1979, on the 3,997.6 midstream km of tidal waterways surveyed in the Northern Territory was 5,472, of which 1,293 were hatchlings. Since only some 50% of hatchlings survive from June of their first year to June of the next (Table 8.4.1, Monograph 1), they should not be included in any estimate of the viable population. We therefore usually give densities and estimates for the actual number of crocodiles present for the non-hatchling classes only. On this basis the overall density of the 4,179 non-hatchling crocodiles sighted is 1.0/km and the 95% confidence levels for the estimate of the number present is 6,724-6,984. This figure and corrections made to it for waterways which were not surveyed is discussed later, as are the results for Queensland and Western Australia.

The density figure of 1.0/km is of very limited value, for the density of non-hatchlings sighted in TYPE 1 and non-TYPE 1 systems is quite different. On the 2,175.5 km of TYPE 1 tidal waterways surveyed, the density of the (4,491-1,197 =) 3,294 non-hatchlings sighted was 1.5/km whereas on the TYPE 2.3 and TYPE 3 systems it was 0.5/km and 0.4/km respectively.

The size class structure of the crocodilians sighted in the TYPE 1, 2 and 3 systems also varies (Table 1). However, it should be cautioned that there can be considerable overlap and merging between the system TYPES. For instance large TYPE 1 tidal waterways such as the Adelaide and Liverpool River systems contain TYPE 2 to TYPE 3 systems as well. If these were subtracted from the systems, the difference would be further exaggerated. Table 1 also shows the percentage which each size class constitutes of the total number of crocodiles sighted. Thus in TYPE 1 systems some 27% of the crocodiles sighted are hatchlings, whereas in TYPE 2-3 systems this figure falls to 14% and in TYPE 3 systems down to 4%, showing a much decreased hatchling recruitment in non-TYPE 1 systems. In TYPE 3 systems the percentage of crocodiles in the hatchling, (2-3') and (3-4') size classes combined is some 11% whereas in TYPE 1 systems it is at least 52%. On the other hand the percentage of crocodiles in the  $\geq$  (4-5') size classes is some 39% in TYPE 1 systems and 73% in TYPE 3 systems. These percentages do not take into account the EO class which amounts to 10%, 16% and 16% for TYPE 1, TYPE 2-3 and TYPE 3 systems respectively. However since large crocodiles are usually more wary than small ones (Webb and Messel 1979), any correction would tend to exaggerate further the differences between the TYPE 1 and non-TYPE 1 systems. It is likely that the difference between the figure of 10% for the EO size class in TYPE 1 systems and 16% for non-TYPE 1 systems is accounted for by the fact that there is a higher fraction of large crocodiles in non-TYPE 1 systems than in TYPE 1 systems. These results for size class structure indicate the utility and importance of our classification of waterways.

In Tables 1A and 1B of the Population Dynamics Chapter we give in the same format the results of surveys since 1979 in the monitored area, and in the Alligator Rivers Region and the Adelaide River. Table 2 of this Chapter gives the results for the resurveys of the waterways of the Gulf of Carpentaria carried out in 1985. For convenience, the earlier results for these latter systems are repeated in Table 2.

## POPULATION STATUS

1979 Estimate for the Northern Territory - On the basis of the surveys carried out up to and including 1979 we estimated in Monograph 1, Chapter 9, the total population of *C. porosus* in northern Australia. We now reproduce that estimate and the basis for it.

Of the 3,997.6 midstream km of tidal waterways surveyed in the Northern Territory in 1979, 54% (2,175.5 km) were TYPE 2-3 and 22% (883.7 km) were TYPE 3 systems. In making corrections for tidal waterways not surveyed, one should use the density appropriate to the waterway TYPE, because as we saw in the Results section the densities are quite different between the different TYPES.

Our estimate of the surveyable distances of tidal waterways not surveyed systematically in the Northern Territory is as follows:

	km
Melville and Bathurst Islands	330
Western Australian border to Gove	280
Gulf of Carpentaria	50
	660

Since practically all of these waterways are non-TYPE 1 systems, many being difficult to enter, and also since we had a very large sample of non-TYPE 1 waterways, it was thought not worthwhile endeavoring to survey them. During 1972 one of the authors (HM) had surveyed most of the

waterways on Melville and Bathurst Islands which were omitted thereafter, and it was found that these waterways contained even fewer *C. porosus* than those tidal waterways on Melville Island chosen for more intensive study (Monograph 6).

The shores of the coastline amounting to some 3,200 km were not surveyed either for a number of reasons. First there is the risk to life involved in trying to do so; secondly, on each occasion that we have surveyed long sections of bays and inlets at considerable cost and danger, we have sighted either no or only sporadic *C. porosus*. Though the density of *C. porosus* along the shores of the coastline may have been greater in bygone days, it is almost negligible at present and must be considerably less than 0.1/km (see Monograph 9). The reasons for this are probably many. The more important are that there are so few *C. porosus* and that they appear to dislike waves intensely (see Appendix A 1.2 of Monograph 1; wave action on the northern Australian coastline is high during much of the dry season). There is also little vegetation to provide cover along the long stretches of sandy and rocky foreshores.

In each tidal waterway surveyed, the survey boats proceeded as far upstream as depth of water would permit. In the case of non-TYPE 1 systems this constituted a much higher fraction of the overall waterway than in the case of TYPE 1 systems which have more extensive drainage courses. In most instances in non-TYPE 1 systems, the extreme upstream sections have no water in them near low tide and thus their omission yields almost negligible error in the estimate for the actual number of *C. porosus* present on the system. The case of TYPE 1 waterways is more complex, for here the waterway courses may have non-navigable (by survey boat) freshwater sections greater in length than the surveyed sections. These are usually beyond the tidal limit and often consist of intermittent waterholes with intervening sections which are dry during the dry season. *C. porosus* is known to inhabit the freshwater sections but its density is small. On these sections of the waterways *C. johnstoni* appears to be the main species (Monographs 2, 3, 12, 13 and 16). The Roper River is an example of such a river system, as are the McArthur, Adelaide, Alligators, Prince Regent, Mitchell, Ord and Victoria River systems. As pointed out in Chapter 6 of Monograph 1, in our discussion of the distributional pattern of *C. porosus*, the number of *C. porosus* sighted in the freshwater section of the Blyth River falls quickly and drastically as one proceeds further upstream. The same phenomenon was discussed again at some length in Monographs 10 and 12, where it was cautioned that care must be taken when comparing non-hatchling *C. porosus* densities of one waterway with another. By including long freshwater sections one can bring down the density figure to very low values. For instance on the Roper River we found a non-hatchling density of 1.14/km. The density of the 20 non-hatchlings sighted on the 68.5 km of freshwater sections above km 85 was only 0.3/km. During the calibration surveys on the Blyth River, the average density of non-hatchlings sighted on the first purely freshwater (km 40-45) section was only 1.1/km compared to at least 2.7/km for the whole river system. The density falls rapidly as one proceeds upstream of km 45. On the basis of the above discussion, one could perhaps add some 1,000 km of TYPE 1 river distance to the 2,175.5 km surveyed, but the density of *C. porosus* on these unknown sections is unlikely to be more than 0.2/km. During 1972 we systematically surveyed waterhole after waterhole on the sections of the Goyder River upstream of the Goyder crossing and sighted only 2 *C. porosus*. The Goyder River runs into the Arfura Swamp which is known to be one of the few large remaining freshwater swamp areas in northern Australia.

The relatively few freshwater swamps both large and small in the Northern Territory are known to contain populations of *C. porosus*, but these have not been inventoried systematically and the present extent of the populations in them remains unknown. However, from the many casual observations already made, we believe it is likely to prove to be considerably less than 20% of the population sighted in tidal river systems.

On the basis of the above and with due reservations being made, our generous estimate for the number of sightings of non-hatchling *C. porosus* in the Northern Territory which were omitted from our tidal river survey is:

Unsurveyed tidal waterways (660 km x 0.5/km)	330
Unsurveyed freshwater sections of TYPE 1 systems (1,000 km x 0.2/km)	200
Unsurveyed foreshores of coastline (3,200 km x 0.05/km)	160
Freshwater swamps, taking 20% of the number sighted in tidal systems	836
	1,526

If one applies the same confidence limits for these 1,526 non-hatchlings as we have for our surveys (this procedure for the assumed 836 non-hatchlings in freshwater swamps is dubious, but is as valid an assumption as any other at present!) then there could be between 2,424 and 2,582 non-hatchlings additional to the 6,724-6984 derived from the surveys. Thus using  $(4,179 + 1,526 =)$  5,705 non-hatchlings, there could be between 9,204 and 9,508 non-hatchling *C. porosus* in the Northern Territory as of October, 1979. We feel it would require unrealistic assumptions to carry this figure much above 10,000. We even retain some doubts about the maximum figure of 10,000; it may well be a substantial overestimate. On the other hand, we do feel that our estimate of 6,724 to 6,984 is a reliable lower one for the actual number of non-hatchling *C. porosus*, for this figure is based upon careful and systematic observations made over a period of almost 5 years and some 50,000 km of waterway travel.

**Western Australia in 1978** - Tidal river systems in the Kimberley were chosen for survey by the Department of Fisheries and Wildlife, Western Australia (Messel et al. 1977, Burbidge and Messel 1979). It is believed that the majority of the large Kimberley tidal waterways were surveyed; the only significant areas not surveyed are the Walcott Inlet-Secure Bay area and the West Arm of the Cambridge Gulf, with their associated rivers and creeks. It is also believed that small populations occur in such areas as the mouth of the Drysdale River. Commonly, small coastal rivers and creeks in the Kimberley have short surveyable tidal sections which are terminated by rocky ledges and often by waterfalls.

We believe that we examined more than half of the better *C. porosus* habitat in the Kimberley. In the 527.3 km surveyed, 898 crocodiles were sighted of which 227 were hatchlings. The 671 non-hatchlings yield a density of 1.3/km and the estimate for the actual number of non-hatchlings present, at the 95% confidence level, is 1,048-1,152. Assuming that the number of non-hatchlings which would be sighted in the areas not surveyed is also 671 we obtain lower limits of 2,127-2,275 for the number of non-hatchlings remaining in the Kimberley as of July 1978. One can extend this estimate (of say 2,500) almost without limit if one cares to make what we feel would be unreasonable assumptions.

**Queensland in 1979** - A sample of four major tidal waterways on the west coast of southern Cape York Peninsula, which were known to have contained some of the best populations of *C. porosus* during the 1950's and 1960's, was chosen by the Queensland National Parks and Wildlife Service for survey. In addition the Port Musgrave area, containing what is believed to be the best remaining tidal waterway habitat for *C. porosus* in Queensland, and the Escape River on north-eastern Cape York Peninsula, were also chosen for survey. As seen in Table 1, the results for the Port Musgrave area and the other areas were quite different. Whereas the non-hatchling density was 1.8/km for the 241.0 midstream km surveyed on the Port Musgrave waterways, the non-

hatchling density for the groups of waterways on south-western Cape York Peninsula (359.7 km) was only 0.4/km surveyed) is 0.9/km and the estimate at the 95% confidence level for the actual number of non-hatchlings present is 945-1,043.

What estimate can one make for the number of non-hatchling *C. porosus* in overall northern Queensland? The lengths of the remaining waterways on the maps look large, but most of the rivers have relatively short navigable sections. Without carrying out further surveys one can only make a broad estimate; it would be surprising if non-hatchling *C. porosus* densities on them were as high as the 0.4/km we found for the southern waterways surveyed. Erring on the generous side, we estimate that there are probably a further 2,400 km of waterways not surveyed. Using a non-hatchling density of 0.4/km this would yield a further 960 crocodiles which would be sighted. On this basis, the estimate at the 95% confidence level for the actual number of non-hatchling crocodiles present, using the  $(606 + 960 =)$  1,566 value, is 2,488 to 2,648 or say 3,000. However, without further surveys one is unable to substantiate this number.

Northern Australia in 1979 - We now have estimates for the populations of non-hatchling *C. porosus* in the Northern Territory, the Kimberley of Western Australia and northern Queensland. However only the figures for the tidal waterways surveyed may be deemed to be reliable; the remainder are probably upper limits and may be over-estimated considerably. With this warning in mind our upper estimates for the non-hatchling *C. porosus* populations were:

Northern Territory	10,000
The Kimberley	2,500
Northern Queensland	<u>3,000</u>

15,500.

'Dry Wet' Seasons in estimating population status - 'Dry wet' seasons play a very important role in the dynamics of *C. porosus* populations, and it was the continuing of the surveys after 1979, in the monitoring area, that allowed us to unravel this as we described in our Population Dynamics Chapter--see Tables 1A and 1B of the same Chapter. By a 'dry wet' we mean a wet season which has considerably less than the usual amount of rainfall and thus does not give rise to extensive flooding of the tidal upstream sections of the waterways. The wet season of 1978-1979 was an exceptionally dry one and those of 1981-1982 and 1982-1983 were also dry ones. As is evident from the Tables, there was in 1979 an increase in the number of sightings in the tidal waterways, right across the Northern Territory. At the time we interpreted this increase as a sign of the expected recovery of the population. Now, however, we believe this interpretation may have been too optimistic. To account for the results in our monitoring area, the only reasonable explanation we are able to give, which is in accord with the observations made during the 1979, 1982 and 1983 surveys following 'dry wet' seasons, is that the Arafura Swamp is acting both as a breeding system (during normal wet season periods) and as a rearing stockyard of varying extent, for sub-adult crocodiles from Arnhem Bay in the east to the King River in the west. The Blyth-Cadell System is a very important component of this. During a severe 'dry wet' season as in 1978-1979, the water levels in small and large swamps fall drastically and crocodiles inhabiting these have no choice but to leave. They can only return to the tidal waterways, both TYPE 1 and non-TYPE 1, and this they do--as they did in 1979 and 1982. Many animals frequenting the alternative freshwater habitat must have come from TYPE 1 tidal breeding systems and hence, as the swamps dry, some of the sub-adult animals probably return to the tidal system from whence they originally came, the others apparently have to frequent non-TYPE 1 tidal systems--even though temporarily--until they can go back to the swamp rearing stockyard or a TYPE 1 system. Some of the returning large animals appear successful in establishing a territory for themselves (and perhaps a few of the 3-6' animals also); the others appear to be excluded yet again--and specially the 3-6' and sub-adult large

animals--on the commencement of the breeding season. When the next 'dry wet' arrives [if there has been the usual wet season(s)], large and sometimes 3-6' animals again are excluded from the swamps and the degree of the process must depend upon just how 'dry' the wet season is--upon how much the swamp water levels fall. The whole process is superimposed upon the normal exclusion and re-entry of animals which takes place in usual years and which accounts for most of the sub-adults sighted in non-TYPE 1 systems. Thus, whether 'dry wet' seasons are the proximal factor involved or not, they are certainly associated with the major influxes of large and sometimes 3-6' animals sighted on the tidal waterways during surveys made in June-July, after a 'dry wet'. Thus 'dry wets' appear to play a very important role in the dynamics of *C. porosus* populations.

As we have said, the influxes of large and sometimes small animals in 1979 were in fact a general phenomenon on the tidal waterways of the Northern Territory (Table 1). It was especially marked on the waterways of the Alligator Region (on the Wildman, for example, 21 large animals were sighted in September, 1978 and 56 were sighted in August, 1979). Both these systems have fairly extensive associated freshwater complexes. Increases also occurred on non-TYPE 1 systems with little associated freshwater complexes, for example on the TYPE 3 waterways of the Milingimbi Complex the number of animals  $\geq 4-5'$  increased from 29 to 63 between 1975 and 1979. In the latter cases the animals could only have come from further afield (in the Milingimbi case, from the Arafura Swamp via the Glyde River). A very interesting exception to the general pattern was the waterways of Arnhem Bay. There was no increase in the number of large animals sighted between 1975 and 1979, and this could be connected with the relative lack of swamp associated with this whole area and the somewhat wetter climate there.

**1985 Update** - Our estimate of 15,500 for 1979 was based, as discussed earlier, on counts carried out in a year when most crocodiles were concentrated into the tidal waterways. Our allowance for the numbers in the relatively scarce swamp areas was very likely too generous; it is hard to know with certainty as systematic and reliable surveying of such freshwater habitat has not been carried out extensively and usually requires methods quite different from those applicable on tidal waterways. In October, 1983 we surveyed the largest remaining open body of water in the Arafura Swamp (the old Arafura billabong) and sighted 70 animals including 32  $\geq 6'$ , concentrated into its 2 km. Taking into account the few remaining open water billabongs and low water level in the swamp, we estimated 400 as a generous upper limit to the number of crocodiles in the swamp at that time.

Our results in the monitored area between 1979 and 1983 (see Tables 1A and 1B of the Chapter on Population Dynamics and the "Overview" paper in Monograph 18) gave no reason for modifying the 1979 estimate by much to obtain the 1983 population.

Though there appears to have been no sustained significant increase in the number of non-hatchling crocodiles sighted on the tidal waterways of the Maningrida area since our surveys started in 1974, the size structure of the animals sighted appears to have been changing slowly. Notwithstanding substantial fluctuations, the ratios of small (2-6") to large ( $\geq 6'$ ), and 3-6' to large animals was decreasing on the Blyth-Cadell, may have been decreasing on the Liverpool-Tomkinson and was decreasing overall on the tidal waterways of the Maningrida monitoring area. Thus there was some indication of the commencement of a slow recovery phase.

In the case of the tidal waterways of the Alligator Region and the Adelaide River System, we were able to show (Population Dynamics Chapter), as expected from the model, an important and apparently continuing recovery was underway; that the Adelaide River System was recovering faster than the rivers of the Alligator Region. The tidal waterways in the Alligator Region indicate the potential for recovery, at a rate equal to or even better than that found for the Adelaide System. However, at present too many crocodiles are being killed in fishing nets so the potential

cannot be realized until the commercial net fishing for barramundi is halted in these rivers, all of which are in Australia's Kakadu National Park. Restoration of habitat after eradication of the feral water buffalo will also aid the full recovery of the population (both in the Alligator Region and the Adelaide River). The Adelaide however does not have the protection of being in a national park.

The present results for the 787 km of tidal waterways resurveyed in the southern Gulf of Carpentaria (Table 2) shows that the *C. porosus* population in this area remains as severely depleted today as it was in 1979. There has been no significant change in this population, however there is some hint, from the smaller numbers sighted in the TYPE 3 creeks, that it is dropping even lower. There can be little hope for these populations in the southern Gulf if barramundi netting in the area is not severely curtailed. Even the *C. porosus* population in the Roper River System is in great danger, if netting is allowed to continue well upstream--to the km 61.5 point. This ensures that the major fraction of the *C. porosus* population in the System is within the netting limit (see Fig. 12.31 Monograph 12). If the Roper System is depleted then there will be little hope for the long term survival of the remnant *C. porosus* population in the other tidal systems in the southern Gulf of Carpentaria, such as the Limmen, Towns, Yiwapa and Nanyarpi nearby. These systems depend to a large degree on animals excluded from the Roper System. They cannot rely on animals excluded from the large McArthur System, for it is already as depleted as they are.

During the past three dry seasons we have resurveyed some 2,111 km of tidal waterways in the Northern Territory as follows:

		km
1983	Northern Arnhem Land, Maningrida area	462.9
1984	Alligator Region - Adelaide River Systems and Cobourg Complex	861.2
1985	southern Gulf of Carpentaria	<u>787.0</u>
		2,111.1

This constitutes more than 50% of the some 4,000 km of tidal waterways surveyed to the end of 1979 in the Northern Territory.

On the basis of the data we have gathered on our resurveys between 1979 and 1983, and during 1983, 1984 and 1985, we can now update our 1980 estimate for the non-hatchling *C. porosus* population in the Northern Territory (Chapter 9 Monograph 1). Keep in mind that such a large portion of the hatchlings are lost each year that they are not a good indicator of population trends. Hatchling numbers may increase dramatically during the hatchling season and decrease during the rest of the year; they are also very variable from year to year. If a census were taken later in the year after many hatchlings have been lost, the same population would be smaller. This is why crocodilian monitoring programmes all over the world, e.g., North America, India, Africa, focus on non-hatchlings. Our 1980 estimate was 10,000 non-hatchlings and allowing for the recovery of the population on the Adelaide and Alligator Rivers we found in 1984, we feel that estimate might be increased by up to 20 percent, perhaps to a figure of some 12,000 non-hatchlings now. One cannot be more precise about such an estimate.



The probability of the *C. porosus* populations in the Kimberley of Western Australia recovering over a period of several decades is fair, especially in the George Water, St. George Basin, Roe-Hunter and Ord River waterways where barramundi net fishing in the rivers is minimal and there is no destruction of nesting habitat by feral water buffaloes. We will be resurveying areas in Western Australia in 1986.

The same cannot be said for most of the tidal waterways in northern Queensland, especially in the light of our resurveys of the southern Gulf of Carpentaria. In these, the density of *C. porosus* is probably already at dangerously low levels and recruitment is minimal. Barramundi net fishing which is allowed in the rivers is not only quickly exhausting the rapidly dwindling barramundi resource but is drowning a substantial fraction of the few remaining large *C. porosus*. It is likely that, with the exception of the Port Musgrave area, the population of *C. porosus* in northern Queensland is still falling and is well on the road to exhaustion.

### MANAGEMENT OF THE *C. porosus* POPULATION

What are the management implications of our results? We are not management authorities, but are aware that a multitude of factors--some of them political--must be taken into consideration. For example, for reasons based on public safety, Australian society could decide that all waterways utilized for business and/or pleasure or which had settlements near them, should be cleared of *C. porosus* and the *C. porosus* should be allowed to exist and perhaps recover, only in a number of designated parks and/or reserves used for scientific and/or tourism purposes (we have suggested some suitable areas in Chapter 9, Monograph 1, p. 439). Such a decision would result in the removal of *C. porosus* from many of the waterways in northern Australia and could have far reaching ecological consequences, many of which probably could not be foreseen beforehand. Based on examples from elsewhere in the world, we know that the removal of a predator from the top of a complex food chain cannot occur without some major consequences. The Australian people would have to decide whether the unhindered enjoyment of the waterways of northern Australia is worth the risk of possibly disastrous consequences to the whole ecology of the waterways. The fishing industry is one group that readily springs to mind as a possible sufferer.

Or it might be decided to encourage the establishment of a commercial *C. porosus* skin industry based upon the wild population. Since some 70% of the 3-6' animals are lost--and these are the most valuable ones commercially--one is tempted to believe that their removal beforehand would yield a valuable resource without harming it. But one must proceed with extreme caution before embarking upon such an enterprise. Undoubtedly the exclusion and/or loss of some 80% of the 3-6' animals is an integral part of the vital process of sorting out the successful from the less successful, or sorting out the stronger and more dominant component of the population. Removing a given fraction of the population might very well remove the stronger component and thus over the long term set the population on a declining course. We simply do not know. On page 15 of Monograph 1, we proposed in 1981 a critical experiment to test the effect of removing a given fraction of the (3-6') *C. porosus* population and proposed that some 25 to 40% of the (3-6') animals be removed annually for a period of 4 to 5 years from the downstream sections of the Adelaide River to see what effect if any this had upon the population in that river. For the experiment to be meaningful, one had to monitor the population changes on another set of control tidal waterways in which the *C. porosus* population remained untouched. The University of Sydney financed the costly monitoring of a control group of waterways for 4 years and this work has now been completed successfully. Though the proposed experiment had very important ramifications for the management and ranching of the *C. porosus* resource, no financial support had been forthcoming, from relevant authorities, for the other half of it. The original opportunity has been

lost, but the experiment still must be done (though at much greater cost) so that important management decisions can be made on an adequate data base.

We have already mentioned two very important factors affecting any possible *C. porosus* recovery, that can be influenced by correct management. The first of these is prevention of further destruction to habitat by the feral water buffalo and a program to allow recovery of already damaged habitat. The second factor is the continuing loss by drowning in fishermen's nets of hundreds of large crocodiles per year (see Monograph 1:437-438). Some of these nets are set legally. Our results show that over 80% of the 3-6' animals are excluded from many TYPE 1 waterways and that this exclusion also involves large animals; that there is great and continuing movement of these animals into and out of the river systems. Allowance of net fishing in or at the mouths of rivers, specially the TYPE 1 waterways is certain to remove an important component of the large animals and could well ensure that the population in those waterways never recovers or even declines. For instance, we believe that the decrease in the number of large animals sighted on the West Alligator and Wildman Rivers shown in Table 9 of the Population Dynamics Chapter is probably due to the continuing heavy commercial net fishing in those rivers. The total lack of any recovery over six and a half years in the waterways of the southern Gulf of Carpentaria, described earlier, is also undoubtedly due to continuing net fishing.

Undoubtedly economic and political considerations are involved in arriving at a reasonable compromise in relation to the matter of commercial net fishing in tidal waterways. We have no desire whatever to become involved in argumentation about it. At the very minimum it is suggested that all net fishing be definitely phased out over a period of two years in rivers included in national parks (it is still legal to set nets in the tidal waterways of Kakadu National Park). The continued loss of very valuable large crocodiles in the quest for the rapidly dwindling barramundi resource should be stopped.

Crocodile farming should be encouraged and removal of eggs from the wild from nests which are known to be flooded during the January-March period might be considered on certain selected tidal waterways. Early November nests or March-April late nests must not be robbed. Because of the heavy losses of hatchlings and 3-6' animals, we feel that release of such animals into TYPE 1 systems, except in cases of very depleted systems, is purely cosmetic and a waste of effort. If restocking is to be considered then TYPE 2-3 or TYPE 3 systems and freshwater complexes should be used, and only  $\geq 4'$  size classes should be released. Even then, many uncertainties remain about the success of such a restocking policy.

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## LITERATURE CITED

- Burbridge, A.A. and H. Messel. 1979. The status of the salt-water crocodile in the Glenelg, Prince Regent and Ord River Systems, Kimberley, Western Australia. Dept. Fish. Wildl. West Aust. Rept. 34:1-38.
- Bustard, R.H. 1970. Report on the current status of crocodiles in Western Australia. Dept. Fish. Fauna West. Aust. Rept. No. 6.
- Messel, H. 1977. The crocodile programme in northern Australia: population surveys and numbers. Pages 205-236 in H. Messel and S. T. Butler, eds. Australian Animals and their Environment. Shakespeare Head Press, Sydney.
- \_\_\_\_\_, et al. 1977. The status of the salt-water crocodile in some river systems of the north-west Kimberley, Western Australia. Dept. Fish. Wildl. West Aust. Rept. 24: 1- 50.
- \_\_\_\_\_, et al. 1979-1986. Surveys of tidal rivers systems in northern Australia and their crocodile populations. Monographs 1-19. Pergamon Press, Sydney.
- \_\_\_\_\_, A. G. Wells, and W. J. Green. 1978. *Crocodylus porosus* population studies. Survey techniques in tidal river systems of northern Australia. Proc. of 4th Working Meeting of the IUCN/SSC Crocodile Specialist Group held in Madras, India, February 6-12.
- Webb, G. J. W. and H. Messel. 1978. Movement and dispersal patterns of *Crocodylus porosus* in some rivers of Arnhem Land, Northern Australia. Aust. Wildl. Res. 5:263-283.
- \_\_\_\_\_ and \_\_\_\_\_. 1979. Wariness in *Crocodylus porosus*. Aust. Wildl. Res. 6:227-234.

Table 1. Number of *C. porosus* sighted within size class on tidal waterways of the Northern Territory, Western Australia and Queensland during night-time spotlight surveys<sup>a</sup>.

System	Date	Total	H	2-3	Numbers in size class					>7	E.O. surveyed	Kilometers surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7							
BLYTH-CADELL	MONOGRAPH 1														
	Oct. 74	387	89	81	147	58	6	2	4	4	91.9	3.2	454- 524	1	
	Nov. 75	353	50	106	81	72	23	4	2	15	94.9	3.2	462- 532		
	Sept. 76	348	82	63	104	46	14	7	6	26	92.0	2.9	403- 469		
	Nov. 76	307	61	61	103	47	10	4	2	19	92.0	2.7	371- 435		
	Apr. 77	327	72	70	108	48	10	2	4	13	92.0	2.8	386- 450		
	May 77	333	88	60	94	55	13	4	1	18	92.0	2.7	370- 432		
	June 77	365	108	36	102	69	13	10	3	24	90.5	2.8	389- 453		
	Sept. 77	386	105	45	132	47	17	4	4	32	90.5	3.1	427- 495		
	Oct. 77	360	112	68	83	47	18	8	3	21	90.5	2.7	375- 439		
	June 78	432	173	65	81	67	15	6	4	21	90.5	2.9	393- 457		
	Sept. 78	399	155	60	79	56	18	8	6	17	90.5	2.7	369- 431		
June 79	465	123	91	93	59	31	16	26	26	94.5	3.6	524- 598			
VICTORIA FITZMAURICE	MONOGRAPH 2														
	Aug. 78	139	13	8	21	22	26	8	13	28	229.1	0.6	184- 230	1	
	Aug. 78	79	9	5	13	25	6	4	11	6	146.6	0.5	98- 132	1	
ADELAIDE	MONOGRAPH 3														
	July 77	417	48	24	88	116	47	35	33	26	226.3	1.6	566- 644	1	
	Sept. 78	381	62	24	71	90	43	33	32	26	221.0	1.4	487- 559		
	Sept. 79	374	53	8	46	75	58	47	64	23	231.6	1.4	490- 562		
DALY MOYLE	Aug. 78	115	5	7	16	25	21	11	18	12	90.0	1.2	159- 201	1	
	Aug. 78	16			1	4	2	1	2	6	10.0	1.6	18- 34	1	
MURGENELLA	MONOGRAPH 4 (14)														
	Oct. 77	95	1	1	8	33	13	6	18	15	45.9	2.0	135- 173	1	
	June 78	173	48	16	4	17	24	23	30	11	44.9	2.8	183- 227		
	Aug. 79	198	47	24	12	22	24	27	26	16	45.6	3.3	223- 273		

Table 1. cont.

System	Date	Total	H	2-3	Numbers in size class					>7	E.O.	Kilometers surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7							
EAST ALLIGATOR	Oct. 77	318	53	18	37	57	41	40	34	38	114.9	2.3	402-468	1	
	June 78	329	39	14	63	51	42	31	51	38	118.9	2.4	442-510		
	Aug. 79	393	53	30	44	58	28	58	64	58	119.2	2.9	521-595		
SOUTH ALLIGATOR	Oct. 77	142			12	24	24	25	31	26	113.8	1.2	209-257	1	
	July 78	157	6	3	4	14	43	24	38	25	113.2	1.3	223-273		
	Aug. 79	164	4	1	4	12	24	31	51	37	114.0	1.4	237-287		
WEST ALLIGATOR	Oct. 77	83	9	2	14	14	15	10	10	9	42.2	1.8	104-138	1	
	July 78	85	23	5	12	9	13	10	6	7	40.4	1.5	86-118		
	Aug. 79	96	12	9	13	14	7	12	14	15	42.2	2.0	120-156		
WILDMAN	Sept. 78	118	53	16	6	8	10	9	7	9	33.5	1.9	91-123	1	
	Aug. 79	155	21	34	15	14	7	17	31	16	33.5	4.0	197-243		
<u>MONOGRAPH 5</u>															
GOOMADEER	Aug. 75	46		27	7	5	4			3	45.3	1.0	61-89	1	
	Sept. 76	52	18	5	8	5	1	3	3	9	45.3	0.8	44-68		
	June 77	50	2	9	13	10	6	2	1	7	45.3	1.1	65-83		
KING	July 79	90	29	14	7	14	10	6	1	9	45.3	1.4	84-116		
	Aug. 75	17	3	3	3	2			4	2	52.0	0.3	15-31	2	
	Aug. 76	37	12	8	7	1	1	1	4	3	52.0	0.5	31-51		
MAJARIE	June 77	38	18	4	5	5	1		1	4	48.7	0.4	24-42		
	July 79	48	3		11	10	9	2	5	8	48.5	0.9	61-87		
	Aug. 75	12	1	1	2	2	1	1	2	2	20.1	0.5	11-25	3	
WURUGOIJ	Aug. 76	7			3					4	20.1	0.4	7		
	July 79	18			1	7	4	1	3	2	24.1	0.7	21-39		
	Aug. 75	4				3	1				16.4	0.2	4	3	
ALL NIGHT	Aug. 76	1								1	16.4	0.1	1		
	July 79	9							4	1	16.4	0.5	9		
	Aug. 75	3				2	2	2			9.1	0.3	3	3	
	Aug. 76	0				2					9.1	0.0	0		
	July 79	6		1				1		4	9.1	0.6	6		

Table 1. cont.

System	Date	Total	H	2-3	Numbers in size class					>7	E.O.	Kilometers surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7							
<b>MONOGRAPH 6</b>															
ANDRANANGOO	June 75	40	14	2	5	6				2	11	47.8	0.5	33- 53	1
	Nov. 75	17		1	4		1	2	2		7	47.8	0.4	20- 36	
	Aug. 76	41	7	1	8	10	3	3	1		8	47.8	0.7	44- 68	
	June 77	43	7	1	5	9	4		3		14	47.8	0.8	47- 71	
	Oct. 79	56	4	1	3	9	7	6		10	16	48.4	1.1	71- 99	
	Oct. 72	15	2	2		3				8		22.4	0.6	14- 28	2-3
	July 75	10	4			1	4			1		22.4	0.3	6	
	Nov. 75	2				2						22.4	0.1	2	
	Aug. 76	17	3	2	3		1	1	5		2	22.4	0.6	15- 31	
	June 77	17	5	1	3	3	1	1	3			22.4	0.5	13- 27	
	Oct. 79	15			3	3	3	2	5		2	22.4	0.7	17- 33	
	Oct. 72	4									4	30.0	0.1	4	2-3
	June 77	17				3	3	3	7		4	30.0	0.6	20- 36	
	Oct. 79	14			1	4	4	4	1		4	36.3	0.4	15- 31	
OVERALL															
JOHNSTON	Oct. 79	20			2	1	5	5	2		5	89.8	0.2	24- 42	
BATH	Oct. 72	0										15.0	0.0	0	2-3
	July 75	0										12.0	0.0	0	
	Oct. 79	5		1	1	1	1		1		1	14.5	0.3	5	
	Oct. 72	0										14.5	0.0	0	
	July 75	1					1					14.5	0.1	1	
	Nov. 75	0										14.5	0.0	0	
	Aug. 76	1								1		14.5	0.1	1	
	Oct. 79	6			1	2	2	1	1		1	14.5	0.4	6	
<b>MONOGRAPH 7</b>															
LIVERPOOL-	July 76	228	19	39	56	27	13	3	3		68	152.2	1.4	314- 372	1
TOMKINSON	May 77	245	40	6	51	59	30	13	5		41	145.1	1.4	307- 365	
	Oct. 77	228	56	7	39	62	24	9	1		30	123.4	1.4	256- 308	

Table 1. cont.

System	Date	Total	H	2-3	Numbers in size class					>7	E.O.	Kilometers surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7							
LIVERPOOL-TOMKINSON	Sept. 78	233	37	18	37	65	19	14	8	35	141.4	1.4	293- 349		
	July 79	515	289	11	39	43	34	29	20	50	150.0	1.5	341- 401		
	Oct. 79	355	161	16	36	37	29	17	23	36	141.1	1.4	290- 346		
	Aug. 75	29		4	11	3		1		10	15.0	1.9	37- 59	2	
	July 76	15	2		3	5	1	1		3	13.6	1.0	14- 28		
NUNGBULGARRI	June 77	14	2	2		6	1	1		2	13.6	0.9	13- 27		
	July 79	35	10		4	4	6	5	2	4	14.8	1.7	31- 51		
	<u>MONOGRAPH 8</u>														
	Oct. 78	7				2		3		2	23.5	0.3	7	1	
	Oct. 78	3				1				2	6.7	0.4	3	2	
ROSE	Oct. 78	4				1				3	7.5	0.5	4	2	
	Oct. 78	15	1		4	2	1	2	1	4	24.4	0.6	15- 31	1	
	Oct. 78	5				1	1	2	1	1	11.0	0.5	5	1	
	<u>MONOGRAPH 9</u>														
	Sept. 75	3			1	1		1			17.6	0.2	3	3	
BENNETT	June 79	10			1	1	3	2	3		53.0	0.2	10- 22		
	Aug. 75	13		1		5	3	2	1	1	34.8	0.4	14- 28	2-3	
	June 79	19		2		2	3	3	3	9	35.7	0.5	22- 40		
	Sept. 75	8		1	1	5	1			5	23.0	0.4	8	3	
	June 79	23	1			2	6	5	4	5	25.0	0.9	27- 45		
DJABURA	Sept. 75	3			1	2					21.6	0.1	3	3	
	June 79	14	1		1	7	3	1		1	25.7	0.5	14- 28		
	Sept. 75	19	3	2	5	1	1	2	1	4	22.6	0.7	18- 34	3	
	June 79	21			2	3	3	4	4	5	23.9	0.9	25- 43		
	Sept. 75	31	5	2	5	3	1	3	6	6	80.4	0.3	33- 53	2	
NGANDADAUDA	July 79	57	14	3	6	10	4	2	12	6	102.5	0.4	58- 84		
	Sept. 75	28			3	6	2	1	4	12	45.9	0.6	35- 57	1	
	July 79	100	36	9	10	9	10	6	6	14	45.9	1.4	89- 121		
	WOOLEN														
GLYDE															

Table 1. cont.

System	Date	Total	H	2-3	Numbers in size class					>7	E.O.	Kilometers surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7	(not used)						
CADELL															
CREEKS	Sept. 75	4		1		1	1				1	7.0	0.6	4	3
HUTCHINSON	Sept. 75	25	6	5	3	4	1	3		2	1	58.3	0.3	22-40	3 &
	July 79	56	10	3	5	9	13	6		1	9	78.5	0.6	61-89	mini 1
KALARWOI	Sept. 75	82	38	15	17	3	4			4	1	38.9	1.1	59-85	1 &
	June 79	132	45	7	16	19	11	16		7	11	40.1	2.2	124-162	2-3
BUCKINGHAM	Sept. 75	100	10	42	8	14	8	1		3	14	31.1	2.9	129-167	2
	June 79	101	16	7	24	17	9	8		4	16	35.3	2.4	120-158	
WARAWURUWOI	Oct. 75	18		1	3	5	4	1		2	2	28.8	0.6	21-39	3
	June 79	34			1	4	3	7		9	10	37.0	0.9	44-68	
KURALA	Oct. 75	16			3	5	2	1		2	3	27.8	0.6	18-34	3
	June 79	26				6	7	3		6	4	36.4	0.7	33-53	
SLIPPERY	Oct. 75	9			2	1	2	1			3	11.0	0.8	9	3
	June 79	20		2	5	7	2	4				10.7	1.9	24-42	
<u>MONOGRAPH 11</u>															
BURUNGBIRINUNG	Oct. 75	13	9	2			2					13.0	0.3	4	2
	May 79	37	3	8	7	8	3	3			5	11.7	2.9	44-68	
PETER JOHN	Oct. 75	142	27	58	17	23	7	3		4	2	41.5	2.8	167-211	1
	May 79	300	136	60	48	21	11	5		3	16	42.1	3.9	243-295	
CATO	Oct. 75	108	59	6	19	10	9	1		3	1	23.5	2.1	66-94	1
	May 79	89	34	19	19	5	3			4	5	23.0	2.4	75-105	
DARWARUNGA	Oct. 75	15		1	4	7	1	1		1		47.8	0.3	17-33	2-3
	May 79	34	1	1	6	10	5	2		2	7	45.0	0.7	42-66	
HABGOOD R.	Oct. 75	101	13	24	14	25	10	2		4	9	22.0	4.0	125-163	1
	May 79	111	23	15	23	23	15	3		2	7	22.1	4.0	125-163	
HABGOOD CK.	Oct. 75	6			1	2	1				2	4.4	1.4	6	3
	May 79	4				3					1	3.4	1.2	4	
BARALMINAR	Oct. 75	15			1	6	4	1		3		25.2	0.6	17-33	2-3
	June 79	30			5	13	4	3			5	26.4	1.1	38-60	



Table 1. cont.

System	Date	Total	H	2-3	Numbers in size class					E.O.	Kilometers surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7	>7					
GOBALPA	Oct. 75	15	2		3	6	2	1		1	19.3	0.7	14- 28	2-3
	June 79	17			3	5	3	2	4		21.3	0.8	20- 36	
GOROMURU	Oct. 75	299	128	95	37	14	7	6	6	6	44.3	3.9	254- 306	1
	June 79	410	134	58	139	31	10	5	7	26	48.0	5.8	420- 486	
LIMMEN BIGHT	May 79	19	1	1		3	8	3	2	1	127.3	0.1	21- 39	2
TOWNS	May 79	55	28	1	6	7	7	2	3	1	57.2	0.5	34- 54	2
ROPER	May 79	430	126	67	41	86	39	34	26	20	262.8	1.2	477- 549	1
YIWAPA	May 79	9			4	2	3				14.6	0.6	9	3
MANGKURDUR-														
RUNGKU	May 79	2				2					6.5	0.3	2	3
CALVART	Apr. 79	2												
EINSTEIN	Apr. 79	1								1	38.4	0.1	2	2
MAXWELL	Apr. 79	0									6.6	0.2	1	3
SCHRODINGER/											2.0	0.0	0	3
FERMI	Apr. 79	1								1	2.0	0.5	1	3
ROBINSON	Apr. 79	0									35.9	0.0	0	2
FAT FELLOWS	May 79	1				1					11.0	0.1	1	3
GALILEO	May 79	0									8.0	0.0	0	3
ARCHIMEDES	May 79	3					1	1		1	6.4	0.5	3	3
PLANCK	May 79	1				1					15.1	0.1	1	3
WEARYAN	May 79	4	2				1	1			34.4	0.1	4	2
FARADAY/DAVY	May 79	1				1					10.5	0.1	1	3
COULOMB	May 79	0									13.3	0.0	0	3
McARTHUR	May 79	28			2	3	6	4	5	8	232.6	0.1	35- 57	1
SALTWATER	Aug. 79	29		1	1	6	4	6	9	2	14.1	2.1	37- 59	3

Table 1. cont.

System	Date	Total	H	2-3	Numbers in size class					>7	E.O.	Kilometers surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7							
<b>MINIMINI</b>															
MIDDLE ARM	Aug. 79	11		1	4	3	1	2			43.8	0.3	11- 25	3	
IWALG	Aug. 79	6			3	2	1				28.5	0.2	6	3	
ARM A	Aug. 79	10			3	1	2	2		2	53.5	0.2	10- 22	3	
ARM B	Aug. 79	5			3		1			1	26.7	0.2	5	3	
ARM C	Aug. 79	3			1		1	1			15.0	0.2	3	3	
ARM D	Aug. 79	7			3	1	1		2		29.3	0.2	7	3	
ILAMARYI	Aug. 79	9			1		3	2	3		19.8	0.5	9	3	
	Aug. 79	16			3	4	3	3	3	3	44.4	0.4	18- 34	3	
<b>MONOGRAPH 17</b>															
PORT DARWIN	Sept. 79	80	4	8	6	8	8	9	16	21	148.6	0.5	107- 143	2-3	
PORT PATTERSON	Sept. 79	10			1	1	2	2	1	3	59.9	0.2	10- 22	3	
PORT HARBOUR	Sept. 79	24	2	1	1	4	4		9	3	109.5	0.2	27- 45	3	
<b>LATEST SURVEY ONLY</b>															
Total TYPE 1		4491	1197	478	629	597	392	353	413	432	2175.5	1.5	5287-5517	1	
% of total			27	11	14	13	9	8	9	10	54				
Total TYPE 2-3		591	82	32	80	105	79	54	62	97	938.4	0.5	790- 880	2-3	
% of total			14	5	14	18	13	9	10	16	23				
Total TYPE 3		390	14	8	20	88	72	61	64	63	883.7	0.4	578- 656	3	
% of total			4	2	5	23	18	16	16	16	22				
Overall total		5472	1293	518	729	790	543	468	539	592	3997.6	1.0	6724-6984	1 to 3	
% of total			24	9	13	14	10	9	10	11					
<b>MONOGRAPHS 4 &amp; 14</b>															
ALLIGATOR REGION	77	638	63	21	71	128	93	81	93	88	316.8	1.8	895- 991	1	
EXCL. WILDMAN	78	744	116	38	83	91	122	88	125	81	317.4	2.0	980-1080		
	79	851	116	64	73	106	83	128	155	126	321.0	2.3	1151-1259		
ALLIGATOR REGION	78	862	169	54	89	99	132	97	132	90	350.9	2.0	1084-1190	1	
	79	1006	137	98	88	120	90	145	186	142	354.5	2.4	1366-1484		

Table 1. cont.

System	Date	Total	H	2-3	Numbers in size class					>7	E.O.	Kilometers surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7							
<u>MONOGRAPH 14</u>															
COBOURG COMPLEX & SALTWATER ALLIGATOR REGION COBOURG COMPLEX & SALTWATER	79	96		1	2	27	15	19	19	13		275.1	0.3	137- 177	3
	79	1102	137	99	90	147	105	164	205	155		629.6	1.5	1521-1645	1 & 3
	<u>MONOGRAPH 6</u>														
ANDRANANGOO,	75	51	18	2	5	7	5	3	11			84.7	0.4	42- 66	1 to 3
DONGAU & TINGANOO	79	77	4	1	3	13	12	9	16	19		85.3	0.9	103- 137	
MELVILLE I.	79	102	4	2	5	16	18	14	19	25		189.6	0.5	141- 181	
<u>MONOGRAPH 5 &amp; 7</u>															
NUNGBULGARITO	75	111	4	35	23	15	8	3	6	17		162.2	0.7	154- 196	1 to 3
KING	79	206	42	15	23	35	31	17	15	28		158.2	1.0	243- 295	
<u>MONOGRAPH 1, 5 &amp; 7</u>															
BLYTH TO KING BUT	75	712	73	180	162	116	46	13	11	111		416.0	1.5	997-1099	1 to 3
USING LIVERPOOL '76 FOR '75	79	1186	454	117	155	137	96	62	61	104		402.7	1.8	1146-1254	
<u>MONOGRAPH 9</u>															
CASTLEREAGH BAY	75	130	14	11	19	27	9	12	14	24		304.2	0.4	168- 212	1 to 3
& HUTCHINSON STR.	79	300	62	17	25	43	42	29	33	49		390.2	0.6	359- 421	
<u>MONOGRAPH 10</u>															
BUCKINGHAM &	75	225	48	58	33	28	20	4	11	23		137.6	1.3	263- 317	1 to 3
ULUNDURWI BAYS	79	313	61	16	46	53	32	38	26	41		159.5	1.6	381- 455	

Table 1. cont.

System	Date	Total	H	2-3	Numbers in size class					>7	E.O. surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7	7					
ARNHEM BAY	75	714	238	187	96	93	43	15	21	21	241.0	2.0	737- 825	1 to 3
	79	1032	331	161	250	119	54	23	22	72	243.0	2.9	1097-1203	
<u>MONOGRAPH 11</u>														
NORTH ARNHEM LAND TO KING	75	1781	373	436	310	264	118	44	57	179	1098.8	1.3	2234-2384	1 to 3
	79	2831	908	311	476	352	224	152	142	266	1195.4	1.6	3066-3242	
<u>MONOGRAPH 1, 5, 7 TO 11</u>														
GULF SOUTH COAST GULF SOUTH COAST EXCL. TOWNS	79	116	31	2	8	16	24	12	11	12	600.7	0.1	120- 158	1 to 3
	79	61	3	1	2	9	17	10	8	11	543.5	0.1	80- 110	1 to 3
<u>MONOGRAPH 12 &amp; 13</u>														
ROPER SYSTEM & COASTAL CREEKS	79	450	126	67	41	90	43	37	26	20	283.9	1.1	495- 567	1 to 3
	78	34	1		4	6	2	7	2	12	73.1	0.5	42- 56	1 to 2
<u>MONOGRAPH 8</u>														
<u>TOTALS</u>														
GULF OF CARPENTARIA NORTH ARNHEM LAND	78, 79	600	158	69	53	112	69	56	39	44	957.7	0.5	683- 767	1 to 3
	79	2831	908	311	476	352	224	152	142	266	1159.4	1.6	3066-3242	1 to 3
DARWIN EASTWARD TO COBOURG INCL. MELVILLE	79	1578	194	109	141	237	181	225	288	203	1050.8	1.3	2195-2345	1 to 3
	78, 79	463	33	29	59	89	69	35	70	79	793.7	0.5	663- 747	1 to 3
DARWIN WESTWARD NORTHERN TERRITORY	78, 79	5472	1293	518	729	790	543	468	539	592	3997.6	1.0	6724-6984	1 to 3

Table 1. cont.

System	Date	Total	H	2-3	Numbers in size class					>7	E.O.	Kilometers surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7							
WESTERN AUSTRALIA - Reports 24 & 34															
LAWLEY	July 77	44	13	1	4	6	8	5	3	4		37.0	0.8	40- 62	2
MITCHELL	July 77	50	8	1	9	12	8	3	6	3		47.7	0.9	56- 82	1
ROE	July 77	176	52	40	27	22	14	8	6	7		68.6	1.8	181- 225	1
HUNTER	July 77	47	11	7	5	10	6	4	2	2		39.3	0.9	47- 71	2
ST. GEORGE												(estimate)			
BASIN ARMS	July 77	72	10	1	2	18	10	15	13	3		36.0?	1.7	86- 118	2 to 3
PRINCE REGENT	July 77	74	15	4	25	12	8	5	1	4		58.6	1.0	82- 112	1
GEORGE WATER & GLENELG	July 78	213	73	33	26	33	18	12	12	6		96.3	1.4	206- 254	1 to 3
												(estimate)			
ST. GEORGE															
BASIN ARMS	July 78	97	25	3	1	13	12	14	25	4		72.0?	1.0	101- 135	2 to 3
PRINCE REGENT	July 78	92	31	11	17	11	8	6	6	2		68.0	0.9	84- 116	1
ORD	July 78	179	14	17	39	50	19	11	8	21		98.4	1.7	245- 297	1
TOTAL LATEST SURVEYS		898	227	113	128	157	93	63	68	49		527.3	1.3	1048-1152	1 to 3
% OF TOTAL			25	13	14	17	10	7	8	5					
QUEENSLAND - MONOGRAPH 16															
NASSAU	Apr. 79	103	4	27	30	23	7	5	3	4		146.3	0.7	142- 182	1
STAATEN	Apr. 79	20		6	3	2	2	3	3	1		74.5	0.3	24- 42	1
GILBERT	Apr. 79	8				1	3	1		3		65.2	0.1	8	1-3
DUCK	Apr. 79	27		2	5	5	3	6	4	2		73.7	0.4	34- 54	1-3
TOTAL		158	4	35	38	31	15	15	10	10		359.7	0.4	228- 278	1 to 3
WENLOCK	Nov. 79	311	83	67	65	44	8	8	4	32		103.7	2.2	344- 404	1
DUCIE	Nov. 79	201	28	52	48	40	16	3	2	12		109.9	1.6	258- 310	1
DULCIE	Nov. 79	1					1					3.5	0.3	1	1
PALM	Nov. 79	9	1		2	1	1			4		6.0	1.3	8	1
NAMALETA	Nov. 79	14		1		7			1	5		17.9	0.8	15- 31	3

Table 1. cont.

System	Date	Total	H	2-3	Numbers in size class					>7	E.O.	Kilometers surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7	7						
PORT MUSGRAVE	Nov. 79	536	112	120	115	92	26	11	7	53	241.0	1.8	654-736	1 & 3	
ESCAPE	Nov. 79	31	3			5	6	2	7	8	42.0	0.7	35-57	1	
TOTAL QUEENSLAND	79	725	119	155	153	128	47	28	24	71	642.7	0.9	945-1043	1 & 3	
& OF TOTAL			16	21	21	18	6	4	3	10					

<sup>a</sup> The midstream distance surveyed and density of non-hatchling crocodiles sighted on it is shown, as are the 95% confidence limits for the estimate of the actual number of non-hatchlings present. The TYPE classification of each waterway is given also (see text).

Table 2. Number of *C. porosus* sighted within each size class on tidal waterways of the southern Gulf of Carpentaria during night-time spotlight surveys carried out during 1979 and 1985.

System	Numbers in size class											95% Levels	TYPE
	H	2-3	3-4	4-5	5-6	6-7	>7	EO					
<b>MONOGRAPH 12</b>													
<b>Limmen Bight</b>													
May 79	19	1	1		3	8	3	2	1	127.3	0.1	21- 39	2
Oct. 85	31 <sup>a</sup>	2	1				4	7	17 <sup>a</sup>	127.3	0.2	37- 59	
<b>Towns</b>													
May 79	55	28	1	6	7	7	2	3	1	57.2	0.5	34- 54	2
Oct. 85	28		1	1	5	9	2	7	3	57.2	0.5	35- 57	
<b>Nayarnpi</b>													
Oct. 85	5							2	3	17.9	0.3	5	3
<b>Roper</b>													
May 79	439	126	67	41	86	39	34	26	20	262.8	1.2	477-549	1
Sept. 85	405	44	134	43	52	31	34	37	30	262.8	1.4	554-630	
<b>Yiwapa</b>													
May 79	9				4	2	3			14.6	0.6	9	3
Sept. 85	5				1		1	3		14.6	0.3	5	
<b>Mangkurdurrungku</b>													
May 79	2					2				6.5	0.3	2	3
Sept. 85	0									6.5	0	0	
<b>MONOGRAPH 13</b>													
<b>Wearyan</b>													
May 79	4	2				1	1			34.4	0.1	4	2
Sept. 84	5			1			1		3	34.4	0.1	5	
<b>Fat Fellows</b>													
May 79	1			1						11.0	0.1	1	3
Sept. 85	1							1		11.0	0.1	1	
<b>Galileo</b>													
May 79	0									8.0	0	0	3
Sept. 85	0									8.0	0	0	
<b>Archimedes</b>													
May 79	3					1	1		1	6.4	0.5	3	3
Sept. 85	0									6.4	0	0	
<b>Faraday/Davy</b>													
May 79	1				1					26.2	0.04	1	3
Sept. 85										26.2	0	0	
<b>McArthur</b>													
May 79	28			2	3	6	4	5	8	232.6	0.1	35- 57	1
Sept. 85	48	2	14	1	3	1	5	9	13	232.6	0.2	61- 89	

<sup>a</sup> Treat with caution as this number probably includes *C. johnstoni*.

## ECOLOGY OF *Crocodylus porosus* IN NORTHERN AUSTRALIA

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Much of the information which follows was obtained during the 15 year study of *Crocodylus porosus* in northern Australia, by various researchers of the University of Sydney Crocodile Research Group.

*C. porosus* ranges from Sri Lanka and the west coast of India through south-east Asia, across to the Philippines and down through the islands to New Guinea and northern Australia (Fig. 1). The species is regarded (generally) as that crocodilian which most readily takes to the sea (Ditmars 1910, Smith 1931, Loveridge 1945, Wermuth 1964, Neill 1971, Guggisberg 1972, Brazaitis 1973) and its wide distribution is attributed to an ability to make long sea journeys (Wermuth 1953, Neill 1971, Brazaitis 1973, Webb and Messel 1978). Its reputation for sea travel is based on sightings at sea (Hornaday 1926) and on the appearance of individuals well away from known populations (Neill 1971). A 3.8 m male *C. porosus* was found at Ponape, Eastern Caroline Islands, some 1,360 km from the nearest population (Allen 1974), while a 3.2 m male with a telemetry transmitter travelled 130 km, of which 80 km was along the sea coast (Webb and Messel 1978).

The species reaches the southernmost limit of its range in Australia (Fig. 1). Here it is restricted to the coastal regions of the far north in Western Australia, Northern Territory and Queensland (Cogger 1975). It occurs primarily in rivers as far upstream as tidal influence extends, but is found also in swamps (fresh and salt), billabongs, lakes and non-tidal rivers up to 150 km or more, inland (Messel, pers. obs.). *Crocodylus johnstoni*, Australia's only endemic species of crocodile, overlaps the range of *C. porosus* in fresh water and also can be found in the saltwater sections if the density of *C. porosus* is low (Messel et al. 1978-1986, 1:459).

The two species can be easily distinguished; the snout of *C. johnstoni* is narrow in comparison to that of *C. porosus*.

The habitat in Australia for *C. porosus* is generally much drier and more inhospitable than in wetter areas of Asia like Papua New Guinea, Malaysia and Burma. Swamp as habitat is much less significant than it is in Papua New Guinea for example.

### HABITAT

Messel et al. (1978-1986) give detailed descriptions of rivers surveyed from the Kimberley region in Western Australia to Cape York Peninsula in Queensland. Taylor (1979) presents a useful



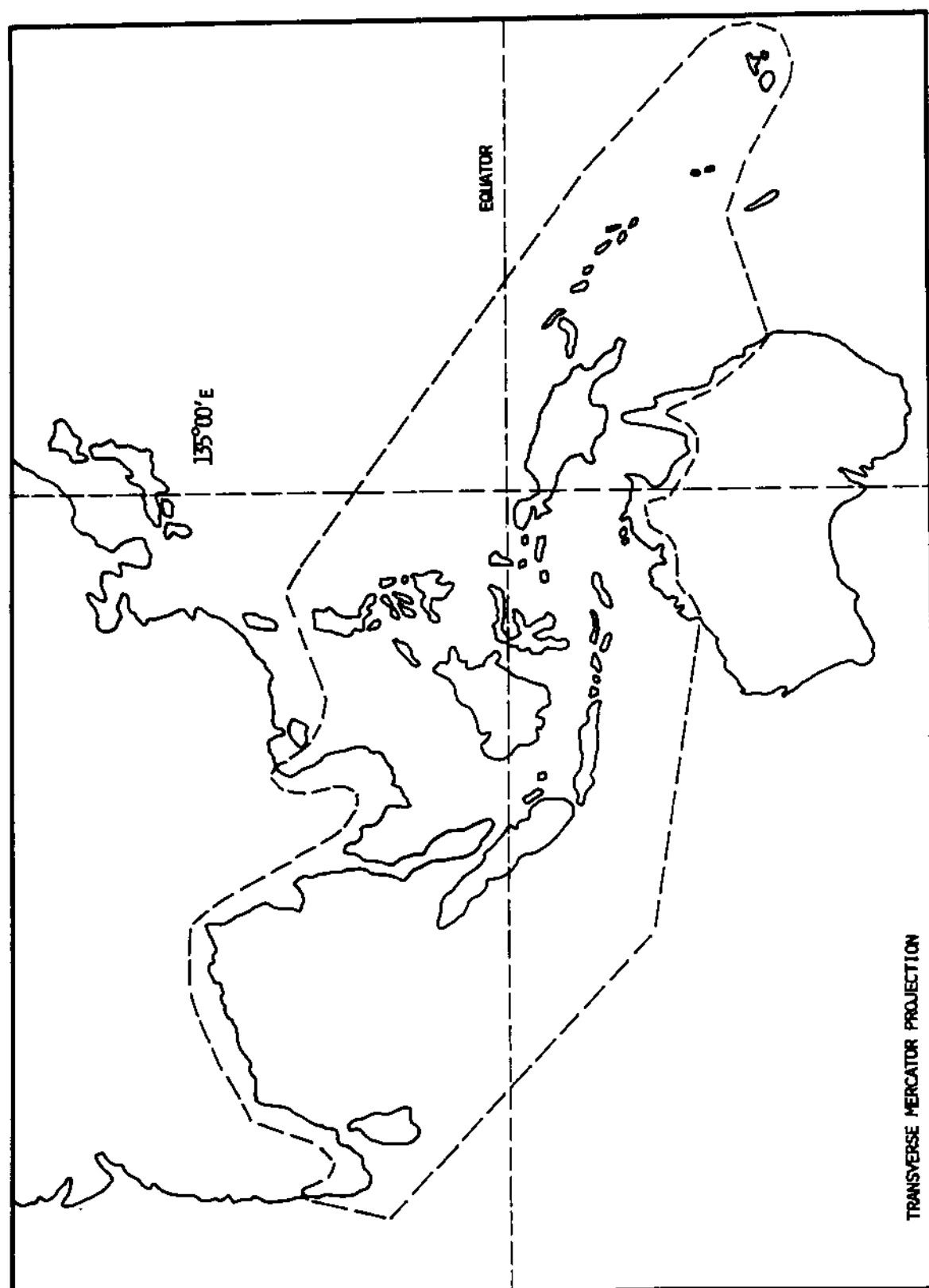


Figure 1. Former distribution of *Crocodylus porosus* (adapted from Neill 1971).

classification of habitat types found on the coastal rivers in the Northern Territory and we now give this, with some additional habitat types.

**Lower Mangrove** - This habitat is characterized by long sloping banks of soft mud, with mangrove species the only riverside vegetation. Such habitat is found in the downstream sections of all rivers. Salinity in these areas is between 20 and 35‰.

**Floodplain** - Floodplain is characterized by open plains, abutting the river, of the grasses *Ischaemum villosum* var. *australe*, *Imperata cylindrica* var. *major* and *Coelorrachis rotbellioides*, and/or the sedges *Cyperus* spp. and *Fimbristylis* spp. Small mangroves *Avicennia marina* and paperbarks *Melaleuca acacioides* sometimes form a sparse line along the river edge. This habitat occurs in downstream sections of all rivers studied (salinity: 20-35‰) and is often associated with lower mangrove habitat.

**Upper Mangrove** - Upper mangrove is characterized by strand communities in floodplain or sparse mangrove areas. The communities are commonly composed of palms *Corypha elata*, ferns *Acrostichum speciosum*, and the vines *Derris trifoliata* and *Flagellaria indica*. River banks in this habitat may be steep with a substrate of firm mud. This habitat occurs in the upper reaches of the Tomkinson, Liverpool and Cadell Rivers (salinity: 0-20‰).

**Freshwater Swamp** - This is characterized by freshwater seepage. Swamps, with water depths ranging from 10 to 300 cm, commonly contain the melaleucas *M. dealbata*, *M. leucadendra*, *M. viridiflora*, the sedges *Baumea rubiginosa* and *Scirpus* sp., and water lilies *Nymphaea gigantea*.

Freshwater swamps often drain into the main river by way of small creeks. The area of swamp may drastically recede during the dry season.

**Floodplain Billabongs** - These are beside the river and fill from either abnormally high tides or wet season rains. They often contain brackish water and may dry out completely during the dry season.

**Eucalypt Forest** - This is characterized by the presence of steep earth banks, lined by sparse forest of *Eucalyptus miniata* and *E. tetradonta* with an understorey of the broad-leaved grasses *Heteropogon* spp., *Coelorrachis rotbellioides*, and *Themeda australis*. Few plants are found at water level and no mangroves are present. This habitat is found on the upper reaches of the Liverpool and Blyth Rivers (salinity: 0-5‰), for example.

**Sand-Phragmites** - This habitat, found, for example, on the upper reaches of the Liverpool River (salinity 0-5‰), is characterized by sandbanks. Abutting these are areas of *Phragmites karka*, *Acacia auriculiformes* and *Pandanus aquaticus*.

**Exposed Shore Communities** - This category is a catch-all for the many dry exposed habitats, often with sharp relief, found near the coast and including beaches, rocky foreshores, cliffs and rocky areas around creeks.

Webb (1977) gives a generalized description of the Liverpool River System, which exemplifies many characteristics of TYPE 1 rivers (see salinity classification below).

The river can be divided into tidal and non-tidal sections. The non-tidal section flows through the rocky Arnhem Land plateau for some 120 km. The river here is narrow, contains fresh, clear water and flows mainly on substrates of rock or sand. The river may expand into swamps, which are typically lined with *Pandanus*, paperbark (*Melaleuca* sp.) and eucalypt forest. By the end of the dry

season, water flow may cease and the river can become a string of isolated water holes. Small numbers of *C. porosus* are found in this freshwater section of the river. Individuals are darker in color than those from the tidal section; some are black on the dorsal surface. This habitat is more typical of *C. johnstoni*, the freshwater crocodile; the interaction between the two species has not been studied in detail (but see Messel et al. 1978-1986, 1-3, 16, and Webb et al. 1983).

In the Liverpool River, the demarcation between tidal and non-tidal sections occurs at the edge of the escarpment. The banks of the tidal section are mainly mud. They are lined with either mangrove forest or floodplain grasses and sedges. There are two tidal cycles per day and tidal range is about 3 m. The water in the tidal section is usually saline and some 20 km upstream appears to be a drowned river valley; the river course fixed by geological structure. Further upstream, the river meanders through an extensive floodplain and there is continual erosion of one bank and deposition on the other.

During the wet season, the non-tidal section of the river receives the runoff from a large area of the escarpment. Water levels rise and there is usually widespread flooding of the tidal section and a flushing of saline water from the river. We have recorded essentially fresh water at the Liverpool River mouth in the wet season.

With the cessation of rain, tidal influence extends back up the river and a salt wedge gradually moves upstream. By the end of the dry season the water is brackish at the upper limit of tidal influence. Most *C. porosus* are in the tidal section of river.

The habitat types described are very much generalized. In other rivers, the proportion of one to the other may change considerably. For example, the tidal sections of the Woolen (Messel et al. 1978-1986, 9) and King Rivers (Messel et al. 1978-1986, 5) are drowned river valleys into which the upstream non-tidal sections drains directly, i.e., there is virtually no meandering flood plain river. In Andranangoo Creek (Messel et al. 1978-1986, 6) on Melville Island, there is no sharp demarcation between tidal and non-tidal. As one moves upstream the environment gradually changes from mangroves and mud to *Pandanus* and paperbark. In addition, large areas of the bank are composed of freshwater swamps. In rivers like the Glyde (Messel et al. 1978-1986, 9, 18) the tidal section peters out in a massive area of freshwater swamp (the Arafura Swamp), into which flows a freshwater river, the Goyder. This latter river resembles the upstream freshwater billabongs of the Liverpool River. In the Mary River, the cessation of wet season rains, and subsequent drying, leaves large closed flooded plain billabongs and only a very minor flowing creek. In the Buckingham River (Messel et al. 1978-1986, 10), the demarcation between tidal and non-tidal sections of the river is sharp, a large cliff face.

### SALINITY

Analysis of the number, distribution and size structure of crocodiles sighted during the general surveys of northern Australian tidal systems indicates that one of the most important parameters characterizing a tidal waterway is its salinity profile. The profile and habitat type image one another and appear to largely determine the suitability or otherwise of the tidal waterway for breeding, nest and rearing. We roughly classified the tidal rivers and creeks on the northern Arnhem Land coastline into three different types of waterways. This classification plays a critical role in the unraveling of the dynamics of populations of *C. porosus* (especially see Messel et al. 1978-1986, 5, 9-11) and is given by:

**TYPE 1** - Tidal river systems meandering through coastal floodplains and having a heavy freshwater input during the wet season. The freshwater inflow decreases but remains sufficient, as the dry season progresses, to prevent the salinity upstream (though progressing upstream gradually) from rising above the sea water values measured at the mouth of the system. Such systems usually have good to excellent nesting habitat and could be expected to have good recruitment potential. The Goomadeer River System was classified as such a system (Messel et al. 1978-1986, 5).

**TYPE 3** - Tidal waterways which also have a heavy freshwater input during the height of the wet season, but in which the freshwater input drops rapidly with the onset of the dry season. These waterways, which usually have short surveyable lengths and often direct openings to the sea, are typified by salinities which during the dry season are above those measured at their mouths and which increase with increasing distance upstream - they are hypersaline and become increasingly so as the dry season progresses. Nesting habitat in such systems is minimal or non-existent. Recruitment potential is also usually low or non-existent. All Night Creek (Messel et al. 1978-1986, 5) is an example of such a system; most of the coastal creeks surveyed on the southern coast of the Gulf of Carpentaria also fall into this category (Messel et al. 1978-1986, 13).

**TYPE 2** - Tidal systems which fall somewhere between TYPE 1 and TYPE 3 above and which tend to show hypersaline characteristics as the dry season progresses. Such systems usually have good to poor nesting habitat and equivalent recruitment potential depending upon how close they are to TYPE 1 or 3 above. The King River (Messel et al. 1978-1986, 5) and Dongau Creek on Melville Island (Messel et al. 1978-1986, 6) are examples of such systems.

It will be seen that each of these three system types has its own characteristic type of salinity variation, both in respect of time of year and distance upstream, and that the salinity characteristics largely determine the nature of the system. Figure 2 shows typical dry season salinity profiles for the three system types. The salinity profile of a system may be said to be its own unique signature. A large river system may have multiple signatures, one for its mainstream and different signatures for its creeks and subcreeks.

## CLIMATE

**Rainfall** - The climate shows two distinct seasons. The 'wet' season (November to April) is associated with the north-west monsoon. The 'dry' season (May to October) is a period of infrequent or no rain. It results from a more northerly extension of anticyclonic weather patterns across the Australian continent during the winter months. During the 'dry' season, south-east trade winds of up to 30 knots are prevalent over the study area.

As an example of climatic variations over a year, we give some data for the Blyth-Cadell study area (Messel et al. 1978-1986, 1) where the most extensive population studies have been carried out. Mean annual precipitation is 1,141 mm at Maningrida and 1,143 mm at Mililingimbi. Seasonal rainfall distribution and number of raindays per month are shown in Fig. 3.

A heavy build up of cumulus cloud occurs in October before the monsoon arrives. During the wet season, the rivers often flood for periods of up to several weeks. Peak flooding usually occurs between January and March.

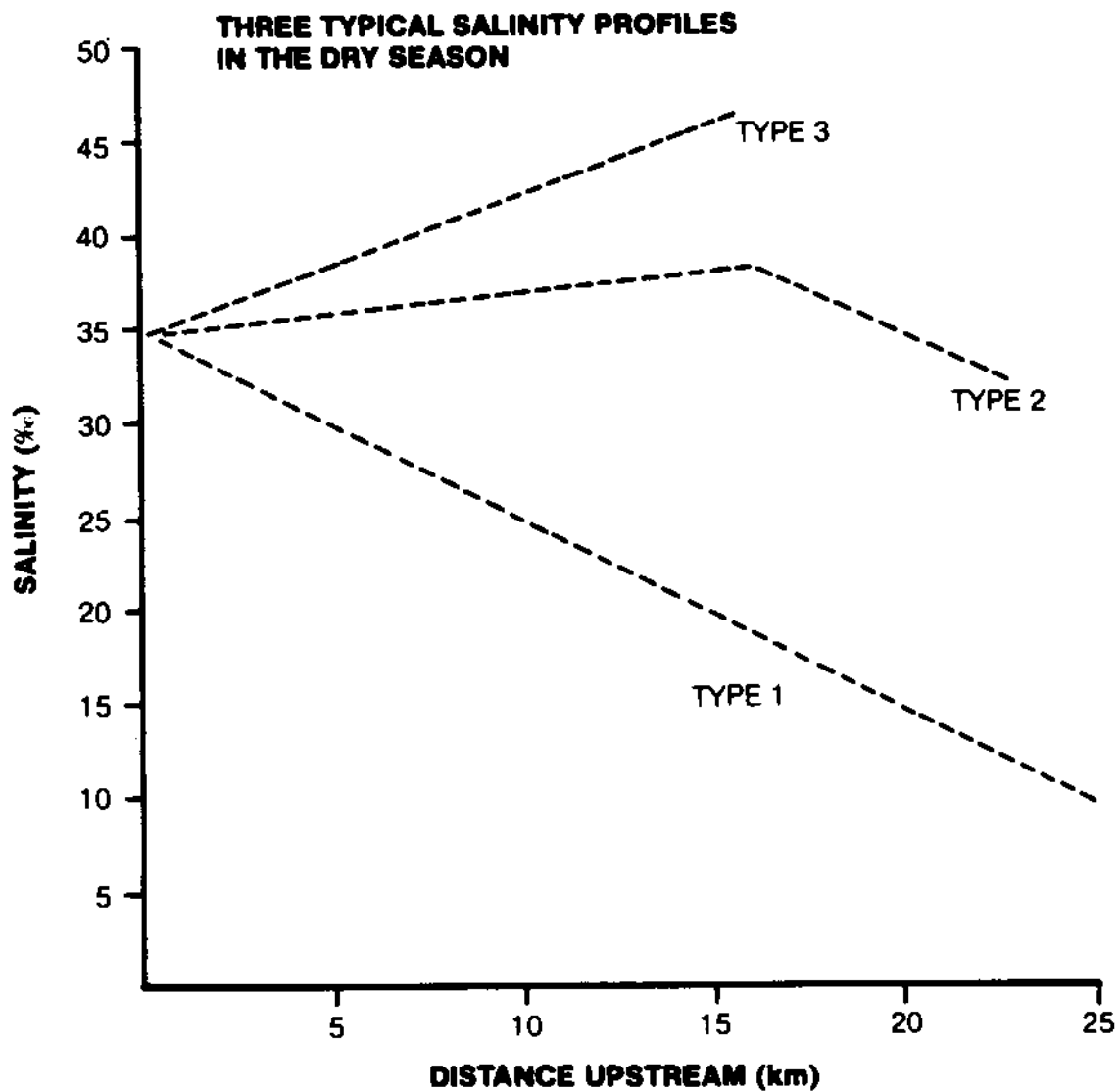


Figure 2. Typical dry season salinity profiles for the three types of tidal systems occurring in the classification scheme described in the text.

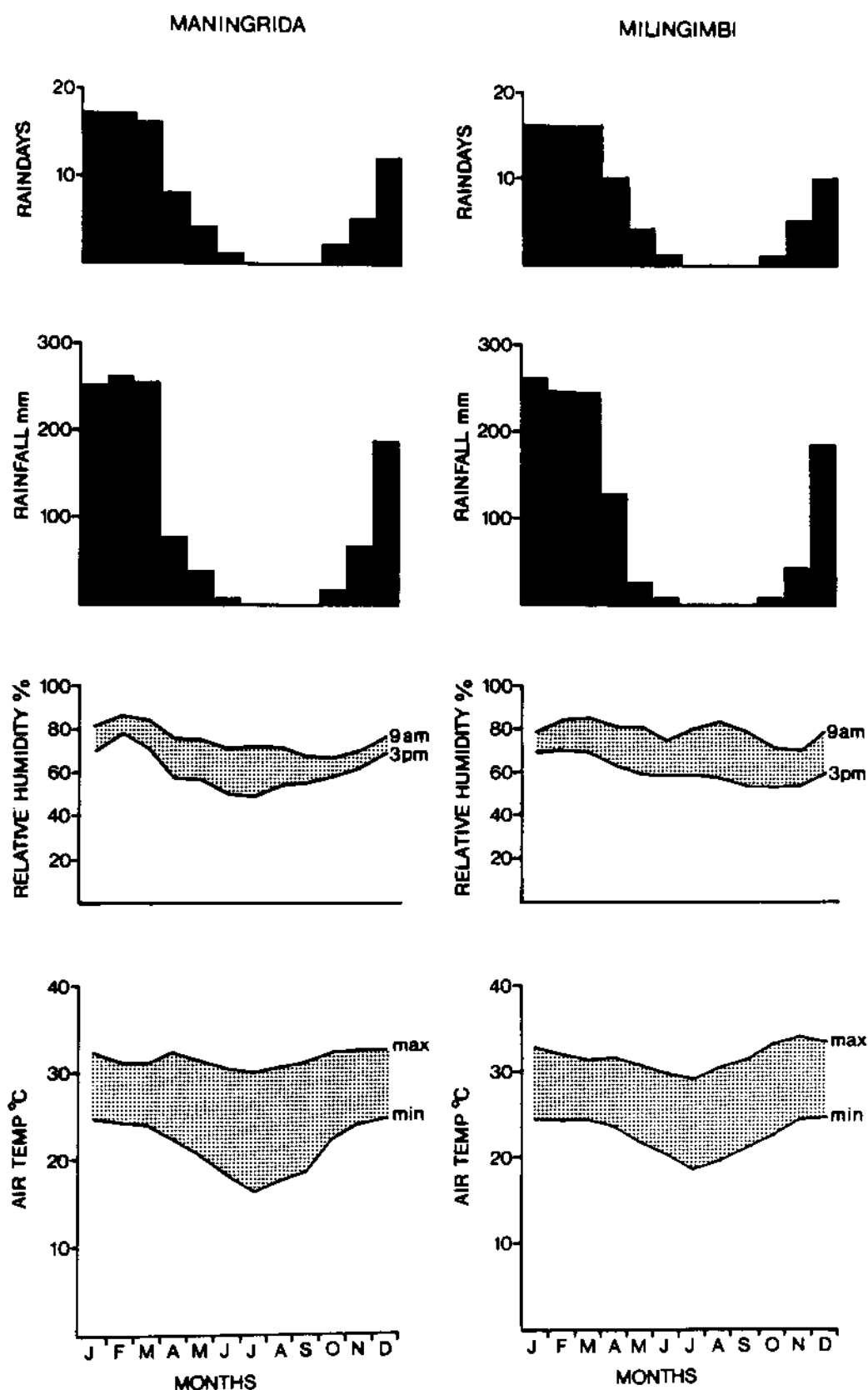


Figure 3. Mean annual number of rainy days, rainfall regimes, mean relative humidity and mean maximum and minimum temperatures at Maningrida and Milingimbi meteorological stations, which are adjacent to the study area.

**Temperature and Humidity** - Seasonal fluctuations in relative humidity and mean maximum and minimum monthly temperatures for weather stations at Maningrida and Mililingimbi are also illustrated in Fig. 3. In the study area, temperatures remain high throughout the year. High rainfall and heavy cloud, common during the 'wet' season, produce high humidity and lessen extremes of temperature.

**Twenty-four Hour Temperature Measurements** - Twenty-four hour temperature profiles of the air (1 m above ground), water and substrate (exposed mud 1-2 cm depth) were measured 32 km upstream from the mouth of the Blyth River (in an area having the highest density of *C. porosus*). Temperatures were recorded at hourly intervals during four seasons (Figs. 4-6; note that substrate temperatures are not shown).

During the wet season, the water temperatures remain constant,  $30 \pm 1^\circ\text{C}$ . During the dry season, water temperatures steadily fall until they reach about  $25^\circ\text{C}$  during June and July (however, water temperatures as low as  $21.9^\circ\text{C}$  were recorded at km 45 in July 1976), begin to rise again and slowly approach  $26^\circ\text{C}$  in September and  $29^\circ\text{C}$  in October. Water temperatures slightly lag air temperatures. Air and substrate temperatures also showed diurnal and seasonal changes. Night temperatures down to  $12.7^\circ\text{C}$  were recorded during the dry season.

Considerable variation in both air and water temperatures may occur over a few days. On 14 June, 1976 (Fig. 4), air and water temperatures fluctuated between  $20\text{--}28^\circ\text{C}$  and  $25\text{--}26^\circ\text{C}$ , respectively. By June 21, after a cold snap, air temperatures had fallen to between  $13\text{--}24^\circ\text{C}$ , while the temperature of the water had dropped to around  $24^\circ\text{C}$ . Similar fluctuations can be seen on the temperature profiles for 22 and 25 September, 1976. The large differences after midnight between air and water temperatures can give rise to heavy fog on the upstream portions of the rivers.

## NESTING

*C. porosus* deposit their eggs in a mound nest which may be constructed from a variety of vegetable debris, with varying proportions of mud, dirt or even sand. The vegetable debris, including leaf litter, rushes, roots, sticks, reeds, grasses, often living green materials as well as dead. Floodplain nests are usually constructed principally of the grass *Ischaemum australe* var. *villosum*, if available. The feet and tail are used to scrape up vegetation and the mouth is also used. The nest is compacted and takes one to several nights to construct. Vegetation and soil from an area up to  $70\text{ m}^2$  is raked together. On completion the nest often has distinct tail groove across the top. Typical dimensions of a nest are 0.5 m high, and 1.6 m in diameter.

Nest sites are typically selected close to permanent water. With the exception of nests constructed in large or small freshwater swamps, off from the downstream high salinity sections of the waterways, or on upstream swamps and/or billabongs, all the other nests appear to be constructed on those sections of the waterway which are brackish by June or July, with salinities around 1 to 10 parts per thousand. These sections are of course completely fresh during the wet season.

It is not clear why there are no nests on the downstream mouth sections of tidal rivers. Nests in swamps have the greatest chance of survival and swamps must be considered optimal habitat for nesting.

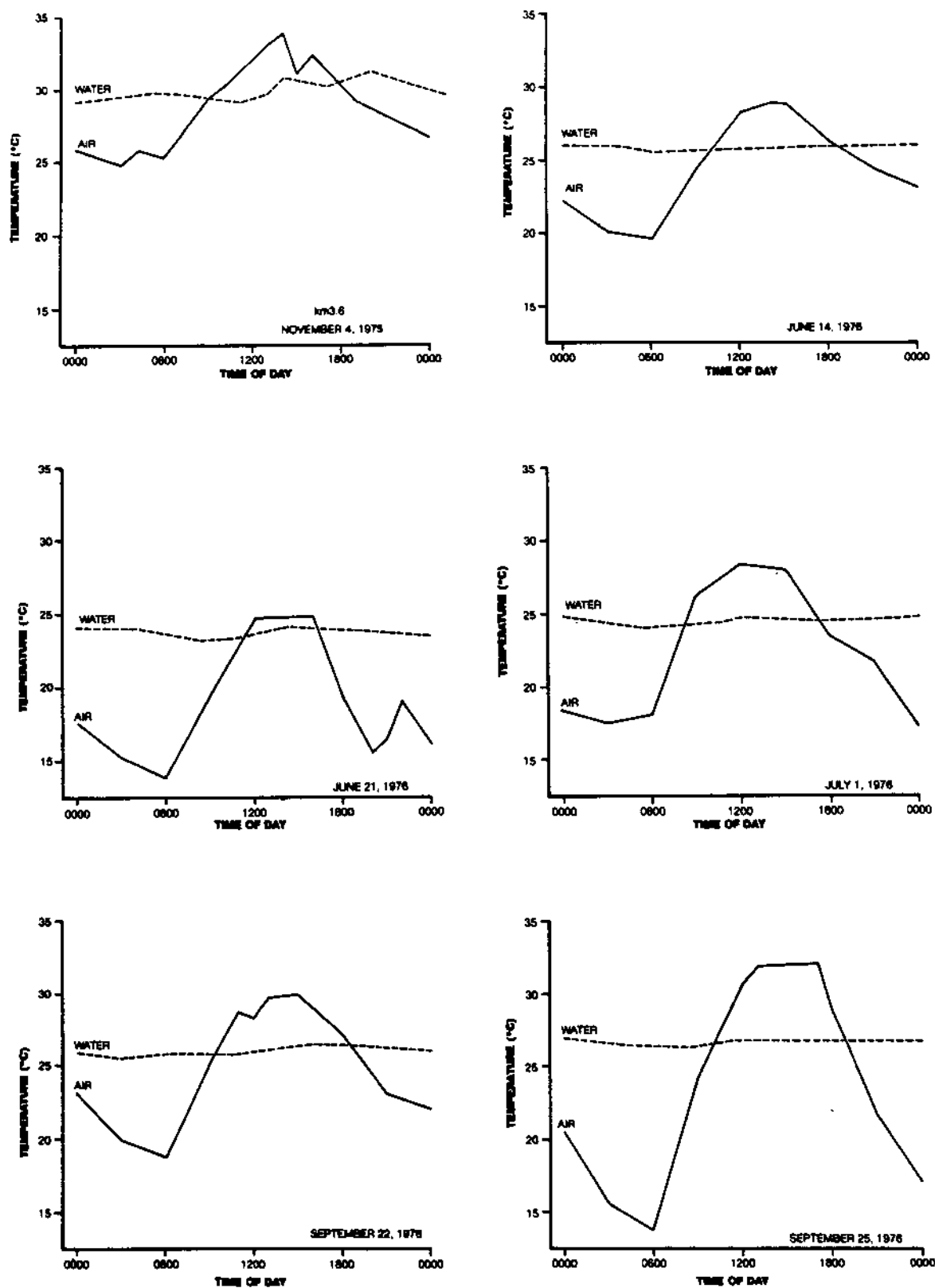


Figure 4. Twenty-four hour temperature profiles of the air (1 m above ground level) and water. Temperatures were recorded at hourly intervals. All measurements were taken at km 32 upstream on the Blyth River (except November profiles which were taken at km 3.6) during 1975 and 1976.



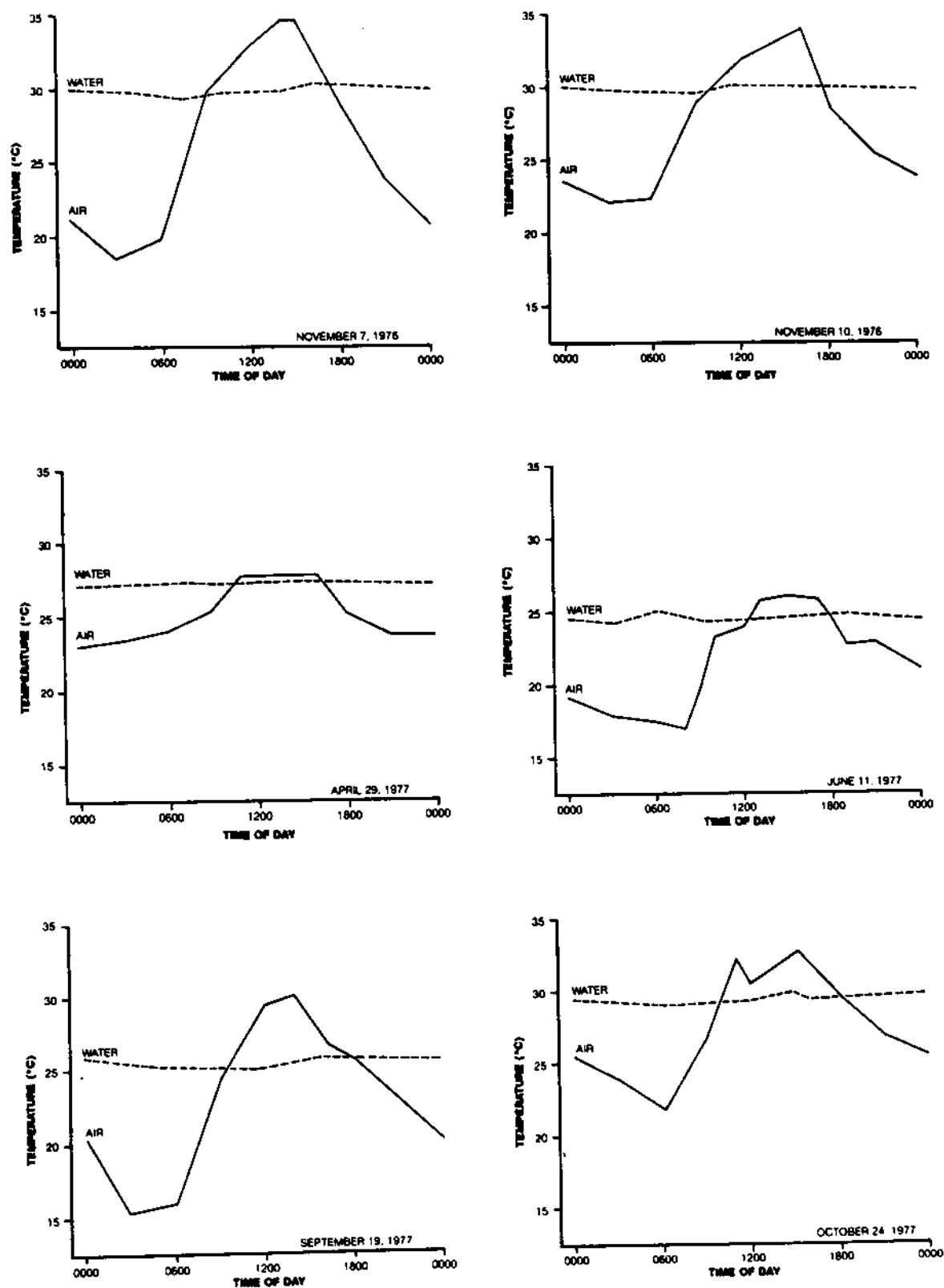


Figure 5. Twenty-four hour temperature profiles of the air (1 m above ground level) and water. Temperatures were recorded at hourly intervals. All measurements were taken at km 32 upstream on the Blyth River during 1976 and 1977.

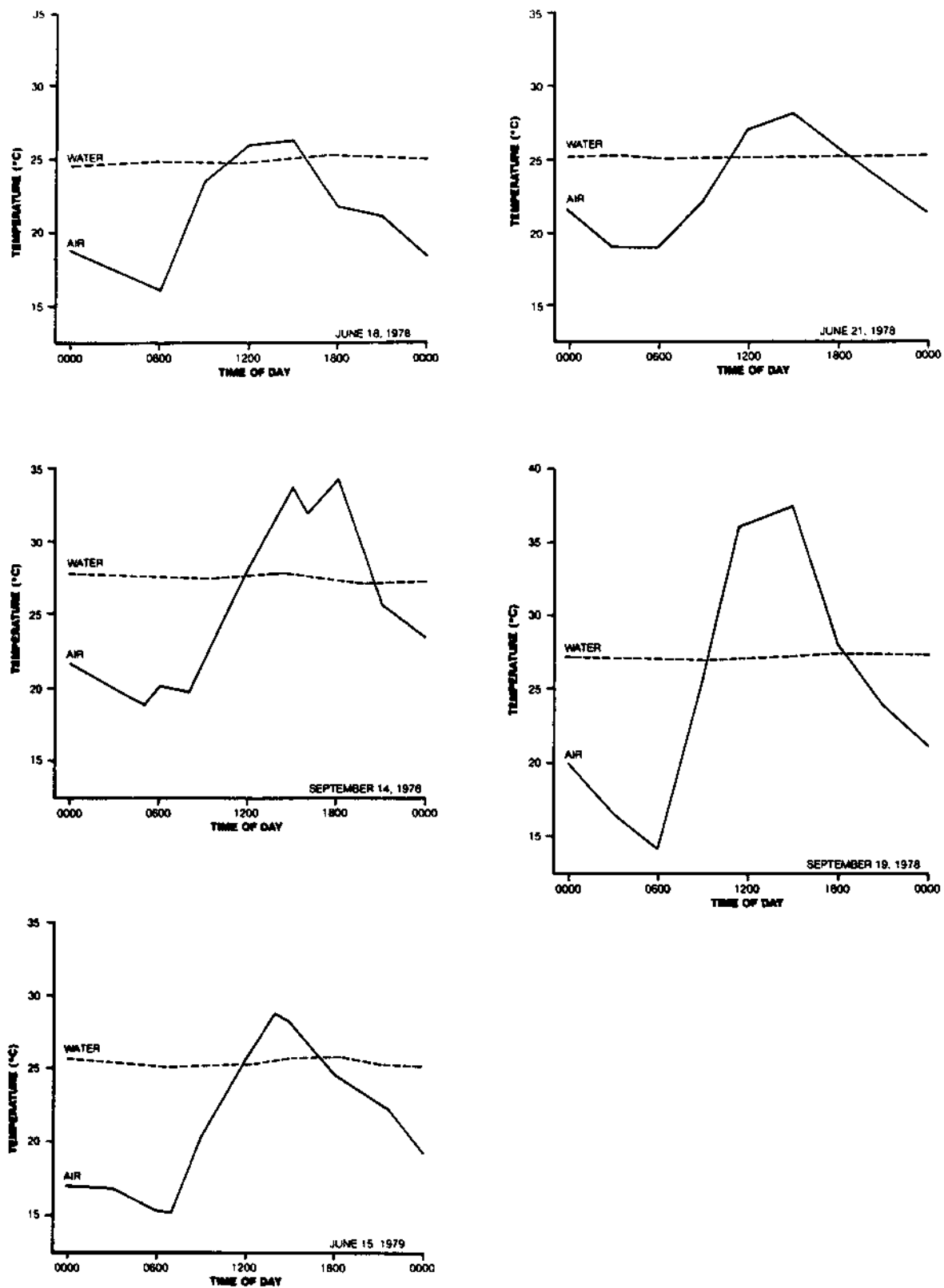


Figure 6. Twenty-four hour temperature profiles of the air (1 m above ground level) and water. Temperatures were recorded at hourly intervals. All measurements were taken at km 32 upstream on the Blyth River during 1978 and 1979.

Webb et al. (1977) describe a number of nests in the Liverpool-Tomkinson area. Nests were built in open grassplain with no shade or protection, beneath small shrubs with only little protection from the sun or wind, beneath dense shrubs and in forests and swamps where they were almost continually shaded and protected from wind, or on one side of a forest where they were completely shaded during some part of the day and either protected or exposed to prevailing winds. Most nests are built on a rich, black, floodplain soil. Riverside nests are not found in mangrove forests. Most are on concave banks where the river comes close to or abuts the adjacent floodplain, or on the floodplain behind the mangroves. One was located on sandy soil in the upper reaches of the river and the remainder were in swamps. A considerable part of most nests was soil, the vegetation being mixed with wet mud during construction. The adult sometimes packed mud onto the nest after the eggs had been laid. Nests in swamps were on a peat-like tangle of roots and debris which formed the swamp floor. This substrate is spongy and the nests were built against, or close to, large trees (usually *Melaleuca* sp.), the roots of which provided a stable foundation.

Associated with most non-swamp nests are a number of wallows; the adult will often lie in these. On occasion the female can be seen lying over the nest. Female *C. porosus* in the wild do not appear, in northern Australia, to defend their nests against approaching humans and usually go straight to the river when approached.

Egg laying probably takes place soon after the completion of the nest. Eggs are deposited in a cavity within the central area of the nest mound. The eggs are laid in rapid succession, the crocodile often using her rear legs to guide them into the chamber. No egg layering is apparent. On completion of egg laying, the opening to the nest cavity is covered over and packed down. The egg cavity is usually deep, with a distance of about 20 cm between the top of the nest and the top of the eggs. Nests without eggs are not uncommon and are not understood. Some of these nests are small with no permanent wallow, whereas others are complete and in all respects resemble nests with eggs. Some may be found adjacent to nests with eggs, suggesting that they are some type of "test" nest. Others are not associated with nests containing eggs. The more likely explanations are:

1. They are made by adolescent *C. porosus*, i.e., "practice" nests
2. They are false starts where conditions at the site were not suitable for completion or changes in weather stopped nest construction.
3. They were intended for eggs and abandoned because of human or other disturbance.

Two unusual nests were found on the Liverpool River (Messel, pers. obs.). The first nest was constructed of grasses and sand only and the eggs were deposited just below the surface, on the side of the nest. Some of the eggs were showing. About a kilometer further upstream a second strange nest was discovered. Rather than constructing a mound, this female had dug and deposited her eggs in a chamber in the black soft soil. Only a small amount of grass was piled over the chamber.

*C. porosus* eggs are hard-shelled, white and develop an opaque ring of heavily calcified shell around the middle of the long axis of the egg if the embryo is alive. This provides the embryo with its vital supply of calcium. Egg numbers average around 50, with typical weight, length and width of 110 g, 8 cm and 5 cm respectively. Some nests, however, contain tiny eggs, averaging around 65 g. Small females may build small nests and lay small eggs.

*C. porosus* nesting is essentially a wet season activity, possibly triggered by rising temperatures, however, late nesting in the March-April period, after the peak of wet season

flooding, is common. Courtship and mating begin in the late dry season (September to November) and probably occur throughout the wet season; the time between mating and egg laying may be four-six weeks. Nest construction and egg-laying may occur between November and May, with the peaks being in the January-February and March-April periods. The latest nest we have found was laid down sometime in June. The incubation period is temperature dependent and averages around 90 days. Internal nest temperature vary diurnally (Webb et al. 1977), with mean daily temperatures varying from 27°C to 33°C, depending on what time of year the nest is constructed. Nesting still incubating at the beginning of the dry season have lower temperatures. Temperature of incubation influences the proportion of males hatching: the higher the temperature the higher the proportion of males.

The female apparently remains near and guards the nest for much of the incubation period and will repair any damage. The female does not attend the nest continually for the entire incubation period, but frequently leaves it for short intervals. She assists the hatchlings by opening the nest (which sometimes has a hard-baked exterior), probing with the snout and digging with fore and hind limbs, in response to their calling within (a high pitched nasal "gn- arr"). The hatchlings use the caruncle, a protruberance on the end of the end of the nose, to slice their way out of the egg.

At least some adult *C. porosus* remain in the water with grouped hatchlings (a creche) for up to and possibly more than two months but creche formation is apparently the exception rather than the rule in many rivers of northern Australia (Messel et al. 1978-1986, 1:332), and may vary with river type and parental age. In 1979, we found seven creches on the Peter John River (Messel et al. 1978-1986, 11:34) and only two on the Goromuru (Messel et al. 1978-1986, 11:11). Could it be that the young females do not provide parental care and only do so gradually, as they get older? Since the badly depleted *C. porosus* population in northern Australia would have a majority of young parents this might account for the lack of creche formation in many cases. Age dependent parental behavior has not been reported before and would be difficult to explain. However, to date no alternative explanation has been found. (Parental care could also depend on the population density, with more care occurring at higher densities.) The breeding age for males might be a minimum of 12 years, and for females, 10 years, though females as young as 7 years have nested on farms apparently (Grigg pers. comm.).

Magnusson (1978) reports some experiments on hatchling vocalization and concludes that there is little doubt that hatchling calls group hatchlings in field. He suggests that, in the absence of an attending adult, dispersal of hatchlings may be an advantage.

A high proportion of nests are lost due to various factors. The main losses are due to flooding of nests, with subsequent drowning of the embryos. In some areas up to 90% of nests can be destroyed by flooding. Predation on *C. porosus* eggs does not appear to be significant. Monitor lizards appear to be the main predator, with wild pigs also occasionally destroying nests and eating eggs, as do native rats. Aborigines still also take eggs as a traditional part of their diet. Birds take a toll of just-hatched hatchlings making their way to the water.

A fully successful nest may be defined as one in which each of the 50 eggs produce one hatchling in the river at hatchling time. Nests may be successful to varying degrees because of many different causes; some of the eggs may be broken, others destroyed by predators; eggs may not be fertile or the nest may be inundated, killing various fractions of the embryos, depending upon the flood level. Undoubtedly flooding causes the greatest full or partial loss of nests. However, the fraction which are lost in this fashion varies from year to year and from one river to another.

On river systems (Messel et al. 1978-1986, 2-4, 12, 13 and 16) where it is sometimes possible to estimate the minimum number of nests from which the hatchlings were derived, the loss factor, from eggs in the nest to hatchlings in the river, appears to be in excess of 90%. It is at this stage of the recruitment cycle where the major losses appear to occur. Once hatchlings are in the river, losses appear much less drastic: some 29% over the mid-dry season, followed by a further loss of some 31% over the ensuing nine months (Table 8.4.1, Messel et al. 1978-1986, 1).

Cannibalism of hatchlings is also another factor that could be important (Messel et al. 1978-1986, 14:43), and would be density dependent. One thing is certain, however, and that is that major flooding leads to the catastrophic loss of nests and in those years hatchling recruitment can only come from freshwater swamp nests and late March-April riverside nests. Were it not for the long nesting period, from early November to mid April, it is unlikely that *C. porosus* would have survived for long on the northern Arnhem Land coastline. In areas such as Papua New Guinea with much more extensive swamp habitat, the situation is different.

The proportion of adult female population that nest annually is poorly known. There is evidence to suggest that some females do not nest each year (Messel et al. 1978-1986, 18:122-124). There is also some evidence that a small proportion of wild females may nest twice in any one season (Webb et al. 1983) and this had already been suggested by Messel et al. (1978-1986, 18:122). Could it be that food supply is the proximal factor involved and that it is the condition factor of the females which determines whether she nests once or twice annually, or not at all, and when the egg laying occurs?

There are still a great many questions to be answered on nesting and undoubtedly these include the hardest ones. On the Blyth-Cadell and Liverpool-Tomkinson River Systems, which have been studied for more than ten years, there are a number of puzzling questions (Messel et al. 1978-1986, 1, 7, 18). For example, in the early to mid-seventies most hatchling recruitment occurred on the Liverpool; since 1976 most has occurred on the Tomkinson. The habitat has not altered and both rivers appear to have almost the same number of large animals. Further, a relatively dry wet season, with little or no flooding is not invariably followed by heavy hatchling recruitment (see our Chapter on Population Dynamics of *C. porosus*).

Webb et al. (1983) examine nesting in a perennial, somewhat elevated, freshwater swamp connected to a meandering tidal floodplain river and in perennial floodplain river channels where floating mats of vegetation overlie freshwater. Nests are constructed on the floating mats. Considerable attention is paid in that paper to embryo mortality and its causes, as well as to the detailed structure of the vegetation.

Habitat required for nesting by *C. porosus* has been described by Magnusson (1978, 1980a) and he has also discussed mortality of eggs (1982) and creche formation (1980b).

## FEEDING

A study of the food items taken by 289 hatchlings and small crocodiles has been made by Taylor (1979), who developed a method of removing stomach contents from these crocodiles without sacrificing the animals (Taylor et al. 1978). Her studies indicate that the food items of hatchlings and small crocodiles predominantly consist of crustacea (crabs and shrimps) with smaller proportions of spiders and vertebrates. She also found that crocodiles >4' in length ate significantly more birds and mammals than crocodiles <4'. She suggests that the diet of *C. porosus*

reflects the local availability of prey - an apparent exception was the absence of fish and fiddler crabs in the diet of *C. porosus* from habitats where these animals are abundant.

Her suggested explanation for the surprising absence of fish in the diet of hatchlings and small crocodiles is that in most instances, these size classes are not sufficiently agile to capture surface fish.

Observations on the Blyth-Cadell system (Messel et al. 1978-1986, 1:Chapter 7) showed fish being taken by juveniles and many attempts being made to catch them. Most of Taylor's animals were <1.0 m in length and most of the Blyth-Cadell observations were for animals 1.0-1.2 m in length. Undoubtedly *C. porosus* becomes more adept with age at catching fish. The typical way for crocodiles up to 4-5' to catch prey was by snapping sideways or by 'arch-lunge' feeding. In the arch-lunge method the crocodile arches its body and then lunges straight forward at considerable speed.

Larger juveniles (>1.2 m) take an increasing number of vertebrate prey. In the river, birds and mammals are not as abundant as crabs and prawns, and must be specifically hunted. The behavior associated with hunting has been observed a number of times and is the same as sometimes reported during attacks on man (Webb et al. 1978).

The crocodile sights or hears a disturbance from a distance and move towards it on the surface until it appears to sight the prey. It then orients its head toward it, dives and swims underwater to where the prey was. The head usually emerges just in front of the prey. If the prey is a bird moving along the edge of the bank, the crocodiles emerge where the prey was when the crocodile dived, i.e., they do not seem to be able to anticipate lateral movement of the prey.

Frequently, the prey escapes when the head emerges, however, if it does not, the crocodile either lunges forward with the jaws agape or snaps sidewise.

A common method for capturing small fish, employed by *C. porosus* 3-6' in length, was often observed for a 3-4' individual living directly across from the research vessel at km 32 on the Blyth River (Messel et al. 1978-1986, 1:453). The crocodile swam within inches of the banks, against the running tide, so that fish passed between it and the bank. The tail was used to block the passage of the fish, and would curl quickly inwards towards the bank, the head would swing simultaneously towards the bank and snap at the fish. Usually, several attempts are made before a successful capture. On other occasions, the crocodile simply swam along the bank against the tide, with its mouth open and snapped at fish as they ran into it.

Adults appear to show opportunistic selectivity in their feeding habits. The normally attack anything over a given minimum size. The types of prey found or reported in adult stomachs are birds, snakes, lizards, turtles, fish, large crabs, other crocodiles, wallabies, buffalo, cattle, and virtually any mammal which comes near the water's edge. Flying foxes are reputed to be a favorite delicacy and we have often found crocodiles in the mangroves beneath flying fox colonies (Messel et al. 1978-1986, 2:color plate 2.17, (5:60). Large crocodiles may be cannibalistic and hatchlings and small juveniles have been found in their stomachs (Messel et al. 1978-1986, 14:43).

*C. porosus* also appear to have a predilection for magpie geese (Messel et al. 1978-1986, 1:Chapter 6, 6). In Appendix A1.3 of Messel et al. (1978-1986, 1) some opportunistic observations on crocodile feeding are described. A 6-7' crocodile was observed to leap out of the water and catch a mullet; a 3-4 m crocodile was observed to catch and kill a 1 m shark. Other items that have been observed being taken include eels, mangrove snakes and cormorants.

Feeding was observed to occur during the day and at night, the crocodiles feeding when food was available, on both rising and falling tides.

Extensive night-time observations of feeding during surveys of crocodile numbers led to no obvious relationships between environmental variables and feeding. There was an indication that, on the sections where growth appeared to be slower, there was more activity directed towards catching food items. On these same sections the percentage of small crocodiles sighted feeding is twice that of hatchlings, probably indicating only that small crocodiles require more of the small food items such as prawns.

### DISTRIBUTION OF ANIMALS

Movement of animals will be discussed also in the chapter on *C. porosus* population dynamics. Here we characterize briefly typical distributions of *C. porosus* on tidal waters. Each monograph in the series by Messel et al. (1978-1986) includes histograms of the distribution of night-time sightings along the waterway, for each size class.

Webb and Messel (1978) discussed the distributional pattern of crocodiles on the Blyth-Cadell Rivers System in a preliminary fashion and referred to the near normal (bell-shaped) distributional pattern of hatchlings and 2-3' crocodiles around the nest sites. They also referred to the further downstream movement, relative to the nesting site, of the 3-4' and 4-5' sized crocodiles and concluded that there were many factors which could presumably affect movement and dispersal patterns of both adult and juvenile *C. porosus*. The results obtained from the Blyth-Cadell study (Messel et al. 1978-1986, 1:Chapter 6) demonstrate that those crocodiles which do remain in the river system are distributed along it in a quite definite fashion. The position of the peak of the distribution (mean distance upstream) varies for each size class and is roughly inversely proportional to size: the mean distance upstream of the hatchling peak is greater than that for 2-3' sized crocodiles; in turn, the mean distance upstream of 2-3' sized crocodiles is greater than that for 3-4' crocodiles. The peak is still quite distinct for the 4-5' size class but is not so evident for the 5-6' size class and specially not for larger crocodiles, which appear to be more evenly distributed along the river.

As we show incontrovertibly in our chapter on *C. porosus* population dynamics, some 80% of crocodiles in the sub-adult classes are lost from the Blyth-Cadell Rivers System. We also show that the same occurs in other TYPE 1 river systems (Messel et al. 1978-1986, 10-12). On this basis, the distributional pattern of crocodiles in size classes  $\geq$  (2-3') is more readily understood. The gradual shifting of the distributional peak downstream, of crocodiles in the 2-4', 4-5' and 5-6' size classes, may be understood, at least in part, on the basis of these crocodiles being on their way out of the river system, as they are forced gradually downstream by the large crocodiles, which are more evenly distributed along the river system. The long distance movers of Webb and Messel (1978) are also easily explained; they are presumably largely (but not solely) that fraction of the respective size classes, which are forced to leave the river - hence the increasing number of long distance movers with increasing size of sub-adults.

Food supply and salinity, which appear to be closely related, undoubtedly also play a role, for, as Taylor (1979) has shown, the diet of *C. porosus* changes as the animal increases in size. Whether or not food supply and/or salinity are the proximal factors involved, it is a fact that the peak of the distributional curve appears to be centered around the brackish sections of the river, especially in the changeover zone from salt to fresh water. On the Blyth River, this occurs on the km 30-35 section. Normal end of the dry season salinities on this section are close to 10‰/oo. As soon as one reaches

the freshwater region of the river, typified by the fringing riverside vegetation, the number of crocodiles sighted drops drastically. This is the normal situation for TYPE 1 rivers. However, if there is extensive swamp adjoining the upper reaches, the density may in fact increase. Examples of such rivers are the Glyde and the South Alligator. Where there are extensive swamp areas there is major movements between the swamp and tidal river (Messel et al. 1978-1986, 4, 14, 18, 19); Jenkins and Forbes 1985) as the dry season progresses.

The distribution on short TYPE 3 systems is usually even. In the Chapter on Population Status and Conservation we will give detailed information on the densities on animals on the various waterway TYPES.

Not many small crocodiles are seen in the wide open mouth sections of rivers where there is rough water and wave action. They appear to dislike rough water.

### SALINITY TOLERANCE

During the course of the crocodile survey program of the University of Sydney many observations of *C. porosus* in water considerably more saline than seawater have been made. The highest reading to date is 78‰, where a (4-5') *C. porosus* was sighted (Messel et al. 1978-1986, 18:140). Messel et al. (1978-1986, 1:Section 7.3) give details of many more observations of crocodiles of all sizes, including hatchlings, in hypersaline waters. These field observations indicate that *C. porosus* are able to tolerate very high salinities but probably for short periods only. The discovery of lingual salt glands in *C. porosus* (Taplin and Grigg 1981) revealed the mechanism for removal of excess salt. It is, however, still unclear whether prolonged exposure to high salinities will increase mortality, especially in hatchlings. Messel et al. (1978-1986, 1:376) describe the observation of a number of hatchlings ( $n = 11$ ) in salinities of up to 50‰, but a resurvey three weeks later showed only two (one in 50‰ salinity). It is unknown whether the missing animals had died or moved out because of the hypersalinity. To test the tolerance of hatchlings to very high salinities, 20 hatchlings were captured on the Tomkinson River, measured, marked and released on Mungardobolo Creek at km 25.3 on July 19. Mungardobolo Creek drains into the Tomkinson and is highly hypersaline (Messel et al. 1978-1986, 7). During the general resurvey of the Liverpool System on October 19, no hatchlings were sighted. The thirteen non-hatchlings sighted were in low tide salinities varying from 38‰ to 58‰. No hatchlings were sighted on the Liverpool and Tomkinson Rivers on either side of Mungardobolo Creek for several km. A further exhaustive search for hatchlings was made by Laurie Taplin (see below) in November. On the night of November 12, a female hatchling No. 1842 was recaptured at km 21.9 on the Tomkinson River. This meant that it had travelled a distance of 13.2 km from its release point. It was in excellent condition. It thus appears likely that of the 12 hatchlings, all except one were predated (most unlikely) or perished because of the high salinity. Our results differ from those of Magnusson (1978) who suggests that hatchling mortality is not affected by high salinities, however, it should be noted that his results were obtained on waters which were not hypersaline.

A mark-recapture study by Grigg et al. (1980) on the Tomkinson River showed little signs of distress in hatchlings that were in salt water for periods of up to 4 months. However, the salinity in their study area only varied from 25-34‰ and so was not hypersaline.

Taplin (1982) characterizes *C. porosus* as not only a remarkably efficient osmoregulator but also the most euryhaline reptile known to date. At both ends of the salinity spectrum, *C. porosus* appears to depend on its food intake to compensate net water or sodium loss.



## METHODS OF MOVEMENT

Methods of Locomotion - Webb (1977) gives a description of methods of movement used by *C. porosus*. There are four main ones; swimming, high walking, the belly run, and the gallop. All were recognized by Cott (1961) in his magnificent study of the Nile crocodile, *C. niloticus*.

When swimming, the front and rear legs are held beside the body, and the complete post-cranial body moves in successive undulations. In the water, crocodiles often drift with the legs hanging down and the tail gently sweeping from side to side. If disturbed, the region of the body behind the head may submerge and the hind feet are spread out. From this posture they can rapidly submerge, backwards.

In the high walk the body is held off the ground except for limbs and tail tip. The limbs move toward each other on one side, while they separate on the other. Crocodiles can "run" using the same basic high walk stance. The tracks of a high walking crocodile are distinctive.

The belly run or slide is typically used when moving from a bank into the water. Using gravity, and as Cott (1961) pointed out, "the polished ventral shields...like the undercarriage of the sleigh", they slide down the bank using the hind limbs to propel them. The tail sweeps from side to side as they move, and in soft mud, this is much like swimming; it leaves a characteristic track.

## LITERATURE CITED

- Allen, G. R. 1974. The marine crocodile, *Crocodylus porosus* from Ponape, Eastern Caroline Islands, with notes of food habits of crocodiles from the Palau Archipelago. *Copeia* 1974:553.
- Brazaitis, P. 1973. The identification of living crocodilians. *Zoologica* 58:59-101.
- Cogger, H. G. 1975. Reptiles and Amphibians of Australia. Reed, Sydney.
- Cott, H. B. 1961. Scientific results of an inquiry into the ecology and economic status of the Nile crocodile (*Crocodylus niloticus*) in Uganda and northern Rhodesia. *Trans. Zool. Soc. Lond.* 29:211-337.
- Ditmars, R. L. 1910. Reptiles of the World. Macmillan, N.Y.
- Grigg, G. C., L. E. Taplin, P. Harlow, and J. Wright. 1980. Survival and growth of hatchling *Crocodylus porosus* in saltwater without access to fresh drinking water. *Oecologia* 47:264-266.
- Guggisberg, C. A. W. 1972. Crocodiles: Their Natural History, Folk-lore and Conservation. Wren Press, Victoria.
- Hornaday, W. T. 1926. Two Years in the Jungle. Charles Scribner's Sons, New York.
- Jenkins, R. W. G., and M. A. Forbes. 1985. Seasonal variation in abundance and distribution of *Crocodylus porosus* in the tidal East Alligator River, northern Australia. Pages 63-69 in G.

- Grigg, R. Shine, and H. Ehmann, eds. The Biology of Australasian Frogs and Reptiles. Surrey Beatty and Sons, Chipping Norton, Australia.
- Loveridge, A. 1945. Reptiles of the Pacific World. Macmillan, New York.
- Magnusson, W. E. 1978. Nesting ecology of *Crocodylus porosus* Schneider, in Arnhem Land Australia. Ph.D. Thesis, University of Sydney.
- \_\_\_\_\_. 1980a. Habitat required for nesting by *Crocodylus porosus* in northern Australia. Aust. Wildl. Res. 7:149-156.
- \_\_\_\_\_. 1980b. Hatching and creche formation by *Crocodylus porosus*. Copeia 1980:359-362.
- \_\_\_\_\_. 1982. Mortality of eggs of the crocodile *Crocodylus porosus* in northern Australia. J. Herp. 16:121-130.
- Messel, H. et al. 1978-1986. Surveys of Tidal River Systems in Northern Australia and their Crocodile Populations, Monographs 1-19. Pergamon Press.
- Neill, W. T. 1971. The last of the Ruling Reptiles: Alligators, Crocodiles and Their Kin. Columbia University Press, New York.
- Smith, M. A. 1931. The Fauna of British India - Loricata, Testudines, Vol. 1. Taylor and Francis, London.
- Taplin, L. E. 1982. Osmoregulation in *Crocodylus porosus*. Ph.D. Thesis, University of Sydney.
- \_\_\_\_\_, and G. C. Grigg. 1981. Salt glands in the tongue of the estuarine crocodile, *Crocodylus porosus*. Science 212:1045-1047.
- Taylor, J. A. 1979. The foods and feeding habits of subadult *Crocodylus porosus* Schneider in northern Australia. Aust. Wildl. Res. 6:347-359.
- \_\_\_\_\_, G. J. W. Webb, and W. E. Magnusson. 1978. A method of collecting stomach contents from live crocodilians (Reptilia, Crocodylidae) J. Herp. 12:415-417.
- Webb, G. J. W. 1977. The natural history of *Crocodylus porosus*: habitat and nesting. Pages 237-284 in H. Messel and S. T. Butler, eds. Australian Animals and Their Environment. Shakespeare Head Press, Sydney.
- \_\_\_\_\_, S. C. Manolis, and G. C. Sack. 1983. *Crocodylus johnstoni* and *C. porosus* coexisting in a tidal river. Aust. Wildl. Res. 10:639-650.
- \_\_\_\_\_, and H. Messel. 1978. Movement and dispersal patterns of *Crocodylus porosus* in some rivers of Arnhem Land, northern Australia. Aust. Wildl. Res. 5:263-283.
- \_\_\_\_\_, \_\_\_\_\_, and W. E. Magnusson. 1977. The nesting of *Crocodylus porosus* in Arnhem Land, northern Australia. Copeia 1977:238-249.
- \_\_\_\_\_, G. C. Sack, R. Buckworth, and S. C. Manolis. 1983. An examination of *Crocodylus porosus* nests in two northern Australian freshwater swamps, with an analysis of embryo mortality. Aust. Wildl. Res. 10:571-605.

\_\_\_\_\_, M. Yerbury, and V. Onions. 1978. A record of a *Crocodylus porosus* attack. J. Herp. 12:267-268.

Wermuth, H. 1953. Systematik der Rezenten Krokodile. Mitt. Zool. Mus. Berl. 29:376-514.

\_\_\_\_\_. 1964. Das Verhältnis zwischen Kopf-, Rumpf- und Schwänzlänge bei den rezenten Krokodilen. Senck. Biol. 45:369-385.

## A MODEL FOR THE POPULATION DYNAMICS OF *Crocodylus porosus* IN NORTHERN AUSTRALIA

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### INTRODUCTION

In our chapter on the population status of *Crocodylus porosus* in northern Australia we describe the survey methods used in monitoring the populations and describe briefly the history of the surveys. More than 100 tidal river and creek systems were surveyed at least once between 1974 and 1979. In some cases the surveys have been continued over a period of ten years.

Intensive population surveys and studies were continued during 1980-1983 on some 330 km of tidal waterways (Figs. 1-3) centered on the Liverpool-Tomkinson and Blyth-Cadell Rivers Systems in northern Arnhem Land and on some 59.3 km of associated alternative habitat. These relatively undisturbed waterways constituted our population dynamics and status monitoring systems. In addition Ngandada Creek and the Glyde River with its associated Arafura Swamp were resurveyed twice in 1983 (Figs. 1, 4-5). All these latter surveys are analyzed in great detail in Messel et al. (1979-1984, 18).

The results of our survey and studies have allowed a picture of *C. porosus* population dynamics in northern Australia to be developed, and this picture is presented in some detail. It enables us to account in a consistent fashion for the results of the surveys and to predict results to be expected on future surveys.

One implication of the picture was that recovery of the crocodile population should occur more rapidly in areas where the TYPE 1 rivers (see Point 1 in the population model) have closely associated extensive freshwater complexes. One of the best such areas remaining in northern Australia is the Alligator Region, where there is the largest concentration of TYPE 1 *C. porosus* systems in northern Australia. For this reason the waterways of the Alligator Region and the Adelaide River were resurveyed in July 1984.

The Adelaide, East Alligator South Alligator, West Alligator, and Wildman River Systems and Murgarella Creek-- all TYPE 1 systems (Fig. 6)--were first systematically surveyed in 1977 (the Wildman in 1978) and then resurveyed in 1978 and again in 1979. Just to the north of the Alligator Region, the largest assemblage of TYPE 3 waterways in northern Australia--the Cobourg Complex consisting of the Ilamaryi and Minimini Complexes and Saltwater Creek--were surveyed for the first time in 1979 (Fig. 6). Our results and discussions of the surveys were presented in Messel et al. (1979-1984, 1, 3, 18) for the Adelaide River System and Messel et al. (1979-1984, 1, 4, 14) for the Alligator Region River Systems and the Cobourg Complex. Detailed descriptions of the waterways were given in those citations also and full work maps in Messel et al. (1979-

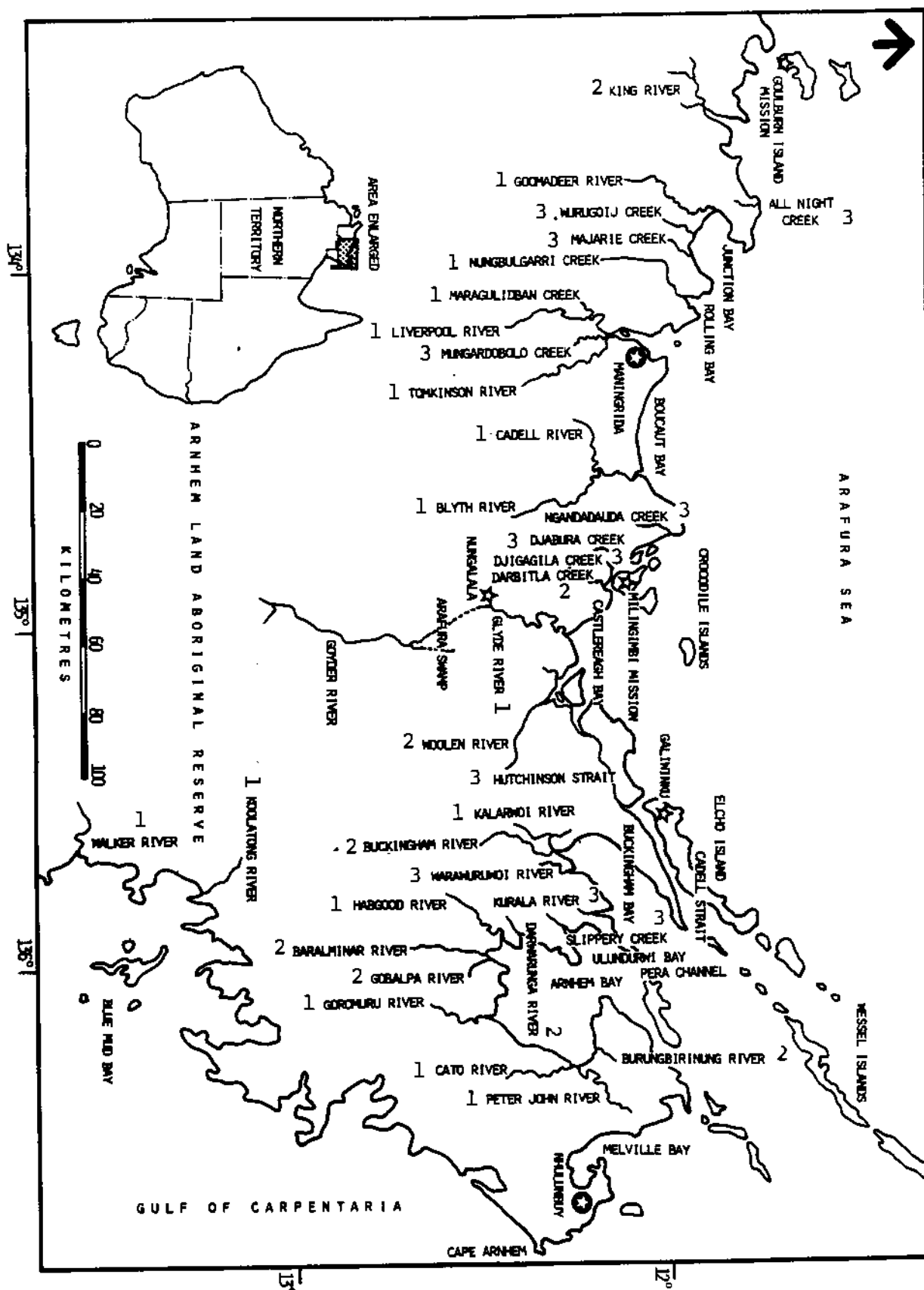


Figure 1. General area map showing the waterways of the monitored area, with their TYPE classifications.

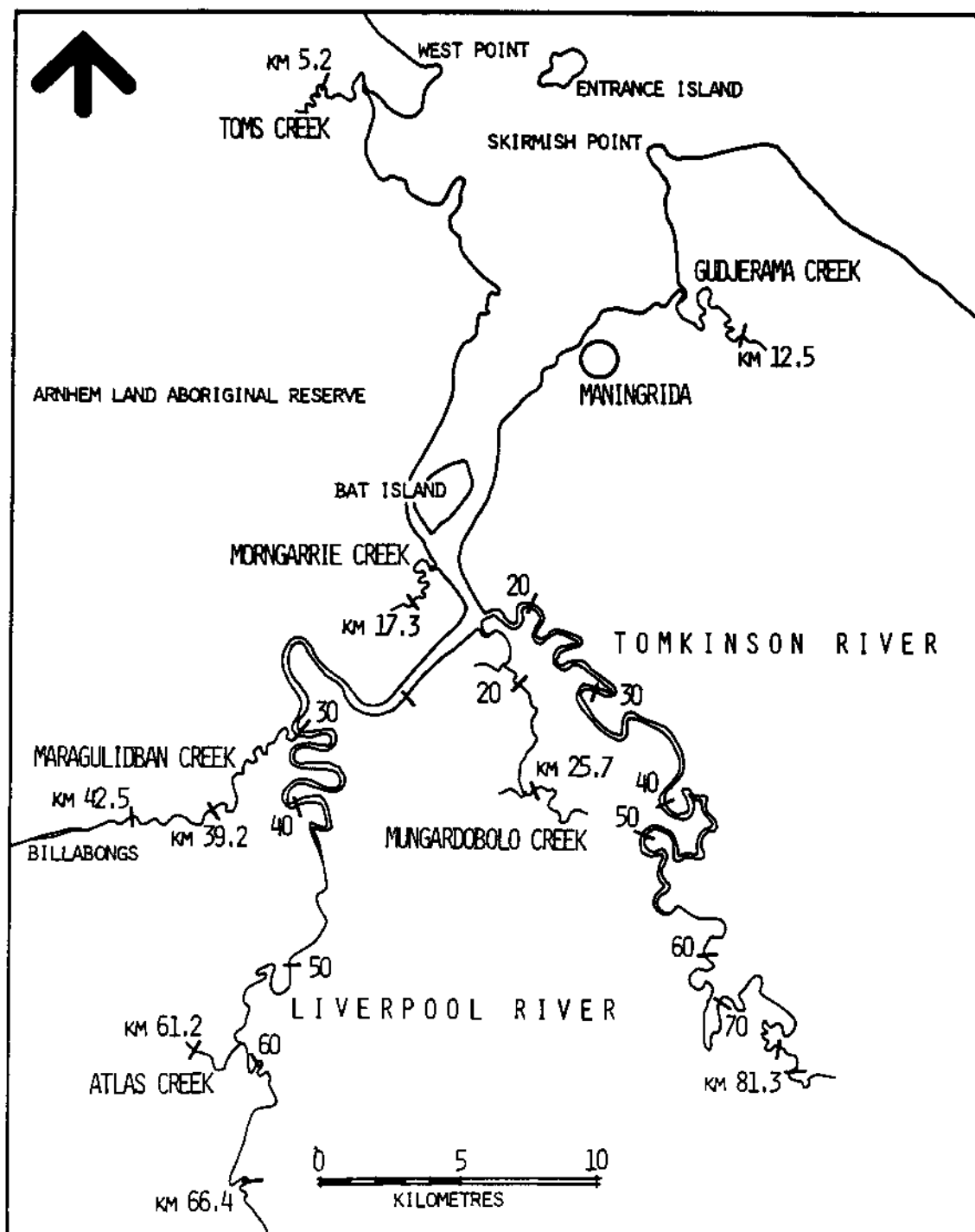


Figure 2. The Liverpool-Tomkinson Rivers.

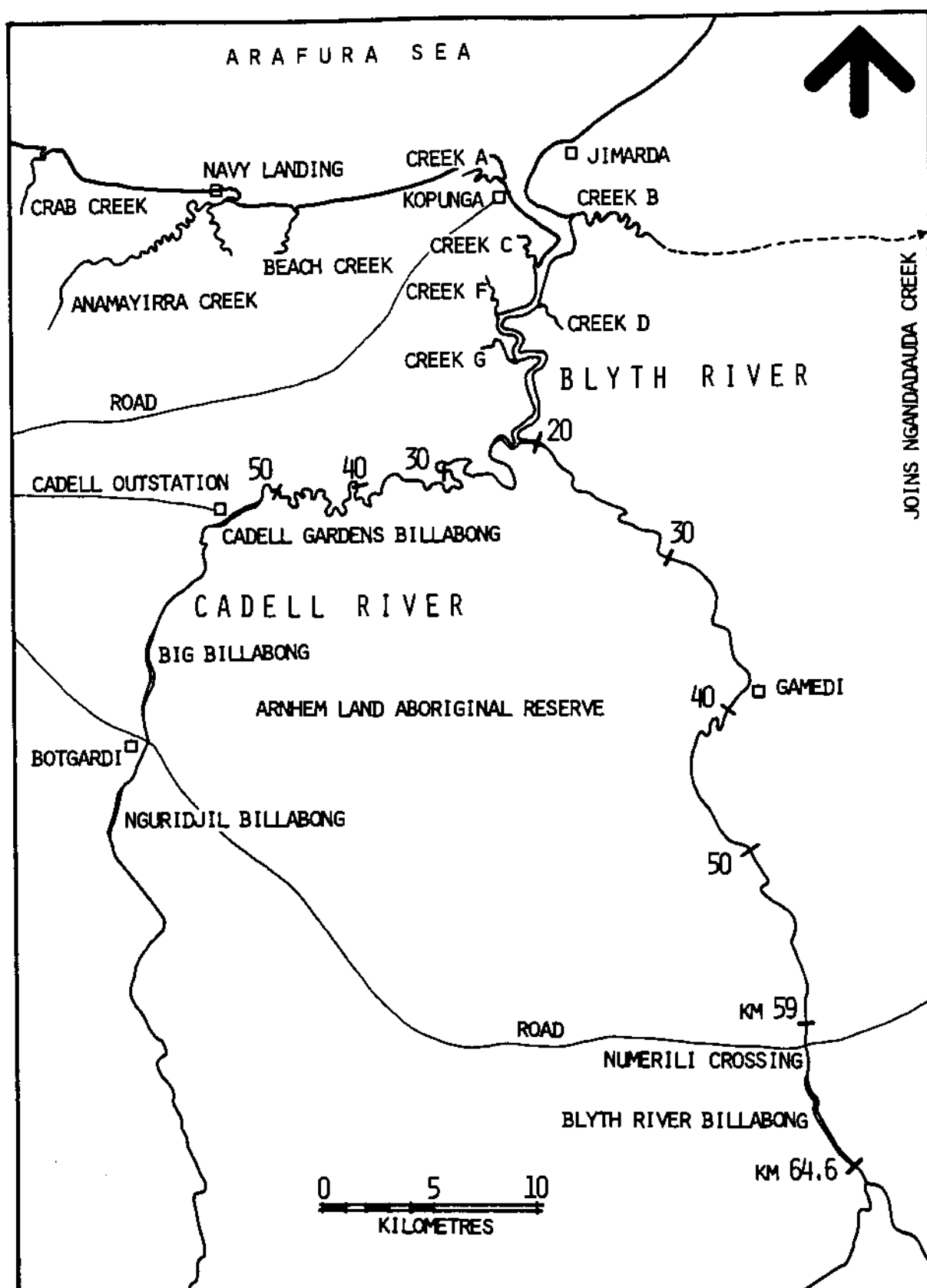


Figure 3. The Blyth-Cadell Rivers.

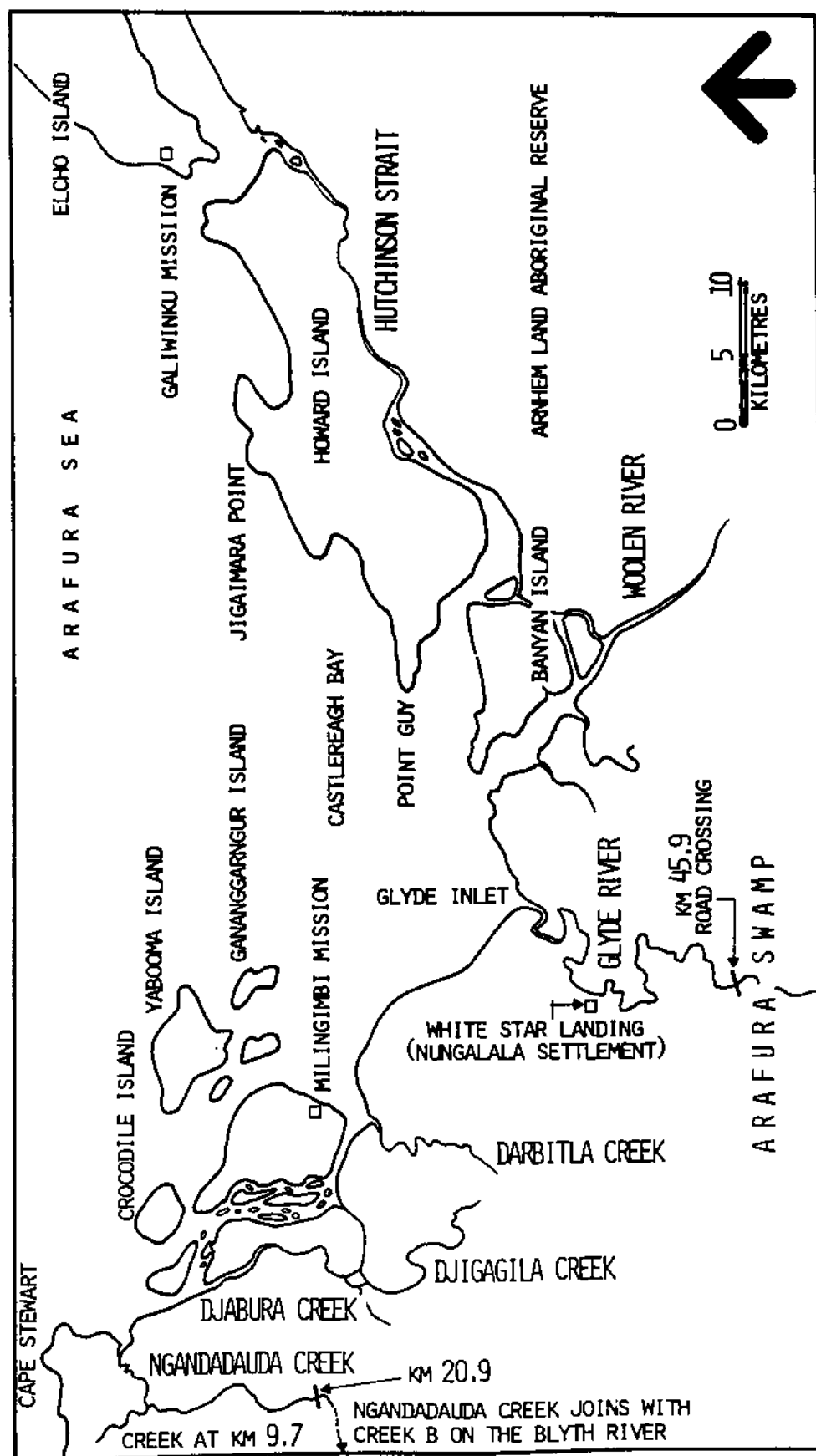


Figure 4. General area map showing the tidal waterways of the Milingimbi Complex and Castlereagh Bay.



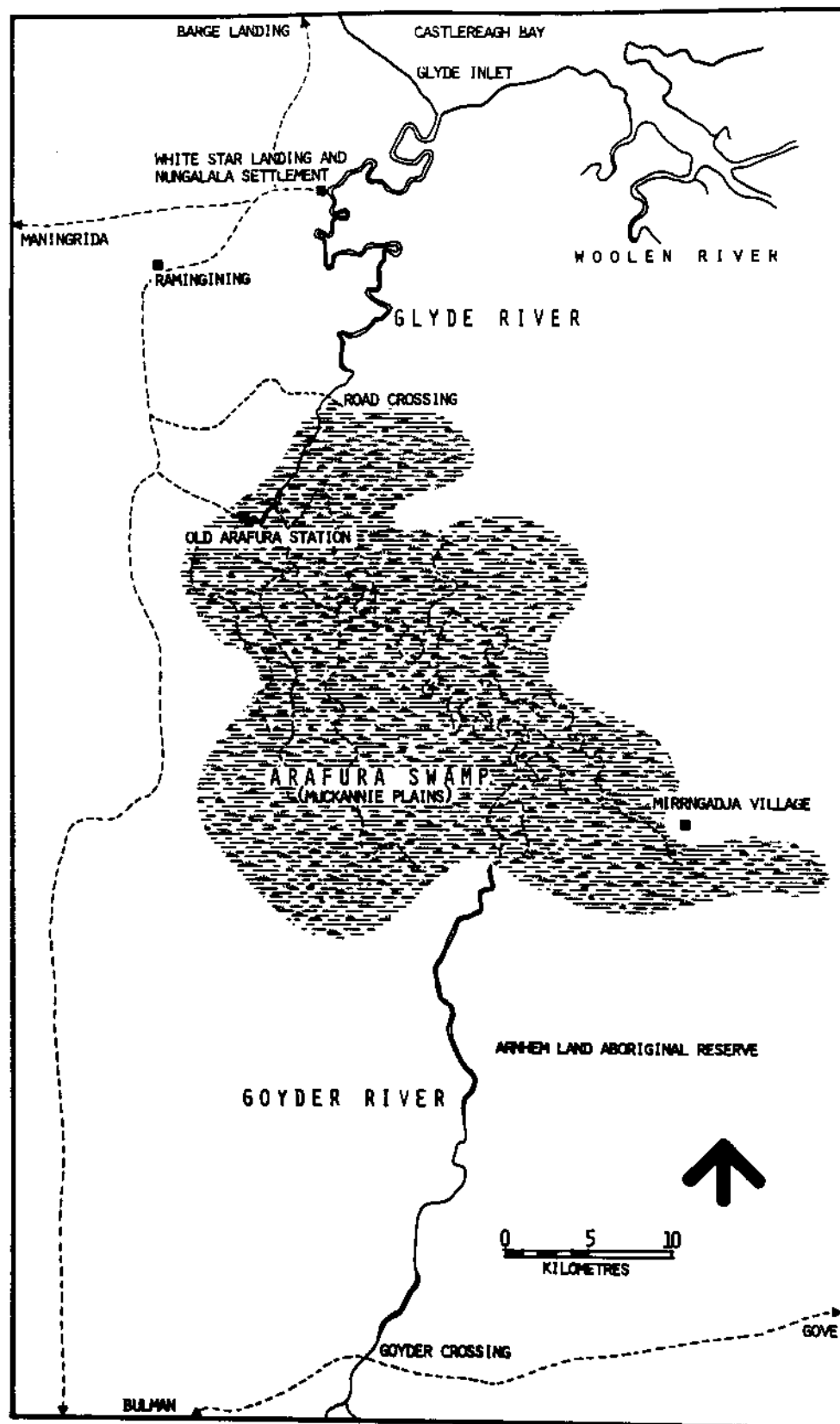


Figure 5. The Glyde-Arafura and Goyder Areas.

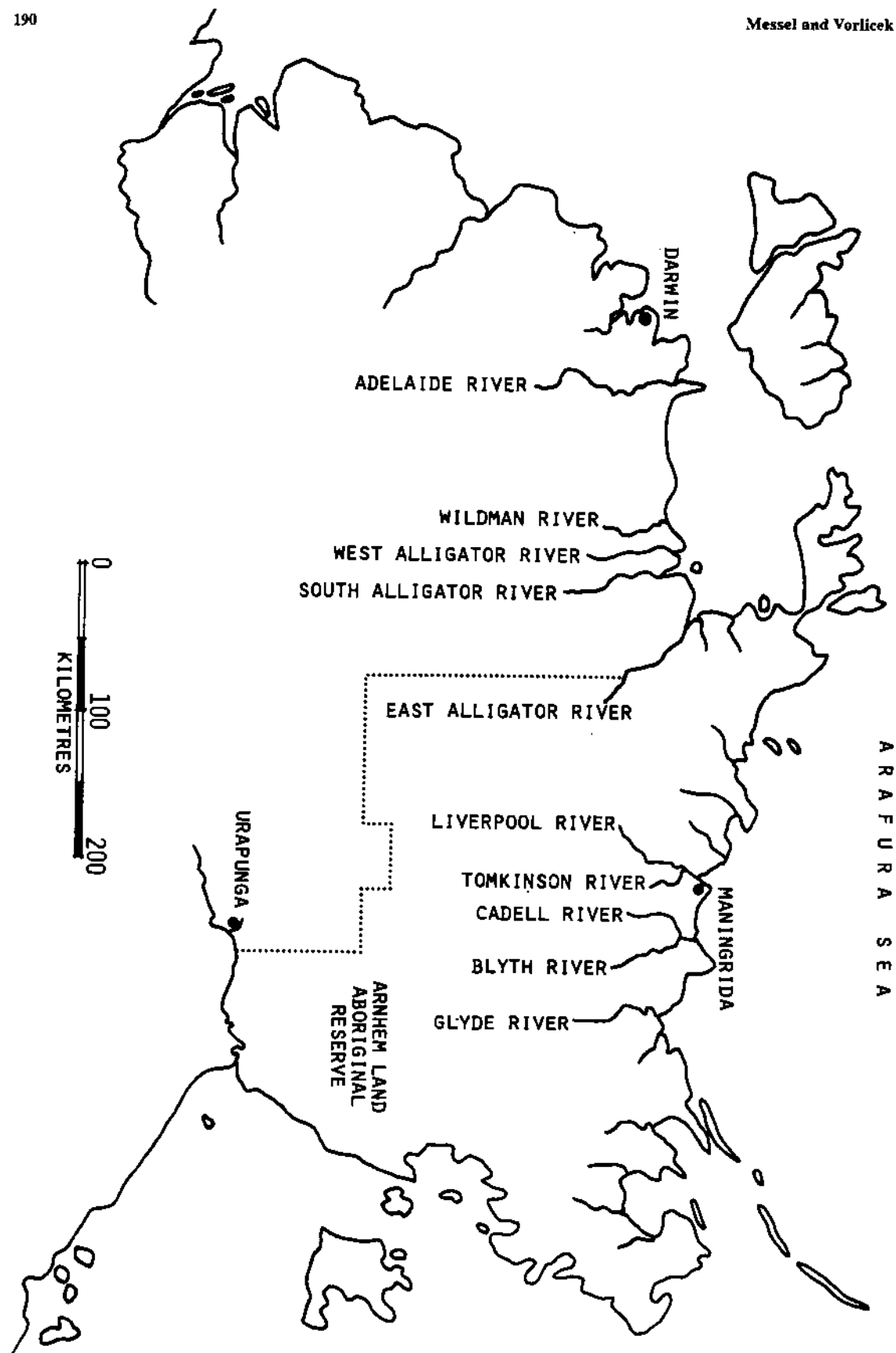


Figure 6. General area map showing rivers and creeks on the Cobourg Peninsula and the Alligator Region. The dotted area shows the Cobourg Mangrove Complex which is one of the largest in Australia.

1984, 15). The results and analysis of the July 1984 surveys is presented in detail in Messel et al. (1979-1984, 19).

Our approach in this chapter is to present the model we have developed and describe how the results obtained in the Maningrida monitored area and Alligator Rivers Region fit the model. This of course is a somewhat circular process, since the model was derived partly from consideration of these results. Other evidence is also presented to support the basic ideas of the model.

We believe that the construction of a mathematical model of *C. porosus* population dynamics would be premature at this stage. There are far too many uncertainties in values for basic biological parameters to allow a sensible predictive model. Examples of such uncertainties include: percentage of mature females in a given population; percentage of mature females nesting; variability in nesting in different years and different rivers; detailed understanding of territorial requirements and so on.

## RESULTS

As we describe in our chapter on population status, when discussing population changes it is essential to consider results for broad groups of waterways as well as those for individual waterways. In Table 1A we present results for each survey of the tidal waterways of the monitored area from 1974 to 1983. The table is in our standard format, which is described in the Results section of the chapter on Population Status, and the reader should refer to this.

In Table 1B we present the results for all surveys carried out in the Alligator Region, Cobourg Complex, and Adelaide River, in the same form as Table 1A. Tables 2 and 3 are obtained using Table 1A, and highlight a number of salient features of the data for the Blyth-Cadell and Liverpool-Tomkinson Rivers Systems. In Tables 4 and 5 we show summary results for the number of crocodiles sighted in the hatchling, small (3-6'), and large size classes during the general night-time surveys of the major components of the Blyth-Cadell and Liverpool-Tomkinson Rivers Systems. The more important size classes are the 3-6', large, and  $\geq 3'$ . Interpretation of small and non-hatchling numbers can be distorted temporarily because of variations arising from the input of 2-3' animals after a heavy hatchling recruitment year. This variation appears to soon disappear once the animals reach the  $\geq 3-4'$  size classes.

Table 6 gives summary results in the different size classes for the waterways of Rolling and Junction Bays. Table 7 does likewise for each of the major components of our monitoring area and for their combined total. Table 8 gives the results for the surveys of the main alternative *C. porosus* habitats associated with the monitored area. The reader is asked to spend a few minutes looking down the columns in Tables 4 to 7 before proceeding. Table 9 for the Alligator Region and Adelaide River Systems has been obtained using Table 1B and presents the results in similar form to Tables 2 and 3, with the sightings grouped into important size classes.

We draw attention to two important points when considering and comparing the results shown in the Tables. The first relates to the matter of errors in size class estimation. We discussed this matter in some detail in Messel et al. (1979-1984, 1:80, 335, 389 and 18:117) and refer the reader to these. The second matter concerns the importance of comparing results for equivalent survey seasons; that is, breeding versus breeding and non-breeding versus non-breeding periods whenever possible (Messel et al. 1979-1984, 18:124-125). For example, October-November surveys should, if possible, be compared with other October-November surveys and not June-July



Table 1A. cont.

System	Date	Total	H	2-3	Numbers in size class					6-7	>7	E.O.	Kilometers surveyed	Density	95% levels	Type
MARJARIE	Oct. 81	17			3	4	2	1	1	3	7		22.0	0.8	20- 36	
	June 82	17	2	1	1	2	2	1	1	3	5		23.8	0.6	17- 33	
	Oct. 82	12				4	5	1	1	1	1		23.3	0.5	13- 27	
	June 83	24	4		4	4	5	2	2		5		24.1	0.8	24- 42	
	Oct. 83	19		1	4	1	6	3	1	1	3		24.1	0.8	22- 40	
	Aug. 75	4				3	1						16.4	0.2	4	3
	Aug. 76	1									1		16.4	0.1	1	
	July 79	9					2	2	4	1	1		16.4	0.5	9	
	June 81	6			1	1	1	1	1	1	1		16.4	0.5	6	
	Oct. 81	8		1	1	1	3			2	2		16.4	0.5	8	
WURUGOIJ	June 82	7				2	2	1	1	1	3		16.2	0.4	7	
	Oct. 82	8	1			2	2	1	1	1	1		16.4	0.4	7	
	June 83	6		1		1	2	1	1		1		16.4	0.4	6	
	Oct. 83	11			2	3	1	2	2	3	3		16.4	0.7	11- 25	
MONOGRAPH 7																
LIVERPOOL-TOMKINSON	July 76	228	19	39	56	27	13	3	3	3	68		152.2	1.4	314- 372	1
	May 77	245	40	6	51	59	30	13	5	41			145.1	1.4	307- 365	
	Oct. 77	228	56	7	39	62	24	9	1	30			123.4	1.4	256- 308	
	Sept. 78	233	37	18	37	65	19	14	8	35			141.4	1.4	293- 349	
	Oct. 79	335	161	16	36	37	29	17	23	36			141.1	1.4	290- 346	
	July 79	515	289	11	39	43	34	29	20	50			150.0	1.5	341- 401	
	Oct. 80	295	71	51	37	32	29	12	14	49			140.6	1.6	337- 397	
	July 81	256	26	52	48	29	23	15	15	48			140.6	1.6	347- 407	
	Oct. 81	254	34	33	50	34	23	14	14	52			141.1	1.6	331- 391	
	June 82	467	193	29	64	50	37	23	17	54			141.1	1.9	416- 482	
NUNGBULGARRI	Oct. 82	384	144	16	48	51	25	21	17	62			141.1	1.7	363- 425	
	July 82	432	121	83	64	56	32	17	15	44			141.1	2.2	475- 466	
	Oct. 83	327	63	77	47	39	34	8	14	45			141.1	1.9	400- 466	
	Aug. 75	29		4	11	3		1		10			15.0	1.9	37- 59	1
	July 76	15	2		3	5	1	1		3			13.6	1.0	14- 28	
	June 77	14	2	2		6	1	1		2			13.6	0.9	13- 27	
	July 79	35	10		4	4	6	5	12	4			14.8	1.7	31- 51	
	June 81	27	2	4	10	4			1	6			14.8	1.7	31- 51	
	Oct. 81	25		2	12	4	2			5			14.8	1.7	31- 51	
	June 82	23		2	8	4	3	1	1	4			14.8	1.6	28- 48	
	Oct. 82	29		1	9	8	2	2	2	4			14.4	2.0	37- 59	

Table 1A. cont.

System	Date	Total	H	2-3	Numbers in size class					E.O.	Kilometers surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7	>7					
NUNGBULGARRI	June 83	55	34	2	6	5	5			3	14.4	1.5	25- 43	
	Oct. 83	38	15	1	5	4	6	1	1	5	14.4	1.6	28- 48	
	Sept. 75	19	3	2	5	1	1	2	1	4	22.6	0.7	18- 34	3
	June 79	21			2	3	3	4	4	5	23.9	0.9	25- 43	
NGANDADAUDA	June 83	30			2	5	7	1	2	13	23.6	1.3	38- 60	
	Oct. 83	21				5	8	4	2	2	23.6	0.9	25- 43	
	Sept. 75	28			3	6	2	1	4	12	45.9	0.6	35- 57	1
	July 79	100	36	9	10	9	10	6	6	14	45.9	1.4	89- 121	
GLYDE	July 83	118	5	9	35	16	8	6	10	29	45.9	2.5	164- 206	
	Oct. 83	91		3	22	12	11	5	11	27	45.9	2.0	130- 168	

1. The midstream distance surveyed and density of non-hatchling crocodiles sighted on each waterway is shown, as are the 95% confidence limits for the estimate of the actual number of non-hatchlings present. The TYPE classification of each waterway is given also.
2. The 1976 results for the Liverpool-Tomkinson given here differ by 20 from those in Table 9.2.1 (Monograph 1) because these animals are now included in the upstream Tomkinson (km 73.7-80.1) on Table 8.
3. Numbers in brackets give numbers of crocodiles removed by Biology researchers before survey.

Table 1B. Number of *C. porosus* sighted within each size class on tidal waterways of Van Diemen Gulf, during night-time spotlight surveys carried out between 1977 and 1984.

System	Date	Total	H	2-3	Numbers in size class					>7	E.O. surveyed	Kilometers surveyed	Density	95% levels	Type
ADELAIDE	July	77	417	48	24	88	116	47	35	33	26	226.3	1.6	556-644	1
	Sept.	78	381	62	24	71	90	43	33	32	26	221.0	1.4	487-559	
	Sept.	79	374	53	8	46	75	58	47	64	23	231.6	1.4	490-562	
	July	84	602	60	36	105	79	64	78	120	60	231.6	2.3	842-936	
MURGENELLA	Oct.	77	95	1	1	8	33	13	6	18	15	45.9	2.0	135-173	1
	June	78	173	48	16	4	17	24	23	30	11	44.9	2.8	183-227	
	Aug.	79	198	47	24	12	22	24	27	26	16	45.6	3.3	223-273	
	July	84	236	7	17	61	28	21	31	57	14	45.6	5.0	346-406	1
EAST ALLIGATOR	Oct.	77	318	53	18	37	57	41	40	34	38	114.9	2.3	402-468	
	June	78	329	39	14	63	51	42	31	51	38	118.9	2.4	442-510	
	Aug.	79	393	53	30	44	58	28	58	64	58	119.2	2.9	521-595	
	July	84	411	22	51	72	35	24	47	60	100	119.2	3.3	598-678	1
SOUTH ALLIGATOR	Oct.	77	142			12	24	24	25	31	26	113.8	1.2	209-257	
	July	78	157	6	3	4	14	43	24	38	25	113.2	1.3	223-273	
	Aug.	79	164	4	1	4	12	24	31	51	37	114.0	1.4	237-287	
	July	84	279	39	15	17	18	25	38	91	36	114.0	2.1	363-425	1
WEST ALLIGATOR	Oct.	77	83	9	2	14	14	15	10	10	9	42.2	1.8	104-138	
	July	78	85	23	5	12	9	13	10	6	7	40.4	1.5	86-118	
	Aug.	79	96	12	9	13	14	7	12	14	15	42.2	2.0	120-156	
	June	84	120	17	2	33	21	18	6	12	11	42.2	2.4	149-189	1
WILDMAN	Sept.	78	118	53	16	6	8	10	9	7	9	33.5	1.9	91-123	
	Aug.	79	155	21	34	15	14	7	17	31	16	33.5	4.0	197-243	
	June	84	226	26	60	46	20	23	24	13	14	33.5	6.0	300-356	1
	Oct.	77	638	63	21	71	128	93	81	93	88	316.8	1.8	895-991	
ALLIGATOR REG. EXCL. WILDMAN	June	78	744	116	38	83	91	122	88	125	81	317.4	2.0	980-1080	
	Aug.	79	851	116	64	73	106	83	128	155	126	321.0	2.3	1151-1259	
	July	84	1046	85	85	183	102	88	122	220	161	321.0	3.0	1514-1638	

MONOGRAPH 3

MONOGRAPH 4 (14)

Table 1B. cont.

System	Date	Total	H	2-3	Numbers in size class					>7	Kilometers		95%	Type	
					3-4	4-5	5-6	6-7	E.O. surveyed		Density	levels			
ALLIGATOR REG. WITH WILDMAN	June	78	862	169	54	89	99	132	97	132	90	350.9	2.0	1084-1190	1
	Aug.	79	1006	137	98	88	120	90	145	186	142	354.5	2.4	1366-1484	
	July	84	1272	111	145	229	122	111	146	233	175	354.5	3.3	1836-1972	
	Aug.	79	29		1	1	6	4	6	9	2	14.1	2.1	37- 59	3
SALTWATER	July	84	25	6		4	3	3	1	6	2	14.1	1.3	22- 40	
	Aug.	79	11			1	4	3	1	2		43.8	0.3	11- 25	3
	July	84	9					2	3	1	3	43.8	0.2	9	
	Aug.	79	6			1	3	2	1		1	28.5	0.2	6	3
MIDDLE ARM	July	84	10			1	1	4	2	1	1	28.5	0.4	10- 22	
	Aug.	79	10				3	1	2	2	2	53.5	0.2	10- 22	3
	July	84	25			3	3	6	5	5	3	53.5	0.5	31- 51	
	Aug.	79	27			1	10	6	4	4	2	125.8	0.2	34- 54	
COMPLEX ARM A	July	84	44			4	4	12	10	7	7	125.8	0.3	59- 85	
	Aug.	79	5				3		1		1	26.7	0.2	5	3
	July	84	9			1	1		4	4		26.7	0.3	9	
	Aug.	79	3				1		1	1		15.0	0.2	3	3
ARM B	July	84	4						1	3		15.0	0.3	4	
	Aug.	79	7			3	3	1	1		2	29.3	0.2	7	3
	July	84	5			2	2			2	1	29.3	0.2	5	
	Aug.	79	9			1	1		3	2	3	19.8	0.5	9	3
ARM C	July	84	7					1	1		2	19.8	0.4	7	
	Aug.	79	16			3	3	4	3	3	3	44.4	0.4	18- 34	3
	July	84	7			1	1	1	1	2	2	44.4	0.2	7	
	Aug.	79	40			11	5	9	9	6	9	135.2	0.3	53- 79	3
COMPLEX ILAMARYI	July	84	32			4	2	7	7	14	5	135.2	0.2	41- 63	
	Aug.	79	67			1	21	11	13	10	11	261.0	0.3	94- 126	3
	July	84	76			4	8	14	17	21	12	261.0	0.3	107- 143	
	Aug.	79	96	1		2	27	15	19	19	13	275.1	0.3	137- 177	3
COBOURG COMP. & SALTWATER	July	84	101	6		8	11	17	18	27	14	275.1	0.3	136- 176	



Table 1B, cont.

System	Date	Total	H	2-3	Numbers in size class					E.O.	Kilometers surveyed	Density	95% levels	Type
					3-4	4-5	5-6	6-7	>7					
ALLIGATOR REG. + COBOURG COMP. & SALTWATER	Aug.	79	1102	137	99	147	105	164	205	155	629.6	1.5	1521-1645	1 & 3
	July	84	1373	117	145	133	128	164	260	189	629.6	2.0	1989-2131	
ADELAIDE + ALLIGATOR REG. EXCL. WILDMAN	July & Oct.	77	1055	111	45	244	140	116	126	114	543.1	1.7	1486-1610	1
	Sept. & June	78	1125	178	62	181	165	121	157	107	538.4	1.8	1491-1615	
	Sept. & Aug.	79	1225	169	72	181	141	175	219	149	552.6	1.9	1667-1797	
	July	84	1648	145	121	181	152	200	340	221	552.6	2.7	2387-2543	
ADELAIDE + ALLIGATOR REGION INCL. WILDMAN	Sept. & June	78	1243	231	78	189	175	130	164	116	571.9	1.8	1596-1724	1
	Sept. & Aug.	79	1380	190	106	195	148	192	250	165	586.1	2.0	1883-2021	
	July	84	1874	171	181	201	175	224	353	235	586.1	2.9	2710-2876	
ABOVE + COBOURG COMP. & SALTWATER	Sept. & Aug.	79	1476	190	107	222	163	211	269	178	861.2	1.5	2037-2181	1 & 3
	July	84	1975	177	181	212	192	242	380	249	861.2	2.1	2864-3034	

Table 2A. Blyth-Cadell Rivers System. Table for the Blyth-Cadell Rivers System showing various size class groupings<sup>a</sup>.

Survey		Total	H	2-5 ft	≥5 ft	2-6 ft (S)	≥6ft (L)	3-6 ft (M)	S:L	M:L
26 Oct.	74	387	89	286	12	292	6	211	48.7	35.2
1 Nov.	75	353	50	263	40	289	14	183	20.6	13.1
Major flooding										
23 Sept.	76	348	82	221	45	240	26	177	9.2	6.8
4 Nov.	76	307	61	217	29	230	16	169	14.4	10.6
11 Apr.	77	327	72	230	25	242	13	172	18.6	13.2
3 May	77	333	88	215	30	231	14	171	16.5	12.2
8 June	77	365	108	215	42	232	25	196	9.3	7.8
16 Sept.	77	386	105	234	47	257	24	212	10.7	8.8
23 Oct.	77	360	112	204	44	226	22	158	10.3	7.2
10 June	78	432	173	219	40	238	21	173	11.3	8.2
12 Sept.	78	399	155	200	44	221	23	161	9.6	7.0
No flooding - driest wet on record										
10 June	79	465	123	251	91	287	55	196	5.2	3.6
4 Oct.	80	400	119	220	61	249	32	160	7.8	5.0
Heavy flooding										
9 July	81	366	76	223	67	253	37	167	6.8	4.5
19 Oct.	81	315	72	179	64	204	39	127	5.2	3.3
Dry wet - minor flooding only										
25 June	82	408	136	166	106	205	67	163	3.1	2.4
6 Nov.	82	347	111	164	72	197	39	154	5.1	3.9
Dry wet - minor flooding only										
15 July	83	465	157	221	87	258	50	160	5.2	3.2
26 Oct.	83	354	73	217	64	246	35	151	7.0	4.3

<sup>a</sup> The 2-3', 3-4' and 4-5 size classes are grouped together (2-5') and the size classes above those in another group (≥5'). We have also grouped the crocodiles sighted into small (2-6'), medium (3-6') and large (≥6'). Also shown are the ratios small/large and medium/large. This Table was obtained by using the data given in Table 1. See caption to Table 3 for division of the EO crocodiles among the various size classes.

Table 2B Liverpool-Tomkinson Rivers System. Equivalent Table for the overall Liverpool-Tomkinson Rivers System<sup>a</sup>.

Survey		Total	H	2-5 ft	≥5 ft	2-6 ft (S)	≥6 ft (L)	3-6 ft (M)	S:L	M:L
Major flooding										
18 July	76	228	19	144	65	169	40	130	4.2	3.3
25 May	77	245	40	129	76	166	39	160	4.3	4.1
27 Oct.	77	228	56	118	54	147	25	140	5.9	5.6
27 Sept.	78	233	37	131	65	156	40	138	3.9	3.5
No flooding - driest wet on record										
16 July	79	515	289	109	117	152	74	141	2.1	1.9
19 Oct.	79	355	161	101	93	136	58	120	2.3	2.1
15 Oct.	80	295	71	136	88	173	51	122	3.4	2.4
Heavy flooding										
2 July	81	256	26	145	85	176	54	124	3.3	2.3
5 Oct.	81	254	34	134	86	166	54	133	3.1	2.5
Dry wet - minor flooding only										
12 June	82	467	193	161	113	207	67	178	3.1	2.7
16 Oct.	82	384	144	135	105	171	69	155	2.5	2.2
Dry wet - minor flooding only										
1 July	83	432	121	217	94	257	54	174	4.8	3.2
13 Oct.	83	327	63	177	87	219	45	142	4.9	3.2

<sup>a</sup> Note that the 1976 survey shows 68 (EO) crocodiles sighted and 34 of these were taken to be large. This is probably too high a figure for the large animals. An intensive recapture programme was carried out in 1975 thus making many more animals more wary than normal. Most of the animals involved in the recapture programme were small. It is thus likely that the true ratios for 1976 are somewhat higher than those shown.

Table 3A. Summary Table showing for each survey of the overall Blyth-Cadell Rivers System the number of crocodiles in the size classes indicated<sup>a</sup>.

Survey Date		Total	H	≥2 ft	≥3 ft	≥4 ft	≥5 ft	≥6 ft	≥7 ft	Kilometers Surveyed	Density
26 Oct.	74	387	89	298	217	70	12	6	4	91.9	3.24
1 Nov.	75	353	50	303	197	114	40	14	7	94.9	3.19
Major flooding											
23 Sept.	76	348	82	266	203	95	45	26	15	92.0	2.89
4 Nov.	76	307	61	246	185	79	29	16	6	92.0	2.67
11 Apr.	77	327	72	255	185	75	25	13	9	92.0	2.77
3 May	77	333	88	245	185	88	30	14	7	92.0	2.66
8 June	77	365	108	257	221	115	42	25	11	90.5	2.84
16 Sept.	77	386	105	281	236	99	47	24	15	90.5	3.10
23 Oct.	77	360	112	248	180	94	44	22	10	90.5	2.74
10 June	78	432	173	259	194	110	40	21	11	90.5	2.86
12 Sept.	78	399	155	244	184	103	44	23	12	90.5	2.70
No flooding - driest wet on record											
10 June	79	465	123	342	251	154	91	55	35	94.5	3.62
4 Oct.	80	400	119	281	192	115	61	32	17	92.9	3.02
Heavy flooding											
9 July	81	366	76	290	204	115	67	37	20	90.1	3.22
19 Oct.	81	315	72	243	166	101	64	39	18	89.2	2.70
Dry wet - minor flooding only											
25 June	82	408	136	272	230	163	106	67	37	91.9	2.96
6 Nov.	82	347	111	236	193	123	72	39	19	92.5	2.55
Dry wet - minor flooding only											
15 July	83	465	157	308	210	142	87	50	24	91.8	3.36
26 Oct.	83	354	73	281	186	113	64	35	19	92.8	3.03

<sup>a</sup> The EO (eye reflection only was seen) classes have been added together in each survey and 50% of these have been distributed equally among the 3-4', 4-5' and 5-6' size classes; the remaining 50% have been distributed to the ≥6 size classes with 1/3 being allocated to the 6-7' size class and 2/3 to size class ≥7. This weights the distribution heavily in favor of large crocodiles, which are known to normally be the most wary. When the EO is an odd number, the bias is also given to the large size classes. For 1974, all EO crocodiles were put in the ≥7 size class.

Table 3B. Equivalent Table for Liverpool-Tomkinson System.

Survey Date		Total	H	≥2 ft	≥3 ft	≥4 ft	≥5 ft	≥6 ft	≥7 ft	Kilometres Surveyed	Density
Major Flooding											
18 July	76	228	19	209	170	103	65	40	26	152.5	1.37
25 May	77	245	40	205	199	142	76	39	19	145.1	1.41
27 Oct.	77	228	56	172	165	121	54	25	11	123.4	1.39
27 Sept.	78	233	37	196	178	136	65	40	20	141.4	1.39
No flooding - driest wet on record											
16 July	79	515	289	226	215	168	117	74	37	150.0	1.51
19 Oct.	79	355	161	194	178	136	93	58	35	141.1	1.38
15 Oct.	80	295	71	224	173	128	88	51	31	140.6	1.59
Heavy flooding											
2 July	81	256	26	230	178	122	85	54	31	140.6	1.64
5 Oct.	81	254	34	220	187	129	86	54	32	141.1	1.56
Dry wet - minor flooding only											
12 June	82	467	193	274	245	172	113	67	35	141.1	1.94
16 Oct.	82	384	144	240	224	166	105	69	38	141.1	1.70
Dry wet - minor flooding only											
1 July	83	432	121	311	228	157	94	54	30	141.1	2.20
13 Oct.	83	327	63	264	187	133	87	45	29	141.1	1.87

Table 4. Sightings on the three major components of the Blyth-Cadell Rivers System<sup>a</sup>.

Survey Date	Blyth Mainstream				Blyth Sidecreeks				Cadell				Totals			
	H	S	M	L	H	S	M	L	H	S	M	L	H	S	M	L
26 Oct. 74	41	207	151	6	1	3	3	0	47	82	57	0	89	292	211	6
1 Nov. 75	41	177	120	11	3	11	7	2	6	101	56	1	50	289	183	14
Major flooding																
23 Sept. 76	48	159	108	14	2	16	14	5	32	65	55	7	82	240	177	26
4 Nov. 76	40	142	108	10	3	16	13	1	18	72	48	5	61	230	169	16
11 Apr. 77	65	142	104	6	3	17	14	3	4	83	54	4	72	242	172	13
3 May 77	74	144	111	10	0	15	15	3	14	72	45	1	88	231	171	14
8 June 77	88	129	107	19	2	23	20	4	18	80	69	2	108	232	196	25
16 Sept. 77	75	164	139	19	2	18	15	2	28	75	58	3	105	257	212	24
23 Oct. 77	76	136	94	14	3	15	11	2	33	75	53	6	112	226	158	22
10 June 78	136	148	99	14	1	21	18	4	36	69	56	3	173	238	173	21
4 Oct. 80	86	171	106	40	1	15	14	9	37	101	76	6	123	287	196	55
Heavy flooding																
9 July 81	48	144	97	27	2	25	22	3	26	84	48	7	76	253	167	37
19 Oct. 81	37	127	75	28	3	13	12	2	32	64	40	9	72	204	127	39
Dry wet - minor flooding only																
25 June 82	84	118	94	41	1	14	13	6	51	73	56	20 <sup>b</sup>	136	205	163	67 <sup>b</sup>
6 Nov. 82	55	116	93	26 <sup>b</sup>	0	9	9	3	56	71	51	11 <sup>b</sup>	111	197	154	39
Dry wet - minor flooding																
15 July 83	146	127	84	35 <sup>b</sup>	2	10	10	2	9	121	66	13	157	258	160	50 <sup>b</sup>
26 Oct. 83	70	140	84	23	0	10	10	2 <sup>b</sup>	3	96	57	10	73	246	151	35 <sup>b</sup>

<sup>a</sup> The table shows the number of *C. porosus* sighted within the hatching, small 2-6', medium 3-6' and large ≥6 size classes on the three major components of the Blyth-Cadell Rivers System: Blyth mainstream, Blyth sidecreeks and Cadell River; 49.8, 12.5 and 29.7 km respectively.

<sup>b</sup> Bias to large.

Table 5. Sightings on the three major components of the Liverpool-Tomkinson Rivers System<sup>a</sup>

Survey Date	Liverpool Mainstream				Liverpool Sidecreeks				Tomkinson			Totals				
	H	S	M	L	H	S	M	L	H	S	M	L	H	S	M	L
18 July	11	64	51	14	4	27	22	7 <sup>b</sup>	4	77	56	20 <sup>b</sup>	19	169	130	40
25 May	13	67	64	12	4	28	27	7 <sup>b</sup>	23	71	69	20	40	166	160	39 <sup>b</sup>
27 Oct.	23	77	73	13 <sup>b</sup>	5	20	20	4*	28	49	46	9	56	147	140	25
27 Sept.	13	69	63	21	7	20	17	5	17	67	58	14 <sup>b</sup>	37	156	138	40 <sup>b</sup>
Major flooding																
No flooding - driest wet on record																
16 July	24	63	59	29	5	24	20	21	260	65	62	24	289	152	141	74
19 Oct.	17	63	51	32	2	21	20	5	142	52	49	21	161	136	120	58
15 Oct.	28	61	51	25	17	25	23	7 <sup>b</sup>	26	87	48	19	71	173	122	51 <sup>b</sup>
Heavy flooding																
2 July	8	75	47	23	1	23	18	8 <sup>b</sup>	17	77	58	24 <sup>b</sup>	26	176	124	54
5 Oct.	2	74	54	19	2	26	22	9 <sup>b</sup>	30	65	57	27 <sup>b</sup>	34	166	133	54
Dry wet - minor flooding only																
12 June	7	66	59	30	8	36	34	10	178	105	85	27	193	207	178	67
16 Oct.	6	82	78	27 <sup>b</sup>	3	32	28	18	135	56	48	25 <sup>b</sup>	144	171	155	69
Dry wet - minor flooding																
1 July	27	74	67	20	3	37	35	11 <sup>b</sup>	91	145	71	24 <sup>b</sup>	121	257	174	54
13 Oct.	21	70	64	19	2	28	25	9	40	121	53	17 <sup>b</sup>	63	219	142	45 <sup>b</sup>

<sup>a</sup> Number of *C. porosus* sighted within the hatchling, small 2-6', medium 3-6' and large ≥6 size classes on the three major components of the Liverpool-Tomkinson Rivers System: Liverpool mainstream, Liverpool sidecreeks and Tomkinson (normally 57.0, 27.4 and 56.7 km respectively, but distances can vary from year to year - see page 16, Monograph 7).

Note specially that during the 1977 and 1978 Tomkinson surveys, the river was surveyed to km 70 only and that a number of small and large crocodiles were thus not counted. Probably not more than 3 or 4 of each were thus omitted. Normally the Tomkinson is surveyed to km 73.7. Also see Table 8.

<sup>b</sup> Bias to large.

Table 6. Sighting on the waterways of Junction and Rolling Bays<sup>a</sup>

Survey Date	Goomadeer			Wuruguij			Majarie			Nungbulgarri			Totals			M/L		
	H	S	L	H	S	L	H	S	L	H	S	L	H	S				
Aug. 75	-	44	2	-	4	-	1	7	4	-	23 <sup>b</sup>	6	1	78 <sup>b</sup>	46	12	6.5	3.8
July-Sept. 76	18	23	11	-	-	1	-	5	2	2	1-	3	2	38	33	17	2.2	1.9
June 77	2	41	7	No survey	No survey	2	10	2	4	51	40	9	5.7 <sup>c</sup>	4.4 <sup>c</sup>				
July 79	29	49	12	-	2	7	-	13	5	10	16	9	39	80	66	33	2.4	2.0
June 81	6	30(7) <sup>d</sup>	7	-	3	3	-	11	8	2	21	4	8	65(7) <sup>d</sup>	56(4) <sup>d</sup>	22	3.0	2.5
Oct. 81	17	25	3	-	7	1	-	12	5	-	22	3	17	66	60	12	5.5	5.0
June 82	18	29	14	-	3	4	2	8	7	-	19	4	20	59	51	29	2.0	1.8
Oct. 82	9	35	10	1	4	3	-	9	3	-	21	8	10	69	61	24	2.9	2.5
June 83	24	27	12	-	4	2	4	15	5	34	19	2	62	65	57	21	3.1	2.7
Oct. 83	33	29	11	-	7	4	-	13	6	15	18	5	48	67	57	26	2.6	2.2

<sup>a</sup> The table shows the number of *C. porosus* sighted within the hatchling (H), small (S) and large (L) size classes on the tidal waterways of Junction and Rolling Bays, which are within the Maningrida monitoring area. Also shown is the number of medium crocodiles and the ratios of small to large and medium to large for the overall systems.

<sup>b</sup> This relatively high number may have resulted from animals leaving the Liverpool System after our intensive catching effort on it during the period of 1973-1975. See page 75, Monograph 7.

<sup>c</sup> Wuruguij and Marjorie Creeks were not surveyed resulting in the omission of a few small and large animals. Hence the value of S/L and M/L are probably slightly TOO HIGH.

<sup>d</sup> Numbers in brackets give number of crocodiles removed by Biology researchers before survey.



Table 7. Sightings within the Maningrida monitoring area<sup>a</sup>.

Survey Date	Blyth-Cadell System			Liverpool-Tomkinson System			Rolling & Junction Bays			L	H	S	M	L	H	S	M	L	>3'	S/L	M/L				
	H	S	M	L	H	S	M	L	H													S	M	L	
Aug./Nov. 75	50	289	183	14	Data unusable			1	78	46	12	Major flooding													
July/Sept. 76	82	240	177	26	19	169	130	40 <sup>c</sup>	20	38	33	17	447	340	83	423	340	83	423	5.4	4.1				
May/June 77	108	232	196	25	40	166	160	39	4	51 <sup>d</sup>	40 <sup>d</sup>	9 <sup>d</sup>	4494	396 <sup>d</sup>	73 <sup>d</sup>	369 <sup>d</sup>	396 <sup>d</sup>	73 <sup>d</sup>	369 <sup>d</sup>	6.2 <sup>d</sup>	5.4 <sup>d</sup>				
October 77	112	226	158	22	56	147	140	25	No surveys		168		298	47	345	7.9	47	345	7.9	6.3 <sup>e</sup>					
September 78	155	221	161	23	37	156	138	40	No surveys		192		299	63	362	6.0	63	362	6.0	4.7 <sup>e</sup>					
									No flooding - driest wet on record																
June/July 79	123	287	196	55	289	152	141	74	39	80	66	33	519	403	162	565	403	162	565	3.2	2.5				
October 80	119	249	160	32	71	173	122	51	No surveys		190		282	83	365	5.1	83	365	5.1	3.4 <sup>e</sup>					
									Heavy flooding																
June/July 81	76	253	167	37	26	176	124	54	8	67(7) <sup>b</sup>	56(4) <sup>b</sup>	22	494(7) <sup>b</sup>	347(4) <sup>b</sup>	113	460	347(4) <sup>b</sup>	113	460	4.4	3.1				
October 81	72	204	127	39	34	166	132	54	17	66	60	12	436	320	105	425	320	105	425	4.2	3.0				
									Dry wet - minor flooding																
June/July 82	136	205	163	67	193	207	178	67	20	59	51	29	471	392	163	555	392	163	555	2.9	2.4				
Oct./Nov. 82	111	197	154	39	144	171	155	69	10	61	24	265	370	132	502	3.3	132	502	3.3	2.8					
									Dry wet - minor flooding																
June/July 83	157	258	160	50	121	257	174	54	62	65	57	21	580	391	125	516	391	125	516	4.6	3.1				
October 83	73	246	151	35	63	219	142	45	48	67	57	26	532	350	106	456	350	106	456	5.0	3.3				

<sup>a</sup> The table shows the number of *C. porosus* sighted within the hatching, small (2-6'), medium (3-6') and large (>6') size classes on the major component tidal systems within the Maningrida monitoring area. Also shown is the ratio of small to large and medium to large crocodiles and the total number of medium plus large animals (that is animals >3').

<sup>b</sup> Numbers in brackets give numbers of crocodiles removed by Biology researchers before survey.

<sup>c</sup> See caption to Table 2B for the Liverpool-Tomkinson.

<sup>d</sup> See Table 6, footnote c.

<sup>e</sup> Because the four waterways of Rolling and Junction Bays were not surveyed in October 1977, September 1978 and October 1980 the totals for those surveys are TOO LOW. Inspection of the results for immediately preceding and succeeding surveys indicates that the totals for the three missing cases are too low by a MAXIMUM of 40(H), 80(S), 66(M), 33(L) and 99(>3'). The ratios shown for these surveys are thus probably TOO HIGH.

Table 8. Sightings on alternative habitats<sup>a</sup>.

Kilometers Surveyed		Oct.-Nov 1981		July-July 1982		Oct.-Nov. 1982		June-July 1983		October 1983		L	H	S	L	H	S	L
		H	S	L	H	S	L	H	S	L	H							
Liverpool River	6.4	No survey		No survey				5	3	-	5	1	-	1	4			
Maraguldiban Ck.	4.9	No survey		-	-	1	-	1	1	-	1	-	-	-	1			
Tomkinson River km 73.7 - 81.3	7.6	11 July 1976 to km 80.1	9	-	18	14	-	11	13	2	18 <sub>1</sub>	9	-	8	9			
Tom's Creek	8.9	1	2	No survey		1	2	-	-	5	1	2 <sub>1</sub>	2					
Crab Creek	3.0	-	2	No survey		-	-	1	-	-	2	1	1					
Anamayirra Creek	7.3	No survey	-	9	7	-	11	5	-	10	6	-	5	3				
Beach Creek	2.2	No survey	-	3	3	-	3	-	-	6	1	-	2	-				
Blyth R. + Billabong km 49.8 - 64.6	13.2	1	2 <sub>2</sub>	3	1	1	3	5	7 <sub>2</sub>	7	1	4 <sub>2</sub>	1	-	8 <sub>4</sub>	4		
Cadell Gardens Billabong	2.0	-	3	No survey		-	2	1	-	2	1	-	2	1				
Cadell Big	4.0	No survey	-	2	3	No survey			-	-	3	-	-	3				

<sup>a</sup> The table shows the number of *C. porosus* sighted within the hatchling, small and large size classes on the main alternative habitats of the Blyth-Cadell and Liverpool-Tomkinson Rivers Systems, such as various fresh and saltwater complexes and the extreme upstream sections of the Systems.

The results for these 59.3 km of waterways are not included in Tables 1 to 7. The first seven habitats listed appear to provide alternative habitat largely for animals from the Liverpool-Tomkinson and Rolling and Junction Bay Systems. Subscripts show the number of 2-3' animals included.

Table 9. Sightings on waterways of Van Dieman Gulf<sup>a</sup>.

Survey		Totals	Hatchlings	(2-3')	(3-6')	Large (≥6)	3-6' Large
<b>ADELAIDE</b>							
July	77	417	48	24	264	81	3.26
Sept.	78	381	62	24	217	78	2.78
Sept.	79	374	53	8	190	123	1.54
July	84	602	60	36	278	228	1.22
<b>MURGENELLA</b>							
Oct.	77	95	1	1	61	32	1.91
June	78	173	48	16	50	59	0.85
Aug.	79	198	47	24	66	61	1.08
July	84	236	7	17	117	95	1.23
<b>EAST ALLIGATOR</b>							
Oct.	77	318	53	18	154	93	1.66
June	78	329	39	14	175	101	1.73
Aug.	79	393	53	30	159	151	1.05
July	84	411	22	51	181	157	1.15
<b>SOUTH ALLIGATOR</b>							
Oct.	77	142	--	--	73	69	1.06
June	78	157	6	3	73	75	0.97
Aug.	79	164	4	1	58	101	0.57
July	84	279	39	15	78	147	0.53
<b>WEST ALLIGATOR</b>							
Oct.	77	83	9	2	47	25	1.88
June	78	85	23	5	37	20	1.85
Aug.	79	96	12	9	41	34	1.21
June	84	120	17	2	77	24	3.21
<b>WILDMAN</b>							
Sept.	78	118	53	16	28	21	1.33
Aug.	79	155	21	34	44	56	0.79
June	84	226	26	60	96	44	2.18
<b>ALLIGATOR REGION EXCL. WILDMAN</b>							
Oct.	77	638	63	21	336	218	1.54
June	78	744	116	38	336	254	1.32
Aug.	79	851	116	64	325	346	0.94
July	84	1046	85	85	453	423	1.07
<b>ALLIGATOR REGION WITH WILDMAN</b>							
June	78	862	169	54	365	274	1.33
Aug.	79	1006	137	98	369	402	0.92
July	84	1272	111	145	549	467	1.18

Table 9. continued.

Survey		Totals	Hatchlings	(2-3')	(3-6')	Large (≥6)	<u>3-6'</u> Large
SALWATER							
Aug.	79	29	--	1	12	16	0.75
July	84	25	6	--	11	8	1.38
MINIMINI							
Aug.	79	11	--	--	8	3	2.67
July	84	9	--	--	6	3	2.00
MIDDLE ARM							
Aug.	79	6	--	--	5	1	5.00
July	84	10	--	--	6	4	1.50
IWALG							
Aug.	79	10	--	--	5	5	1.00
July	84	25	--	--	13	12	1.08
MINIMINI COMPLEX							
Aug.	79	27	--	--	18	9	2.00
July	84	44	--	--	23	21	1.10
ARM A							
Aug.	79	5	--	--	3	2	1.50
July	84	9	--	--	1	8	0.13
ARM B							
Aug.	79	3	--	--	1	2	0.50
July	84	4	--	--	--	4	0.00
ARM C							
Aug.	79	7	--	--	5	2	2.50
July	84	5	--	--	2	3	0.67
ARM D							
Aug.	79	9	--	--	2	7	0.29
July	84	7	--	--	2	5	0.40
ILAMARYI							
Aug.	79	16	--	--	8	8	1.00
July	84	7	--	--	3	4	0.75
ILAMARYI COMPLEX							
Aug.	79	40	--	--	20	20	1.00
July	84	32	--	--	8	24	0.33
COBOURG COMPLEX							
Aug.	79	67	--	--	38	29	1.31
July	84	76	--	--	31	45	0.69

Table 9. continued.

Survey		Totals	Hatchlings	(2-3')	(3-6')	Large (≥6)	3-6' Large
COBOURG COMPLEX & SALTWATER							
Aug.	79	96	--	1	50	45	1.11
July	84	101	6	--	43	52	0.83
ALLIGATOR REGION + COBOURG COMPLEX & SALTWATER							
Aug.	79	1102	137	99	419	447	0.94
July	84	1373	117	145	592	519	1.14
ADELAIDE + ALLIGATOR REGION EXCL. WILDMAN							
July & Oct.	77	1055	111	45	600	299	2.01
Sept. & June	78	1125	178	62	553	332	1.67
Sept. & Aug.	79	1225	169	72	515	469	1.10
July	84	1648	145	121	731	651	1.12
ADELAIDE + ALLIGATOR REGION WITH WILDMAN							
Sept. & June	78	1243	231	78	582	352	1.65
Sept. & Aug.	79	1380	190	106	559	525	1.06
July	84	1874	171	181	827	695	1.19
ABOVE + COBOURG COMPLEX & SALTWATER							
Sept. & Aug.	79	1476	190	107	610	569	1.07
July	84	1975	177	181	870	747	1.16

<sup>a</sup> This Table was prepared using the results given in Table 1B and groups the crocodiles sighted into the important size classes shown.

Table 10. Sightings in 1979 and 1983 for combined systems<sup>a</sup>.

Survey	Total	H	Size Class Numbers				>7	km EO	95% Surveyed	Density	Levels	TYPE
			2-3	3-4	4-5	5-6						
June & July 1979	1253	487	125	156	139	100	69	111	414.9	1.8	1201-1312	1 & 3
July & July 1988	1199	345	198	180	145	92	49	150	411.5	2.1	1342-1459	

Survey	Totals	H	2-3	Large 3-6		Large ≥6
				3-6	≥6	
June & July 1979	1253	487	125	450	191	2.36
June & July 1983	1199	345	198	492	164	3.00

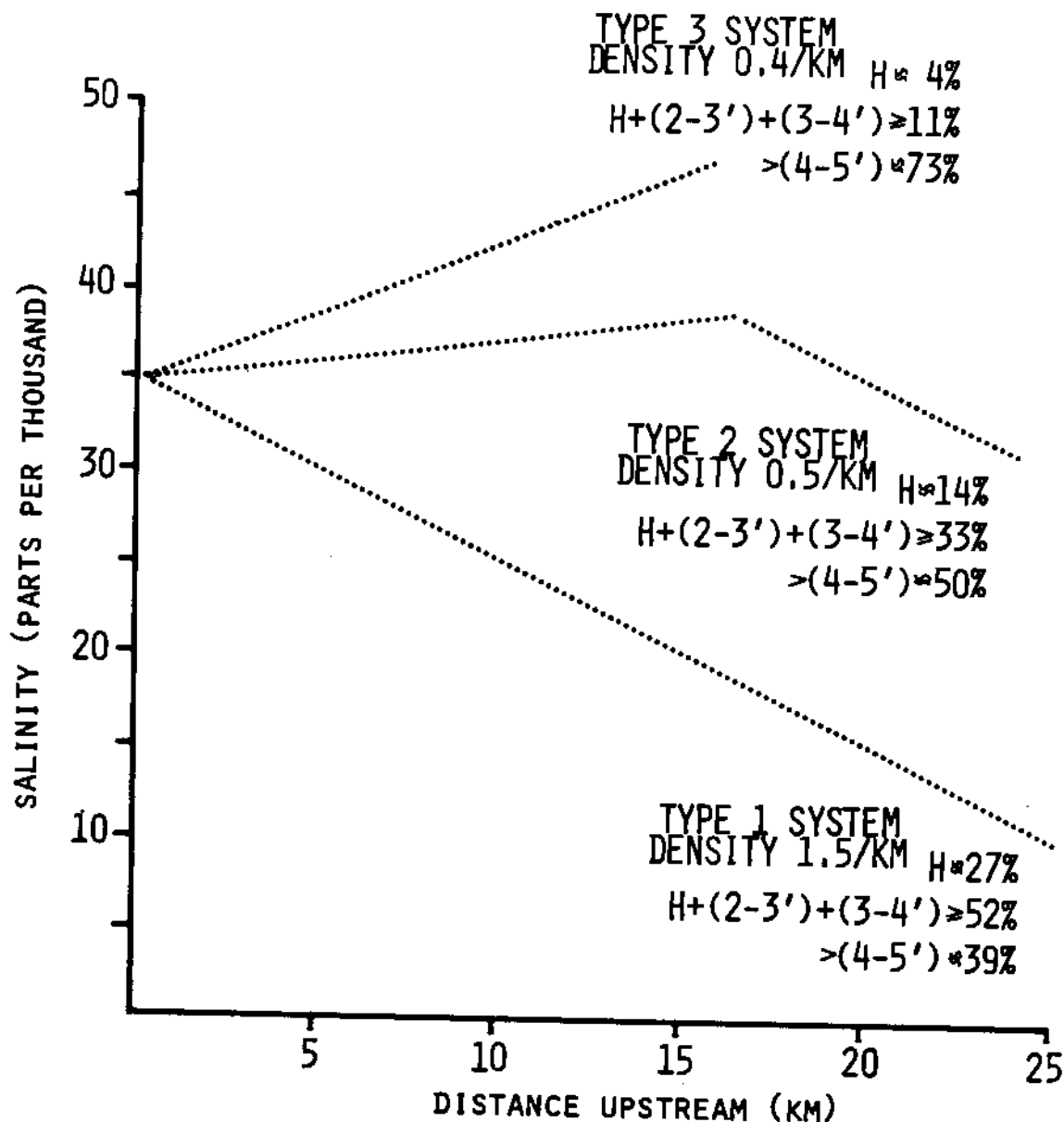
<sup>a</sup> The table shows combined results for the Blyth-Cadell and Liverpool-Tomkinson Rivers Systems, Goomadeer and Clyde Rivers, and Nungbulgarri, Majarie, Wuruguij and ngandadauda Creeks (obtained using Table 1A). The results are given first in the form of Table 1 and then in the form of Table 9 to facilitate comparisons. Note that the 1983 survey was made after the 'dry wet' of 1982-1983 and hence animals were again concentrated into the tidal waterways, but not to the same degree as in 1979 when surveys were carried out after the 'driest wet' on record.

ones. In the case of the 1984 June-July surveys of the tidal waterways in the Alligator Region, results can be most meaningfully compared with those for the June-July 1978 and August 1979 surveys rather than the October 1977 one. However, even in the case of the 1979 results, considerable caution must be used, for the 1978-1979 wet season was the driest on record and many of the animals that would have normally been in the associated freshwater complexes at the time of the survey were forced back into the tidal waterways (see Messel et al. 1979-1984:1, 4, 14, and specially 18 where this matter is discussed in detail). In the case of Murgarella Creek, the concentration appears to have taken place in 1978 (Messel et al. 1979-1984, 4:18 and 14:76).

### A MODEL FOR THE DYNAMICS OF *C. porosus* POPULATIONS

As stated previously, the model which we have built up and have been refining (specially see Messel et al. 1979-1984[1 and 18]) as more data are obtained not only enables us to account in a consistent fashion for the vast store of field observations and results we have accumulated for some 100 tidal waterways in northern Australia, but also enables us to predict successfully results to be expected on future individual surveys. The model runs as follows:

1. The tidal waterways of northern Australia have been classified according to their salinity signatures into TYPE 1, TYPE 2, and TYPE 3 systems shown in Fig. 7 (see our chapter on ecology of *C. porosus* for more detail on this). TYPE 1 systems are the main breeding ones and non-TYPE 1 systems are usually poor or non-breeding systems. It is the TYPE 1 systems and the freshwater billabongs and semipermanent and permanent freshwater swamps associated with them which account for the major recruitment of *C. porosus*; the other systems contribute to a lesser degree and they must depend largely upon TYPE 1 systems and their associated freshwater complexes for the provision of their crocodiles. Non-TYPE 1 systems also sometimes have freshwater complexes associated with them but these are normally quite minor.
2. As indicated in Fig. 7, our results show that in TYPE 1 systems some 27% of the crocodiles sighted are hatchlings (of which some 50% are normally lost between June of one year and June of the next, Messel et al. 1979-1986, 1:394), whereas in TYPE 2-3 systems this figure falls to 14% and in TYPE 3 systems down to 4%, showing a much decreased hatchling recruitment in non-TYPE 1 systems. In TYPE 3 systems the percentage of crocodiles in the hatchling, 2-3', and 3-4' size classes combined is some 11% whereas in TYPE 1 systems it is at least 52%. On the other hand the percentage of crocodiles in the  $\geq 4-5'$  size classes is some 39% in TYPE 1 systems and 73% on TYPE 3 systems. Some 79% of the non-hatchling crocodiles are sighted on TYPE 1 waterways and 21% on non-TYPE 1 waterways (Messel et al. 1979-1986, 1:419).
3. The relatively few large, and more frequent small freshwater billabongs and semipermanent and permanent freshwater swamps associated with tidal waterways are known to contain *C. porosus* but have not been inventoried systematically, except in a few cases. The accurate extent of their non-hatchling *C. porosus* populations is unknown. Based upon the fact that the number of large freshwater swamp areas, with substantial perennial water (normally bordering old river channels), in northern Australia is very limited--perhaps 400 km<sup>2</sup> maximum--and upon limited observations, we estimated that in 1979 the non-hatchling *C. porosus* population was less than 20% of the non-hatchling population sighted in tidal systems. We now believe that the 20% figure was an overestimate for 1979--an unusual year associated with one of the "driest wet" seasons on record.
4. It appears that the populating of non-TYPE 1 systems (hypersaline or partially hypersaline coastal and non-coastal waterways) results mostly from the exclusion of a large fraction of the sub-adult crocodiles from TYPE 1 systems and any freshwater complexes associated with them. Adult



### THREE TYPICAL SALINITY PROFILES IN THE DRY SEASON

Figure 7. Typical dry season salinity profiles for the three types of tidal river systems occurring in the model's classification scheme. In a TYPE 1 system the salinity decreases steadily as one progresses upstream from that of seawater measured at the mouth of the waterway ( $=35\text{‰}$ ). In contrast, the salinity in a TYPE 3 system increases steadily as one progresses upstream. TYPE 2 systems fall somewhere between TYPE 1 and TYPE 3 systems and tend to show hypersaline tendencies as the dry season progresses. As shown above, the non-hatchling density and size structure of the crocodiles sighted in the three kinds of systems differ strikingly.



crocodiles appear generally to tolerate hatchlings, 2-3', and sometimes even 3-4' sized crocodiles in their vicinity (but not always--they sometimes eat them, Messel et al. 1979-1986, 14:43, or kill them, [1]:334), but not larger crocodiles. Thus once a crocodile reaches the 3-4' and 4-5' size classes, it is likely to be challenged increasingly not only by crocodiles near or in its own size class (Messel et al. 1979-1986, 1:454-458) but by crocodiles in the larger size classes and to be excluded from the area it was able to occupy when it was smaller. A very dynamic situation prevails with both adults and sub-adults being forced to move between various components of a system and between systems. Crocodile interactions or aggressiveness between crocodiles in all size classes increases around October--during the breeding season (Messel et al. 1979-1986, 1:445 and 18:109) and exclusions, if any, normally occur around this period. A substantial fraction (~80%) of the sub-adults, mostly in the 3-6' size classes but also including immature larger crocodiles, are eventually excluded from the river proper or are predated upon by larger crocodiles.

5. Of those crocodiles that have been excluded, some may take refuge in freshwater swamp areas and billabongs associated with the waterway from which they were excluded or in the waterways' non-TYPE 1 creeks if it has any. Others may travel along the coast until by chance they find a non-TYPE 1 or another TYPE 1 waterway, however in this latter case they may again be excluded from it; others may go out to sea and possibly perish, perhaps because of lack of food, as they are largely shallow water on edge feeders, or they may be taken by sharks. Those finding non-TYPE 1 systems, or associated freshwater complexes frequent these areas, which act as rearing stockyards, for varying periods, until they reach sexual maturity, at which time they endeavor to return to a TYPE 1 breeding system. Since a large fraction of the crocodiles sighted in non-TYPE 1 systems must be derived from TYPE 1 systems and their associated freshwater complexes, they are, as seen in (2) above, predominantly sub-adults in the  $\geq 3'$  size classes or just mature adults (Messel et al. 1979-1986, 1:431). Both sub-adults and just mature adults might attempt to return and be forced out of the system many times before finally being successful in establishing a territory in a TYPE 1 system or in its associated freshwater complex. Crocodiles may have a homing instinct (this important point requires further study) and even though a fraction of crocodiles may finally return to and remain in a TYPE 1 system or in its associated freshwater complex, the overall sub-adult numbers missing--presumed dead--remain high and appear to be at least 60-70%.

6. Normally, the freshwater complexes (swamps and/or billabongs) associated with tidal systems, are found at the terminal sections of small and large creeks running into the main waterway, or at the terminal sections of the mainstream(s). Though this alternative habitat is usually very limited in extent, sporadic (and sometimes extensive yearly) nesting does take place on it. There are, however, several fairly extensive freshwater complexes associated with TYPE 1 tidal systems and these are important as they may act both as rearing stockyards and as breeding systems, just as the TYPE 1 waterway does itself. Examples of these are the Glyde River with the Arafura Swamp (Messel et al. 1979-1986, 9), the Alligator Region Rivers with their wetlands (Messel et al. 1979-1986, 4, 14), and the Daly, Finniss, Reynolds, and Moyle rivers with their wetlands (Messel et al. 1979-1986, 2). Not only can the loss factor, which appears to occur during the exclusion stage, be expected to be lower for movements into and out of swamp areas associated with a TYPE 1 waterway than for movement into and out of coastal non-TYPE 1 systems, but the loss of nests due to flooding can also be expected to be less. We have observed nests made of floating grass cane mats in the Daly River Aboriginal Reserve area. Thus recovery of the *C. porosus* population on TYPE 1 tidal waterways, with substantial associated freshwater complexes, can be expected to be faster than on other systems (Messel et al. 1979-1986, 1:445, 14:98 and also see important results for the 1984 resurvey of Alligator Region and Adelaide River systems appearing in 19 and discussed here later).

7. Because of the ~80% exclusion and at least 60-70% losses of sub-adult crocodiles as they proceed toward sexual maturity, there appears to have been no significant sustained increase in the

non-hatchling *C. porosus* population on the some 500 km of tidal waterways monitored in the Maningrida area of northern Australia since the commencement of our systematic surveys in 1974, a period of ten years (Messel et al. 1979-1986, 18). With the exception of the Glyde River, these waterways have only minor freshwater complexes associated with them.

8. Though there appears to have been no sustained significant increase in the number of non-hatchling crocodiles sighted on the tidal waterways of the Maningrida area since our surveys started in 1974, the size structure of the animals sighted appears to have been changing slowly. Notwithstanding substantial fluctuations, the ratios of small (2-6') to large ( $\geq 6'$ ), and 3-6' to large animals was decreasing on the Blyth-Cadell, may have been decreasing on the Liverpool-Tomkinson and was decreasing overall on the tidal waterways of the Maningrida monitoring area. Thus there was some indication of the commencement of a slow recovery phase.
9. For the 861 km of tidal waterways of the Alligator Region, with their substantial freshwater complexes, and the Adelaide River System, there was strong evidence, as of July 1984, that an important and sustained recovery was underway (as predicted in 6 above).
10. Though there are wide fluctuations, specially after "dry wet" seasons when the animals are concentrated into the tidal waterways, it appears that as the number of large crocodiles in a tidal waterway increases, there is a tendency for the number of sub-adults in the 3-6' size classes to decrease or only increase marginally. Thus the total number of 3-6' and large animals sighted appears generally to be holding steady or only increasing slowly. This density dependent behavior has an important bearing on the rate of population growth and on the size structure of the population.
11. When a steady state is reached in a "recovered" population, the ratio of 3-6' to large animals might be considerably less than one.
12. An important and remarkable fact becomes evident if one excludes the 3-4' size class and focuses on the 4-5' and 5-6' size classes only. Regardless of how large the recruitment may be, the number of animals sighted in the 4-5' and 5-6' size classes seems to remain essentially constant or only increases slowly. Thus a major bottleneck occurs for these size classes. It is as if there are a definite number of slots for these animals on a given river system and that the number of these slots only increases slowly--if at all (note specially the results for the Blyth-Cadell and Liverpool-Tomkinson waterways in Messel et al. 1979-1986, 1, 18 and the 1984 results for the Alligator Region and Adelaide River systems appearing in 19). The crocodiles themselves appear to be primarily responsible for the very heavy losses of  $\approx 70$  percent that occur in the process of trying to secure these slots or to increase them in number.
13. If one considers a group of 100 of the sub-adult crocodiles in a TYPE 1 tidal system without a substantial freshwater complex associated with it, one can expect some 80 to be excluded from it, at least 60-70 to end up missing--presumed dead--fewer than 15-20 to successfully establish territories on the system without having to leave it, and the remainder might eventually also return and establish a territory, specially after becoming sexually mature. The very nature of this matter is such as to preclude precise figures and they must be looked upon as broad estimates only, however detailed study of our results (Messel et al. 1979-1986, 18) now indicates that the missing--presumed dead figure is likely to be in excess of 70. For systems with substantial freshwater complexes associated with them, this figure is likely to be considerably less.
14. When there is an exclusion of sub-adult animals, mostly 3-6' in size but also including immature larger animals, this takes place mainly in the breeding season, normally commencing around September-October and apparently lasting throughout the wet season. Any influx of

animals, in the 3-6' and/or large size classes, appears to occur mainly in the early dry season and to be completed in the June-early September period, but in some years may be earlier.

15. After a single "dry wet" season there is a substantial influx of large and sometimes 3-6' animals, forced out of freshwater complexes, into the tidal waterways and these are sighted during June-July surveys. Surveys made in October-November of the same year, usually reveal a substantial decrease in the number of 3-6' and/or large animals sighted; however, the number of large animals sighted sometimes remains higher than previously seen and hence a number of the new large animals do not return from whence they came. These animals appear successful in establishing a territory on the waterway, and it could be the waterway from which they had originally been excluded. The "dry wet" variation in the number of animals sighted appears to be superimposed upon the variations normally found during surveys following usual wet seasons--which generally result in extensive flooding on the upstream sections of the tidal waterways. Hatchling recruitment on the tidal waterways is generally greatly enhanced during "dry wet" seasons but appears to be greatly reduced in major swamp habitat. The reverse appears to be true during normal or heavy wet seasons.

## DISCUSSION

### The Monitored Area

The results of our surveys in our monitored area centered on Maningrida have been essentially summarized in points 9 to 15 of our model and are discussed in detail in Messel et al. (1979-1986, 18).

In Fig. 8 we have plotted, using Table 8, the number of 3-6', large and their sum, 3-6' plus large, or  $\geq 3'$  animals sighted on surveys over the past 8 years of the Liverpool-Tomkinson, Blyth-Cadell, and the 4 waterways of Rolling and Junction Bays. The waterways of Rolling and Junction Bays would not be surveyed every time the Blyth-Cadell and Liverpool-Tomkinson were, thus resulting in a number of incomplete totals. These cases are referred to in the caption of Table 7, and certain corrections are suggested. The number of large crocodiles sighted on the overall Systems during the surveys of 1976 was 83 and the number of 3-6' animals was 340. The number of both 3-6' and large crocodiles sighted then essentially held steady or even declined slightly until June-July 1979 when there was a dramatic jump following the "driest wet" on record of 1978-1979. In Messel et al. (1979-1986, 18) we discuss in detail where these additional animals may have come from and show that the results are explicable on the basis of their being forced out of the Arafura Swamp which was being used both as a breeding system and a rearing stockyard. By the time of the June-July 1981 surveys the number of 3-6' animals sighted was back to almost the same figure as in 1976 (347 versus 340), whereas the number of large crocodiles remained at a higher level, 113 versus 83. Obviously a number of the returning large animals were being successful in establishing a territory for themselves, probably in the very waterways from which they had been excluded, but many of their less successful rivals were joining the ranks of the missing--presumed dead in the process. Then came the two "dry wets" of 1981-1982 and 1982-1983. Again there was an influx, this time of 72 3-6' and 58 large animals: 392 3-6' and 163 large animals (amazingly the number for 1979 had been 162) were sighted. Again a substantial fraction of the increase, specially for large animals could only have been derived from animals excluded from the Arafura Swamp. In June of both 1979 and 1982, concentrations of large animals were sighted at the mouth of the Blyth River, showing that they were entering and leaving the System through the mouth. By the time of the June-July 1983 surveys the number of large animals sighted had dropped to 125

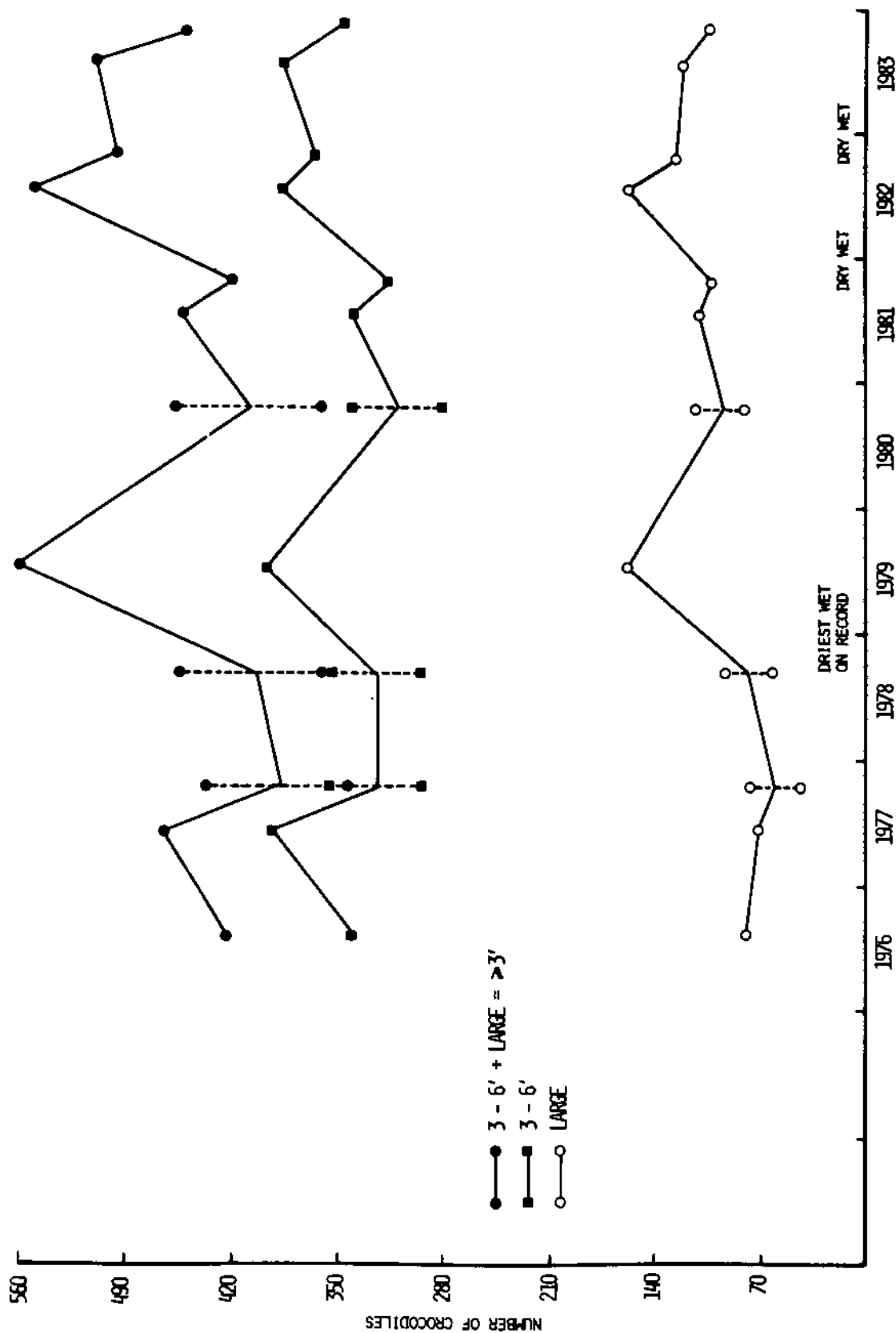


Figure 8. A plot of the number of 3-6', large ( $\geq 6'$ ) and their sum, 3-6' plus large or  $\geq 3'$  animals for surveys carried out on the Liverpool-Tomkinson, Blyth-Cadell and Rolling and Junction Bays Rivers Systems during the eight years 1976 to 1983. For those years in which the waterways of Rolling and Junction Bays were not surveyed, we have plotted the numbers shown in Table 7 and the maximum figures also, but have drawn the line through the average value only.

whereas the number of (3-6') animals remained almost constant (392 versus 391). Then came the expected drop in numbers for the October 1983 survey when 350 3-6' and 106 large animals were spotted.

Obviously only a relatively small number of additional 3-6' animals may have been successful in establishing a territory for themselves during the 8 year period: it is as if there were a fairly definite number of slots or territories on the waterways for the 3-6' animals and the number and size of those slots can vary depending upon a complex set of factors of which food supply is one. Of course the 3-6' animals utilizing these in 1983 were not the same animals which filled those slots in 1976. Superimposed upon this is the increasingly aggressive behavior of the animals as the October-November period approaches and the more aggressive behavior of the large animals towards the 3-6' ones during the breeding season.

The picture in the Maningrida area for the large animals is along the same lines. Comparing the surveys of July-September 1976 with those of June-July 1983 indicates that an additional (125 versus 83) 42 large animals had or were well on the way to establishing a territory for themselves. Study of Tables 4, 5, and 6 reveals that, as expected, those territories were in the TYPE 1 waterways. On the other hand, since only 106 large animals were sighted during the October 1983 survey, it is apparent that a number of large animals which held a territory in the July 1983 period could not do so once the breeding season commenced. Again one must realize that one is viewing a highly dynamic situation: a large animal may be successful in holding a territory for only a limited period. Even the largest animals may eventually be deposed by younger and more aggressive ones. This continual battle for the eventual right to breed is documented for many species. The losses involved during this process in the case of *C. porosus* are startlingly high, and this includes the large size classes.

A broad estimate for the minimum percentage of 3-6' crocodiles which are excluded and/or lost from the monitored area may be obtained by noting (Table 7) that 340 3-6' and 83 large animals were sighted during the July 1976 survey and that the July 1983 surveys revealed 125 large crocodiles only. Each of the 3-6' animals Of 1976 would, if they survived, be in the large size class by 1983 and hence the minimum percentage which have been excluded and/or lost (minimum because we have assumed that all the increase originated from the 340) by July 1983 is  $(340 - 125)/340$  or 64%. Again if we assume that the 'dry wet' of 1981-1982 had concentrated back into our monitored waterways nearly all of the surviving large animals originally recruited there--and none originating from elsewhere--then 76% becomes the estimate for the missing--presumed dead--3-6' animals  $((340 - 80)/340)$  or 76%.

Obviously the exclusions and/or losses of animals in all size classes have to date nearly equalled the input. It should be stressed that the large size classes are included; that they also suffer substantial exclusion and/or losses for we know from our recapture work (see Messel et al. 1979-1986, 18) that some 3-6' animals do enter the large size class and yet the overall number of large animals sighted only increases marginally.

In order to eliminate the various possibilities as to where the large number of apparently missing crocodiles could be, we surveyed, in 1982 and 1983, all of the alternative habitat (such as small coastal creeks and billabongs) in the monitoring area that we could gain entry to, using boats, vehicles, and a helicopter. This was a very expensive and time-consuming exercise, but one we felt had to be done. The results given in Table 8 show that the alternative habitat does provide some important rearing stockyards for both large and small animals, but the number of animals involved is small compared to the hundreds missing (much more detail on the alternative habitat may be found in Messel et al. 1979-1986, 18). As pointed out previously, the Arafura Swamp appears to be the main haven of refuge for the excluded crocodiles.

## RESULTS IN VAN DIEMEN GULF

In Tables 1B and 9 we have combined the results from 1977 to 1984 for the tidal waterways surveyed, from the Ilamaryi River in the Cobourg Peninsula to the Adelaide River in Adams Bay. The various combinations shown allow one to view the results from a number of different angles and to assess the recovery of *C. porosus* in this broad geographical area of northern Australia. In Figs. 9 and 10 we have plotted, using Table 9, the results of the Van Diemen Gulf surveys in the same manner as in Fig. 8 for the monitored area.

1. One point which stands out strongly for each of the combinations shown is the inflated number of animals sighted during the July 1984 survey in the 3-4' size class (Table 1B) and that this in turn has inflated the 3-6' size class number count (Figs. 9 and 10) and the 3-6'/large ratio (Table 9). These animals in the 3-4' size class are the result of the excellent breeding season during the "dry wet" of 1981-1982 and a large fraction of them are unlikely to enter the 4-5' and 5-6' size classes. Excluding such fluctuations, which appear to level out rather quickly, the number of 3-6' animals sighted normally remains fairly constant (see Table 2). However, as we have accumulated more and more data, it has become clear that it is the 4-5' and 5-6' size classes which provide most of the bottleneck and that the neck size appears to remain surprisingly constant for a given tidal system. This appears to be as true for the waterways of Van Diemen Gulf as for those in the monitored area.

2. Examining the results in Table 1B for the "Alligator Region plus Cobourg Complex and Saltwater"--629.6 km--shows that the number of 4-5' plus 5-6' animals sighted during the 1979 and 1984 surveys were 252 and 261 respectively. Interestingly the number of (6-7') animals positively identified was 164 on each survey.

For the "Adelaide plus Alligator Region with Wildman"-- 586.1 km--the 4-5' plus 5-6' counts for 1978, 1979, and 1984 were 364, 343, and 376 respectively. Considering the errors-- of up to one size class--which can easily arise in size class estimation, this is an amazing constancy.

If one then adds in the results for the Cobourg Complex and Saltwater, the 4-5' plus 5-6' counts for 1979 and 1984 become 385 and 404 respectively--again surprisingly constant for the 861.2 km of tidal waterways surveyed.

The same exercise may be carried out for the Blyth- Cadell and the Liverpool-Tomkinson River Systems, using Table 1A and again one finds a similar constancy in the number of 4-5' plus 5-6' animals sighted.

3. Though the number count for the 4-5' plus 5-6' size classes appears to remain closely constant from survey to equivalent survey, this is not the case for large animals. Once the animals have passed through the bottleneck, their numbers appear to continue to increase--in spite of various and continuing losses within their size classes as well (Table 9 and Figs. 9 and 10).

For the "Alligator Region plus Cobourg Complex and Saltwater"--629.6 km--the numbers of large animals sighted on the 1979 survey was 447 while the 1984 survey yielded 519 large animals.

For the "Adelaide plus Alligator Region with Wildman"-- 586.1 km--the number of large animals sighted during the 1978, 1979, and 1984 surveys was 352, 525, and 695 respectively. And if

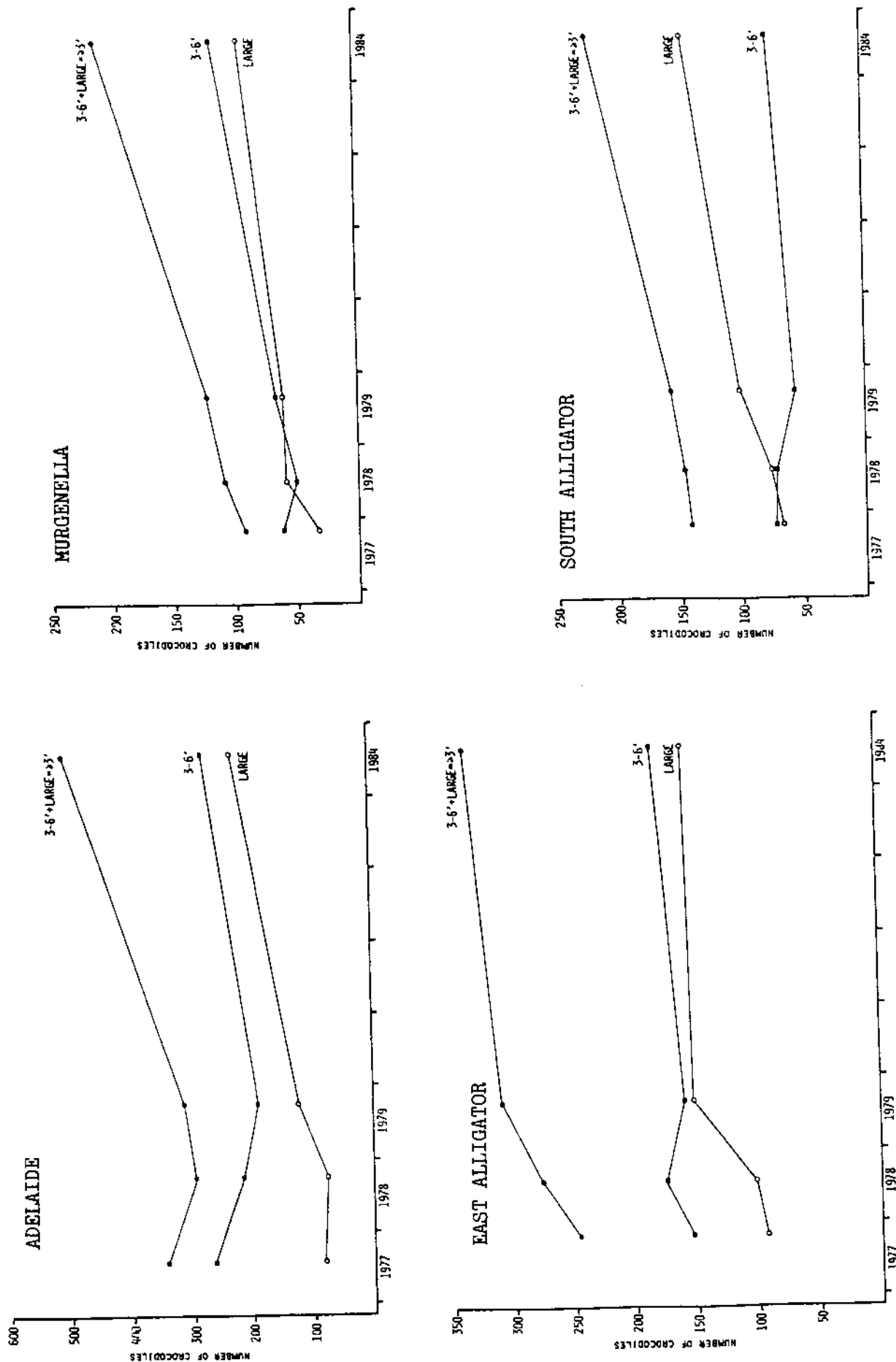


Figure 9. A plot of the number of 3-6', large ( $\geq 6'$ ) and their sum, 3-6' plus large or  $\geq 3'$  animals for surveys carried out on the Adelaide River, Murgarella Creek, East Alligator River, and South Alligator River.

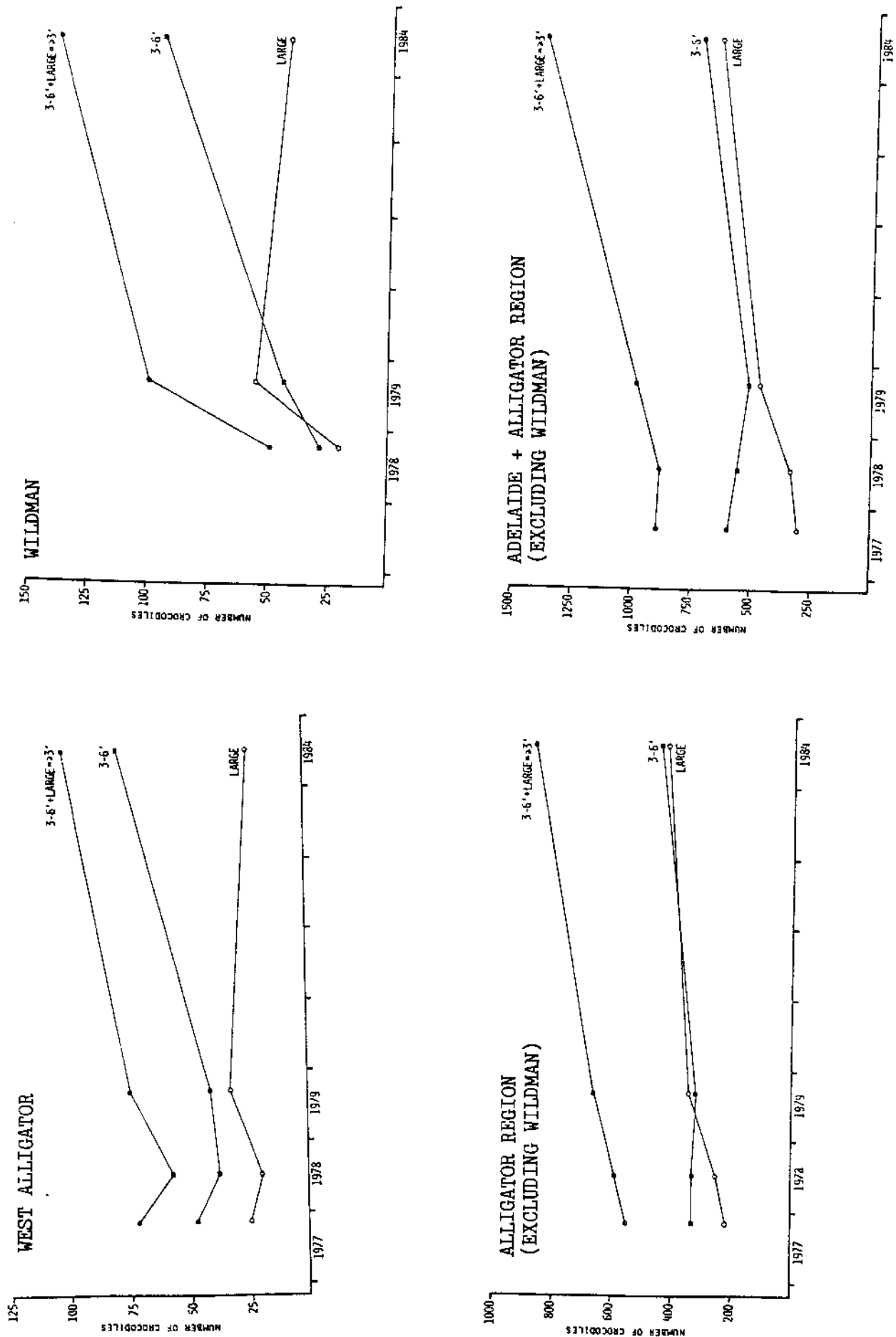


Figure 10. A plot of the number of 3-6', large ( $\geq 6'$ ) and their sum, 3-6' plus large or  $\geq 3'$  animals for surveys carried out on the West Alligator River, the Wildman River, and the combined results for the Alligator Region (excluding the Wildman) and for the Adelaide River plus the Alligator Region (excluding the Wildman).



one adds in the Cobourg Complex and Saltwater Creek, then the number of large animals sighted on the 861.2 km of these tidal waterways during the 1979 and 1984 surveys is 569 and 747 respectively.

4. As already pointed out previously, the "dry wet" season of 1981-1982 apparently resulted in heavy hatchling recruitment and this in turn resulted in a high 3-4' animal count during the July 1984 survey. As has been shown during the course of our lengthy study on the Blyth-Cadell and Liverpool-Tomkinson Rivers Systems such fluctuations are soon smoothed out (Messel et al. 1979-1986, 1, 18 and Tables 1A and 2). The heavy 3-4' animal count in turn inflated the 3-6' count which in turn halted the decreasing 3-6'/large ratio (Table 9 and Figs. 9 to 10). Furthermore, the heavy losses of large animals through drowning in barramundi nets set in the tidal waterways of Kakadu National Park also leads to an artificially high ratio. Some idea of the impact of net fishing may be gained by comparing the results in Table 9 for Murgarella Creek, where net fishing is not allowed, and the West Alligator River, where it is allowed. If commercial net fishing was halted in the tidal waterways of the National Park, one could be confident that the ratio would continue to fall over the long term. However only repeated, careful, and systematic surveys of the overall waterways in the area can provide a long term check on this matter.

5. The density of non-hatchling crocodiles sighted during the 1984 resurvey increased in each of the systems and areas (Table 1B). For the overall 861.2 km of tidal waterways resurveyed, the increase was from 1.5/km for 1979 to 2.1 for 1984. This increase is significant statistically at >99% level of confidence and importantly the increase is not made up of increases in the 3-6' size classes (870 versus 610) only, but there was also a large increase in the number of large animals sighted (747 versus 569).

6. Along the waterways of the Alligator Region, there has been much destruction of riverine habitat by feral water buffalo. This is especially so for the South Alligator and accounts for the minimal hatchling recruitment. We believe that recruitment in the associated freshwater complexes must play an important role in the Alligator Region, especially for the South Alligator.

7. The total number of *C. porosus* sighted on the 261.0 km of waterways comprising the Cobourg Complex increased from 67 for the 1979 survey to 76 for the 1984 one. This increase is not statistically significant and the density figure for the Complex increased from 0.26/km to 0.29/km only.

Thus the present results support the view that a sustainable recovery in the *C. porosus* population is in progress in the Adelaide River System and in the tidal waterways of the Alligator Region. Furthermore this recovery is very much in accord with the predictions of our model. The recovery is much stronger than that found for the tidal waterways in the Maningrida area. In Table 10, we have combined data for 1979 and 1983 from Table 1A for the 411.5 km of tidal waterways monitored in the Maningrida area, which encompass the Coomadeer, Liverpool-Tomkinson, Blyth-Cadell, and Glyde Rivers Systems and various TYPE 3 creeks in the area, and presented these in the same form as the results shown in Tables 1A and 9. This then permits us to compare survey results for the monitored tidal waterways in the Maningrida area with those for the 861.2 km of waterways bordering Van Diemen Gulf. Comparing Tables 9 and 10 highlights immediately and strongly the difference between the regions. The explanation for the difference in recovery rates is straightforward. Whereas the freshwater complexes associated with the TYPE 1 waterways in the Maningrida area are scant, and hence most of the animals excluded from the tidal systems in the area had little choice but to leave the systems (and later endeavor to return or to be killed if they remained). In this process the losses in the 3-6' and large size classes are very high. On the other hand, in the Alligator Region, there are substantial freshwater complexes associated with the TYPE 1 tidal waterways and many of the excluded animals take refuge in these and they are used both as rearing stockyards and as breeding systems. In freshwater complexes there are many more

places for crocodiles to hide from other crocodiles than on a river with only two banks. The losses in this case could be expected to be lower (see points 5 and 6 of our model) and the recovery rate faster than on systems without associated freshwater complexes. For the overall waterways in the Alligator Region we found that the exclusion and/or loss factor varied between 47 and 82%. This latter high figure can probably be attributed largely to the loss of crocodiles through drowning in nets. Were it not for this, the figure would undoubtedly have been much lower and the recovery more spectacular.

For the Adelaide River System, two important factors appear to come into play. Though many of the former freshwater complexes associated with the System have been destroyed by feral water buffalo, the waterway has in addition an extensive (101.8 km) system of mostly TYPE 3 waterways on its downstream sections and hence when animals are excluded from the breeding sections they can take refuge in these without leaving the System. The exclusion and/or loss factor for the Adelaide System was only between 31 and 45%, compared to the 80 to 90% or more, for the waterways in the Maningrida area (Messel et al. 1979-1984, 18:127, 134, 155). The increase from only 81 large animals sighted on the Adelaide during the July 1977 survey to 228 large animals sighted on the July 1984 one is the consequence of these smaller losses. Given another decade or two of protection, the Adelaide System may begin approaching its former crocodile numbers.

An important implication of our results is that in much wetter climates than northern Australia, with much more extensive swamp areas (such as New Guinea, Malaysia, Thailand, Burma, for example) recovery could be expected to be faster, given enough animals to allow a recovery.

#### LITERATURE CITED

- Cott, H. B. 1961. Scientific results of an inquiry into the ecology and economic status of the Nile crocodile (*Crocodylus niloticus*) in Uganda and northern Rhodesia. Trans. Zool. Soc., London 29:211-337.
- Magnusson, W. E. 1979. Dispersal of hatchling crocodiles (*Crocodylus porosus*). J. Herp. 13:227-231.
- Messel, H., et al. 1979-1984. Monograph 1-18, Surveys of Tidal River Systems in Northern Australia and Their Crocodile Populations. Pergamon Press, Sydney.
- Webb, G. J. W., and H. Messel. 1977. Abnormalities and injuries in the estuarine crocodile, *Crocodylus porosus*. Aust. Wildl. Res. 4:311-319.
- \_\_\_\_\_, and \_\_\_\_\_. 1978. Movement and dispersal patterns of *Crocodylus porosus* in some rivers of Arnhem Land, northern Australia. Aust. Wildl. Res. 5:263-283.

## APPENDIX--SUPPORTIVE EVIDENCE

In this appendix we summarize some of the data that provides additional support for our model. A full appreciation of course requires a complete reading of all the monographs and their analysis of individual systems (a somewhat daunting task admittedly!).

### THE 1979 HATCHLING INPUT ON THE TOMKINSON

A spectacular illustration of the dramatic losses of small animals may be given by considering the fate of the very large hatchling input on the Tomkinson River in 1979. In June 1979, 289 hatchlings were sighted on the Liverpool-Tomkinson System; 260 of these were on the Tomkinson. There was an increase in the number of 3-6' animals on the Tomkinson from 62 in July 1979 to 85 in June 1982, which we believe was due to the return of some of the 1979 hatchlings to the mainstream from extreme upstream sections, because they were now in the size class to be excluded. By October many of these animals were gone from the system. In summary the number of 3-6' animals in the Liverpool-Tomkinson System was 120 in October 1979 and 142 in October 1983--the very large recruitment in 1979 had produced virtually no result.

### RESULTS IN ARNHEM BAY

The waterways of Arnhem Bay (Messel et al. 1979-1984, 11) provide further evidence for the losses in the sub-adult size classes.

Arnhem Bay, because of the relatively narrow channel leading into it, is an enclosed system with three groups of waterways (Group 3 has the Goromuru River only). Each group has a major *C. porosus* breeding river in it, the Peter John, Habgood and Goromuru Rivers, which can supply *C. porosus* to adjacent waterways. Although we have no direct evidence, it would be surprising if there was no movement of *C. porosus* between the three groups.

We showed that there was a significant increase in the number of non-hatchling *C. porosus* sighted in the three groups of rivers from the October 1975 to the May-June 1979 surveys and hence that the population of *C. porosus* in Arnhem Bay is increasing (but see remarks on Arnhem Bay in Status Chapter). However, the increase is slow and there is strong evidence for continuing heavy losses (disappearance) in the transition from the 2-3', 3-4', and 4-5' size classes to the  $\geq 5-6'$  size classes. Comparing the number of crocodiles in the 2-3', 3-4', and 4-5' size classes for the combined rivers of Arnhem Bay in October 1975 and the number in size classes  $\geq 5-6'$  in May-June 1979 reveals that the loss (disappearance) of crocodiles in the transition from the 2-3', 3-4', and 4-5' size classes to size classes  $\geq 5-6'$  was some 88%.

There was no increase in large crocodiles sighted in Arnhem Bay in 1979, which is against the trend for most of the waterways surveyed in 1979. The reasons for this could be twofold: (a) the climate is wetter in the Arnhem Bay area; (b) there is only limited freshwater swamp.

## DISTRIBUTION OF ANIMALS

In our ecology chapter we briefly discussed typical distributions of animals along a TYPE 1 waterway and how this fitted in with the idea of a movement of larger size classes downstream. Each system has of course its own peculiarities and we shall now give some examples, with references for the supportive details.

In 1979 we found for the overall Kalarwoi River (Messel et al. 1979-1984, 10:28) that the losses of animals was considerably less than in other systems of similar type. The much lower percentage missing is undoubtedly connected with the fact that the Kalarwoi River has a TYPE 1 breeding, northern branch and a TYPE 2-TYPE 3 rearing stockyard adjoining it (the Kalarwoi mainstream). The subadult crocodiles displaced from the TYPE 1 breeding section need not travel out to sea (where a large fraction may perish) but can seek refuge in the adjoining TYPE 2-TYPE 3 mainstream. Since there is little or no breeding on this section, there is likely to be less competition between the sub-adult and adult size classes. The present result also provides additional evidence for the view that the high losses in the other TYPE 1 systems are associated with the sea movement of *C. porosus* from one system to another. A similar mechanism also applies for the Adelaide River, as we discussed in the results for Van Diemen Gulf.

The upstream section (km 73.7-81.3, Table 8) of the Tomkinson has a size class structure typical of a non-TYPE 1 system and appears to function as a refuge for larger animals excluded from the breeding sections of the river. The less desirable far upstream sections of the Liverpool and Blyth also appear to function in the same way, with higher numbers being sighted there in October surveys (excluded from main sections with onset of breeding season) than in June-July surveys (Messel et al. 1979-1984, 18:138).

The sighting of a different size class structure on each resurvey of TYPE 3 systems (but of course always mainly animals  $>4'$ ) fits in with these systems being mainly inhabited by itinerant animals that move in and out of such systems.

Webb and Messel (1978) classified crocodiles into short and long distance movers. In terms of our model the long distance movers are simply the crocodiles unable to secure a territory and we also see why there is an increasing number of long distance movers with increasing size of sub-adults.

## INJURIES, DEATHS, AND INTERACTIONS

During a daytime survey of the Tomkinson River in May 1975 a freshly killed 5' *C. porosus* was found at km 22 and was preserved. This animal had been captured, marked and released 2 years previously. The dead animal had a distinct pattern of crocodile teeth punctures and was presumably bitten to death by a larger crocodile. During the night-time survey of km 73.7-81.3 section of the Tomkinson River on 1 November 1982 (breeding season) a 7-8' freshly dead male *C. porosus* was found floating in the water at km 73. It appeared to be in excellent condition and had blood coming from its nostrils--it was probably killed by a blow from a larger crocodile.

On the survey of the Cadell River carried out on 6 November 1982, a 7-8' crocodile was sighted at km 45.9 (the breeding area) with a near leg that was almost completely torn off--obviously done by a larger crocodile.

A 14' animal found drowned in a fisherman's net on the Wildman River in August 1979 had the remains of three small crocodiles in its stomach--possible direct evidence of the cannibalism which we strongly suspect is a major factor in *C. porosus* population dynamics and density control. In July 1983 on the Glyde River, the lower half of an 8-9' crocodile was seen floating in the river. As we approached, the carcass was attacked by a 9-10' crocodile. Considering the concentration of large crocodiles in the Glyde at this time, it is quite likely that the dead animal had been killed by another and that we witnessed another case of cannibalism.

Webb and Messel (1977) found that there was no significant increase in injury frequency in size classes up to 4-5'; however, in size classes above this, injury frequency was high. This of course fits in completely with our model.

Appendix A1.4 of Messel et al. (1979-1984, 1) gives a number of examples of observations of territorial behavior and displays, including a detailed account of the interaction of two 3-4' crocodiles over several months in 1976. A single example will be given here.

At 1334 hrs at km 22, on the Blyth River, on 16 September 1978, a 7-8' crocodile was sighted basking on a gently sloping mud bank, near low tide. We were approaching it slowly in the survey boat in order to get a photograph. When the survey boat was some 30 meters away, the crocodile started to move towards the water. Suddenly a 6-7' crocodile rushed out of the water and chased the 7-8' one, snapping at its tail. The 7-8' crocodile raced along the mud bank in a semicircular path into the water, with the 6-7' crocodile still chasing it. By this time, the survey boat was only 2 to 3 meters away from the 6-7' crocodile, which had its back arched well out of the water. As we approached closer, the crocodile blew a thin stream of water from its nostrils into the air. We could see no sign of the 7-8' crocodile. The 6-7' specimen gradually submerged its back and just the head was left visible.

#### OBSERVATIONS OF CROCODILES IN MUD

During the night-time surveys many crocodiles have been observed buried in mud (Messel et al. 1979-1984, 1:Chapter 7). Often the mud is very thin and physiologically a crocodile in mud is like one in the water. In most instances only the eyes, cranial platform, and snout are showing. The phenomenon is also observed during daytime. After examining and dismissing salinity and temperature as the reasons, the only explanation for the behavior that we could think of was that of camouflage. Crocodiles bury themselves in mud to hide from other crocodiles and so escape territorial interactions. The same mechanism is the basic explanation of the observation of crocodiles on the bank (Messel et al. 1979-1984, 1:Chapter 7). We have often witnessed crocodiles being chased out on the bank at night by other crocodiles.

#### DISPERSAL OF HATCHLINGS

In June 1978 all hatchlings on the Blyth-Cadell System that could be caught were marked and released. They were systematically recaptured in September 1978 and again in June 1979 (Messel et al. 1979-1984, 1:Chapter 8). A few recaptures of the same animals were made in October 1979 (Messel et al. 1979-1984, 1:Chapter 8) and October 1980 (Messel et al. 1979-1984, 18:Chapter 5). The pattern that emerges is again that of some animals hardly moving at all and some moving large distances. Looking at the 11 recaptures in October 1980, 3 animals on the Cadell were recaptured within 200 meters of their initial capture as hatchlings. Long distance movement is

related to food supply but the number of male long distance movers is very significantly greater than the number of female long distance movers. Could interactions be greater for males even at this early stage? The fact that the males had more tail injuries than females supports this view. Webb et al. (1978) and Magnusson (1978) give further results on hatchling dispersal.

#### RECAPTURES OF 1980, 1981 AND 1983

These recaptures on the Liverpool-Tomkinson System were of animals initially captured in 1973-1976. The details are given in Messel et al. (1979-1984, 18:63-65 and in our chapter on Growth of *C. porosus*. One female (131) stayed in the same area on the upstream Tomkinson for two years and some time after reaching 4' moved to the midsection of the Liverpool--this agrees with our model. A male (517) was captured at 5' size at km 19 on the Tomkinson; one year later it was at km 73 on the Tomkinson; eight years later it was back at km 18. This is suggestive of the animal being excluded to the non-breeding section of the Tomkinson and returning when large enough to establish a territory. Animal 184 (a male) was captured as a hatchling on Maragaldiban Creek and recaptured three more times over a period of 10 years; all captures were within 1 km or the initial capture. This animal is one of the 10-15% we believe manage to establish a territory in the area where they were born and never leave. Animals 382 and 1059 also hardly moved over a period of six years.

#### CONCENTRATION OF LARGE ANIMALS AT MOUTHS OF RIVERS

It is unusual to see concentrations of large (or small) animals near the mouth of rivers. We have seen it, however, on a few occasions, and these observations are understandable in terms of our picture of movement between the Arafura Swamp and the monitored area.

On the June 1979 survey, on the Blyth mainstream, the number of large animals sighted increased dramatically from 15 to 40 and from 23 to 55 for the overall Blyth-Cadell System. For us it was exciting to see so many large animals; they were mostly concentrated at the mouth region of the Blyth River and on the sidecreeks of the downstream section of the river. Where had these animals come from and were they coming into the river or leaving it? Since they were not sighted during the September 1978 survey, the evidence points to these animals trying to gain entrance to the waterway.

By October 1980 most of these additional large animals were gone again. We interpret this to mean large animals excluded from the Arafura Swamp after the dry wet of 1978-1979 were trying to enter the Blyth. Exactly the same phenomenon occurred in June 1982 after the dry wet of 1981-1982; 31 large *C. porosus* were sighted on the km 0-15 section of the Blyth River and its sidecreeks. By November 1982 the number of large *C. porosus* on the Blyth-Cadell System had dropped by 15 and the decrease occurred almost exclusively on the mouth section.

In July 1979, on the Glyde River, we observed 12 animals between km 0 and km 1.2 in size classes  $\geq 4'$ . This was the first occasion we had seen such a concentration of *C. porosus* at a river mouth. These would be largely animals excluded from the Arafura Swamp and leaving the river or waiting to return. Because of this 1979 observation we were expecting a similar observation in July 1983 after the "dry wet" of 1981-1982, and so it turned out. Furthermore, there were 19 animals sighted on the km 0-5 mouth section and the majority of these were large; 15 of the animals were sighted between km 0 and 2, strongly indicating that they were either entering or leaving the river

(in fact the October survey indicates they were entering the system). Three pairs of these large crocodiles were sighted interacting; that is, one was in the water directly facing one up on the bank. Further discussion may be found in Messel et al. (1979-1984, 18).

The large increase in the Milingimbi Complex (Messel et al. 1979-1984, 9) in 1979 also supports the idea of movement out of the Arafura Swamp via the Glyde River.

The idea of movement between the monitored area and the Glyde River is made more plausible by the sighting in 1976 in the Milingimbi Complex of a 12' male with a transmitter on its head that was originally caught at km 49 on the Tomkinson one year earlier.

#### OBSERVATIONS WITH OTHER SPECIES

Cott (1961) remarked on the losses of small *C. niloticus* between the ages of about two and five years, crocodiles go into retreat in less desirable habitat and this cryptic behavior has probably been forced on them by the habit of cannibalism. Studies of *C. acutus* in Florida also indicate that a substantial fraction of sub-adult *C. acutus* remain unaccounted for (J. Kushlan, 5th Working meeting, Crocodile Specialist Group, 1980).

## ECOLOGY OF THE AMERICAN CROCODILE, *CROCODYLUS ACUTUS*

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### SPECIES IDENTIFICATION AND DISTRIBUTION

The American crocodile, *Crocodylus acutus*, is a large, relatively longirostrine crocodile widely distributed in the coastal regions of the northern neotropics. Although individuals have been reported historically to reach lengths of up to 6.25 m (Alvarez del Toro 1974) and 7.0 m (Schmidt 1924, Medem 1981), today *C. acutus* longer than 4 m are rare. The general morphological characteristics of the species have been described elsewhere (Mertens 1943, Brazaitis 1973), yet because of morphological similarities with two other species (*Crocodylus moreletii* and *Crocodylus intermedius*), misidentifications of the species have not been uncommon, even among herpetologists. Frequent past confusion among these and other New World crocodilians has created nightmarish problems for nomenclatural review (Smith and Smith 1977).

Among all living crocodilians, *C. acutus* has the most reduced and irregular arrangement of dorsal osteoderms, usually with no more than 4 scutes in any of the 14-17 continuous precaudal scute rows (Ross and Mayer 1983). The American crocodile is also unique in the degree of development of a median preorbital elevation (MPE) on the snouts of adults and subadults (Brazaitis 1973, Alvarez del Toro 1974, Medem 1981). Although the size and shape of the MPE appears to vary somewhat geographically, and some preliminary evidence suggests that its size may be sexually dimorphic (pers. obs.), the MPE is a consistent and distinctive morphological feature among adults. Other species of crocodiles may have an MPE, but never as pronounced as in *C. acutus*. The combination of these two characteristics, irregular reduced dorsal scutes and the MPE, is sufficient to distinguish *C. acutus* from other crocodiles, with the possible exception of *C. moreletii* which has both characters developed to a slightly lesser degree. Morelet's crocodiles are best distinguished from *C. acutus* on the basis of ventrolateral scute intrusions on the base of the tail (Ross and Ross 1974).

The general distribution of the American crocodile includes both the Atlantic and Pacific coasts of southern Mexico, Central America, and northern South America, as well as the Caribbean islands of Cuba, Jamaica, Hispaniola and the southern tip of Florida, USA. The exact limits of the past and present mainland distribution of the species are somewhat confused due to a lack of systematic survey work, and the past misidentification of species. This is especially true for the Atlantic coast drainage. On the Mexican Gulf coast, *C. acutus* has definitely been recorded as far north as Cozumel Island (Field Museum of Natural History, FMNH 34563), Bahia de la Ascencion and Isla de Mujeres (Quintana Roo), and Laguna de Catemaco (Vera Cruz; Ross and Ross 1974). Literature accounts of *C. acutus* north of Vera Cruz on the Gulf coast appear to be based largely on misidentified *C. moreletii*.



The southernmost limit of *C. acutus* on the Atlantic coast of South America is similarly confused. Specimens of the American crocodile have been reported from the Paria Peninsula in Venezuela and on Trinidad, although the latter records probably represent vagrant animals (Medem 1983). Large crocodilians are known from the Orinoco delta region (F. Pannier, S. Gorzula, pers. comm.), but their specific identity is not known. Apparently, no members of the Crocodylidae are found south of the Orinoco delta.

The limits of the Pacific mainland distribution are better known due to the lack of congeners, and habitat limits to distribution. Crocodiles have been recorded from as far south as the Rio Tumbes and Rio Chira in northern Peru (Hofmann 1970, Medem 1983). In Mexico, the northwestern limit of crocodile distribution historically was the state of Sinaloa (Ross and Ross 1974, King et al. 1982).

The American crocodile reaches the northernmost limit of its range in Florida, USA. Although once found as far north as Lake Worth on the eastern coast of Florida, the current crocodile distribution now centers on Florida Bay. The present and past distribution of crocodiles in Florida are reviewed by Ogden (1978) and Kushlan and Mazzotti (1986).

Outside of its currently recognized range, *C. acutus* was also apparently found on the Bahamas (based on pre-Columbian fossils; King et al. 1982), and on the Cayman Islands, where specimens were collected as recently as 1939 (Grant 1940).

## HABITAT RELATIONS

### Macrohabitat

The American crocodile is typically found in freshwater or brackish water coastal habitats including, but not restricted to: the estuarine sections of rivers, coastal lagoons, and mangrove swamps (Alvarez del Toro 1974, Medem 1981). Although it is principally a coastal species, *C. acutus* is ecologically adaptable and is known to extend its distribution inland, especially along the courses of larger rivers and their associated wetlands habitat (Medem 1981). Individuals have been reported at altitudes of up to 610 m in Honduras (Schmidt 1924) and 1220 m in Mexico (Rio Tehuantepec: American Museum of Natural History, AMNH 100634). The species also inhabits landlocked lakes of varying salinities: freshwater (Schmidt 1924), brackish (Thorbjarnarson 1984, 1988), and hypersaline (Inchaustegui et al. 1980).

The American crocodile is regularly found on small offshore islands and atolls throughout its range. On many of these islands adult crocodiles can apparently exist without access to freshwater, although the presence of a freshwater source may be critical for the survival of hatchlings (see Temperature and Salinity Relations).

The adaptability of *C. acutus* in terms of habitat requirements extends to the use of disturbed, or man-made habitats. Although crocodiles are known to occupy man-made bodies of water in Venezuela (Embalse de Pueblo Viejo, Embalse de Tacarigua; Seijas 1986b), and Panama (Gatun Lake; Dugan et al. 1981, Rodda 1984), the most extensive use of disturbed habitats is in southern Florida. On Key Largo, crocodiles commonly occupy borrow pits and canals. Indeed, virtually all the nesting on Key Largo (which accounts for some 30% of the total nesting in Florida) is done on peat spoil banks created by dredging canals in mangrove areas (P. Moler, pers. comm.). A small population of crocodiles also inhabits the cooling canal system of the nuclear power plant at Turkey

Point. Nesting has occurred on several occasions in the spoil banks along the cooling canals (Gaby et al. 1985). Crocodiles are also known to occur in the cooling canal system of another power plant in Ft. Lauderdale (P. Moler, pers. comm.).

### Microhabitat, Activity and Movements

Within the broad definition of *C. acutus* habitat outlined above, certain microhabitat features strongly influence the distribution of crocodiles in any given area. Crocodiles are principally inhabitants of shoreline habitats, preferring an amalgam of shallow and deep water areas, land for basking or nesting, and aquatic or semiaquatic vegetation for cover or increased habitat productivity. In addition to micro-environmental features, social factors play an important role in determining crocodile distribution. Crocodile size, population density, and population size-class structure all probably interact with environmental factors to define the overall pattern of habitat usage for any given population. Aside from these factors, the presence of humans or pattern of human activity may also modify crocodile habitat use. In most situations crocodiles are retiring and avoid areas frequented by humans. For instance, in Etang Saumatre, Haiti, a temporal habitat segregation was noted with crocodiles nocturnally entering areas used by people during the day (pers. obs.).

Because detailed information on many aspects of habitat selection is lacking, the following discussion centers on some of the more obvious factors that influence crocodile distribution and activity. This information is based primarily on work done on three crocodile populations: southern Florida; Etang Saumatre, Haiti; and Gatun Lake, Panama.

**Hatchlings and Juveniles** - Among nesting females (see following section) and recently hatched young, terrestrial habitat features are important in defining habitat requirements, as they determine where nesting can occur and the type of habitat into which the young are born. When nests are located adjacent to suitable habitat for hatchlings, the young may remain in the vicinity of the nest for several weeks, months, or even years (Alvarez del Toro 1974; Thorbjarnarson 1984, 1988; Rodda 1984).

In Florida, hatchling crocodiles frequently prefer to remain hidden in vegetation during the day, using such areas as mangrove prop roots, shoreline ledges or beach wrack for cover (Lang 1975b, Mazzotti 1983). In Panama, Rodda (1984) found 10 and 22 month old *C. acutus* along shorelines protected from waves and usually bordered by woody vegetation. In these areas the young crocodiles were frequently seen in floating mats of *Hydrilla*. In Etang Saumatre, Haiti, juvenile and hatchling crocodiles would spend most of the day hidden in root mats of *Conocarpus erectus* that grew in shallow water near the nesting beaches. At dusk, the crocodiles would leave their protected retreat sites and move to more open shoreline habitats or floating algae mats where they would forage (Thorbjarnarson 1984, 1988). Juvenile and hatchling crocodiles in Etang Saumatre were mostly sedentary. Of 10 recaptures, 8 were found at the original point of capture (mean interval 143 days). One juvenile dispersed 1.8 km over 339 days.

When the habitats adjacent to the nest are unsuitable for hatchlings, the neonates may disperse almost immediately. Factors which may cause dispersal are probably diverse, but are known to include wave exposure (Ogden 1978, Mazzotti 1983), and hypersaline aquatic environments (Inchaustegui and Ottenwalder pers. comm., pers. obs.). Mazzotti (1983) found hatchling *C. acutus* would disperse from wave exposed nest sites soon after hatching, moving up to 1.5 km from the nest in the following month. Lang (1975) and Ogden (1978), reported similar results from their studies in south Florida. Movements were either along the shore or inland into

protected, interior, shallow water habitats. In some cases hatchlings were noted to move overland for periods of up to 10 days without access to water (Mazzotti 1983). The general pattern of movements was away from exposed habitats and into sheltered mangrove lined creeks. Hatchlings from nests along creek sites dispersed less and tended to remain in the nest area for at least one year. Virtually all hatchling movements were nocturnal.

Rodda (1984) radio-tracked a group of 10 month old ( $N = 9$ ), and 22 month old ( $N = 1$ ) *C. acutus* along a sheltered shoreline in Gatun Lake, Panama. Census work in the area suggested that some of the crocodiles would remain near their nest for at least 22 months after hatching. Over a two-month period the radio-equipped crocodiles were found to remain within relatively restricted home ranges. The 10 month old crocodiles moved within an average of 330 m of shoreline, and spent approximately 80% of their time within a narrower core range of 200 m. The one 22 month old individual moved over 650 m of shoreline.

In the same study, Rodda (1984) examined a series of factors (water temperature, wind speed and direction, sun or moon visibility and altitude, moon phase, cloud cover, and water level) in relation to activity levels. Crocodiles were found to move significantly less during moonlit periods (no clouds, moon more than half full and  $> 30^\circ$  from the horizon). A diurnal pattern of movements was found with activity showing a sharp increase just prior to dusk, then increasing steadily until 0300 h. A similar pattern was noted for the mean percentage of animals at the water's surface. Movements during the day (0900-1700 h) were unusual.

Larger juvenile crocodiles (and subadults) may enter a dispersal phase and move much more than smaller individuals (see following section). Some juvenile crocodiles in southern Florida are known to disperse well away from their nest sites (P. Moler, pers. comm.). One individual (84.5 cm TL) moved a minimum distance of 13.1 km over 18 months from its point of origin at the Turkey Point power station (Gaby et al. 1985).

**Adults and Subadults** - In southern Florida, Mazzotti (1983) reported that adult crocodiles spend most of their time in protected red mangrove (*Rhizophora mangle*) habitats. Over 75% of their observations of adults were in inland or protected coves characterized by deep water, often with undercut banks (see Burrows section) or overhung by mangrove prop roots. Some adults were also found to move to areas of high food availability such as active bird rookeries.

In Etang Saumatre, a brackish water lake in Haiti, adult and subadult crocodiles were found to be significantly more abundant in 5 of the 11 defined lakeshore habitat types (*Conocarpus* fringe, *Conocarpus* flats, *Salicornia* flats, submerged forest, and canal marsh), and were noted to avoid two habitats (rocky shore with medium and steep gradients (Thorbjarnarson 1984, 1988). Three principal environmental factors were considered to be important in determining habitat use: exposure to wave action, food availability and the presence of nesting habitat. The preference of certain habitats over others was attributed in part to the availability of suitable nesting beaches, or to food availability; an active heron rookery in the submerged forest, and the abundance of fish prey species in the *Conocarpus* flats. However, for all habitats the degree of wave exposure was apparently the overriding factor. Classifying lakeshore areas by the degree of wave exposure, crocodiles of all size classes were found in the highest density in protected areas (11.76/km) and in the lowest density in exposed areas (0.83/km) with an intermediate value for moderately exposed areas (7.79/km). A similar avoidance of wave action was noted in adjacent Lago Enriquillo (pers. obs.) and has been reported for *C. acutus* in Florida (P. Moler, pers. comm.), as well as for other crocodilians (Cott 1961, Graham 1968, Woodward and Marion 1978, Messel et al. 1981). Considering that the crocodile's respiratory and visual systems may be severely compromised by waves, avoidance of wave action is a very understandable feature of habitat preference and probably is a general attribute of habitat selection among all crocodilians.

A radio-telemetry study of adult crocodiles in Florida conducted by J. Kushlan and F. Mazzotti (Mazzotti 1983) determined that among 7 adult females ( $> 2.5$  m TL) minimum activity areas averaged 89 ha, and demonstrated seasonal shifts in range associated with the nesting season. Main activity areas were located in protected creeks or ponds, but during the nesting season females would move to the more exposed nest sites in Florida Bay. This study and others have shown that habitat preference in adult females is strongly influenced by the availability of nesting habitat. Females demonstrate an increase in activity and movements during the breeding season (Gaby et al. 1985, Mazzotti 1983) which are often reflected in seasonal differences in habitat selection.

The two radio-equipped male crocodiles (2.3 m, 2.9 m TL) had larger activity areas (98 ha, 216 ha respectively) but did not enter the exposed Florida Bay to any significant degree. One male was noted to have a disjunct activity range occupying a river site, and interior ponds. One stay in the pond region coincided with the active nesting phase of a colony of wood storks (*Mycteria americana*; Mazzotti 1983).

Another type of seasonal activity shift was noted for *C. acutus* by Medem (1981) in freshwater riverine habitats in Colombia. Crocodiles were reported to leave the larger rivers during the wet season to avoid the swift currents and move into lagoons or other inundated areas adjacent to the main river course. Use of the main river channel was restricted primarily to the dry season.

Seasonal activity shifts associated with drought have also been commented on by various authors. Medem (1981) reports that *C. acutus* will bury itself in the mud for periods of up to 2-3 months, or remain in burrows (see below) when its normal habitat dries out. Similar accounts have been given by Varona (1980) for Cuba, Donoso Barros (1966) for Venezuela, and Casas and Guzman (1970) for Mexico.

No quantitative data exist describing daily variation in activity levels in adult or subadult *C. acutus*. Although most data suggest that hatchling and juvenile crocodiles are almost completely nocturnal, possibly to avoid diurnal predators such as raptors and wading birds, adult crocodiles are frequently active during daylight hours. Various behaviors, such as basking (Alvarez del Toro 1974), territorial defense and mating (Alvarez del Toro 1974, Garrick and Lang 1977, Inchaustegui et al. 1980) have been observed during the day. However, for adults as well as juveniles, foraging appears to be mainly a nocturnal activity (Alvarez del Toro 1974, pers. obs.).

Intermediate size-classes of *C. acutus* (large juveniles- subadults, 1.0-2.0 m total length) are frequently found in somewhat marginal habitats. Mazzotti (1983) noted that crocodiles in this size range were often found isolated from the adults and hatchlings and to be located in somewhat inaccessible areas. Gaby et al. (1981, 1985) observed a higher percentage of juveniles and subadult (27% of total) in hypersaline water than adults (5%). In Etang Saumatre subadult crocodiles were more likely to be found along exposed shorelines, and in fact one such marginal habitat (sand-grass-mud) was a statistically "preferred" habitat for subadults (Thorbjarnarson 1984, 1988). In coastal Haiti, juvenile and subadult crocodiles were more frequently reported from small, isolated patches of habitat away from breeding populations.

In the radio-telemetry study in Everglades National Park, Florida (Mazzotti 1983), the one subadult animal followed, a female, was found to move more than adults, and to have a larger minimal activity range (262 ha, 262 fixes), averaging 1.4 km between fixes. In Etang Saumatre, some subadults would also move considerable distances. One subadult male was found to have shifted entirely across the lake, a shoreline distance of 22 km, over a period of 306 days.

The dispersal phase of large juveniles and subadult crocodiles may be an integral part of the population dynamics of *C. acutus* and other crocodilians. The population model proposed by Messel et. al (1982) for *C. porosus* may have broad applicability to other species of crocodilians, especially *C. acutus* which is very similar in ecology to *C. porosus*. The data on habitat selection and movement that do exist for *C. acutus* seem to support the presence of dispersal and segregation phases of large juvenile and subadult crocodiles at a time when they may be coming into territorial conflict with adults.

**Segregation of Size-Classes** - In Florida, the spatial segregation of crocodiles by size-class has been observed in all three sub- populations. As noted above, Mazzotti (1983) reported intermediate-sized crocodiles were not frequently found together with hatchlings or adults. In the cooling canal system at Turkey Point, adult, subadult, and juvenile crocodiles were found in different habitats, with segregation taking place mostly with respect to water salinity (Gaby et al. 1981, 1985). A similar segregation has been noted among the crocodiles on Key Largo (P. Moler, pers. comm.) where physical habitat structure may play an important role. The spatial segregation of crocodiles by size-class may represent a difference in the physical habitat requirements of different sized crocodiles, or it may reflect social factors and agonistic encounters between size-classes as proposed in the Messel et al. (1982) model for *C. porosus*.

However, in other populations of *C. acutus* that have been studied, size-class segregation by habitat type is less clear-cut. In both Etang Saumatre and Lago Enriquillo, hatchling, juvenile, subadult and adult crocodiles were all found together in the same areas (Thorbjarnarson 1984, 1988). In these situations, an important regulatory factor determining the degree (or absence of) size-class segregation, may be population density. It may not be a spurious fact that size-class segregation has been noted in a population inhabiting coastal mangrove habitat in Florida, where population density was lower (see Population Ecology), and the available spectrum of habitats is greater. In the lacustrine crocodile populations on Hispaniola, greater crocodile densities and more limited habitat availability may result in a greater degree of size-class overlap in habitat usage. At the other extreme is the situation reported by Schmidt (1924) in Lago Ticamaya, Honduras, which had an extremely high crocodile density with a total lack of small juveniles. In this case the extremely high density may have triggered density-dependent population control measures which may have lead to the complete exclusion of smaller individuals from the main population body, or mortality via mechanisms such as cannibalism. Schmidt does report finding the remains of a 1.2-1.5 m crocodile in the stomach of a larger specimen, but under circumstances such as these cannibalism is difficult to distinguish from scavenging.

### Temperature and Salinity Relations

Studies of the temperature relations of *C. acutus* have primarily involved hatchling (Mazzotti 1983) and juvenile (Lang 1979) crocodiles. Lang (1979) noted that under laboratory conditions the preferred body temperature of fasting *C. acutus* was similar at night ( $28.0^{\circ}\text{C}$ ) and during the day ( $27.9^{\circ}\text{C}$ ), but was slightly elevated following feeding (day  $29.5^{\circ}\text{C}$ , night  $29.3^{\circ}\text{C}$ ). Testing for the upper limits of thermal tolerance in hatchlings, Mazzotti (1983) found observable signs of heat stress when cloacal temperatures exceeded  $38^{\circ}\text{C}$ .

Under field conditions, Mazzotti (1983) noted that hatchling *C. acutus* selected the coolest available microhabitats during the day, becoming active when surrounding temperatures dropped to within  $1^{\circ}\text{C}$  of the microhabitat temperature. The resulting pattern of activity indicates that hatchlings seek out the lowest available temperatures in order to avoid heat stress (Mazzotti 1983).

These data for hatchling *C. acutus* agree with the hypothesis of Lang (1975c) of *Crocodylus* as thermoconformers whose basic thermoregulatory strategy is to avoid rapid heating during the day.

No specific studies have examined the thermal relations of adult *C. acutus* but, in contrast to hatchlings, adults are well known to bask, especially during the morning or late afternoon hours. Basking is usually accomplished by hauling out on land, but in areas where suitable terrestrial habitat is not available, or a disturbing human presence is found, crocodiles will bask in a high emergent floating posture in the water (Alvarez del Toro 1974, Medem 1981, pers. obs.). Conversely, during the heat of the day adults are known to remain hidden in deep water (Alvarez del Toro 1974), or in cool, shaded aquatic situations (pers. obs.).

At times crocodiles will remain on land at night, and this behavior results in lowered body temperatures (Cott 1961, Graham 1968, Lang 1975c). In Lago Enriquillo and Etang Saumatre, this behavior was frequently noted in response to intense wave action (pers. obs.), but it may also occur in calm water areas. Crocodiles on land have also been observed gaping both during the day and at night, an action considered by various authors to be thermoregulatory in nature (Alvarez del Toro 1974, Loveridge 1984). Besides a temperature regulation function, gaping may also be used to dry out the mouth lining to control the growth of algae or fungi, or to desiccate aquatic ectoparasites (pers. obs.).

The salinity relations of *C. acutus* are of obvious importance as the species is frequently found in saline environments. A relatively large literature exists on the osmoregulation of *C. acutus* and other crocodilians.

Mazzotti (1983) found crocodiles in Everglades National Park occupied a wide range of salinities (0-35 parts per thousand (ppt)), with mean salinity values varying somewhat between size classes (adults 12.1 ppt, subadults 12.6 ppt, juveniles 20.1 ppt) and time of year (winter 12.4 ppt, spring 19.6 ppt, summer 17.3 ppt, and fall 15.1 ppt). The seasonal shift in mean salinity was associated with a population move towards the Florida Bay during the spring and the greater use of inland areas during the fall when freshwater discharge was at its highest. Average salinity for females (17.3 ppt) was higher than for males (10.8 ppt) and reflected to some degree the use of nesting sites in the higher salinity Florida Bay region.

Also in south Florida, Gaby et al (1985) reported finding crocodiles in salinities ranging from 0 to 40 ppt, and Dunson (1982) observed hatchlings in water up to 43 ppt. Gaby et al. (1985) also noted a size-class segregation by water salinity with adults more frequently observed in freshwater areas (38% of observations), as opposed to only 13% for juveniles and subadults. These two smaller size-classes had a greater tendency to be found in brackish (53%) or hypersaline water (27%). The mean water salinity for captured juveniles was 25.2 ppt.

In terms of osmoregulation, body size plays an extremely important role. Individuals larger than 200 g can fast in seawater for long periods without developing severe salt balance problems (Ellis 1981, Mazzotti 1983). Adult crocodiles, with a relatively small surface area to volume ratio, can presumably remain in saline water for extended periods. In Lago Enriquillo, crocodiles lived in water of up to 70-80 ppt for many years prior to the hurricanes of 1979 and 1980. However, in the same lake hatchling crocodiles would perish as a consequence of the hypersaline water unless they happened to disperse into one of the freshwater marsh areas that fringe the lake (Inchaustegui and Ottenwalder, pers. comm.).

The most crucial period for *C. acutus* in terms of osmoregulation is the first year or two of life. At small body sizes, a large surface area to volume ratio results in an increased capacity for water flux in relation to body mass. Hatchling crocodiles under laboratory conditions do not

maintain mass in full strength sea water (35 ppt), even when fed fish *ad lib* (Dunson 1970, Evans and Ellis 1977, Ellis 1981). However, field observations indicate that hatchlings not only tolerate salinities of up to 43 ppt, but under some circumstances grow extremely rapidly in hypersaline environments (Carney 1971, Gaby et al. 1981). An extra-renal salt excreting gland has been found in the tongue of *C. acutus* and all *Crocodylus* examined to date (Taplin and Grigg 1981). But under natural conditions of blood plasma salt levels, this extra renal excretory pathway apparently plays little or no osmoregulatory role in *C. acutus* (Dunson 1982). In the absence of major physiological adaptations for life in saline water, Mazzotti (1983) suggested that osmoregulation is accomplished primarily by behavioral means. The principal behavioral mechanism for maintaining water balance is probably drinking brackish water made available ephemerally by rains (Mazzotti 1983). Under laboratory conditions it was found that small *C. acutus* maintained in saline water will drink brackish water. Over a 10 day period, hatchlings were found to maintain mass in seawater (35 ppt) if provided with fish to eat, and placed in brackish water (4 ppt) for one day per week (Mazzotti 1983).

### Burrows

The construction and use of burrows or dens by *C. acutus* has been widely observed and commented upon throughout the species range: Florida (Hornaday 1904, Dimock and Dimock 1908, Ogden 1979), Mexico (Casas and Guzman 1970, Alvarez del Toro 1974), Honduras (Schmidt 1924), Nicaragua (Camacho 1983), Colombia (Medem 1981), Venezuela (Donoso Barros 1966), Jamaica (L. Garrick, pers. comm.), Haiti and the Dominican Republic (pers. obs.). Burrows are used principally by adult crocodiles living in riverine habitats, although Medem (1981) also reports dens from lakes and mangrove swamps in Colombia. Other accounts of *C. acutus* from lacustrine habitats indicate that crocodiles do not dig burrows in these areas, perhaps because of a lack of suitable shorebank conditions or less seasonal variability in water levels (Etang Saumatre, Lago Enriquillo, pers. obs.; Lago Ticamaya, Schmidt 1924).

According to Medem (1981), burrow construction differs in relation to habitat type. Along rivers or in lakes, burrows are excavated in elevated banks and have from one to three entrances. In mangrove swamps they are usually found in the most elevated areas under the roots of mangroves or dead trees, or even in mounds of decomposing leaf litter. Varona (1980) reports that in Cuba, *C. acutus* burrows have an oval entrance, exposed at low tide, widening inwards. The burrow ascends and the roof of the terminal chamber is above the water level, sometimes even with "ventilation" holes to the surface. Crocodiles are reported to enter and leave the burrow head first so the terminal chamber needs to be large enough to allow the crocodile to turn around.

Burrows can be quite large. One burrow measured by Medem (1981) along the Rio Palenque in Colombia had two entrance tunnels (2.75 m, 5.80 m in length), one above the water, the other submerged, with a very large terminal chamber (8.5 m x 7.2 m). Ogden (1979) reported that in Florida crocodile burrows were often maintained near creek bank nest sites and were 3-9 m in length with entrances at or below the water line.

Burrows are probably used under various circumstances, as a refuge for resting and thermoregulation, an aestivation site for prolonged drought, or for protection from natural predators or man.

### Habitat Relations with Other Crocodilians

Over its extensive range in the northern Neotropics, *C. acutus* overlaps, partially or entirely, the range of four (and possibly five) crocodilians: *Alligator mississippiensis*, *Caiman crocodilus*, *Crocodylus rhombifer*, *C. moreletii* and possibly *C. intermedius*. The range of distribution overlap is: *Alligator*, southern Florida; *Caiman*, Caribbean drainage Honduras-Venezuela, Pacific drainage Oaxaca, Mexico-southern Ecuador; *C. rhombifer*, Cuba and the Isle of Pines; *C. moreletii*, Atlantic drainage southern Mexico-Guatemala; and *C. intermedius* possibly in the vicinity of the Orinoco delta. Indeed, on a macroscopic scale, the only parts of the range of *C. acutus* where it is not sympatric with another crocodilian are on the islands of Jamaica and Hispaniola, and in northwestern Mexico (Sinaloa-Guerrero).

Reports of ecological relations between *C. acutus* and other crocodilians are restricted primarily to habitat partitioning, and in some areas even this situation is confused. Where *C. acutus* is sympatric with another large, primarily freshwater species, it is generally restricted to brackish water habitats, and does not penetrate far into interior, freshwater areas (*Alligator* (Kushlan and Mazzotti 1986), *C. rhombifer* (Gundlach 1880; Barbour and Ramsden 1919; Varona 1966)), although the situation with *Alligator* is somewhat complicated by potential temperature limitations (Kushlan 1982). In Cuba, *C. rhombifer* is reportedly behaviorally dominant over even larger *C. acutus* in captivity (Varona 1966) and may actively exclude *C. acutus* from freshwater habitats. Although *C. acutus* ranges far up into freshwater rivers along the northern coasts of Colombia and Venezuela, it apparently never has been found far up into the Orinoco river, habitat of the large, freshwater *C. intermedius* (Medem 1981).

In regions where *C. acutus* is sympatric with a smaller crocodilian, habitat use normally includes a greater variety of freshwater environments. In Mexico, *C. acutus* ranges well upstream in many of the larger rivers, and also was frequently found in lakes (Alvarez del Toro 1974). In the same areas, the smaller species of crocodilians are found principally in small streams, or swampy, slow moving sections of rivers (*Caiman crocodilus*), or in small, turbid streams, swamps or swampy lakes (*C. moreletii*; Alvarez del Toro 1974). Similarly, in the Rio Atrato in Colombia, Medem (1981) noted a definite habitat segregation existed with *C. acutus* in the river and major tributaries, and *Caiman* confined to the surrounding swamps and smaller tributaries. A similar situation is presently found in eastern Honduras (pers. obs). In northern Venezuelan rivers, Seijas (1986b) found a broad overlap in the habitat usage between *C. acutus* and *Caiman crocodilus*. It was noted, however, that in areas where the two species were found together, the population levels of *Caiman* were considerably reduced. Other studies have also found that in the recent absence of *C. acutus*, other crocodilians have expanded into typical *C. acutus* coastal habitat: *C. moreletii* (Belize; Quintana Roo, Mexico; C. Abercrombie and M. Lazcano-Barrero, pers. comm.), *C. crocodilus* (Colombia, Medem 1981; Venezuela, Seijas 1986a). Medem (1981) and Seijas (1986a) have pointed out that in many instances, the ecological niche expansion of *Caiman* may be a direct result of the over-exploitation of the more commercially valuable *C. acutus* populations.

### REPRODUCTIVE ECOLOGY

#### Territoriality, Courtship and Mating

Based on studies of captive crocodiles in Florida (Lang 1975a, Garrick and Lang 1977), and observations made on wild crocodiles in Mexico (Alvarez del Toro 1974) and the Dominican Republic (Inchaustegui, Ottenwalder, Robinson, pers. comm.) the breeding system of *C. acutus* is



polygynous. Adult males defend territories during the breeding season, excluding other males but permitting females to enter for courtship. Males are reported to interrupt the courtship activities of smaller neighboring males (S.Inchaustegui, J.A.Ottenwalder, D.Robinson, pers. comm.). Male territorial defense is composed of a series of stereotyped postures, frequently followed by actual or mock fighting. Territorial intruders are often approached in a head-emergent, tail-arched posture prior to fighting. Combat frequently includes lunges and chases. Following an aggressive encounter, dominant males commonly assume a raised "inflated posture" (Garrick and Lang 1977). Alvarez del Toro (1974) reported that, when encountering one another, territorial males would lift their snouts out of the water, snort loudly, and spurt water through their nostrils ("narial geysering" of Garrick and Lang 1977).

Indirect evidence of a polygynous mating system was also found in Etang Saumatre, Haiti (Thorbjarnarson 1984, 1988). Twenty-seven adult crocodiles were located in four distinct groups adjacent to the major nesting beaches one month prior to the peak oviposition period. The groups were well defined during the day, with a mean intergroup distance of 4.7 km, but at night would break up as individuals dispersed along the shoreline. These groups were inferred to be courtship assemblages, and contained one large male, and several smaller adults (presumably females but possibly including subdominant males). The male:female sex ratio of adult crocodiles captured in the same area shortly following the oviposition period was 1:3. At the same time, the corresponding sex ratio for another section of the lake, removed from the nesting beaches, was highly male biased (5 males:0 females) and indicated that a certain fraction of the adult male population may have been excluded from breeding.

Courtship and mating are exclusively aquatic activities. The main advertisement display of male *C. acutus* is a series of one to three headslaps (Garrick and Lang 1977). Courtship is usually initiated by the female, and typically consists of a somewhat stereotyped sequence of behaviors with females snout-lifting, swimming in slow circles around the male, or placing her head on the snout or back of the male. Males frequently respond to this activity by emitting a very low frequency sound, termed a sub-audible vibration (SAV) by Garrick and Lang (1977). The SAV is given from a typical "head-emergent tail-arched" posture, and causes the water on the males back to agitate upwards in what has been termed a "water dance" in alligators (Vliet 1987). Following the SAV are a further series of behaviors that include snout lifting and rubbing, bubbling, and temporary submergences. Copulation is done in shallow water and usually lasts several minutes (Lang 1975a, Garrick and Lang 1977).

The role of vocal signals in the establishment of territories, and courtship in *C. acutus* is not well understood. Garrick and Lang (1977) reported no bellowing in their study of captive individuals, but Herzog (1974) noted one instance of a captive *C. acutus* bellowing on land. Alvarez del Toro (1974) described bellowing in *C. acutus* in Mexico, noting that bellows are primarily heard during the early nighttime or morning hours, and were more frequent during the courtship season. The bellows are said to be answered by other males in the vicinity. A similar account is given by Medem (1981) for *C. acutus*, who also states that bellows can sometimes be heard in the afternoon, and are audible from afar.

Alvarez del Toro (1974) reported that females are territorial towards one another, but upon the approach of an adult male would snout lift and roar in an unusual fashion. Varona (1980) also indicated that in Cuba nesting females are territorial, and up to 5-6 may compete for one nest site. In other parts of its range, however, female *C. acutus* are apparently less territorial around the nest site and may nest colonially or in small groups: Florida (Kushlan 1982), Haiti (Thorbjarnarson 1984, 1988), Dominican Republic (pers. obs.).

### Minimum Reproductive Size and Breeding Effort

The minimum reproductive size of male *C. acutus* is somewhat problematical as estimates must be based on size estimates of animals copulating (and producing fertile clutches), or anatomical examination. A further complication is that individuals may be physiologically mature, but excluded from breeding due to social factors.

Medem (1981) reported a captive 2.19 m total length (TL) male that mated with a 2.36 m TL female in Colombia. The resulting clutch, however, was infertile and suggests that the male was not yet sexually mature. The smallest reported lengths of mature males come from Etang Saumatre, Haiti, where two males captured adjacent to the nesting beaches during the breeding season, and assumed to be mature, were 2.82 m and 2.88 m TL (Thorbjarnarson 1984, 1988).

More data exist on the size of sexually mature females based on nesting individuals. Nevertheless, estimates vary considerably throughout the range of the species, suggesting that minimal size for reproduction needs to be treated as a population parameter, perhaps reflecting environmental or genetic differences in growth rates, and/or age at sexual maturity.

Alvarez del Toro (1974) reported never finding a reproductive female less than 2.8 m TL. Similarly, in Cuba, the reported minimum reproductive size of females is 2.7-3.0 m TL (Varona 1980). However, in other areas females are known to nest at much smaller sizes. Klein (1977) suggested 2.4 m TL as a minimum reproductive size for female *C. acutus* in eastern Honduras. In Etang Saumatre, females begin nesting at around 2.2-2.3 m TL, and never attain lengths over 2.5 m TL (Thorbjarnarson 1984, 1988). Based on the growth rates from recaptured individuals, the minimum reproductive age of females in Etang Saumatre is approximately 10 years. A similar minimum reproductive size in females was noted for nearby Lago Enriquillo (pers. obs.) as well as in Jamaica (L. Garrick, pers. comm.).

In Florida, Ogden (1978) estimated the total lengths of 8 *C. acutus* seen at nesting beaches was 3.9 m, 3.5 m, 3.1 m, 2.8 m (two nests), and 2.5 m (three nests; mean = 2.95 m). Also in Florida, Mazzotti (1983) estimated minimum nesting size to be 2.25 m TL, and captured 6 females at nests with total lengths of: 2.28 m, 2.47 m, 2.57 m, 2.59 m, 2.96 m, 3.08 m (mean = 2.66 m).

Estimates of breeding effort (the annual percentage of adult females that nest) have been made for two crocodile populations, Everglades National Park (Mazzotti 1983), and Etang Saumatre (Thorbjarnarson 1984, 1988). Both values were derived indirectly from estimates of the total adult female population size, and the known number of nests. The two populations had similar values: Florida 72%; Haiti 63.8%, and are comparable to published values for other populations: *A. mississippiensis*, 68.1% (although see Wilkinson (1984) for a much lower value); *C. niloticus*, 80% (Cott 1961); 67% (Blomberg et al. 1982); 87.6% (Graham 1968); 63% (Hutton 1984); and *C. johnsoni*, 90% (Webb et al. 1983).

### Nest Site Selection

The American crocodile typically lays its eggs in a hole nest excavated into sand or soil near the waters edge. However, *C. acutus* appears to be one of the most adaptable of crocodilians in terms of nesting requirements and has been known to nest in a variety of situations. The use of soil or mangrove peat "mound" nests have been well documented in Florida (Campbell 1972,

Ogden 1978, Mazzotti 1983). Even more noteworthy are accounts that *C. acutus* will make small mound nests of scraped up vegetative litter. Under these circumstances the females are reported to dig a shallow hole into which the eggs are laid, then covered with leaf litter, grass or dead branches, forming a definite mound (although smaller in size than the nest mounds made by the sympatric *C. moreletii* and *Caiman crocodilus* (Alvarez del Toro 1974, Medem 1981). However, this behavior has not been well documented in the wild and probably plays an insignificant role in overall nesting ecology.

The ecological significance of hole versus mound nesting was discussed by Campbell (1972), who refuted the phylogenetic importance attributed to nesting mode described by Greer (1970, 1971). Campbell noted that mound nests are found most frequently in species that inhabit low-lying areas, swamps and marshes. He went on to speculate that individual differences in nest morphometry within a population may reflect the past nesting experience of specific females.

Perhaps of even greater importance in defining nesting mode is the timing of nesting in relation to rainfall or water level variation. True mound nesters (e.g. the Alligatoridae) typically nest in the rainy season, frequently during peak water levels. Hole nesting crocodiles normally nest during periods of falling water levels (i.e. the dry season), with hatching taking place towards the beginning of the rainy season (see Timing of Nesting). However, with a hole nesting species such as *C. acutus*, the tendency to "mound" nests may be an adaptive response to nesting in low-lying areas where the probability of nest flooding is high (see Clutch Size, Fertility and Egg Mortality).

The following sections will provide accounts of nesting mode in two crocodile populations in very different habitats: the coastal lowlands of southern Florida, and the inland lakes of Hispaniola. The descriptions serve to highlight some of the variability in nest site selection.

**South Florida** - The principal nesting areas of *C. acutus* in southern Florida are found along creek banks, in exposed sandy beaches in Florida Bay, in man-made canal berms along the mangrove-lined bay side of Key Largo, and in the cooling canal system of the Turkey Point power plant (Ogden 1978, Mazzotti 1983, Gaby et al. 1985). Ogden (1978) noted a diversity of nesting sites in Florida Bay, but that all nests were located in well drained soil and had a deep water approach. Ogden classified nest sites into three major types which are, verbatim:

1. Open thickets of hardwood trees along the edges of 4 to 8 meter wide, deep water creeks with vertical, 0.5 to 1.0 m marl or muck banks.
2. Surrounded by varying amounts of hardwood shrubs and trees at the heads of narrow, shell-sand beaches.
3. In thickets of shrubby black mangrove (*Avicennia nitida*) behind marl banks rising 15 to 30 cm above water.

In Florida Bay two basic nest soil substrates are found: porous sand-shell soil, and marl; the latter having a very fine particle size and a high percentage of organic matter. The soil water content and resultant oxygen diffusion differ widely between the two soil types and play a significant role in determining egg physiology (Lutz and Dunbar-Cooper 1984; see Incubation and Nest Environment).

Ogden (1978) reported that 13 of 14 primary nest sites investigated had significant elevations (mounds) above the surrounding terrain. The elevations ranged from 9 to 65 cm (mean = 31 cm) and were apparently not correlated with location or soil type. Maximum diameters of nest mounds ranged from 1.0 m to 4.6 m (mean = 2.4 m, N = 14).

Eight of the 17 nests studied by Mazzotti (1983) in Florida Bay were classified as "mound" nests. During the course of this study subterranean flooding was found to be a major source of egg mortality. Under these circumstances mounding may be an adaptive feature reducing the probability of nest flooding (Mazzotti 1983: see Clutch Size, Fertility and Egg Mortality).

In five nests measured by Lutz and Dunbar-Cooper (1984), the mean depth to the top of the egg clutch was 33.5 cm. The corresponding depth to the bottom of the clutch averaged 51.0 cm.

Crocodile nests on Key Largo and Turkey Point are located in mangrove peat berms created during the construction of canals (Gaby et al. 1985, P. Moler, pers. comm.). The berms are generally elevated well above water level where the probability of nest flooding is usually minimal. On Key Largo the nests are normally situated in the open sun, although several nest sites are located under a low canopy of mangrove.

**Hispaniola** - The nesting biology of *C. acutus* has been studied in the Dominican Republic by Inchaustegui et al. (1980), and in Haiti by Thorbjarnarson (1984, 1988). The majority of the data from these studies deals with crocodiles in landlocked lakes: Lago Enriquillo in the Dominican Republic, and Etang Saumatre in Haiti.

Crocodile nests in Lago Enriquillo are located primarily in raised, sandy banks on two of the three largest islands in the lake. Additional nesting areas are found in several sandy to gravelly beaches situated around the lake's perimeter. Most nesting beaches are located in well drained sandy soils situated adjacent to calm water areas protected from the frequently intense surf that results from the easterly trade winds (6 of 7 major nesting beaches, pers. obs.). Courtship and mating were observed to take place in one of these calm-water refugia (Inchaustegui et al. 1980), and presumably a similar situation exists in the other areas. With a recent rise in lake level (about 5 m in 2 years following hurricanes in 1979 and 1980), crocodiles shifted nesting beaches as the old sites became inundated. However, in most areas nesting has continued in adjacent, higher, sites. The combination of suitable soil conditions with an adjacent calm-water refugium was sufficiently limiting as to lead to colonial nesting, with some beaches having 20-30 nests. All nests in Lago Enriquillo are hole-type nests.

In Etang Saumatre, which has no large islands, nesting is concentrated along 6.6 km of the uninhabited eastern lakeshore (Thorbjarnarson 1984, 1988). Nests are usually located in elevated sandy areas that were former lake shorelines, frequently on coralliferous limestone outcrops that extend down to the lakeshore. These areas provide a well drained nesting substrate, a deep water approach, and usually an adjacent calm-water refugium on the lee side of the limestone outcropping. Mean nest distance from the lakeshore was 27.5 m (range 7-47 m, N = 31) and height above the lake averaged 1.2 m (range 0.6-2.1 m, N = 31). Fifteen of 26 (57.7%) active crocodile nests were located in or adjacent to former charcoal making sites used in the past by local villagers. These charcoal sites provided a semi-open area in the surrounding thorn-scrub vegetation association, with a friable soil/charcoal fragment mixture. The use of former charcoal making sites for nesting has also been reported by Ottenwalder (pers. comm.) in the mangrove swamps of the Rio Massacre, Dominican Republic. However, in this situation the charcoal areas are raised mounds and represent the most elevated, well drained sites available.

In Etang Saumatre, nine physical parameters were measured at crocodile nest sites (Table 1). A stepwise discriminant analysis was performed among 15 null sites (chosen randomly, distance to lake fixed at 25 m), and 15 nest sites using 7 nest parameters (height above lake, soil moisture, percent shrub/tree canopy coverage, percent grass coverage, percent leaf litter coverage, height of woody vegetation, and distance to nearest tree). The analysis indicated that only soil moisture was important in distinguishing nest sites (mean 6.6% water by weight), from null sites (20.3% water; p

$< 0.01$ ). Percent shrub coverage was significantly higher at null sites ( $p < 0.05$ ), but was correlated with soil moisture.

Nests in Etang Saumatre are hole-type nests with no mounding notable. The nest excavation is angled diagonally back into the soil. Mean perpendicular depth to eggs was: clutch top 24.1 cm (SD 4.7 cm,  $N = 13$ ), and clutch bottom 37.9 cm (SD 4.3 cm,  $N = 12$ ). Mean horizontal width of the egg chamber is 32.4 cm (SD 4.3 cm,  $N = 12$ ). Because of a lower density of nesting females colonial nesting was not evident as it is in nearby Lago Enriquillo. The greatest number of nests found on any one beach was three.

**Other Areas** - Aspects of the nesting biology have also been noted in Jamaica (L. Garrick, pers. comm.), Cuba (Varona 1980), Mexico (Casas and Guzman 1970, Alvarez del Toro 1974), Panama (Breder 1946, Dugan et al. 1981), Honduras (Schmidt 1924, Klein 1977), Colombia, Venezuela and Ecuador (Medem 1981, 1983). These accounts support the generalization that *C. acutus* prefers to nest in sandy beaches, but is very adaptable and will nest in marginal areas such as gravel (Schmidt 1924, Alvarez del Toro 1974), wet, mucky soils (Varona 1980), wood chips (L. Garrick, pers. comm.), or even make small, mound-type nests from vegetative matter (Alvarez del Toro 1974, Medem 1981, 1983).

Alvarez del Toro (1974) described a typical *C. acutus* nest in Chiapas, Mexico as being located in a sandy beach, beyond the bare sand fringe and usually near a shrub thicket. In Jamaica, Garrick (pers. comm.) noted that *C. acutus* nests were mounded, and found in sandy beaches located adjacent to mangrove swamps that provide habitat for the female. Along rivers, nests are positioned high up on banks in areas cleared by the female.

In Honduras, Schmidt (1924) found a crocodile nest in a gravel beach on an island in Lago Ticamaya, and Klein (1977) mentioned nests being located in sandy river bars. In Panama, *C. acutus* nests have been found in a clearing on a small forested island adjacent to Barro Colorado Island (Dugan et al. 1981), in a small lighthouse clearing in a forested mainland peninsula also near BCI (Rodda 1984), and in open, sandy river bars in the Rio Chucunague drainage (Breder 1946).

Table 1: Mean values of nine parameters for *C. acutus* nests in Etang Saumatre, Haiti. From Thorbjarnarson 1988.

Nest Parameter	Mean (SD)	Range	N
Distance to Lake (m)	27.5 (11.8)	7-47	31
Height above Lake (m)	1.2 (0.5)	0.6-2.1	31
Soil pH	6.2 (1.6)	5.2-7.1	15
Soil Moisture (% water)	6.6 (3.1)	3.4-14.3	12
Shrub/Tree Coverage (%)	30.1 (14.5)	10-60	29
Grass Coverage (%)	5.9 (5.8)	0-20	29
Leaf Litter Coverage (%)	18.4 (8.6)	10-30	29
Height of Vegetation (m)	3.4 (0.6)	2.0-4.5	27
Distance to Nearest Tree (m)	2.1 (1.1)	0.5-5.0	27

### Nestling Behavior and Parental Care

Although Duval (1977) reports an interval of 84-107 days between observed copulation attempts and nesting in a captive situation, most reports from other captive and wild populations indicate that oviposition follows courtship activity by 1-2 months (Alvarez del Toro 1974, Garrick and Lang 1977, Varona 1980, Inchaustegui et al. 1980). Gravid females will begin visiting potential nest sites up to 4-6 weeks prior to laying (Ogden 1978, Thorbjarnarson 1984, 1988). These early visits are usually brief (less than one hour) and of irregular occurrence and provide the females with the opportunity to make shallow exploratory excavations. The nocturnal visits increase with frequency as the time for oviposition approaches, and egg laying usually follows several nights of more lengthy visits and increased digging activity (Ogden 1978). In Florida, digging is restricted to primary or secondary nest sites, usually found within 35 m of one another (Ogden 1978), but in Etang Saumatre, where more potential nest sites are available, excavations are frequently scattered among several sites (Thorbjarnarson 1984, 1988). Gravid females in both Lago Enriqueillo and Etang Saumatre were noted to infrequently drop their eggs prematurely while walking along the beach searching for nest sites (both lakes), or even in the water (Lago Enriqueillo). The etiology of this premature oviposition is unclear.

Nesting sites in Etang Saumatre are reused regularly. Forty-six percent of the nests located in 1984 were used the previous year, 15 % were used previous to 1983, and 39% were located in apparently new sites (Thorbjarnarson 1984, 1988). Similar to the situation in adjacent Lago Enriqueillo, a rising lake level since 1980 has forced some crocodiles to seek new nesting sites.

Female *C. acutus* in Lago Enriqueillo emerge from the water to nest shortly after dark (pers. obs.). One female was discovered in the final stages of egg laying at 2315h on 12 February 1982. Detailed behavioral observations of oviposition by a captive female were made in Isla Salamanca National Park, Colombia by Pachon, Ramirez and Moreno (cited in Medem 1981). Using her hind legs the female dug a nest cavity on 15 March, and the following night began excavating another hole from 0015h to 0400h. Once the digging was completed, the female remained motionless atop the nest until egg laying began at 0525h. Oviposition was accomplished with the female positioned with her hind legs over the edge of the hole, head slightly elevated, pectoral region pressed against the ground, and abdomen arched upwards. The first abdominal contractions lasted 5 minutes. During the next 21 minutes, 15 eggs were laid, the time interval between eggs diminishing from 5 min. 20 sec., to 5 seconds. Eighteen minutes after the last egg was deposited, the female began covering the eggs with soil and leaf litter, gradually shaping a mound 80 cm in diameter, and 10 cm high. This was apparently the females' (2.36 m TL) first nesting attempt and this may partially account for the small clutch size (Medem 1981).

Female *C. acutus* will remain in the vicinity of the nest during incubation (Alvarez del Toro 1974, Ogden 1978, Thorbjarnarson 1984, 1988). In some areas females are reported to actively protect nests, excluding other crocodiles or potential nest predators from the nest locale: Mexico (Alvarez del Toro 1974), Cuba (Varona 1980), Panama (Dugan et al. 1981); although this behavior is individually variable. In other areas females provide little or no nest protection: Florida (Ogden 1978) and Haiti (pers. obs.). There is no evidence that males play any role in nest defense in the wild.

Dugan et al. (1981) observed an adult female *C. acutus* protecting her nest by chasing away ovipositing iguanas. Iguanas would dig up crocodile eggs during the construction of nest burrows, and on 12 occasions the crocodile seized iguanas near her nest. The authors concluded that this behavior was a mixture of nest defense and predation.

Towards the end of the incubation period, female crocodiles will begin to make nocturnal visits to their nests, laying their heads atop the nest to listen for the release calls of the hatchlings (Ogden and Singletary 1973). Triggered by the grunts of the young, the female opens the nest using her front feet. Photographs of a wild crocodile opening a nest in Florida suggest that the female will help the hatchlings emerge from their eggs by gently squeezing the eggs between the tongue and palate (Ogden and Singletary 1973). Following hatching, the young are gathered in small groups into the female's mouth, where they are carried in the depressed gular pouch, and ferried to the water's edge. The female photographed in Florida (using an automatic device) carried a total of 34 hatchlings in 12 trips between the nest and the water (Ogden and Singletary 1973). Similar nest opening behavior has been observed or inferred for *C. acutus* throughout the species range (Alvarez del Toro 1974, Inchaustegui et al. 1980, Medem 1981, Thorbjarnarson 1984, 1988).

In some instances hatching is not simultaneous for all eggs and females may leave underdeveloped eggs buried in the nest, returning at a later date to open them (Ottenswalder, pers. comm.; pers. obs.). Mazzotti (1983) also noted that in Florida females may leave fully developed, vocalizing eggs in the nest. In one case a female hatched a nest during three visits over a four day period. In Lago Enriquillo, female crocodiles may remain on land in shaded areas with their hatchlings, or leave them under vegetation during the day (Inchaustegui et al. 1980). This behavior may have been related to the hypersaline lake water and resultant osmotic problems for hatchlings (pers. obs.; see Temperature and Salinity Relations).

The degree of maternal care for recently hatched *C. acutus* appears to vary considerably throughout the species range. The results of most studies suggest that the formation of distinct pods of young and maternal care of neonates is minimal in this species (Mazzotti 1983, Thorbjarnarson 1984, 1988; Rodda 1984). However, under certain conditions the formation of pods may be influenced by the habitat into which the young are born. In areas exposed to wave action or in hypersaline water the dispersal of hatchlings is almost immediate (see Habitat Selection, Activity and Movements) and there is virtually no group cohesion among the hatchlings. Nevertheless, in some areas adult crocodiles have been seen in the vicinity of loosely grouped hatchling assemblages (Mazzotti 1983, Thorbjarnarson 1984). Alvarez del Toro (1974) reported that in Mexico, hatchlings would remain grouped together near the female for several weeks following hatching. However, even in suitable juvenile habitats in south Florida and Haiti, pod formation is also ephemeral (Gaby et al. 1985, Thorbjarnarson 1984, 1988; P. Moler, pers. comm.). Campbell (1973) noted that young *C. acutus* are relatively non-vocal, and this observation has been supported in the wild by observations made by Mazzotti (1983). In as much as hatchling vocalizations serve to maintain group integrity, and/or communication with an adult, the non-vocal nature of hatchling *C. acutus* is another indication of lack of social cohesion in the young.

The seemingly unremarkable amount of maternal protection for hatchlings *C. acutus* may be a consistent character of the species, or it may reflect a recent change in behavior associated with human-related disturbance. Rand and Troyer (1980) have suggested that in Gatun Lake, Panama, past hunting has selectively eliminated adults that protected their young. Furthermore, as crocodilians are long lived animals with recognized learning ability (Bustard 1968, Webb and Messel 1979), a diminution in parental care may also be a learned response based on past experience with humans. Indeed, some historical accounts suggest that a higher degree of parental care may have existed in the past (e.g. Esquemeling 1678).

### Timing of Nesting

The American crocodile, following the typical pattern for hole-nesting species, nests during the dry season, with hatching occurring near the beginning of the rainy season. According to the generally accepted hypothesis first presented by Cott (1961) for *C. niloticus*, oviposition during the dry season reduces the probability of nest flooding, and results in the young emerging during a time of increasing habitat and food availability. However, in *C. acutus* there exists a considerable amount of variation in the timing of egg-laying in relation to rainfall pattern. Nests in some regions hatch prior to the beginning of the rainy season, and in others during the early to mid-rainy season. A summary of *C. acutus* nest timing by geographic area is presented in Table 2. A more detailed analysis awaits further information on local nesting patterns and rainfall/water level schedules.

In Mexico, and along the Caribbean coast south to Costa Rica, *C. acutus* oviposits from March to May, the eggs hatching during the first half of the rainy season (June-August; Schmidt 1924, Carr 1953, Casas and Guzman 1970, Alvarez del Toro 1974, A. Carr, L. Ogren, pers. comm.). In Panama, and the Pacific coast of Costa Rica and Colombia, crocodiles tend to hatch somewhat earlier, even though the rainfall patterns are similar (Breder 1946, Dugan et al. 1980, Rodda 1984, W. Timmerman, pers. comm.). In these areas crocodiles hatch prior to the initiation of the rains. In the extremely wet Choco region of Pacific Colombia where little seasonal variation in rainfall exists, crocodiles apparently follow the same timing of nesting (Medem 1981).

Table 2: Timing of *C. acutus* nesting in relation to geographic area and rainfall pattern. See text for references.

Region	Timing of Nesting		
	Oviposition	Hatching	Rainy Season
Mexico:			
Pacific coast	March-May	June-Aug	June-Oct
Atlantic coast			
south to Costa Rica	March-May	June-Aug	May-Dec
Pacific coast			
Costa Rica-Colombia	Jan-Feb	April-May	May-Nov
Ecuador, Peru	Oct-Dec	Jan-March	Jan-April
Caribbean:			
Colombia	March	June	May-Nov
Venezuela	April-May	July-Aug	May-Nov
Caribbean Islands:			
Jamaica	March-April	June-July	May-Oct
Cuba	March	June	May-Oct
Hispaniola	Jan-April	April-July	April-Oct
Florida	April-May	July-Aug	May-Oct



South of Colombia rainfall patterns change drastically, becoming much dryer with a rainy season extending from January to April. The crocodiles in this region adapt accordingly and oviposit from October to December, suggesting that the eggs would hatch during the first half of the wet season (Medem 1981, Fiallos et al. ms).

Data are scanty for crocodile nesting along the Caribbean coast of Colombia and Venezuela, which has a typical Caribbean weather pattern (rains May-Oct/Nov). In Colombia, Medem (1981) reports that *C. acutus* nests hatch in April-May, but it is not clear to which part of the country he is referring. The only site specific datum is from Isla Salamanca where a captive female laid on 16 March (Medem 1981). Information from Venezuela suggests that in most coastal areas *C. acutus* hatch in April (Rio Yaracuy) or May (Lago Maracaibo region) (A.E. Seijas, pers. comm.), but in the arid region of Falcon state, the nests of one crocodile population near Chichiriviche are known to hatch in late August or early September. One nest at the Jatira Reservoir was found in the process of hatching on 28 August 1987 (A.E. Seijas, pers. comm.). However, in this arid region the peak rainfall is in November-December. These data would suggest that nesting in Venezuela follows the general Caribbean pattern, with the exception of the Falcon region where nesting is delayed, perhaps due to arid conditions and a delayed peak in rainfall.

The islands of Cuba, Jamaica, and Hispaniola share the typical Caribbean climatic pattern, and here *C. acutus* have a nesting schedule comparable to other Caribbean areas. Oviposition takes place primarily during March and April, and nests hatch during June-July (Inchaustegui et al. 1980, Varona 1980, L. Garrick, pers. comm.), i.e. during the first half of the rainy season. The notable exception to this is in Etang Saumatre, Haiti, where nests are constructed in late January and early February, and hatch late April-early May at the very beginning of the rainy season (Thorbjarnarson 1984, 1988).

In southern Florida, a similar seasonal rainfall pattern exists, but crocodiles are delayed by low winter and spring temperatures and do not nest until April-May, with the young hatching July-August (Ogden 1978, Kushlan and Mazzotti 1986). Captive crocodiles in southern Florida that originated from Jamaica follow the typical Florida nesting schedule (ovipositing April-May; Garrick and Lang 1977), indicating that at least with respect to temperature limitations timing of nesting is environmentally malleable.

### Incubation and Nest Environment

Reported incubation periods for *C. acutus* nests range from 80 to 90 days (Table 3), although in one artificially incubated nest it was 107 days (Duval 1977). The length of incubation is temperature dependent, but under natural conditions nest temperatures appear not to fluctuate greatly. Over a 24 day period, Lutz and Dunbar-Cooper (1984) found a mean daily temperature variation of 1.4° C in a nest in southern Florida. During a 30 hour interval, the maximum temperature fluctuation among 6 nests in Haiti was 0.9° C (top of egg clutch), and 0.6° C (bottom; Thorbjarnarson 1984, 1988). Due to the thermal buffering effects of the soil, in both studies maximum nest temperatures were reached at night.

Among seven nests in Florida, Lutz and Dunbar-Cooper (1984) noted a trend of increasing nest temperature with time. Mean nest temperature increased from 30.9° C in late May-early June, to 34.3° C in early August. The rise in mean nest temperature was correlated with an increasing trend in mean air temperature.

The study of Lutz and Dunbar-Cooper (1984) also examined gas exchange in *C. acutus* nests. In southern Florida crocodiles nest in two distinct soil types, and the physical properties of the soil play an important role in determining gas exchange characteristics of the nest. Marl nests have a much finer soil particle size (primarily less than 246 microns), a higher mean water content (29.2% by weight), and a lower oxygen diffusion ( $1.96 \times 10^{-4}$  cm/sec at 15% water content). Sand/shell nests have a larger particle size (0.5-3.3 mm), a lower mean water content (10.3%), and a higher oxygen diffusion ( $1.51 \times 10^{-4}$  cm/sec at 16% water). Although the results were more clear-cut in the sand/shell soil, nests in both soil types demonstrated an increase in  $PCO_2$ , and a decrease in  $PO_2$  during incubation. The lower potential for gas diffusion resulted in lower  $PO_2$  and higher  $PCO_2$  levels in the marl nests.

Lutz and Dunbar-Cooper (1984) also noted a 15% decrease in egg mass (water loss) during incubation. Somewhat similar results were reported by Moore (1953) who suggested that under normal conditions a clutch of crocodile eggs loses 8.6% of its mass by day 70 of incubation.

Table 3. Reported egg incubation periods in *C. acutus*. Data from Alvarez del Toro (1974); Varona (1980); Inc and Kushlan and Mazzotti (1986).

Location	Incubation Period (days)
Cuba	80-90
Florida	85
Mexico	80
Dominican Republic	84

Table 4: Reported values of clutch size for *C. acutus* N is the number of nests examined. Data from Kushlan and (1986); Lutz and Dunbar-Cooper (1984); Ogden (1978); Medem (1981); Breder (1946); Schmidt (1924); Inchausteg (1980); Thorbjarnarson (1988); and Alvarez del Toro (1971).

Location	Clutch Size	N
Florida	38.0	46
	39.1	8
	44	20
Colombia	40-60	-
Panama	46	1
Honduras	22	1
Dominican Republic	23.8	80
Haiti	22.5	14
Mexico	30-60	-

### Clutch Size, Fertility and Egg Mortality

Reported values for clutch size in *C. acutus* (Table 4) range from lows of 22 (Schmidt 1924) and 22.5 (Thorbjarnarson 1984, 1988), to high figures of 81 (Ogden 1978) and 105 (Medem 1981). Extremely large clutches of eggs may be the result of more than one female ovipositing at the same nest site (Kushlan and Mazzotti 1986). This interpretation is supported by evidence from Florida and Haiti where two clutches known to have been laid by different females were laid in the same nest hole (Kushlan and Mazzotti 1986, Thorbjarnarson 1984, 1988).

Clutch mass from one nest in Florida was 5.2 kg (Lutz and Dunbar-Cooper 1984). Mean clutch mass from 14 nests in Haiti was 2.18 kg, and averaged 4.4% of adult female body mass (Thorbjarnarson 1984, 1988). Reported values of individual egg masses (early in incubation) are 91.3 g (Lutz and Dunbar-Cooper 1984), 97.0 g (Thorbjarnarson 1984, 1988) and 103.4 g (Duval 1977).

Mean egg dimensions are more often reported in the literature than egg mass and can be used to better show the variation in egg size. However, there is not enough evidence to determine if egg size varies with female size, or between populations. The largest reported mean egg dimensions are from Panama (52.0 x 79.0 mm, N = 46; Breder 1946), and Chiapas, Mexico (54 x 80 mm; Alvarez del Toro 1974). Smaller eggs have been reported from Haiti: 45.4 x 76.5 mm (Thorbjarnarson 1984, 1988), Cuba: 42-47 x 73-81 mm (Barbour and Ramsden 1919), and Honduras: 42-42.5 x 70-76 mm (Schmidt 1924), 46.6 x 75.4 mm (Thorbjarnarson and Vliet, unpubl. data). Large eggs containing two embryos have been reported from Cuba (Barbour and Ramsden 1919), where one nest contained two twin eggs (100 x 50 mm). The embryos were apparently well formed and healthy. A similar twin egg has been reported by Blohm (1948) for *C. intermedius* in Venezuela.

Egg fertility levels (determined by egg banding) have been reported from nests in south Florida and Haiti. Unbanded eggs could be the result of infertility, or early embryonic failure. In Florida, Kushlan and Mazzotti (1986) reported 90% of 314 eggs examined were banded. The range of values for individual nests was 46-100%, with only one nest having fewer than 84% banded eggs. In Haiti a similar value of 9.9% unbanded eggs was determined from seven clutches (range 70.6-100% banded) (Thorbjarnarson 1984, 1988).

Other than egg fertility rates, nest hatching success is influenced by three environmental factors: flooding, desiccation, and predation. An increase in soil moisture reduces soil oxygen diffusion capacity (Lutz and Dunbar-Cooper 1984), as well as that of the eggshell (Ferguson 1985). Although *C. acutus* nests during the dry season, in areas where nests are located in low-lying areas, flooding may be an important factor in egg mortality. In the Florida Bay region, flooding drowned two of 17 (11.8%) of the nests studied by Kushlan and Mazzotti (1986), and partially destroyed two other nests. Flooding was subterranean and hence was not recognizable unless the nests were excavated. It is perhaps significant that four of nine "hole" nests experienced flooding mortality, whereas none of the eight "mound" nests flooded.

In areas where female *C. acutus* have access to higher, well drained nesting sites, flooding mortality is usually minimal. On Key Largo and at Turkey Point in Florida, females nest in raised spoil banks and the nests experience little or no flooding mortality (P. Moler, pers. comm.). In Etang Saumatre, Haiti, only one of 15 (16.7%) nests examined was lost to flooding and this was due to excessive surface runoff from a nearby arroyo.

Egg desiccation has been reported to cause egg mortality in Florida. Mazzotti (1983), found 27 eggs from four different nests to have air sacs, which according to Ferguson and Joanen (1983) are indicative of excessive egg water loss.

Although predation is usually considered to be the most important factor governing nest success in *C. acutus*, few quantitative estimates of predation rates are available. Kushlan and Mazzotti (1986) reported that during 1971-1982, 14% of 99 clutches in Florida were predated. Raccoons (*Procyon lotor*) were the only nest predators observed. Although Dugan et al. (1981) reported that nesting iguanas would dig up crocodile eggs, all other reported nest predators are mammals: *Procyon lotor*, *P. cancrivora*, *Nasua narica*, *Dusicyon thous*, *Conepatus* sp., *Canis latrans*, *Mephitis macroura*, and *Spilogale augustifrons* (Alvarez del Toro 1974, Medem 1981, Camacho 1983, Kushlan and Mazzotti 1986). On Hispaniola, an island with a depauperate mammalian fauna (both natural and man induced), few natural nest predators are found and nests are rarely depredated other than by man. A 0% natural predation rate was found among nests in Etang Saumatre (Thorbjarnarson 1984, 1988).

### DIET

The diet of *C. acutus* follows the typical ontogenetic shift described for other species of crocodilians (Cott 1961, Chabreck 1971, Taylor 1979, Webb et al. 1982). Hatchlings and juvenile crocodiles feed primarily on aquatic and terrestrial invertebrates (Alvarez del Toro 1974, Medem 1981, Thorbjarnarson 1984, 1988) or small fish (Schmidt 1924, Alvarez del Toro 1974). With increasing size, crocodiles feed increasingly on larger vertebrate prey with fish being the dominant food item (Alvarez del Toro 1974, Medem 1981, Thorbjarnarson 1984, 1988).

Among hatchling and juvenile *C. acutus* the most commonly reported prey are aquatic insects (Dytiscidae, Hydrophilidae, Belostomatidae) and their larvae (Libellulidae), and snails (Alvarez del Toro 1974, Medem 1981). In Etang Saumatre, Haiti (Thorbjarnarson 1984, 1988), the dominant prey items flushed from the stomachs of hatchling crocodiles (less than 0.5 m TL; N = 8) in terms of biomass were fiddler crabs (*Uca bergersii*, 33.5% of prey mass), Hymenoptera (25.0%), and amphipods (25.0%). Among juveniles (0.5-0.9 m TL; N = 28), the principal prey were *Uca* (62.3% by mass), odonate larvae (10.3%), and Coleoptera (8.9%). Other frequently encountered prey were: Arachnida, Lepidoptera, Scolopendera, Hymenoptera, and Gerridae. Only 9.3% of the crocodiles under 0.9 m TL contained fish (N = 64), principally small poeciliids (*Limia* sp., *Gambusia hispaniole*). Other than fish the only vertebrate remains found in juveniles' stomachs were one turtle (*Pseudemys decorata*), and unidentified bird remains.

Alvarez del Toro (1974) reported that in Mexico, subadult crocodiles feed on insects (*Belostoma*, *Disticus*, *Hydrophilus*), fish, frogs, small turtles, birds, and small mammals. Two specific crocodiles mentioned (1.1 m, 1.2 m TL) had catfish (*Mollinesia*), a dove (*Zenaidura macroura*) and a marsupial (*Philander laniger*) in their stomachs. Subadult crocodiles in Etang Saumatre (0.9-1.8 m TL; N = 5) fed principally on aquatic invertebrates including odonate larvae (35.3% by mass), *Uca* (32.6%), and spiders (14.5%), but also took an increasing number of birds (17.7%; Thorbjarnarson 1984, 1988).

Adult crocodiles, while primarily piscivorous, feed on a variety of prey. Schmidt (1924) reported that one 3 m crocodile in Honduras contained a turtle shell, remains of a 1.2-1.5 m crocodile, and peccary hoofs. Besides two marine catfish, Medem (1981) found fragments of *Pomacea* snails in the stomach of a 3.17 m crocodile in Colombia. Medem (1981) also mentions observing a crocodile eat a turtle (*Podocnemis lewyani*). Alvarez del Toro (1974) comments on the

formerly widespread problem of crocodiles eating domestic livestock in Mexico. Based on a small sample of crocodiles in Etang Saumatre, fish (primarily Cichlidae) and birds were the most common prey items. Adults were also seen to eat turtles and domestic animals (dogs, goats; Thorbjarnarson 1984, 1988).

Observations on feeding behavior in Etang Saumatre indicate that crocodiles use both active and passive modes of foraging. Juvenile crocodiles were frequently seen at night along shallow water shorelines making rapid sideswipes at surface disturbances. This method of foraging probably accounted for the high percentage of non-aquatic invertebrates in their diet. The presence of odonate larvae in crocodile stomachs suggests young crocodiles may also actively forage amongst submerged vegetation and/or bottom sediments (Thorbjarnarson 1984, 1988).

Adult crocodiles in Etang Saumatre were also frequently observed in shallow water areas where concentrations of cichlids (*Cichlasoma haitiensis*, *Tilapia mossambica*) were found. Crocodiles were observed to remain stationary on the bottom, occasionally making sideswipes at passing fish. Crocodiles also concentrated under a heron rookery during the birds nesting period, ostensibly to catch young that fall out of the nest (Thorbjarnarson 1984, 1988). Medem (1981) mentions an unconfirmed fishing technique used by crocodiles in Colombia. Floating at the surface with the mouth partially open, the crocodile regurgitates small quantities of partially digested food. The food attracts fish to the vicinity of the crocodile's mouth where they are caught using rapid sideswipes.

## POPULATION ECOLOGY

**Population Density, Biomass, and Size-Class Structure** - Published values for crocodilian population density rarely reflect true steady-state population levels, but tend rather to indicate the intensity of past or present human exploitation of crocodiles. Furthermore, differences in census methodology, and habitat type frequently make interpopulation comparisons difficult. Nevertheless, density values can be informative, and published figures are tabulated for crocodile populations in southern Florida, Honduras, Venezuela, and Haiti (Table 5).

Density values from Florida are expressed in units of time and so are not directly comparable to the other figures which are calculated on the basis of crocodiles per kilometer of shoreline. Nevertheless, the data for Florida indicate a very low density crocodile population.

The density values for Honduras (0.51/km) and Venezuela (1.57/km) are principally from coastal lagoons and mixed coastal habitats respectively, and represent populations severely depleted by hunting.

The highest reported densities of *C. acutus* come from lacustrine habitats. Schmidt (1924) reported an extremely high crocodile density in Lago Ticamaya, Honduras. Etang Saumatre, in Haiti, had an overall crocodile density of 6.3/km (including all crocodile size-classes), even though the population has been somewhat depleted by hunting and other human-related mortality. Excluding the exposed, rocky shorelines avoided by crocodiles, the ecological density in Etang Saumatre was 9.6/km. The crude and ecological densities for crocodiles over 1.8 m total length were 1.0/km and 1.5/km respectively. Within the lake crocodile density varied between habitats. Among the major habitat subdivisions (with more than 1 km shoreline) mean densities ranged from a high of 14.5/km (*Conocarpus* fringe) to 0.2/km for the rocky, steep shore gradient areas (Thorbjarnarson 1984, 1988).

Table 5: Reported densities of wild populations of *C. acutus*. Sources: Mazzotti (1983); Klein (1977); Seijas (1986 Thorbjarnarson (1988).

Location	Survey Method	Mean (Range)	Habitat Type
Florida, Everglades N.P.	boat,night	0.21/hr (0.13-0.40)	coastal mangrove
	helicopter (day)	0.61/hr (0.30-1.15)	
	fixed wing (day)	0.63/hr (0.0-0.97)	
Eastern Honduras	boat,night	0.51/km (0.0-2.4)	river
Venezuela	boat,night (day)	1.57/km (0.08-3.67)	river, coastal mangrove
Haiti, Etang Saumatre	boat,night	6.3/km (0.16-21.25)	lake

A population estimate was made for Lago Enriquillo, Dominican Republic, based on nesting levels reported by Inchaustegui and Ottenwalder (pers. comm.), and nesting effort information and population demographic data from adjacent Etang Saumatre (Thorbjarnarson 1984, 1988). The total adult crocodile population was calculated to be 385-525 (based on 100-150 nests annually), or 3.0-4.0 adults/km of shore (crude density). Assuming a similar population structure as in Etang Saumatre, overall density (including all size-classes) is estimated to be 18.9-25.7/km (Thorbjarnarson 1984, 1988). Even using the conservative lower figure, Lago Enriquillo would have the highest density for any *C. acutus* population known, and among the highest reported for any species of crocodile.

The most complete data set for *C. acutus* density in a variety of coastal habitats is that of Seijas (1986b) from Venezuela. Among 6 coastal rivers, the highest mean density of crocodiles was 2.2/km (Rio Yaracuy, maximum subsection density 3.5/km, section B). Of those areas that had crocodiles, the lowest riverine density was 1.07/km (Rio Neveri). In mangrove swamp habitats, crocodile densities ranged from 3.67/km (Turiamo) to 0.08/km (Cuare). The only density value for a freshwater reservoir was 1.02/km.

Crocodile biomass values have been calculated only for lake habitats in Hispaniola (Thorbjarnarson 1984, 1988). In Etang Saumatre, crude biomass was estimated to be 66.6 kg/km shoreline. Excluding habitats avoided by crocodiles the ecological biomass figure was 101.7

kg/km. Based on the above mentioned population estimate for Lago Enriquillo, Dominican Republic, crude biomass in this lake was calculated to be 188.4-256.1 kg/km.

The size-class distribution of three *C. acutus* populations have been reported: Florida (Gaby et al. 1985, Mazzotti 1983), eastern Honduras (Klein 1977), and Etang Saumatre, Haiti (Thorbjarnarson 1984, 1988; Table 6). Whereas the values for Florida and Haiti represent data obtained during nocturnal boat surveys, the Honduras figures are from commercially harvested animals and hence may be somewhat biased towards larger individuals, and do not include crocodiles less than one meter total length.

A large percentage of the crocodiles sighted in Everglades National Park (46.9%) were subadults (1.5-2.0 m TL).

Although the size-class limits vary somewhat, a smaller percentage of the population at Turkey Point, Florida (18.7%, 1.21-1.83 m TL, Gaby et al. 1981) and Etang Saumatre (10.7%, 0.9-1.8 m TL, Thorbjarnarson 1984, 1988) were in the subadult size range. In both these two populations, a larger percentage of small crocodiles was found: 56.3% Turkey Point, 74.3% Etang Saumatre (less than 1.21 m and 0.9 m TL respectively).

Among these three crocodile populations the percent composition of adults was similar: Everglades 24.5%, Turkey Point 25.0%, Etang Saumatre 15.7%. As the Etang Saumatre figures include hatchling crocodiles, a comparable figure to the Florida values for percentage of adults would be somewhat higher. Seijas (1986b) estimated that only 35 of 293 (11.9%) of the crocodiles (including hatchlings) seen in Venezuela were adults. An even smaller percentage of adults (3.7%) was noted by Garrick (pers. comm.) from a sample of 268 crocodiles captured in Jamaica.

**Sex Ratio** - Figures for *C. acutus* population sex ratios are available for Florida, Etang Saumatre, Haiti, and eastern Honduras. Among adult and subadult crocodiles captured in the Everglades National Park, Mazzotti (1983) found a female biased sex ratio of 2.4:1 ( $N = 17$ ). At the nearby Turkey Point site, a slightly male biased ratio (0.75:1,  $N = 7$ ) was noted (Gaby et al. 1985). Together these data suggest an overall 2:1 female biased sex ratio (Kushlan and Mazzotti 1986).

In Etang Saumatre, the sex ratio of 28 adult and subadult crocodiles captured was 0.75:1. Including juveniles, the overall sex ratio was still male biased 0.69:1 ( $N = 54$ ; Thorbjarnarson 1984, 1988) although the difference was not found to be significant (binomial test  $Z = 1.22$ ).

Based on a sample of 32 *C. acutus* commercially harvested in Honduras, Klein (1977) reported 14 females and 18 males (0.78:1). A larger sample of 92 wild captured crocodiles over 1.83 m TL was sexed at the Hacienda El Tumbador crocodile farm in Honduras (King, Thorbjarnarson and Vliet, unpubl. data). The majority of crocodiles in this sample came from the Rio Aguan and were composed of 40.2% males, 59.7% females. Although strongly female biased, this difference was not significantly different.

**Growth Rates** - Published values of growth rates in *C. acutus* are mostly from the first year or two of life (Table 7) and indicate that during this period animals can grow extremely rapidly. Over the first several months following hatching, growth rates are very high, and in some instances (e.g. Florida) may exceed 0.3 cm TL/day, although the more normal value for this time are in the 0.1-0.2 cm TL/day range (P. Moler, pers. comm.).

In most populations the initial rapid burst of growth slows considerably in older hatchlings and juveniles (Haiti and Panama 0.05-0.10 cm TL/day), but in Florida crocodiles up to 621 days old have been reported with mean growth rates of up to 0.134 cm TL/day (Gaby et al. 1981).

Table 6: Size-class distributions of four *C. acutus* populations. SC=Size class, PP=Percent of population. References in text.

LOCATION							
Florida				Honduras		Haiti	
Everglades NP		Turkey Pt					
SC	PP	SC	PP	SC	PP	SC	PP
0.50	6.1					0.3- 0.9	74.3
0.75	12.2	0.60-					
1.00	8.2	1.20	56.3	1.0-			
1.25	2.0			1.5	20.3	0.9- 1.8	10.0
1.50	20.4	1.21-					
1.75	14.3	1.83	18.7	1.5-			
2.00	12.2			2.0	31.3		
2.25	18.4					1.8- 2.7	10.7
2.50	2.0	>1.83	25.0	2.0-			
2.75	4.1			2.5	26.6		
				2.5-		>2.7	5.0
				3.0	14.1		
				3.0-			
				3.5	6.2		
				>3.5	1.6		
Sample size	49		16		64		447



Table 7: Reported growth rates of free-living juvenile *C. acutus*. Sources: Thorbjarnarson (1988); P. Moler (pers. comm.); Gaby et al. (1981), Mazzotti (1983), Rodda (1984).

Location	Size or Age Class	Mean Growth Rate (cm TL/day)	N
Haiti	0-3 months	0.111-0.135	13
	0.3-0.9 m	0.058	10
	0.9-1.8 m	0.090	2
Florida	0-81 days	0.117-0.214	85
	0-124 days	0.158	9
	0-621 days	0.134	5
	0-17 months	0.112	-
Panama	0-10 months	0.088-0.105	-
	0-22 months	0.052-0.070	-

These latter data, from Turkey Point, may be considered somewhat anomalous in that the crocodiles are inhabiting cooling canals with elevated temperatures. However, comparable growth rates in *C. acutus* have been noted in other parts of Florida (Lang 1975b, P. Moler, pers. comm.). The rapid growth of Florida crocodiles is all the more remarkable as due to low winter temperatures, crocodiles do not grow during 4 months of the year (December-March, P. Moler, pers. comm.).

Growth data from crocodiles more than two years old are scanty. Two crocodiles in the 0.9-1.8 m size class in Etang Saumatre grew at an average rate of 0.09 cm TL/day (Thorbjarnarson 1984, 1988). Garrick (pers. comm.) recaptured a 6 year old crocodile (tagged when 58.7 cm long) that grew at an average rate of 0.05 cm TL/day over the interval. A six year 11 month old crocodile from Key Largo was 2.03 m TL (P. Moler, pers. comm.). This indicates an average growth rate of approximately 0.08 cm TL/day.

**Mortality** - Mortality in post-hatching *C. acutus* is highest during the first few years of life when the crocodiles are small and vulnerable to a host of predators, or environmental problems (e.g salt balance, low temperature). Quantitative estimates of survivorship of hatchling crocodiles in southern Florida indicate that mortality rates vary considerably from place to place. Gaby et al (1985) noted that at Turkey Point, approximately 11% of captured hatchlings survived at least one year. Ogden (1978) and Lang (1975b) radio tracked a group of 17 hatchlings for periods of up to 6 weeks. Ogden (1978) reported that at least one half of this sample died during the course of the study. On Key Largo, based on recaptures and resightings of marked individuals, hatchling survivorship can be much higher and in some years > 50% of the hatchlings may survive their first year (P. Moler, pers. comm.). Based on recaptures from one cohort, an estimate of minimal survivorship to 4 years is 25%. However, hatchling and juvenile mortality vary considerably from year to year, and these values may represent near maximum survivorship values (P. Moler, pers. comm.).

Potential predators of young crocodiles are numerous and include large wading birds (*Ardea herodias*, *Nycticorax nycticorax*, *Casmerodius albus*), raptors (*Buteo magnirostris*, *Herpetotheres cachinnans*, *Heterocnus mexicanus*) and mammals (*Procyon lotor*, *Felis pardalis*, *F. weidii*, *F. jagourandi*, *Canis latrans*; Alvarez del Toro 1974, Inchaustegui et al. 1980, Medem 1981, Camacho 1983, Thorbjarnarson 1984, 1988). Crabs (*Callinectes* sp., *Cardisoma guanhumi*) have also been observed depredating, or implicated in predation on hatchling crocodiles in Florida (Lang 1975b, Ogden 1978). Several species of predatory fishes have been reported to eat small crocodiles (*Pseudoplatystoma fasciatus* (Medem 1981), *Lepisosteus tropicus* (Camacho 1983)). Mazzotti (1983) mentions lemon sharks (*Negaprion brevirostris*), snook (*Centropomus undecimalis*) and tarpon (*Megalops atlantica*) as potential natural predators of *C. acutus* in Florida coastal waters.

With increasing crocodile size the predators of *C. acutus* diminish rapidly in number. Other than man, large crocodiles have few potential predators. Alvarez del Toro (1974) reports that jaguar (*Panthera onca*) will kill subadult crocodiles and mentions one instance of an adult jaguar killing a 2.5 m *C. acutus*. Medem (1981) states that near Isla Fuerte, Colombia, fatal attacks by white sharks (*Carcharodon carcharias*) on adult crocodiles were not uncommon in the past.

Mortality due to cannibalism in *C. acutus* is not well understood, but apparently occurs under certain circumstances, particularly in high density situations. In the formerly dense *C. acutus* population in Lago Ticamaya, Schmidt (1924) reported finding the remains of a 1.2-1.5 m crocodile in the stomach of a 3 m individual. He also reports a colleague seeing a large crocodile eating a smaller one. Varona (1980) cites Gundlach reporting that large *C. acutus* will eat small ones.

Under certain circumstances mortality of hatchling or small juvenile crocodiles may be directly related to environmental factors. The cool winters in Florida are known to limit growth in small crocodiles, and it is possible that short-term cold spells could cause mortality. Osmoregulatory failure is also important in some areas. In at least one population, Lago Enriquillo, it is the primary source of hatchling mortality (Inchaustegui et al. 1980, pers. obs.). Ogden (1978) and Mazzotti (1983) also mention hurricanes as potential factors in crocodile mortality in southern Florida.

#### LITERATURE CITED

- Alvarez del Toro, M. 1974. Los Crocodylia de Mexico. Mexico D.F.:Inst. Mexicano de Recursos Renovables.
- Barbour, T. and C.T. Ramsden. 1919. The herpetology of Cuba. Mem. Mus. Comp. Zool. 47:202-210.
- Blohm, T. 1948. Observaciones sobre los caimanes traídos del Rio Orinoco en Abril de 1946. Mem. Soc. Cienc. Nat. La Salle 8:123-129.
- Blomberg, G.E.D., B.C. St. Pierre, K.D. Smith, S.M. Caddell, and S.R. Pett. 1982. Simulated population dynamics of crocodiles in the Okavango River, Botswana. Pages 343-375 in Crocodiles. IUCN Publ. N.S.), Gland, ISBN 2-8023-209-X.
- Brazaitis, P. 1973. The identification of living crocodilians. Zoologica 56:115-170.

- Breder, C.M. 1946. Amphibians and reptiles of the Rio Chucunague drainage, Darien, Panama, with notes on their life histories and habits. Bull. Am. Mus. Nat. Hist. 86:429-431.
- Bustard, H.R. 1968. Rapid learning in wild crocodiles *Crocodylus porosus*. Herpetologica 24:173-175.
- Camacho, M.G. 1983. Notas de los crocodilia en Nicaragua. Instituto Nicaraguense de Recursos Naturales y del Ambiente.
- Campbell, H.W. 1972. Ecological or phylogenetic interpretations of crocodilian nesting habits. Nature 238:404-405.
- \_\_\_\_\_. 1973. Observations on the acoustic behavior of crocodilians. Zoologica 58:1-11.
- Carney, S.W. 1979. Growth of crocodile hatchlings in south Florida canals of varying salinities. Unpubl. Ms.
- Carr, A. 1953. High Jungles and Low. Univ. Florida Press, Gainesville.
- Casas, G.A. and M.A. Guzman. 1970. Estado actual de las investigaciones sobre cocodrilos Mexicanos. Mexico. D.F.: Inst. Nac. de Investigaciones Biologico Pesqueras.
- Chabreck, R.H. 1971. The foods and feeding habits of alligators from fresh and saline environments in Louisiana. Proc. S. E. Assoc. Game Fish & Comm. 25:17-24.
- Cott, H.B. 1961. Scientific results of an inquiry into the ecology and economic status of the Nile crocodile (*Crocodylus niloticus*) in Uganda and Northern Rhodesia. Trans. Zool. Soc. London 29:211-356.
- Dimock, A.W. and J. Dimock. 1908. Florida Enchantments. New York, Outing Pub. Co.
- Donoso Barros, R. 1966. Contribucion al conocimiento de los cocodrilos de Venezuela. Physis 26:265-274.
- Dugan, B.A., A.S. Rand, G.M. Burghardt, and B.C. Bock. 1981. Interactions between nesting crocodiles and iguanas. J. Herpetol. 15:409-414.
- Dunson, W.A. 1970. Some aspects of the electrolyte and water balance in three estuarine reptiles, the diamondback terrapin, american and "salt water" crocodiles. Comp. Biochem. Physiol. 32:161-174.
- \_\_\_\_\_. 1982. Salinity relations of crocodiles in Florida Bay. Copeia 1982:374-385.
- Duval, J. 1977. La primera reproduccion de los cocodrilos Americanos en el ZOODOM. ZOODOM 2:12-15.
- Ellis, T.M. 1981. Tolerance of sea water by the American crocodile, *Crocodylus acutus*. J. Herpetol. 15:187-192.
- Esquemeling, J. 1678. The Buccaneers of America. Dover Publications Inc., New York.

- Evans, D.H. and T.M. Ellis. 1977. Sodium balance in the hatchling American crocodile, *Crocodylus acutus*. *Comp. Biochem. Physiol.* 58A:159-162.
- Ferguson, M.W.J. 1985. Reproductive biology and embryology of the crocodilians. Pages 329-500 in C. Gans, F. Billet and P.F.A. Maderson, eds. *Biology of the Reptilia*, Vol.14, Development A. John Wiley and Sons, New York.
- \_\_\_\_ and T. Joanen. 1983. Temperature-dependent sex determination in *Alligator mississippiensis*. *J. Zool.* 200: 143-177.
- Fiallos, A.P., R.A. Zambrano, and T.H. Fritts. (no date). Estudios basicos sobre el cocodrilo (*Crocodylus acutus*) en la cuenca del Rio Guayas, Ecuador. Unpubl. ms.
- Gaby, R., M.P. McMahon, B.A. Bonsack, W.N. Gillies, and J. Gleman. 1981. The population of the American crocodile, *Crocodylus acutus* (Reptilia, Crocodylidae) at the Turkey Point power plant site. Coral Gables: Metcalf and Eddy, Inc.
- \_\_\_\_, \_\_\_\_ , F. Mazzotti, W.N. Gillies, and J.R. Wilcox. 1985. Ecology of a population of *Crocodylus acutus* at a power plant site in Florida. *J. Herpetol.* 19:189-195.
- Garrick, L.D. and J.W. Lang. 1977. Social signals and behavior of adult alligators and crocodiles. *Am. Zool.*:225-239.
- Grant, C. 1940. The herpetology of the Cayman Islands. *Bull. Inst. Jamaica, Sci. Ser.* 2:1-65.
- Graham, A. 1968. The Lake Rudolf crocodile (*Crocodylus niloticus*) population. Report to the Kenya Game Department.
- Greer, A.E. 1970. Evolutionary and systematic significance of crocodilian nesting habits. *Nature* 227:523-524.
- \_\_\_\_. 1971. Crocodilian nesting habits and evolution. *Fauna* 2:20-28.
- Gundlach, J. 1880. Contribucion a la Erpetologia Cubana. Habana, G. Monteil.
- Herzog, H.A. 1974. The vocal communication system and related behaviors of the American alligator (*Alligator mississippiensis*) and other crocodilians. Msc. Thesis, Univ. Tenn., Knoxville.
- Hofmann, R.K. 1970. La distribucion actual del cocodrilo Americano (*Crocodylus acutus* Cuvier) en el Departamento de Tumbes. *Informe Tecnico* 25:1-25.
- Hornaday, W.T. 1904. *The American Natural History*. New York: Charles Scribner's Sons.
- Hutton, J.M. 1984. The population ecology of the Nile crocodile, *Crocodylus niloticus* Laurenti, 1768, at Ngezi, Zimbabwe. University of Zimbabwe, Harare.
- Inchaustegui, S., J.A. Ottenwalder, C. Sanlley, and D.G. Robinson. 1980. The reproductive biology of *Crocodylus acutus* in the Enriquillo Lake, Dominican Republic. Abstr. SSAR-HL Meetings, Milwaukee, Wis.

- King, F.W., H.W. Campbell, and P. Moler. 1982. Review of the status of the American crocodile. Pages 84-98 in *Crocodiles*. IUCN Publ. (N.S.), Gland, ISBN 2-8032-209-X.
- Klein, E.H. 1977. A status evaluation of the crocodilians of Eastern Honduras. Unpubl. Ms.
- Kushlan, J.A. 1982. The status of crocodilians in south Florida. Pages 99-107 in *Crocodiles*. IUCN Publ. (N.S.), Gland, ISBN 2-8032-209-X.
- \_\_\_\_ and F.J. Mazzotti. 1986. Population biology and status of the American crocodile in south Florida. Pages 188-194 in *Crocodiles*. IUCN Publ. (N.S.), Gland, ISBN 88032-306-1.
- Lang, J.W. 1975a. American crocodile courtship. *Am. Zool.* 16:197.
- \_\_\_\_. 1975b. The Florida crocodile, will it survive? *Chicago (Field) Mus. Nat. Hist. Bull.* 46:4-9.
- \_\_\_\_. 1975c. Thermoregulatory behavior of adult American alligators. *Am. Zool.* 15:797.
- \_\_\_\_. 1979. Crocodilian thermal behaviors: Alligators vs. crocodiles. *Am. Zool.* 19(3).
- Loveridge, J.P. 1984. Thermoregulation in the Nile crocodile, *Crocodylus niloticus*. *Symp. Zool. Soc. Lond.* 52:443-467.
- Lutz, P. and A. Dunbar-Cooper. 1984. The nest environment of the American crocodile (*Crocodylus acutus*). *Copeia* 1984: 153-161.
- Mazzotti, F.J. 1983. The ecology of *Crocodylus acutus* in Florida. PhD. Thesis. Pennsylvania State University. University Park, Pa.
- Medem, F. 1981. Los Crocodylia de Sur America. Vol. 1. Los Crocodylia de Colombia. Bogota: Ed. Carrera 7a Ltd.
- \_\_\_\_. 1983. Los Crocodylia de Sur America. Vol. 2. Bogota: Carrera 7a Ltd.
- Mertens, R. 1943. Die rezenten Krokodile des Natur-Museums Senckenberg. *Senckenbergiana* 26:252-312.
- Messel, H., G.C. Vorlicek, A.G. Wells, and W.J. Green. 1981. The Blyth-Cadell rivers system study and the status of *Crocodylus porosus* in tidal waterways of northern Australia. Methods for analysis, and dynamics of a population of *C. porosus*. Monog. 1. Pergamon Press, Oxford.
- \_\_\_\_, \_\_\_\_\_, \_\_\_\_\_, and \_\_\_\_\_. 1982. Status and dynamics of *Crocodylus porosus* populations in the tidal waterways of northern Australia. Pages 112-173 in *Crocodiles*. IUCN Publ. (N.S.), Gland, ISBN 2-8032-209-X.
- Moore, J.C. 1953. The crocodile in the Everglades National Park. *Copeia* 1953:54-59.
- Ogden, J.C. 1978. Status and nesting biology of the American crocodile, *Crocodylus acutus* (Reptilia, Crocodylidae) in Florida. *J. Herpetol.* 12:183-196.
- \_\_\_\_. 1979. American Crocodile. In: *Rare and Endangered Biota of Florida*, Vol. 3, Amphibians and Reptiles. Univ. Presses of Florida, Gainesville.

- \_\_\_\_\_ and C. Singletary. 1973. Night of the crocodile. Audubon 75:32-37.
- Rand, A.S. and K. Troyer. 1980. Reduced parental care in *Crocodylus acutus* in Panama, causes and implications. Abstr. SSAR-HL Meetings, Milwaukee, Wis.
- Rodda, G.H. 1984. Movements of juvenile American crocodiles in Gatun Lake, Panama. Herpetologica 40:444-451.
- Ross, F.D. and G.C. Mayer. 1983. On the dorsal armor of the Crocodilia. Pages 305-331 in A.G.J. Rhodin and K. Miyata, eds. Advances in Herpetology and Evolutionary Biology. Museum of Comparative Zoology, Cambridge.
- Ross, C.A. and F.D. Ross. 1974. Caudal scalation of Central American *Crocodylus*. Proc. Biol. Soc. Wash. 87:231-234.
- Schmidt, K.P. 1924. Notes on Central American crocodiles. Field Mus. Nat. Hist. Zool. Ser. 12:77-96.
- Seijas, A.E. 1986a. Situacion actual de las poblaciones de babas y babillas (*Caiman crocodilus*) en la region norte- costera de Venezuela. Pages 28-36 in Crocodiles. IUCN Publ. 4 (N.S.), Gland, ISBN 2-88032-306-1.
- \_\_\_\_\_. 1986b. Situacion actual del caiman de la costa, *Crocodylus acutus*, en Venezuela. Pages 96-108 in Crocodiles. IUCN Publ. (N.S.), Gland, ISBN 88032-306-1.
- Smith, H.M. and R.B. Smith. 1977. Synopsis of the Herpetofauna of Mexico Vol. V. Guide to Mexican Amphisbaenians and Crocodilians. John Johnson. North Bennington, Vt.
- Taplin, L.E. and G.C. Grigg. 1981. Salt glands in the tongue of the estuarine crocodile *Crocodylus porosus*. Science 212: 1045-1047.
- Taylor, J.A. 1979. The food and feeding habits of subadult *Crocodylus porosus* in northern Australia. Aust. Wildl. Res. 6:347-360.
- Thorbjarnarson, J.B. 1984. Status and Ecology of the American Crocodile in Haiti. Msc. Thesis. University of Florida, Gainesville.
- \_\_\_\_\_. 1988. Status and Ecology of the American Crocodile in Haiti. Bull. Fla. State Museum 33(1):1-86.
- Varona, L.S. 1966. Notas sobre los crocodilidos de Cuba y descripcion de una nueva especie del Pleistoceno. Poeyana 16:1-34.
- \_\_\_\_\_. 1980. The status of *Crocodylus acutus* and *C. rhombifer* in Cuba. Unpubl. Ms.
- Vliet, K.A. 1987. A Quantitative Analysis of the Courtship Behavior of the American Alligator (*Alligator mississippiensis*). Ph.D Thesis. University of Florida, Gainesville, FL. 199 pp.
- Webb, G.J.W., R. Buckworth, and S.C. Manolis. 1983. *Crocodylus johnstoni* in the McKinlay River area, N.T. III. Growth, movement and the population age structure. Aust. Wildl. Res. 10:383-401.

- \_\_\_\_\_, S.C. Manolis, and R. Buckworth. 1982. *Crocodylus johnstoni* in the McKinlay River area, N.T. I. Variation in the diet, and a new method of assessing the relative importance of prey. Aust. J. Zool. 30:877-899.
- \_\_\_\_\_, and H. Messel. 1979. Wariness in *Crocodylus porosus* (Reptilia, Crocodylidae). Aust. Wildl. Res. 6:27-34.
- Wilkinson, P.M. 1984. Nesting ecology of the American alligator in coastal South Carolina. Study Completion Report, S.C. Wildlife and Marine Resources Dept.
- Woodward, A.R. and W.R. Marion. 1978. An evaluation of factors affecting night-light counts of alligators. Proc. 32nd Ann. Conf. S.E. Assoc. Fish Wildl. Agencies. 32:291-302.

**PRESENT KNOWLEDGE ON  
THE WEST AFRICAN SLENDER-SNOURED CROCODILE,  
*Crocodylus cataphractus* CUVIER 1824  
AND THE WEST AFRICAN DWARF CROCODILE  
*Osteolaemus tetraspis*, COPE 1861**

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**INTRODUCTION**

Very little has been published on the three crocodile species occurring in west Africa. This is particularly true for the two species endemic to west Africa, the west African long-snouted or slender-snouted crocodile (*Crocodylus cataphractus*, Cuvier 1824) and the west African stumpy, broad-fronted or dwarf crocodile (*Osteolaemus tetraspis*, Cope 1861). By contrast, for the Nile crocodile (*C. niloticus*, Laurenti, 1766), which ranges over the whole of tropical Africa, there is much information available from east and southern Africa. This lack of information on the west African crocodile populations results from a number of factors:

- the very secluded habitat of the forest dwellers *C. cataphractus* and *O. tetraspis*, which severely restricts field investigations;
- the evolution of national parks and the development of wildlife management has been comparatively slow in west African countries. This has been particularly the case in the forest zones;
- The belly skin of the west African forest crocodiles is less valuable for commercial exploitation, this reduces the interest of the skin industry;
- The size of west African crocodiles is less spectacular and their population density is lower, so reducing their show effect in reserves and on farms.

In essence this chapter tries to give a short overview on our present understanding of the biology and ecology of *C. cataphractus* and *O. tetraspis*, gathered by researchers both on field investigations in west Africa and in captive-breeding in zoos on several continents.

**SPECIES PRESENTATION**

The 3 species of crocodiles occurring in west Africa belong to 2 genera: The genus *Crocodylus* represented by two species and the genus *Osteolaemus* represented only by one.

Based on exact description of these species, given by Villiers (1958), the basic distinguishing characteristics of these crocodiles are shown in Table 2.



Table 1. Species of west African crocodiles.

Scientific name	<i>Crocodylus niloticus</i> Laurenti 1766	<i>Crocodylus cataphractus</i> Cuvier 1824	<i>Osteolaemus tetraspis</i> Cope 1861
English name	Nile crocodile	Slender-snouted crocodile	Dwarf crocodile
French name	Crocodile du Nil cuirassé	Crocodile à nûque large	Crocodile à front
German name	Nil-krokodil	Panzer-krokodil	Stumpf-krokodil
Dioula name	Bamba gbèman	Bamba da Jan	Bamba fiman

Table 2.

Species	<i>Crocodylus niloticus</i>	<i>Crocodylus cataphractus</i>	<i>Osteolaemus tetraspis</i>
snout length	1-2/3 - 2X > basal width	2-2/3 - 3-1/3 X > basal width	about = basal width
dental format	18-19 / 15	17-18 / 15	16-17 / 14-15
nuchal scales	2 transverse series 1st 4 scales 2nd 2 scales	2 transverse series 1st 2 scales 2nd 2 scales	3 transverse series 1st 2 big scales 2nd 2 big scales 3rd 2 very small scales
coloration	back: bright olive/ bronze or dark green; belly: pale yellowish	back: dark olive; belly: bright yellowish with dark patches	back: black with yellowish patches on tail & jaw; belly: pale yellowish with many blackish patches
Maximum length	4-5 m*	3-4 m	1.8 m

\* in west Africa

## SYSTEMATICS AND EVOLUTION

The crocodiles were first classified in a the order Crocodilia by Gmelin in 1788. In 1766 Laurenti established the species *C. niloticus*. In 1824 Cuvier became the first to distinguish a second species in Africa, *C. cataphractus*. It was only in 1861 that the species *O. tetraspis* was established by Cope. Another crocodile from Zaire was described by Schmidt (1919) as *Osteoblepharon osborni*. Inger (1948) later annulled this new genus and described this crocodile as *Osteolaemus osborni*, but since Wermuth and Mertens (1961) it has been regarded as a subspecies of *O. tetraspis*, called *O. tetraspis osborni*.

The systematic classification of the three west African crocodile species is shown in Table 3.

Table 3.

Phylum	Chordata
Sub-Phylum	Vertebrata
Class	Reptilia
Order	Crocodylia
Suborder	Eusuchia
Family	Crocodylidae
Subfamily	Crocodylinae
1st Genus	<i>Crocodylus</i>
1st Species	- <i>niloticus</i>
2nd Species	- <i>cataphractus</i>
2nd Genus	<i>Osteolaemus</i>
2nd Species	- <i>tetraspis</i>

According to a theory of Greer (1970), all Recent crocodilians derive from a hypothetical ancestor which built its nest by digging a hole in the ground. From this ancestor some crocodilians evolved in such a way that they started to construct mound nests on the surface of the ground by heaping up dead leaves and rotting vegetation. In terms of their pattern of nest construction the two forest species of west African crocodiles belong to this branch of evolution, whereas the Nile crocodile remained in the principal line, continuing to construct their nests under the earth.

## GEOGRAPHICAL DISTRIBUTION

In contrast to *C. niloticus*, which is found all over tropical Africa and Madagascar, the range of the two other species is limited to the equatorial forest zones, centered in the tropical rain forest around the Gulf of Guinea and the River Congo. Passing through the deciduous forest coming to the gallery forests in the Guinean and Sudanese savanna, they are found more and more rarely. Table 4 shows the countries and river systems from west to east where their presence has been documented.

Table 4.

Country	<i>Crocodylus cataphractus</i>	<i>Osteolaemus tetraspis</i>
Senegal and Gambia	Saloum delta, River Gambia and its tributaries Senegal-, Falémé- and Casamance rivers and their tributaries (Pooley 1982)	Saloum delta, River Gambia and its tributaries (Villiers 1956a, b, 1958, 1959, Pooley 1982)
Guinea Bissau	no information available	no information available
Guinea	tributaries to River Niger Kourai, Sankarani and Boa rivers (Waitkuwait 1986)	Kourai, Sankarani, Boa Bafing, Mafou rivers (Waitkuwait 1986)
Sierra Leone	Moa and Morro rivers (Waitkuwait 1986)	River Jong at Magburaka (IUCN 1979)
Liberia	Mano, Loffa, St. Paul, Mani, Cess, Sangwin and Douabé rivers (Waitkuwait 1986)	Mani, Loffa, St. Paul, Mani Cess, Sangwin and Douabé rivers (Waitkuwait 1986)
Mali	Baoulé, Bagoé, Kankélaba rivers (Waitkuwait 1986)	Baoulé, Bagoé, Kankélaba rivers (Waitkuwait 1986)
Ivory Coast	Baoulé, Bagoé, Sassandra, Bafing, Nzo, Lobo, Cavalla, Hana, Meno, Néka, Tabou, Dodo, Néro, San Pedro, Bandama, Maraoué, Badénou Solomougou, Nzi, Boubo, Go Comoé, Iringou, Kongo, Kolonkoko, Agnéby, Bia and Tanoé rivers; Grand Lahou, Ehrié, Aby, Tendo and Ehy lagoons (Waitkuwait, 1986)	Baoulé, Bagoé, Sassandra Bafing, Nzo, Lobo, Cavalla, Hana, Meno, Néka, Tabou, Dodo, Néro, San Pedro, Bandama, Maraoué, Badénou, Solomougou, Nzi, Boubo, Go, Comoé, Iringou, Kongo, Kolonkoko, Agnéby, Bia and Tanoé rivers, Grand Lahou, Ebrié, Aby, Tendo and Ehy lagoons (Waitkuwait 1986)
Burkina Faso	Comoé, Black-Volta, Bougouriba rivers (Waitkuwait 1986)	Comoé, Black-Volta, Bougouriba rivers (Waitkuwait 1986)
Ghana	Black-Volta, Tanoé, Bia rivers (Waitkuwait 1986); Densu, Pra, Mole, White Volta rivers, Obosum and tributaries, Dwija and tributaries, Sene and tributaries, Lake Volta and Lake Kainji (Pooley 1982)	Black-Volta, Tanoé, Bia rivers Offin and (Waitkuwait 1986) Bia rivers, other small forest rivers, Volta Lake (Pooley 1982)

Table 4. (cont.).

Togo	Mono and Oti rivers (Tornier 1901, Waitkuwait 1986)	Mono and Oti rivers (Waitkuwait 1986); Mare at Kini Kopé (Tornier 1901, IUCN 1984)
Benin	River Ouémé (Pooley 1982, Waitkuwait 1986)	Ouémé, Mékrou and Alibori rivers (Pooley 1982, Waitkuwait 1986)
Niger	no information available	no information available
Nigeria	Gaji, Yankari, Barkono, Benue rivers (Pooley 1982)	River Sombreiro near Abua (King 1955); more common in forest rivers in central east, less common in west (Pooley 1982)
Cameroon	tributaries of the River Cross (Tornier 1902, Abercrombie 1978)	near Douala, small rivers of Mount Cameroun (Tornier 1902, Pooley 1980)
Chad	Chari, Aouk, Aoukalé, Bangoran rivers, Lake Chad (Pooley 1982)	no information available
Central African Republic	River Oubangui and tributaries (Gournay pers. comm.)	Birao region (Pooley 1982)
Gabon	River Ogooué, small coastal and inland rivers (IUCN 1979, Pooley 1980)	mangroves near Libreville, swamp areas of Woleu N'tem and Ogooue Ivindo (Pooley 1982)
Congo	Oubangui, Sanga and other rivers near to the Central African border (Pooley 1982, Waitkuwait 1986)	Oubangui, Sanga and other rivers near to the Central African border (Pooley 1982, Waitkuwait 1986)
Zaire	Dungu, Népoko, Uele, Oubangui, Zaire rivers (Pooley 1982, Waitkuwait 1986)	Subspecies <i>O. t. osborni</i> in the northeast, lower parts of River Zaire. Subspecies <i>O. t. tetraspis</i> in the upper parts of River Zaire (Pooley 1982)
Tanzania	only in Lake Tanganyika in Luichi, Malagarasi rivers (Pooley 1982)	not present
Angola	only in rivers at the border to Zaire and Cabinda (Pooley 1982)	only in the Cabinda enclave (Pooley 1982)
Zambia	Luapula, Kalungwishi rivers, Lakes Mweru, Mweru Wantipa and Tanganyika (Pooley 1982)	not present

## BIOLOGY AND ECOLOGY

A comparative analysis of the biology and ecology of two related species living in the same environment should show particular adaptations in terms of different habitat preferences, nesting areas, reproductive timing and behavior, feeding resources, according to the different ecological niches inhabited. In this way the two species coexist rather than compete within the ecosystem. For this reason one can find a situation of only partial competition reflecting the degree of the relationship between the two species.

**Habitat** - Table 5 shows the habitat preferences of the two crocodile species indicated by hunters and fishermen in 60 villages in the Ivory Coast in questionnaires conducted by Waitkuwait (1986).

Table 5.

Species	<i>Crocodylus cataphractus</i>	<i>Osteolaemus tetraspis</i>
uncovered, bright water	23 (38.3%)	4 (6.7%)
covered shady water	23 (38.3%)	13 (21.7%)
swamps and swamp forests	14 (23.3%)	43 (71.7%)
total number of answers	60 (100%)	60 (100%)

This table shows that *C. cataphractus* prefers to stay mainly in the open waters of rivers, lakes or lagoons. *O. tetraspis* enters these only occasionally, preferring swamps beside the open water systems and water pools remaining in periodically flooded swamp forests. It remains in the vicinity of slow flowing waters and calm bays, and stays in burrows beside the waterline.

These results are confirmed by night-counts in different biotopes of the Ivory Coast (Waitkuwait 1986). In the Comoé National Park situated in Sudanese savanna only 1 *O. tetraspis* for every 15 *C. cataphractus* could be found. In the Tai National Park in rain forest the crocodile population of the Hana River was found to be composed of 95.5% *C. cataphractus* and 4.5% *O. tetraspis*. In the Azagny National Park, a swamp area separating two lagoons, all crocodiles found on the actual floating vegetation mat which constitutes the Rhaphia Swamp were *O. tetraspis*; whereas all *C. cataphractus* observed in this area were found in the water of the channels dug out for the tourist management of the park.

Also, elsewhere *O. tetraspis* has been found in small water pools, often far away from the nearest open water. In the interior of Comoé National Park it has been observed several times in the so called "mares," where they remain during the dry season in self-made burrows (Waitkuwait 1986, Gilbert pers. comm.). Similar observations have been made by Villiers (1956a) in the Niokolokoba National Park in Senegal. This was again confirmed for the Marahoué National Park in the contact zone forest savanna in the Ivory Coast (Waitkuwait 1986). Even in the tropical rain forest in the interior of Tai National Park it shows this habitat preference. Up to 10 individuals of different age classes (juveniles, subadults, adults) have been observed throughout the year in the same small water pools. They stayed there permanently, some individuals going on short journeys

and returning afterwards (Waitkuwait 1986). It was found that *O. tetraspis* walks around often in the forest, especially during the night or after a heavy rainfall. Several times it has been observed crossing tracks in the forest some km away from the nearest flowing water (Waitkuwait 1986, Hoppe, Merz, Martin pers. comm.).

It has also been observed in water collecting basins at the head of rain forest creeks (Boesch, pers. comm.) and in banana plantations situated on low lying grounds (Gournay, pers. comm.). One *O. tetraspis* stayed for several years in a well, the only water point, isolated in the center of a large oil palm plantation in the Ivory Coast (Maroncelli, pers. comm.).

In contrast to this in all these biotopes *C. cataphractus* has never been observed far from water. It stays in all kinds of rivers mainly covered by dense, shady vegetation, and it avoids uncovered bright sunny areas. The conditions in which its typical habitat is found becomes more scarce as one moves away from rain forest to savanna, as well as where the water courses become wider (Villiers 1956a, 1958, Waitkuwait, 1986).

**Nest construction** - As *C. cataphractus* and *O. tetraspis* live in habitats covered by dense vegetation, insolation - the normal source of heat for other reptiles - is reduced. One would suppose that it is for this reason both species construct mound nests of dead leaves and rotting vegetation collected from within a diameter of several meters. The mounds are flat on two sides and steeply sloped on the other two sides and have a furrow across the top made by the female lying on the nest or creeping over it. The nests are built in several stages. The female uses fore and hind limbs for the construction. It is thought that the decomposition of the vegetative materials of the mound guarantees the heating of the egg chamber, necessary for embryo development. This nest building behavior has been described in the wild by Villiers (1956, 1958) and Waitkuwait (1982, 1986), and in captive breeding by King (1955), Beck (1978), Sims and Sing (1978), and Tryon (1980).

Table 6 shows the nest dimensions for the two west African mound nest builders as found by Waitkuwait (1986) in the wild.

Table 6 Dimensions of the mound nests.

Species	<i>Crocodylus cataphractus</i>	<i>Osteolaemus tetraspis</i>
height (cm)	58.6 ± 11.6	47.5 ± 17.1
length (cm)	134.7 ± 36.7	131.3 ± 19.3
width (cm)	152.4 ± 29.6	123.8 ± 50.2
sample	n = 31	n = 4

The sizes of the nests seem to vary according to environmental temperature which depends on the season and on the density of the vegetation surrounding the nesting place. For this reason the size doesn't allow species classification of the nests. Tryon (1980) used damp hay as nesting material in captive breeding of *Osteolaemus* and found that the nest size varied directly to the amount of added material. The nests at Fort Worth Zoo were tightly packed and urination and defecation took place on the clutch and throughout the nest mound. Teichner (1976) gave one

nest dimension for *Osteolaemus* of 91 x 61 x 41 cm, and Sims and Singh (1978) described a nest 70 x 50 cm for this species.

**Nest site** - In contrast Waitkuwait (1986) found that a species classification of the nests is possible according to the species specific nest site chosen by the female crocodile, as can be seen in Table 7.

Table 7. Nest sites of mound nests.

Species	<i>Crocodylus cataphractus</i>	<i>Osteolaemus tetraspis</i>
Distance from water (m)	3.8 ± 2.2	16.9 ± 22.2
Height over water level (m)	1.8 ± 0.7	1.4 ± 0.6
Sample	n = 73	n = 4

Corresponding to their habitat preferences, the two species also avoid any competition in the choice of their nesting areas. The distribution of *C. cataphractus* mound nests was found to be linear, following the river banks, whereas the distribution of *Osteolaemus* nests was found to be bi-dimensional.

In 3 successive years from 1981 to 1983, 12 nests of *C. cataphractus* were observed by Waitkuwait (1986) alongside the Gabo River in the interior of the Tai National Park. Table 8 shows the average distance between the nests.

Table 8. Average distance between *C. cataphractus* nests.

Year:	1981	1982	1983
distance (km)	1.13	0.7	1.66
standard variation (km)	±0.67	±0.49	±1.72
sample (nests)	n = 12	n = 12	n = 12

From the observed variations of the distances between two nests, it can be derived that either the females choose a new nest site every year within their territory, or they change their territory, or even that some females do not reproduce every year.

In 1982 and 1983, only two nests were found to be constructed on a nest of the previous year.

Knoepfler (1974) speculated that *Osteolaemus* may use the same mound in successive years.

**Nesting period.** Table 9 shows the period of nesting activities of *C. cataphractus* and *O. tetraspis* in the tropical rain forest of the Ivory Coast found by Waitkuwait (1981, 1982, 1985, 1986).

Table 9. Dates of nesting activities.

Species	<i>Crocodylus cataphractus</i>	<i>Osteolaemus tetraspis</i>
date of nest construction	April 8 $\pm$ 18 days	April 30 $\pm$ 60 days
date of hatching	July 17 $\pm$ 18 days	September 15 $\pm$ 76 days
main nesting period in the year	March 21 to Aug. 4 over 136 days/year	March 1 to November 30 over 274 days/year

Nest construction for both species starts at the end of the dry season in the Tai forest when the most of fallen leaves are available for the nest mounding, so the subsequent nesting period covers principally the season of high rainfall. One can see that the main nesting period stretches over a longer period of time for the *O. tetraspis* than for the *C. cataphractus*.

High water levels in the small forest rivers during egg incubation and hatching seem to be very important for *C. cataphractus* so that the female can remain in water close by to guard the eggs and hatchlings. Whereas in rivers these conditions are found for only part of the year, the swampy habitat chosen by *O. tetraspis* offers almost all year round the necessary hydrological conditions for its nesting almost all the year. The main nesting period for both species has been defined as the period during which 2/3 of all nests constructed per year can be observed (data based on the standard variation calculation), 1/3 of nests being constructed outside this period according to climatic fluctuations or to differences in the individual behavior of the females.

**Chronological order of reproductive activities.** Available data are very scarce. Tryon (1980) states that both sexes of *Osteolaemus* mature at age five years and that courtship and mating of captive *Osteolaemus* starts every year in late November in Fort Worth Zoo. Copulation peaks during March and April. Drumming, neck rubbing, and male combat are described as courtship behaviour by Beck (1978), Teichner (1976, 1978) and Tryon (1980). The last author found that *Osteolaemus* females are unreceptive in late April and early May. Nest building began in June (Teichner 1976, 1978, Tryon 1980), actual laying occurred 5 to 47 days after mounding. Waitkuwait (1982) mentions that courtship and mating of *C. cataphractus* in Abidjan Zoo takes place in February and March. Actual oviposition occurred between a few days and one week after nest mounding.



**Eggs and incubation** - Just as the *Osteolaemus* female is small in size (about 1.50-1.60 m) in comparison with the *C. cataphractus* female (about 2.2 m), the same difference in clutch and egg size has been found by Waitkuwait (1986), as shown in Table 10.

Table 10. Clutch and egg size.

Species	<i>C. cataphractus</i>	<i>Osteolaemus tetraspis</i>
egg number per nest	16.0 $\pm$ 7.0	10.0 $\pm$ 4.0
egg length (mm)	85.5 $\pm$ 3.2	68.9 $\pm$ 2.4
egg diameter (mm)	52.9 $\pm$ 1.5	37.1 $\pm$ 1.2

The mean clutch size shown above for *Osteolaemus* is consistent with data published by Greer (1975), Knoepfler (1974), Beck (1978), Wilson (1977), Hara and Kikuchi (1978), Sims and Singh (1978), Teichner (1976, 1978), and Helfenberger (1981), gathered during captive breeding of this species. Tryon (1980) found that the mean egg number for 25 *Osteolaemus* clutches was 13.28. Data on egg length and diameter published by him are consistent with the data in Table 10.

In contrast the data on egg incubation show no species-specific differences. The length of the incubation period is determined to be 100  $\pm$  10 days for *C. cataphractus* as well as for *O. tetraspis* (Waitkuwait 1981, 1982, 1986). Other data on length of incubation period are available from the captive breeding of *O. tetraspis*: 84 days (Wilson 1977), 118 days (Hara and Kikuchi, 1978), 109 days (Tryon 1980), and 84 days (Helfenberger, 1981). Incubation temperatures range between 26°C and 34°C in mound nests of both species (Waitkuwait 1981, 1982, 1986), being constant in each nest (with daily fluctuations of less than 0.5°C) and about 5°C greater than the environmental temperature.

Figures 1 and 2 show temperature data gathered on a *C. cataphractus* mound nest in the Tai National Park. The endogenous heat in conjunction with the insulation given by the nest walls creates a largely autonomous microenvironment. However, as shown in Figure 1, the outside influences are not completely cut off. A longterm drop in the outside temperature, as recorded in June and July, resulted also in a lowering of the temperature in the nest.

*O. tetraspis* was bred successfully in captivity at incubation temperatures fluctuating between 25°C and 34°C (Tryon 1980) and 27°C and 33°C (Helfenberger 1981). The humidity in mound nests of both species was also found to remain constant over the whole incubation period (Waitkuwait 1981, 1982, 1986). Table 11 shows the percentage of dry matter in the nesting material.

In the air space of the egg chamber the relative humidity was therefore almost always at saturation point.

Table 11. Dry matter of mound nests.

Nest of	% Dry matter
<i>C. cataphractus</i> from forests	45.3
<i>C. cataphractus</i> from savanna	47.8
<i>O. tetraspis</i> from swamps	37.2

**Hatching of the young and behavior of the mother** - As for most of the crocodile species, it has also become apparent for *C. cataphractus* and *O. tetraspis* that the mother crocodile guards and visits the nest during the whole of the incubation period (King 1953, Tryon 1980, Waitkuwait 1982, 1986). On captive *Osteolaemus* it could be observed that the female spent up to 50% of her time on guarding the nest, that vocalization and aggressiveness, even against man, increased (Tryon 1980, Helfenberger 1981). Wild breeding *C. cataphractus* females were found to be very shy (Waitkuwait 1981, 1982). Cracks developed on the eggs and the young became vocal in answering movements in the nest surroundings by croaking heavily for about 1-2 days before actual hatching.

The mother crocodile is alerted by the calling of the young and is stimulated to excavate the nest and to help in hatching the young. For this she picks up the neonates partly emerged from the eggs, rolls them between her jaws until the eggshells have been removed, and transports the neonates in her mouth into water. This hatching process has been described by Tryon (1980) on captive *Osteolaemus* in the Fort Worth Zoo and has been observed on wild *C. cataphractus* and *O. tetraspis* (Waitkuwait 1981, 1982, 1986).

After hatching, the mother crocodile stays in the vicinity of the young to protect them. Communication is guaranteed by the vocalization of the young; Tryon (1980) found the calling of the young was not species-specific.

Waitkuwait (1982) observed that of the 17 eggs in a wild *C. cataphractus* nest 2 eggs were predated, 10 hatched successfully, embryonic death occurred in two, and 3 eggs were probably infertile.

Of 85 *Osteolaemus* eggs incubated at Fort Worth Zoo, Tryon (1980) found that 37 hatched, 39 were infertile, 2 contained fully formed but dead embryos, 2 contained living anomalies, and 1 contained twin crocodiles. Table 12 shows the total length of neonate *C. cataphractus* and *O. tetraspis* (Waitkuwait 1986).

Table 12.

Species	<i>Crocodylus cataphractus</i>	<i>Osteolaemus tetraspis</i>
total length (mm) at hatching	315.1 $\pm$ 23.3	279.3 $\pm$ 4.0

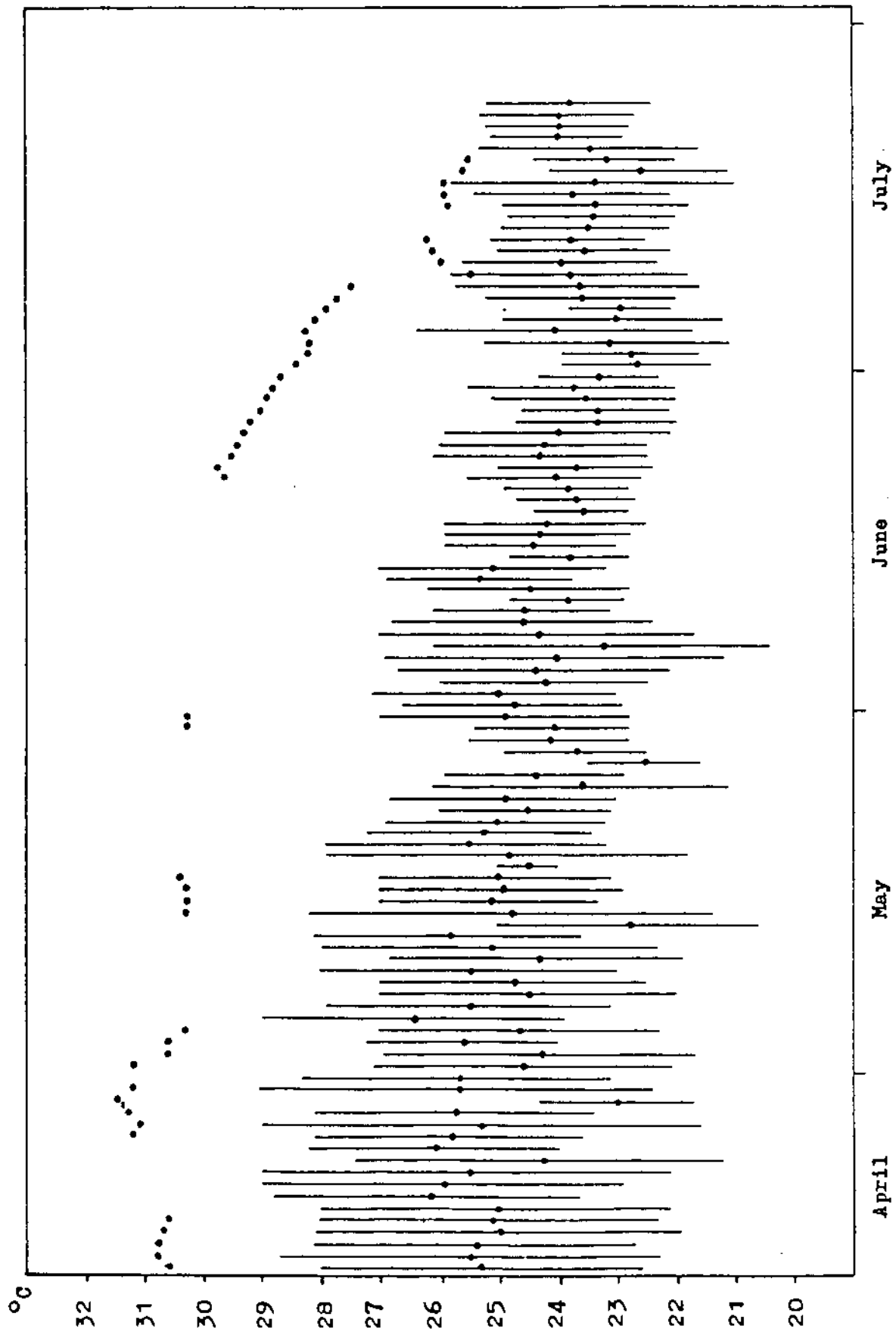


Figure 1. The nest temperature (above) in relation to the amplitudes outside the nest (below) from 14 April to 24 July 1980.

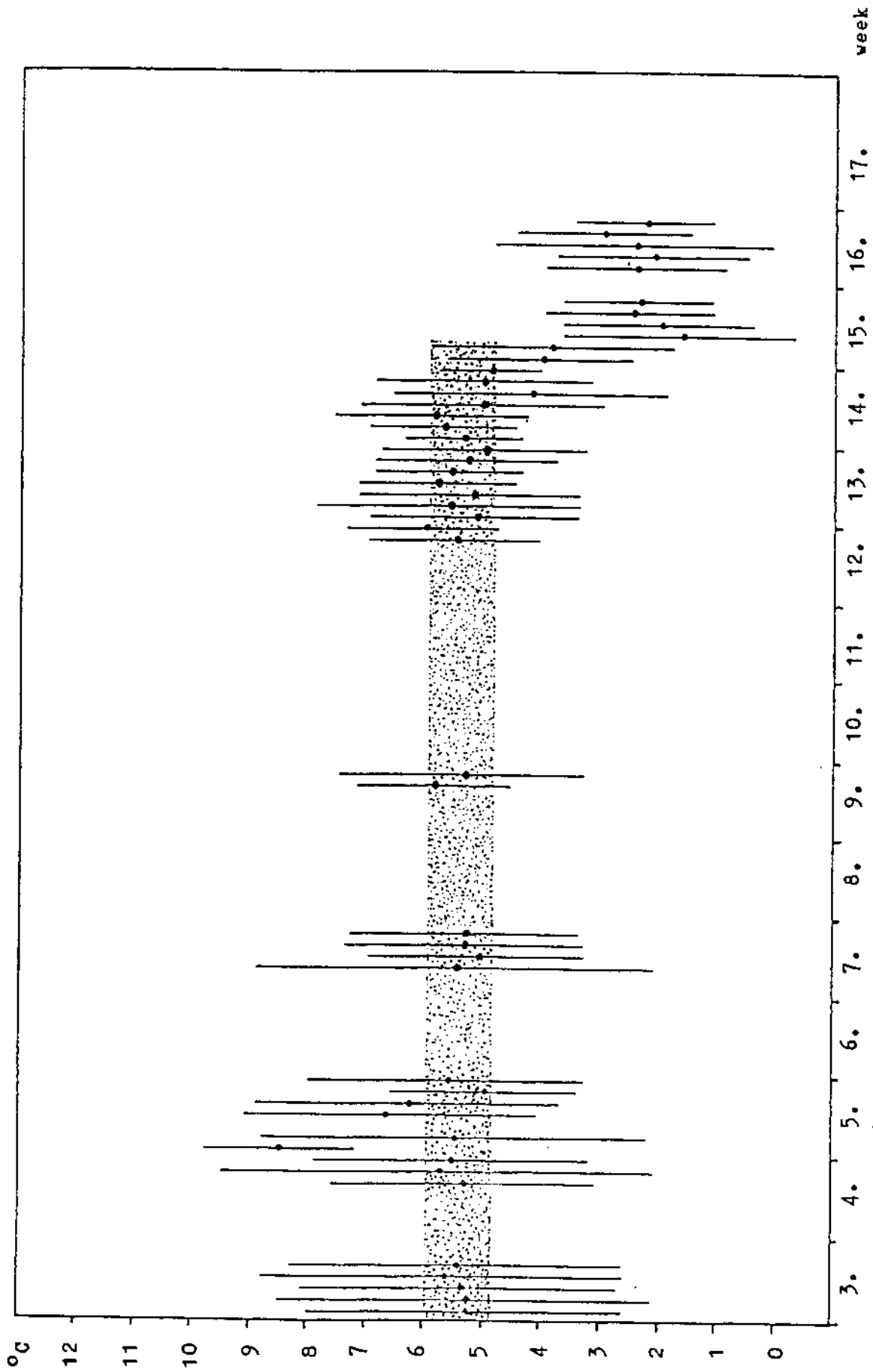


Figure 2. The constant difference between the incubation temperature and the mean day temperature outside the nest from the third week of incubation to the opening of the nest in the fifteenth week.

Tryon found the mean total length per clutch of *Osteolaemus* hatchlings at Fort Worth Zoo to be between 216.7 and 242.5 mm. Captive bred *Osteolaemus* neonates measured by Helfenberger (1981) showed a total length of 19 cm.

**Feeding** - Progressive differentiation of the body proportions of the two species occurs during growth. This finally results in adult *C. cataphractus* having a total length and a relative head and tail length greater than that of *O. tetraspis*. One would suppose that this phenomenon of allometry reflects different specializations concerning species-specific modes of hunting and ranges of prey.

*C. cataphractus* develops a slender snout and a long tail, both of which are necessary for a rapid hunting in water. The slender-snouted crocodile preys principally on fish and aquatic birds. Its large size also allows it to attack small- or medium-sized mammals, such as duikers (Cephalophinae), rodents (Rodentia), genetines (Viverrinae), monkeys (*Colobus* sp., Cercopithecidae), etc., which come to drink in the rivers (Waitkuwait 1986). In contrast, *O. tetraspis* has a stumpy, large snout and a short tail which favor land-based hunting in its swampy habitat. Some rare observations indicate that it feeds on amphibians, reptiles, annelides, crabs, and fish, (Villiers 1958, Waitkuwait 1986). Hatchlings of both species seem to have the same feeding regime as *C. niloticus* hatchlings, which was described in detail by Cott (1961): larvae of aquatic insects, tadpoles, etc.

**Enemies** - In general, predation on crocodiles occurs principally at the egg and hatchling level. According to Waitkuwait (1982, 1986) the following animals in the tropical rain forest of the Ivory Coast are potential predators against crocodile eggs and juveniles: Nile monitor (*Varanus niloticus*), otters (*Lutra maculicollis*, *Aonyx capensis*), water mongoose (*Atilax paludinosus*), tree civet (*Nandinia binotata*), genetines (Viverrinae), leopard (*Panthera pardus*), golden cat (*Felis aurata*), herons (*Egretta alba*, *Ardea purpurea*), birds of prey (Accipitridae), and soft-shelled turtles (*Trionyx triunguis*). Although predation has been observed several times, it is apparent that the density of predators in tropical forests is too low to severely reduce the crocodile population. The only predator threatening crocodile populations in west Africa is, like elsewhere, man, both through commercial hunting and increasingly through habitat destruction. As a consequence of human influences the west African crocodile populations are presently collapsing. This was confirmed by Ivorian hunters and fishermen (Table 13; Waitkuwait 1986).

Table 13. Frequency of Crocodiles in the Ivory Coast according to hunters and fishermen.

Frequency	<i>Crocodylus niloticus</i>	<i>Crocodylus cataphractus</i>	<i>Osteolaemus tetraspis</i>	Total
no answer	0 (0%)	7 (8.6%)	3 (3.7%)	10 (4.1%)
not or no more occurring	10 (12.3%)	14 (17.3%)	6 (7.4%)	30 (12.3%)
rare	62 (76.5%)	55 (67.9%)	60 (74.1%)	177 (72.8%)
less rare to locally frequent	9 (11.1%)	5 (6.2%)	12 (14.8%)	26 (10.7%)
frequent	0 (0%)	0 (0%)	0 (0%)	
Total number of answers	81 (100%)	81 (100%)	81 (100%)	243 (100%)

## LITERATURE CITED

- Abercrombie, C. L. III. 1978. Notes on west African crocodilians (Reptilia, Crocodilia). *J. Herp.* 12:260-262.
- Beck, C. 1978. Breeding the west African dwarf crocodile at Memphis Zoo. *Internatl. Zoo Yearbook* 18:89-91.
- Cott, H. B. 1961. Scientific results of an inquiry into the ecology and economic status of the Nile crocodile (*Crocodylus niloticus*) in Uganda and Northern Rhodesia. *Trans. Zool. Soc. Lond.* 29:211-337.
- Cuvier, G. 1880-1824. *Memoires sur les squelettes des crocodiles.*
- Greer, A. E. 1970. Evolutionary and systematic significance of crocodilian nesting habits. *Nature* 227:523-524.
- \_\_\_\_\_. 1975. Clutch size in crocodilians. *J. Herp.* 9:319-322.
- Hara, K., and F. Kikuchi. 1978. Breeding the west African dwarf crocodile at Ueno Zoo, Tokyo. *Internatl. Zoo Yearbook* 18:84-87.
- Helfenberger, N. 1981. Ein Beitrag zur Fortpflanzungsbiologie von *Osteolaemus t. tetraspis*. *Herpetofauna* 11:9-11.
- Inger, R. F. 1948. The systematic status of the crocodile *Osteoblepharon osborni*. *Copeia* 1948:15-19.
- IUCN. 1979. Crocodile Specialists Group Newsletter No. 16:1.
- \_\_\_\_\_. 1984. Crocodile Specialists Group Newsletter 3(1):5.
- King, W. S. 1955. Stumpy crocodile farm. *Niger. Fld.* 18:171-174.
- Knoepffler, L. P. 1974. Faune du Gabon (amphibiens et reptiles) 11 - crocodiles, cheloniens et sauriens de l'ogoue - Ivindo et du Woleu N'Tem. *Vie Milieu* 14:111-128.
- Pooley, A. C. 1982. The status of African crocodiles in 1980. Pages 174-228 in D. Dietz, F. W. King, and R. J. Bryant, eds. *Crocodiles: Proc. 5th Working meeting Crocodile Specialist Group.* IUCN, Gland, Switzerland.
- Schmidt, K. P. 1919. Contributions to the herpetology of the Belgian Congo based on the collection of the American Museum Congo Expedition, 1909-1915. Part 1. Turtles, crocodiles, lizards and chameleons. *Bull. Amer. Mus. Nat. Hist.* 39:385-624.
- Sims, K. J., and J. Sing. 1978. Breeding the west African dwarf crocodile at Kuala Lumpur Zoo, with observations on nest construction. *Internatl. Zoo Yearbook* 18:83-84.
- Teichner, O. 1976. Breeding the west African dwarf crocodile. *Metro Toronto Zool. Soc. Newsletter* 8(3):4.

- \_\_\_\_\_. 1978. Breeding the west African dwarf crocodile at Metro Toronto Zoo. *Internatl. Zoo Yearbook* 18:88-89.
- Tornier, G. 1901. Die Crocodile, Schildkröten und Eidechsen von Togo. *Archiv f. Naturg.* 7. Jahrg.:65-88.
- \_\_\_\_\_. 1902. Die Crocodile, Schildkröten und Eidechsen von Kamerun. *Zool. Jahrb. Abh. F. System.* 15:663-667.
- Tryon, B. W. 1980. Observations on reproduction in the west-African dwarf crocodile with a description of parental behaviour. *SSAR Contributions to Herpetology* No. 1.
- Villiers, A. 1956a. Un crocodile nouveau pour le Sénégal, *Osteolaemus tetraspis*. *Notes Afr.* 70:80-81.
- \_\_\_\_\_. 1956b. Le Parc National du Niokolo-Koba, Reptiles. *Mem. Inst. Franc. Afr.* 48:143-162.
- \_\_\_\_\_. 1958. Tortues et Crocodiles de l'Afrique Noire Francaise. *Inst. Franc. d'Afr. N. Initiations Africaines* No. XV Dakar.
- \_\_\_\_\_. 1959. Crocodiles de l'Afrique Noire Francaise. *Nature (Paris)*. 3287:126-131.
- Waitkuwait, W. E. 1981a. Untersuchungen zur Brutbiologie des Panzer-krokodils (*Crocodylus cataphractus*) im Tai-Nationalpark in der Republik Elfenbeinküste. *Dipl. Arbeit Uni Heidelberg*.
- \_\_\_\_\_. 1982c. Investigations into the breeding biology of the slender-snouted crocodile *Crocodylus cataphractus*. Paper contributed to the Symposium on Crocodile conservation and utilization and 6th working meeting of the Crocodile Specialists Group. Victoria Falls, Zimbabwe.
- \_\_\_\_\_. 1985. Investigations of the breeding biology of the West-african slender-snouted crocodile *Crocodylus cataphractus* Cuvier, 1824. *Amphibia-Reptilia* 6:387-399.
- \_\_\_\_\_. 1986. Contribution à l'étude des crocodiles en Afrique de l'ouest. *Nature et Faune* No. 1 Abidjan.
- Wilson, C. 1977. Memphis Zoo hatches west African dwarf crocodiles. *AAZPA Newsletter* 10(10):8.

## ECOLOGY OF THE MUGGER CROCODILE

Rom and Zai Whitaker

Madras Crocodile Bank  
Madras, India

**Distribution and Status.**-- The mugger crocodile (*Crocodylus palustris*) has a roughly triangular range. In the west they are found in southeastern Iran in the Sarbaz River where there are probably fewer than 50 left. Eastwards, in Pakistan, their position is also precarious where perhaps less than 100 survive in two or three localities including a manmade lake and the Nara Canal. The once famous captive groups at the sacred Muslim shrine, Mango Pir near Karachi now consists of just a few individuals.

In Nepal there are small populations of mugger in several of the tributaries of the Ganges that cross the "terai", the plains at the base of the Himalayan foothills. These include the Karnali in the west and the Rapti/Narayani which flows through Chitawan National Park.

In Bhutan there may have been a few mugger in the cold Manas River, but like the gharial it is extinct there now. In Bangladesh are 5 individuals living in a sacred tank at Bagerhat near Khulna.

Sri Lanka has more mugger than the rest of the subcontinent put together, mostly concentrated in the two large National parks, Yala and Wilpattu. There were an estimated three thousand mugger in Sri Lanka in 1977 but there has been no follow-up survey since then. Rapid agricultural and industrial development are putting mugger under the same pressure that led to their extirpation in India.

In India mugger were once widespread and common, living in a wide range of habitats. India has few freshwater swamps and the species name *palustris* is not really appropriate. The mugger is now rare throughout its Indian range but is still found in rivers, reservoirs, tanks (man made lakes), jungle ponds, irrigation channels and streams. The highest elevation recorded for a mugger is at 420 m in Corbett National Park. Table 1 gives a state by state breakdown of mugger status in India.

**Historical Record.**-- The mugger figures in Hindu mythology and the local myths of many groups and tribes of people in India. Makara is the Sanskrit name for the mugger and is the vehicle of the rain god Varuna. The mugger is the unlikely totem of the Mogri people in a part of Gujarat where a live mugger hasn't been seen for at least two generations. The mugger is often depicted as being the vehicle of the river goddess Gangadevi, a benign aspect which is a welcome relief from the usual deadly approach.



Table 1. Mugger in India

	Mugger in the past	Wild mugger now excluding hatchings)*	Rearing projects	Captive mugger	Release
Jammu & Kashmir	?	NIL	--	--	--
Himachal Pradesh	NIL	NIL	--	--	--
Rajasthan	YES	100+	YES	300+	10
Punjab	YES	NIL	--	--	--
Haryana	YES	NIL	--	--	--
Uttar Pradesh	YES	100+	YES	100+	50
Bihar	YES	100+	YES	100+	50
West Bengal	YES	20+	YES	--	--
Sikkim	NIL	NIL	--	--	--
Assam	YES	FEW	--	--	--
Tripura	?	NIL	--	--	--
Mizoram	?	NIL	--	--	--
Nagaland	?	NIL	--	--	--
Manipur	?	NIL	--	--	--
Orissa	YES	200+	YES	200+	75
Andhra Pradesh	YES	300+	YES	400+	250
Tamil Nadu	YES	200+	YES	3000+	210
Kerala	YES	100+	YES	100+	--
Karnataka	YES	100+	YES	50+	--
Goa	YES	NIL	YES	FEW	--
Maharashtra	YES	100+	YES	100+	15
Gujarat	YES	300+	YES	500+	--
Madhya Pradesh	YES	100+	YES	--	25
TOTALS		1720		4850	685

\*Estimates only

Makara often appears on Indian temples as gargoyles and may be fused with the body and feet of another animal, typically a lion. A stone crocodile devours a fish in one prominent carving at the Sun Temple in Konarak, Orissa (Fig. 1).

Till recent decades crocodiles used to inhabit temple tanks in Kerala where they remained unmolested never bothering human bathers. Similarly, mugger were common in most of the North Indian rivers and Kipling in his story "Mugger Ghat" makes ironic reference to their cleansing presence in rivers into which hundreds of human corpses are still consigned each week.

Today the traditionally amicable relationship between man and mugger can rarely be illustrated in India; mugger are too scarce. In Sri Lanka, however, there are many places where people bathe in "crocodile infested waters" without fear. The occasional attacks that occur have invariably been attributed to saltwater crocodiles. Mugger attacks may sometimes happen but these are likely to be cases of mistaken identity or mispredation.

There were enough hide hunters and sportsmen with few reverent feelings for crocodiles to reduce them to shreds in the first half of this century. By the 1960s mugger were only holding out in a few reserves or very remote areas and in 1974 the total population of wild adult mugger in India was probably under 1000.

**Feeding Habits and Role in the Environment.**-- As we have already indicated, mugger are a more "socially acceptable" species of crocodile, some of which will routinely attack man.

Their food in the wild has been little studied and what is known is summarized in Table 2. Dunbar Brander (1927) lists animal remains which he found in mugger shot by him; men, leopards, wild dogs, hyaenas, spotted deer, sambar, nilgai, four-horned antelope, barking deer, monkeys, dogs, goats, calves, pigs, ducks, storks, and other birds. The remains of mammals and hard-bodied insects are frequently recorded partly because of the hair, hooves and chitin which are relatively easy to detect. Remains of fish, frogs and reptiles are harder to see yet may form the larger part of the mugger's diet in some areas and in some seasons.

One sample of 60 mugger scats collected at the rice-growing area of Vakkaramani, Tamil Nadu indicated selective hunting for rats during the period (May) rats must live close to water (Table 3). Crocodiles can therefore be unlikely, but effective agents of pest control.

In general, the mugger's role in nature is as master predator of its aquatic environment. The implications of this role to man was described by Cott (1961) in a classic study on the Nile river system in Africa. There, wherever crocodiles were exterminated the Tilapia fishery declined; precisely the opposite of what was intended by ridding the rivers of this predator. What was not realized, however, is that crocodiles control the numbers of the voracious catfish which feed predominantly on the eggs and young of the commercially more desirable Tilapia.

Here in India such studies have been made. However, there is a made to order study area in the form of Amaravathi Reservoir in Tamil Nadu. Stocked with the exotic *Tilapia mossambica* in the 1950s it had the highest fish yield per acre in the state and possibly the entire country by the 1970s. Amaravathi has plenty of cormorants, turtles, otters and other fish predators including crocodiles. It has south India's largest wild breeding population of crocodiles which is no coincidence and certainly indicates the positive effects of crocodiles on commercial fisheries.

As master aquatic predator, the mugger helps raise genetic quality by feeding on weak, sick and injured fish, birds and mammals. As a scavenger the mugger probably once played a role in keeping the rivers clean, feeding on human bodies and animals carcasses.



Figure 1. Stone crocodile at the Sun Temple, Konarak, Orissa, India.

Table 2. Food Item Found in Stomachs of or Observed Being Eaten by Mugger.

Food Item	Reference
Water beetles, water bugs	D'Abreu, 1915
Winged termites, moths, beetles	Authors, pers. obs.
Snails, bivalves	D'Abreu, 1915
Frogs: <i>Rana</i>	D'Abreu, 1915
Fish: <i>Tilapia</i> , <i>Chela</i> , <i>Mystus</i> , <i>Bagarius</i> , eel	Various authors & pers. obs.
Snakes: <i>Ptyas</i> , <i>Xenochropis</i> , <i>Vipera</i>	Whitaker & Whitaker, 1984
Birds: Egrets, herons, kites, waterhens, peacocks, dadchicks, pigeons	Various authors
Mammals: monkey, otter, dog, rats (and see text)	Authors, pers. obs.

Table 3. Contents of Scats Collected at Vakkaramari, Tamil Nadu.

Prey remains	% occurrence
Fish scales	10%
Lesser bandicoot hair	100%
Gerbil hair	20%
Watersnakes scales	10%
Bird feathers	10%

Small mugger have been regularly observed feeding on insects attracted to lights put over the hatchling pens. They are agile and often catch moths and flying termites on the wing. Large mugger have been observed catching monkeys, dogs and brahminy kites. When pools are drying out mugger are seen to "herd" fish by moving slowly sideways and locking them off in small inlets. The mugger will gradually shrink the area until the fish start darting and leaping in panic. Many of the fish try to escape via the only opening available-the open mouth of the mugger-and are caught.

Like other crocodiles a healthy mugger may go for months without food. Because of common droughts in the range of the mugger, it may have no access to food for long periods. But this cycle of periodic drought is a dynamic one for crocodiles, the most dramatic examples of which can still be observed in parts of Sri Lanka. In and around Yala National Park in the south, most of the tanks (man made lakes) dry up each year. Huge concentrations of fish are confined to smaller and smaller areas which crocodiles sometimes walk overland considerable distances to visit and gorge themselves. This short, sudden surfeit of fish can tide over the mugger for months to come if necessary. Walking overland is also a strategy to find water and the authors have found mugger in dry, thorny scrub jungle, apparently headed for permanent water many kilometers away. Tunnelling is another favorite mugger strategy to beat the heat. Nineteen mugger tunnels were found at Hiran Lake in Gujarat one drought year (1975). They had flattened entrance holes averaging 75 cm across and most were 2 meters to 4 meters deep. Stream dwelling mugger use tunnels as year round residences, preferring embankments with heavy root systems.

## REPRODUCTIVE BIOLOGY AND RESEARCH

**Sexual Maturity.**-- Female mugger of 1.8 meters lengths and others of 6 years 8 months of age (2.2 m) have laid fertile eggs. However, smaller and younger females (1.6 m, 4 1/2 years) have laid infertile eggs and are likely to be able to breed at the age and size under some circumstances.

**Timing of Breeding Season.**-- The period between and including courtship, mating, nesting and hatchling of young extends from November to June in South India. Courtship and mating commence in November coinciding with the north-east monsoon, nesting in February with the beginning of the dry season, hatchling with the height of the dry season and the beginning of the south-west monsoon (April-June) (see Fig. 2). In northern India the breeding cycle tends to be one month later. At Jaipur Zoo, Rajasthan from 1967-71, occurred between 26 June and 6 July. In Sri Lanka, June-July are reported as the laying months and August-September the hatchling months for mugger.

**Territoriality and Dominance.**-- Although fighting sometimes occurs on the introduction of a new individual in an established captive group, mugger are fairly tolerant of conspecifics, particularly during the seasonal concentrations which occur in the dry season. During the breeding season both sexes become increasingly territorial. The dominant male asserts his dominance by swimming displays in the 'tail up' position, head-slapping and chasing and biting subordinate males, sometimes onto the shore. This behavior has been recorded for males of other species as well, such as *Crocodylus novaeguineae* and *C. niloticus*. D'Arbreu (1915) noted that large wild mugger "usually" have shortened tails, some missing the terminal 9-10 segments. This is not the case with most wild mugger observed today and could be a indication of much less frequent interaction (i.e. chasing and fighting) among the adults of once large and concentrated populations.

Roaring or bellowing has rarely been heard in mugger but it is reported in the literature; this vocalization is likely to be a territorial signal as it is in the American alligator.

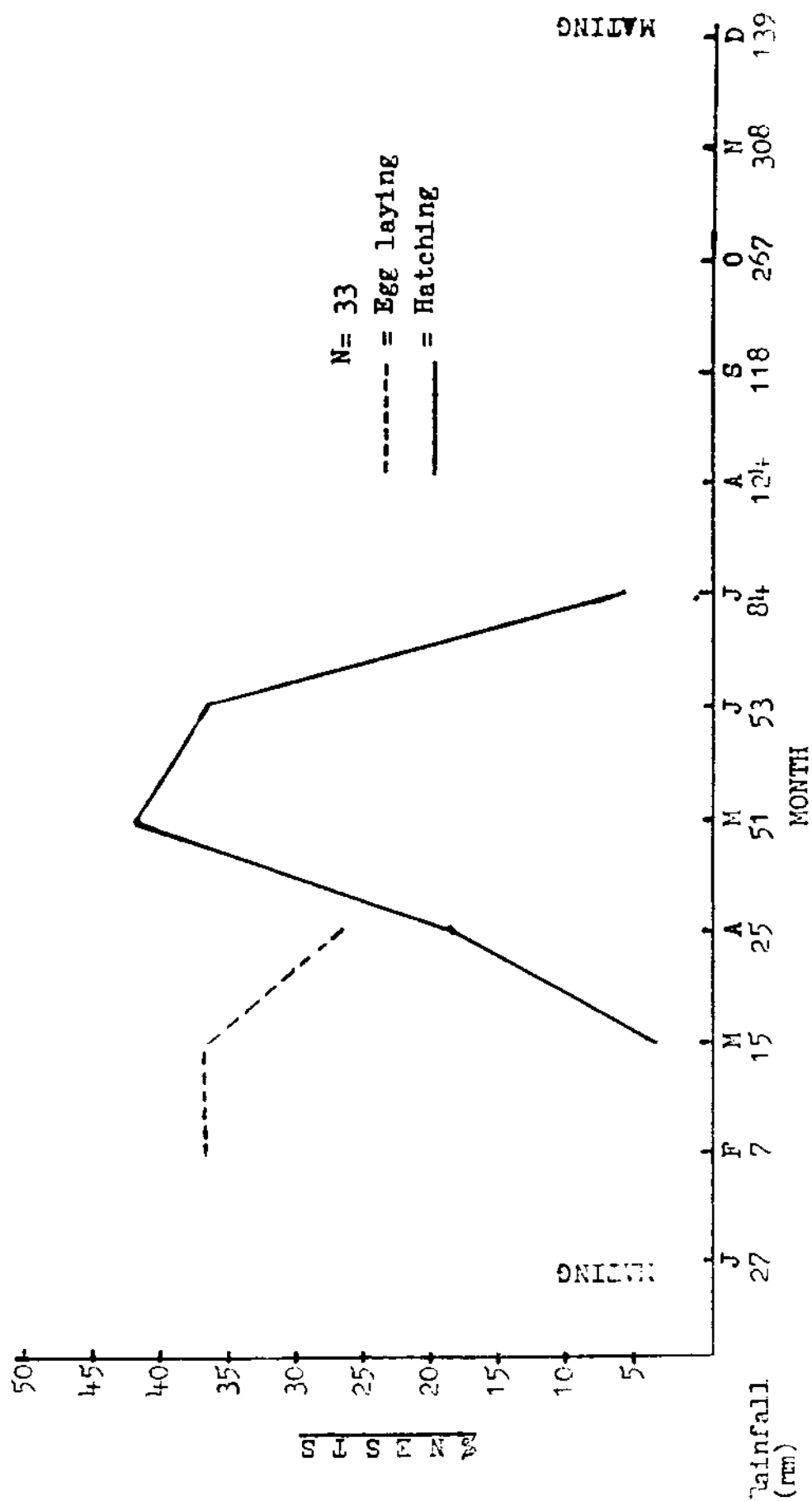


Figure 2. Timing of mugger breeding season.

A raised, threatening posture, called 'slimming' by Garrick et al. (1978) is frequently observed in captive juveniles and subadult males. The animal raises its body by fully extending its legs, sometimes slightly compressing its body laterally and breathing deeply. This is occasionally initiated by the approach of another mugger to a favored basking spot but also by apparent individual rivalry and seems to be an early manifestation of the establishment of social hierarchy. This posture is rarely used when confronted by an animal (or human), the most common threat then used being a raised forebody with open mouth, hissing and leaping forward if cornered or further threatened. A challenged, subdominant mugger of either sex may run or raise the head in submission, often accompanying the signal with a low, openmouthed gurgling sound. Other behaviors observed in mugger which are possible social signals include 'yawning' and 'ear flapping'.

**Courtship and Mating.**— Often a headslap by a male (which starts from the head up position) signals approach and courtship. Male approach to a female prior to courtship is usually in the tail-up position, with pointed, single caudal scales arched well out or slightly out of the water. Following a head slap, geysering may be observed as described by Garrick et al (1978): "a stream (spout) of water about 10 to 20 cm in height resulting from a release of air from the external nares while the snout is just under the surface of water".

During courtship, circling, bubble blowing, raising and touching jaws is usually observed. Figure 3 provides a summary of these behaviors.

Females were observed bubbling at times other than during mating and it is perhaps a courtship signal. Female mugger occasionally head-slap in answer to males as do *Alligator mississippiensis*, and were twice observed to roll over in the water, exposing the belly as reported by Cott (1961) for *C. niloticus*.

During one courtship sequence a female mugger was observed repeatedly mock biting the male's head. When the male mounts the female the pair submerges, often surfacing and submerging alternatively. Mating progresses while they are fully or partially submerged. Copulation lasts from five to fifteen minutes. During courtship and mating a high degree of tolerance is shown toward other animals. Adult females and a sub-adult male were seen circling, nudging and in intermittent physical contact with a pair during courtship on several occasions. Courtship and mating were always observed in water though copulation on dry land was recorded at the Jaipur Zoological Gardens. At Madras Crocodile Bank a male mounted and made repeated copulation attempts on a female in the act of nesting.

On several occasions during courtship the throat glands of females in the head-raised posture were briefly everted and withdrawn. It is likely that the scent glands function in some attraction and stimulatory capacity during pre-mating courtship. Prater reported that the scent glands in the throat and vent secrete a brownish liquid with a musty odor. He feels that the secretion is most active during the mating season and postulates that its release in the water enables individuals to find each other. This secretion has been observed as a waxy brown substance but seems to have very little detectable odor.

Dharmakumarsinhji (1947) made the first observations on breeding of wild mugger. He described the tail up and head emergent posture of the female prior to copulation. His observations agree with those of the authors, including the submerging, re-emerging cycle seen during copulation.

**Nest Construction and Egg Laying.**— The female digs a body pit with alternate scraping of all four limbs and the nest hole with alternate scooping motions of the hind limbs. Nest hole digging

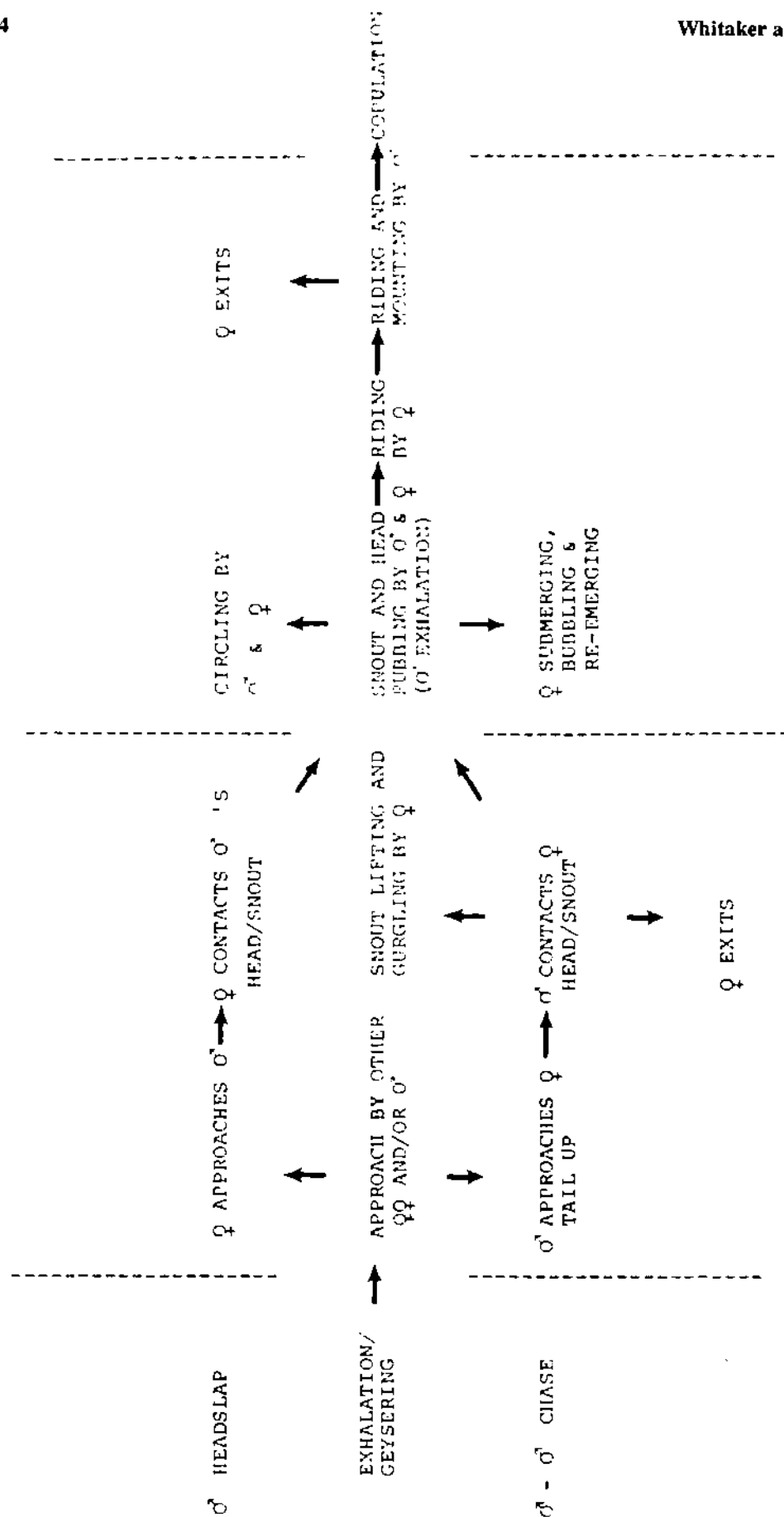


Figure 3. Summary of mugger courtship behavior (after Garrick and Lang 1977).



may take 30 to 60 minutes after which the female straddles the hole and lays her 26 to 30 eggs in about 20 minutes.

After laying, the female may insert both feet into the egg chamber and gently push the entire clutch to the back of the cavity of the L-shaped hole (Fig. 4). For this manoeuvre and while nest-packing the tail and chest are used for support. She then begins a slow scratching with alternate movements of her hind legs, gently pushing sand into the nest hole. Sand is scraped over the nest and periodically packed by treading with the hind feet, then she may start turning on her nest, making a number of full circles, completely flattening the nest area.

During wild egg collection programs, in field study and surveys over 50 wild nests were observed. Tables 4 and 5 give some of the physical characteristics of the nests. Hole length apparently corresponded to the length of the female mugger's hind leg. In most nests the soil at the egg cavity level was damp.

Locations included artificial reservoirs without shade, small densely vegetated streams, and tidal lagoons. At Amaravathi Reservoir the tracks of a mugger were followed into a hilly scrub forest over 1 km from the reservoir to where a 2.4 m female was found. She later nested here but unsuccessfully, as the soil was too shallow. This unusual nesting behavior was postulated to be due to the excessive human disturbance in the area (before protection, 90% of the eggs were taken each season by herdsmen and firewood collectors). At Amaravathi, nine out of eleven nests were situated on slopes facing east.

At Amaravathi, Kilikudi and Sathanur, trial nest holes were a common feature near nests. Mugger usually dig one or more trial nest holes before making the final egg chamber. At Vakkarameri a female was seen making a trial nest in daylight and 2-3 trail nest holes were found for each nest.

**Clutch and Egg Size.**-- Mugger lay 25-30 eggs; details of clutch sizes in different localities are given in Table 6. Clutch sizes were similar in north and south Indian nests. The average size of 340 eggs from wild nests in south India was 7.7 x 4.7 cm and weighed an average of 128 gm, closely corresponding to captive bred eggs measured at Madras Crocodile Bank (MCB).

**Incubation Period and Nest Temperature.**-- In captivity mating begins about two months before the first egg laying, suggesting a developmental period of 40-60 days. Incubation of mugger eggs averages about 2 months. Nest temperatures in wild nests in south India ranged from 18°C at 6 AM to 33°C in early afternoon. In 1980 the overall nest temperature average at MCB was 31.3°C for the four months of February - May.

**Multiple Clutches Per Season.**-- When double clutching was first observed at MCB in 1976 in a 19 year old female (Nova) it was thought to be exceptional or aberrant behavior. Since then however, the laying of two clutches per season has become the norm for 6 females. Table 7 illustrates the details of the multiple nesting which occurred in 1979-1985. Clutch size and hatching success were slightly lower in 'B' nests. The mean distance between A and B nests was 22.5 m, while nests of different females averaged only 5 m apart.

Double clutching at MCB may be a result of the combination of high temperatures and high feeding rates. There seem to be three possibilities which might explain the phenomenon:

- a) single mating with arrested development of second clutch
- b) single mating and storage of sperm
- c) double mating

Crocodylus palustris  
EGG PLACEMENT WITHIN NEST

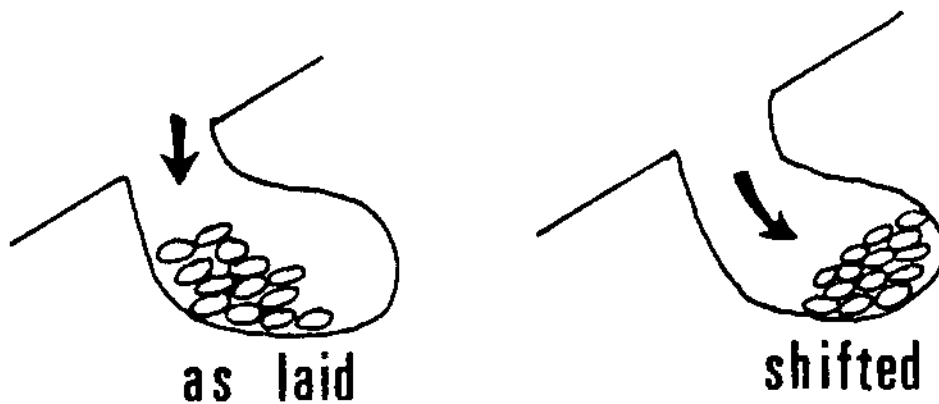


Figure 4. The female uses her feet to shift the egg clutch to the back of the nest cavity.

Table 4. Data on 50 Wild Mugger Nests in Tamil Nadu.

Hole length (cms)	Hole width (cms)	Distance from water	Height above water line (m)	Layer of sand/earth covering eggs (cms)
35 - 56	22:14-31	10m:1m-2km	6.2:1.5-10	19.5:13-26

Table 5. Soil Type and Shade at 59 Wild Mugger Nest Sites (% Nests).

Gravel/sand	Sand	Black clay	Loamy soil	Humus
37	34	17	10	1.7
Unshaded	Partly shaded	Fully shaded		
86	7	7		

Table 6. Clutch Sizes of Mugger Nests.

Place	N	Clutch Size x : range
Sathanur reservoir, Tamil Nadu	5	27:17-35
Amravathi reservoir, Tamil Nadu	11	31:26-35
Vakkaramari, Tamil Nadu	3	32:18-46
Kilikudi, Tamil Nadu	3	19:16-21
MCB (9 females)	49	24: 8-39
Hiran Lake, Gujerat	2	25
Powai Lake, Maharashtra	1	17
Jaipur Zoo, Rajasthan	5	32:22-41
TOTAL	79	26: 8-46

Table 7. Number of Females Double Nested 1979 - 1985 (MCBT).

Year	Number of females nested	Total number of nests	Number of females double nested
1979	7	13	6
1980	11	15	6
1981	9	16	7
1982	12	15	4
1983	9	12	3
1984	12	20	6
1985	18	27	9

Sporadic mating of mugger is observed late in the season (March/April) and more recently a second peak similar to the December activity has been noted. While the period of egg development in first and single clutches appears to be about 60 days there was an average of only 41 days between first and second nests. There is no evidence of double clutching in wild mugger and indeed has not been observed as a normal strategy in any other crocodilian. The implications of double clutching for commercial farming are obvious, whether it could be of some survival value for wild mugger is a matter for conjecture. There may be a complex relationship between double nesting and temperature determined sex (see Research); a strategy that could enhance survivorship of hatchlings during a drought year.

**Protection of Nest.**-- Nest defense has been observed both in the wild and in captivity. At MCB nesting females defended nest sites and adjacent water areas and engaged in threat displays. They often thrashed their tails from side to side and made repeated serious charges at intruders, both crocodilian and human. If undisturbed the female will spend most of the incubation time at her nest and in the water near by. One female fasted throughout incubation, while other, younger females were less attentive to nests and did not fast. An MCB employee, checking early morning nest temperatures was attacked and badly bitten by a nest guarding female. Now temperatures are recorded electronically.

The role of the male mugger in nest attendance was recently observed at MCB. The male *C. niloticus* takes part in nest excavation and hatchling transport as does the New Guinea crocodile. In 1985 the adult male of pit 8 (Makara), was observed excavating a nest, transporting hatchlings to the water and excluding all of the adult females from the vicinity (Fig. 5).

**Hatchling, Release and Transport of Young.**-- The following observations were made on a captive female at Madras Snake Park and typify activity at a mugger nest upon hatching.

A female was observed at 0100 excavating her nest with her front feet and head, leading 6 hatchlings to the pond 6 m away, and communicating with them by grunting. She later excavated 5 more young and they were heard calling sporadically all night. At 0900 the female chased the keeper from the enclosure. She pushed hatchlings out onto the palm leaves outside the pool with her snout.

At 0950 the male was with the hatchlings in the main pond and the female in the adjacent pond. The female picked up a hatchling in her mouth and carried it to the main pond, shaking it out of her mouth where the other hatchlings, were grouped.

At 1010 she went again to her nest (in response to the muted grunt of another hatchling) and dug with her front and (less often) hind feet. She moved clockwise over her nest, sometimes putting her nose in and biting clods of earth.

An egg was removed with the jaws, jerked back, and gently punctured by the front teeth. The hatchling slipped into the buccal pouch, squirming. She brought it, tail visible between her teeth, to the pond. It was observed that the hatchlings spent the first day almost entirely on dry land.

At 1100 another hatchling was picked up at the nest by the female and brought to the same spot next to the pond.

**Creche Formation and Defense of Young.**-- In one captive group 13 hatchlings remained in the group or creche initially formed by the female for two months. They stayed with the male and female for 12 months through the next breeding season and no aggression toward the young on the

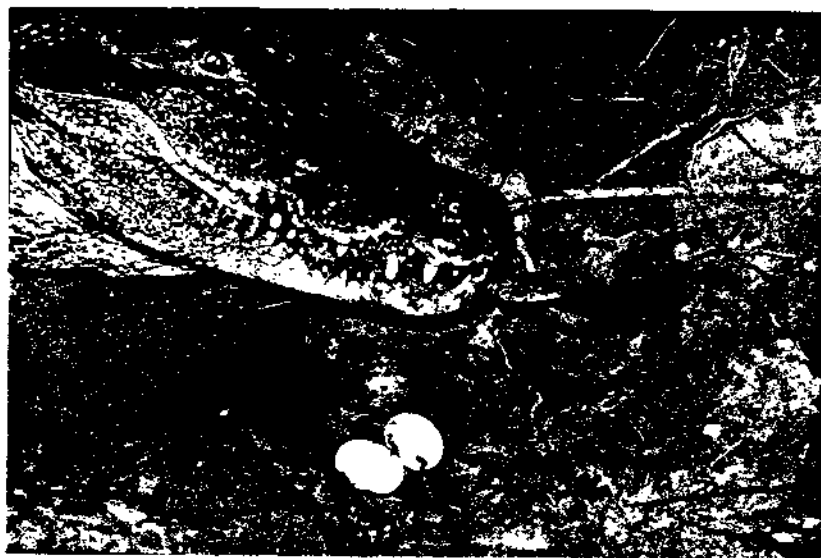


Figure 5. Male mugger transporting young from nest (photo: Jeff Lang).

part of either was observed. Groups of hatchlings were reported several times by fishermen and others and wild creche groups of mugger hatchlings were found by the authors at Kedarhalla in Tamil Nadu, and at several places in Sri Lanka.

At MCB during capture of hatchlings from undetected nests, mature males, females and sub-adult males will make repeated lunges and charges out of the water and almost over the 1.5 m wall. Wild mugger, apparently of both sexes, responded to distress cries mimicked by us by approaching, leaving the water and charging.

**Conservation and a Future for the Mugger.**-- Realization that the mugger was on its way to oblivion on the Indian subcontinent came just in time. Surveys carried out by the Zoological Survey of India, Bombay Natural History Society and Madras Snake Park startled the environmental community when results showed how few mugger were actually left. South India's largest wild breeding population, at Amaravathi reservoir in Tamil Nadu, had a mere 14 breeding females. The largest population in the north, at Hiran lake in Gir National Park, had perhaps 20 breeding females.

Tamil Nadu has taken the lead in producing large number of captive hatched mugger from eggs collected at the wild nesting sites with perhaps 6000 eggs collected since 1977. Survival rates of eggs and hatchlings have been variable but are somewhere in the region of 30 to 60% from available data.

Mugger from Tamil Nadu have been sent to a number of states for restocking, an activity that was questioned from the standpoint of mixing different geographic forms of mugger. However, to establish and re-establish wild breeding populations was the first urgent priority and in most cases there were not even remnant populations remaining at the restocking sites.

Because of the lack of input on the field research and public relations side of mugger conservation it is getting more and more difficult to find release sites. In Tamil Nadu, objections from the State Fisheries Department, Public Works Department (dams) and local fishermen have effectively blocked several restocking proposals. Arguments that mugger are good for commercial fisheries by eating predators and won't hurt dam maintenance crews are simply not supported by scientific studies and the right public education.

**Research.**-- The Government rearing centers and the Madras Crocodile Bank have been carrying out research on the mugger since the early 1970s. Some of the basic findings have already been described but there are a number of other avenues of work not yet given much airing.

For example, mugger are now known to use the gaits described as the high walk and gallop as do better known species like the Nile crocodile. Recent work at the Madras Crocodile Bank has demonstrated that the sex of the mugger is determined in the egg. Temperature is the key factor, as has been found for other crocodilians and many turtles species. In the case of the mugger, higher temperature produce males which is reflected in the overall sex ratio averages for three years breeding at the Bank. Eggs laid in the cooler month of February had 7% males, in March 32% males and those laid in April, the hottest month, 45% males. Continuing research will eventually determine the exact temperatures that produce males and females and the critical period of embryonic development in which sex is determined. Other studies include behavior analysis and its relation to environmental parameters and the phenomenon of double clutching.

**Crocodile Management.**-- But the entire FAO/UNDP and Government input into crocodile conservation in India was not only to halt the extinction of the species. Conservation demands a dynamic full circle approach to caring for wildlife, that's when it becomes management.

Table 8. Captive Breeding of Mugger in India.

I. Zoological Parks	Breeding since	Total stock reared
Ahmedabad	1960	250+
Baroda	1964	?
Bannerghatta	1984	?
Delhi	1976	100
Goa	1983	?
Indira Gandhi Park	1978	150
Jaipur	1960	300+
Kanpur	1985	?
Madras Snake Park	1975	150
Nandankanan Park	1982	100+
Nehru Park	1980	150+
<u>II. Crocodile Rearing Centers</u>		
Madras Crocodile Bank	1976	1800+
Tikerpada, Orissa	1982	100+
Silipal, Orissa	1983	50+
Hyderabad, Andhra Pradesh	1984	50+
Sathanur, Tamil Nadu	1983	50+
Amaravathi, Tamil Nadu	1983	50+
Guindy, Tamil Nadu	1985	?
Kukkrail, Uttar Pradesh	1985	?
TOTAL		3300+



Table 9. Egg Collection and Rearing Centers for Mugger in India.

India	Year commenced	Number of eggs collected	Number of muggers reared
Hoganakal, Tamil Nadu	1976	800+	500+
Amaravathi, Tamil Nadu	1977	2000+	1200+
Sathanur, Tamil Nadu	1976	2000+	1500+
Guindy, Tamil Nadu	1977	500+	100+
Gir, Gujarat	1977	1500+	600+
Hyderabad, Andhra Pradesh	1977	900+	500+
Neyyar and Parambikulam, Kerala	1977	300+(?)	150+(?)
Taroba, Maharashtra	1979	200+	75+
Others	--	200+	50+
TOTALS		8700+	4775+



Figure 6. The mugger.

Mugger are resources to be managed. There is a thoughtful but slightly unrealistic attitude by a vocal segment of people living in the range of the mugger that crocodiles should not be farmed or culled. What is becoming more and more easy to demonstrate is that this attitude can be certain death to wildlife species that compete with or even seem to compete with man in any way.

Mugger have had little positive publicity. The only mystique surrounding them is that from the horror stories. They elicit fear and loathing from most people and are probably second only to snakes in lowness on the animal popularity poll. Without some very strong economic (and perhaps secondly, ecological) motives to save and propagate mugger, there is little likelihood of drumming up sustained support for the cause, particularly here in India. The harshness of living conditions for several hundred million people seems to leave little scope for worrying about the future of the mugger. In fact it is remarkable, a considerable credit to the late Prime Minister, Indira Gandhi, that crocodile conservation has received the attention it has in India.

The merits of a closed cycle mugger breeding operation or a ranching scheme is beyond the scope of this chapter and is discussed elsewhere. It is true that mugger are ideal candidates for propagating for skins and by-products. A single female can produce an average of 20 surviving offspring per year, each of which would be worth Rs. 1500/- in the third year. Thus a female mugger's annual "production" is worth about Rs. 30,000/- (US \$2500).

The Government of Tamil Nadu was given the first go ahead signal for commercial farming by the Indian Board for Wildlife in 1982 but the project is not yet underway. While divergent opinions will continue to exist, no one can dispute the fact that the mugger has a better chance surviving in large numbers as a managed resource than as a generally unwelcome predator (Tables 8 and 9).

#### ACKNOWLEDGMENTS

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#### LITERATURE CITED

- Cott, H.B. 1961. Scientific results of an inquiry into the ecology and economic status of the Nile crocodile (*C. niloticus*) in Uganda and Northern Rhodesia. Trans. Zool. Soc. London 29:211-356.
- D'Abreu, E.A. 1915. Notes on the mugger (*C. palustris*) contents of their stomach, folklore, etc. J. Bombay Nat. Hist. Soc. 37:202.
- Dharmakumarshinhji, K.S. 1947. Mating and the parental instinct of the marsh crocodile. J. Bombay Nat. Hist. Soc. 47(1):174.
- Garrick, L.D., J. W. Lang, and H. A. Herzog, Jr. 1978. Social signals of adult American alligators. Bull. Amer. Mus. Nat. Hist., 160(3):153.

- Whitaker, R. and Whitaker, Z. 1984. Reproductive biology of the mugger. *J. Bombay Nat. Hist. Soc.* 81(2):297-316.

## STATUS AND CONSERVATION OF THE ASIAN CROCODILIANS

Rom and Zai Whitaker

Madras Crocodile Bank  
Madras India

### INTRODUCTION

The eight species of Asian crocodilians have declined drastically in numbers, especially in the past 25 years. The story of their extermination is now into what could be the final chapter. Of the eight only the New Guinea crocodile is still fairly common in the wild. Intensive hide hunting managed to shift the focus from Africa to Asia and then South America as each area dried up (Fig. 1). Often there has been a second or third round of mopping up where a second, "inferior grade" species was available or when remote areas were opened up. Areas such as the island of Borneo, now split between Malaysia, Indonesia and tiny Brunei, which still contain large tracts of unsettled land, have only fragments of once substantial *Crocodylus porosus* and inland *Tomistoma* populations.

There is little accurate documentation of skin harvests of Asian crocodilians but what recent statistics are available are given in Table 1 to put into perspective what a profitable industry crocodiles could be for many indigenous peoples if used as a properly managed resource. Ross (1982b) asks a key question: "How do we integrate a policy dealing with an animal which is potentially dangerous, disliked and lives in areas suitable for fish ponds and rice paddy without completely eradicating it?"

For the purpose of this chapter, "Asia" is defined as ranging from the mugger habitat of Iran eastward to the Indonesian border with Papua New Guinea.

### THE ASIAN CROCODILIANS

#### *Crocodylus palustris* -- Mugger, marsh crocodile

The mugger has the widest range of any of Asian freshwater species. It is highly adaptable and occupies a variety of habitats including hill streams and saltwater lagoons. In Iran, Pakistan, Nepal and Bangladesh there are very few left and with the exception of those in the few protected areas there is little future for the mugger in these countries. If considerable effort was made to rehabilitate the mugger, combined with stringent habitat protection and perhaps a commercial motive in these four countries, the mugger would have the chance of making a limited comeback.

In India the mugger has been fully protected under the Wildlife Protection Act to 1972 and is the subject of a conservation program that began in 1975. Nearly every state had at least a few

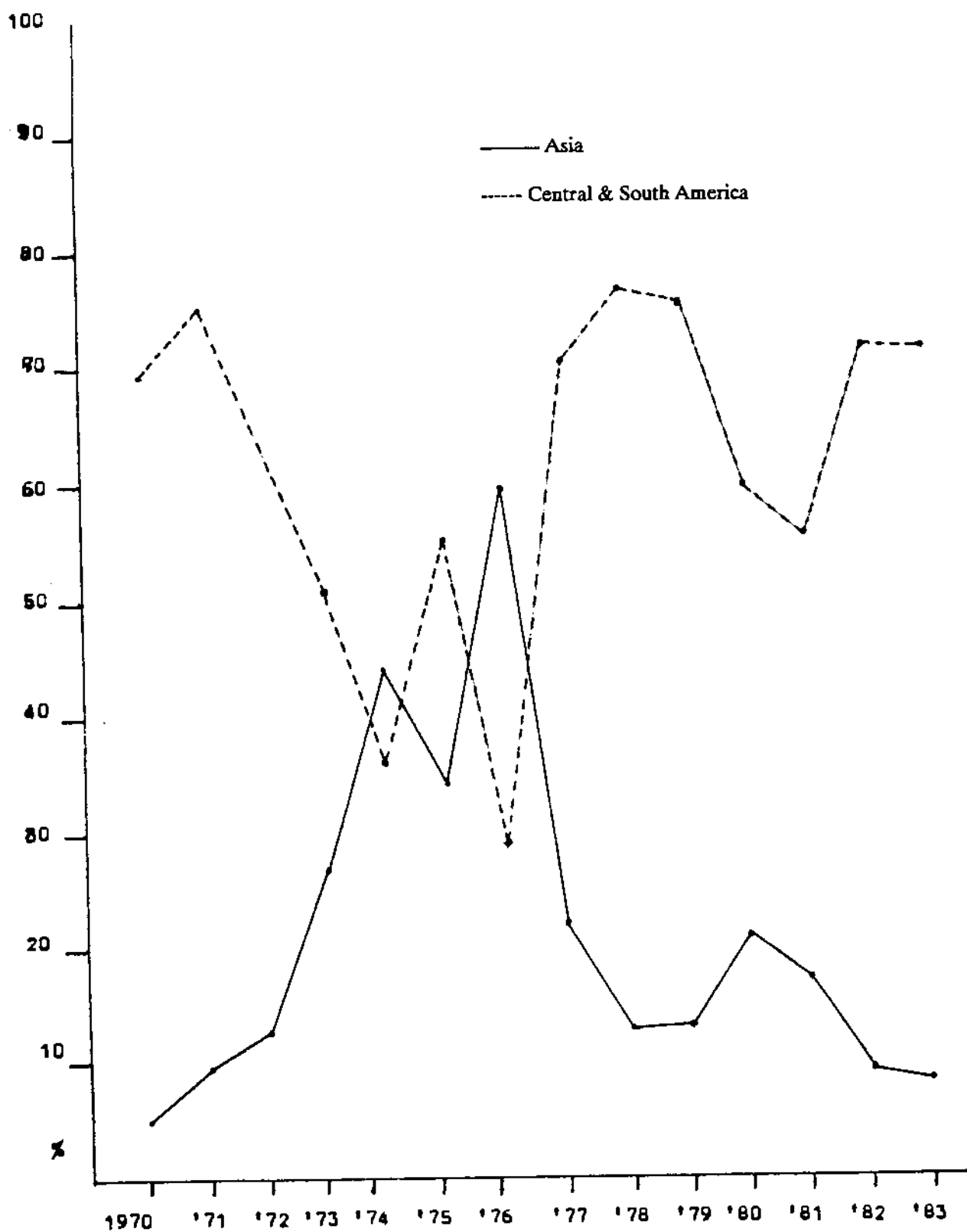


Figure 1. Rise and fall of the Asian crocodile skin trade since 1970 (courtesy of Tom Milliken, TRAFFIC/Japan).

Table 1. The Asian Crocodile Skin Trade (in Kilograms).

Country	YEARS														TOTAL
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	
Singapore	3064	2457	7930	17213	7285	10503	7619	6782	2475	4244	6552	3434	1424	91	80073
Malaysia	3292	5497	2582	1046	289	--	--	260	--	--	--	1357	1000	--	15341
Philippines	688	2568	891	809	617	104	664	353	264	1479	215	110	55	193	7950
Indonesia	770	275	1962	3162	1889	5037	5439	9373	5731	9543	7476	9554	15222	19348	94781
Thailand	--	--	20	--	--	--	2500	--	4576	6035	4008	2885	1299	--	21323
Pakistan	--	--	--	--	--	--	--	--	--	--	64	--	--	--	64
Sabah	--	28	--	--	--	--	--	--	--	--	382	621	100	--	1131
TOTAL	7814	10825	13385	22320	10080	15644	16222	16768	3046	21301	18697	17979	18100	19632	220663

Courtesy of Tom Milliken, TRAFFIC (Japan).

mugger left by the early 1970's but past hunting for skin and meat, collection of eggs for food and loss of habitat made the prognosis for mugger survival look grim.

Now, a decade later, government efforts (in some cases with FAO/UNDP assistance and private input), have secured a future for the mugger in India. At least 17 different zoos and rearing centers in the country have bred mugger in captivity and thousands of eggs have been collected from the wild for captive hatching and rearing for restocking programs. Several sanctuaries have been set up specifically for mugger and one state, Tamil Nadu, has been given Central Government approval to set up an experimental commercial crocodile farm.

In Sri Lanka mugger were common as recently as the late 1970's but were taking a battering from itinerant fishermen who netted them for the meat, discarding the skin. Large reservoir populations of mugger outside of the two large National Parks, Yala in the south-east and Wilpattu in the north-west have been decimated, particularly during drought years. Even now there are tanks (man made lakes) on the periphery of the Parks in which 100 or more mugger can be seen. Meanwhile massive development projects like the Mahaweli Ganga scheme in North Central Province take little note of the importance of the mugger as an economic resource nor of its role in the aquatic ecosystem. Mugger will survive in Sri Lanka's National Parks but it will be unfortunate if nothing is done to ensure that they remain an integral part of the island's remarkable wildlife. The Sri Lankan mugger population offers us the only chance to study an Asian freshwater crocodile in what must be close to original population densities.

#### *Crocodylus siamensis* -- Siamese crocodile

Once reportedly common in parts of Thailand, the Siamese crocodile's range extended to the Indochinese region and parts of Indonesia (Kalimantan, Sumatra, Java). Today the only known wild individuals survive at Bung Boraphet Reservoir in Nakhon Sawan province, Thailand where there may be 50 left.

The Siamese crocodile breeds readily in captivity and the Samut Prakan Crocodile Farm near Bangkok has over 20,00. Here they have been encouraged to hybridize with *C. porosus* though the owner assures us that pure stock is being separately maintained. It has also been bred in at least two zoos in the United States and at this time captivity seems to be where the species will remain.

#### *Crocodylus porosus* -- Saltwater crocodile, estuarine crocodile

The saltwater crocodile has the widest present day range of any crocodilian. Its ability to swim long distances in the open sea allowed it to colonize almost the whole of tropical coastal Asia besides many inland areas. The female produces large clutches of eggs and can be a formidable defender of her nest. But the large size and occasional man-killing tendency of big saltwater crocodiles have worked against the species. In addition, the skin industry prefers the smaller scales and larger surface area of saltwater crocodile skins to any other. More accessible to hunters than the inland freshwater species, saltwater crocodile populations were quickly reduced to remnants by the mid 1960's.

In the extreme east of its range the saltwater crocodile exists in safer numbers than most of the Asian crocodiles. Australia and Papua New Guinea have both spent considerable money and effort on managing their crocodiles and it is paying off, particularly in Papua New Guinea where the million dollar skin industry brings money to the poorest districts with few or no other exportable resources.



Just over the border from Papua New Guinea is the Irian Jaya Province of Indonesia where adult saltwater crocodiles are being rapidly wiped out for skins. In a few locations, important populations such as at the large, peninsular island of Pulau Kimaam near Merauke in the southeast are receiving some protection. From here westwards to India, the situation gets progressively worse. Probably the only significant populations in the entire remaining area of Asia are in some of the more remote inland areas of northern Sumatra (for example Sungai Kuba, Rian Province), the well managed breeding populations at Bhitarkanika Sanctuary in Orissa (India) and in parts of the Andamans and Nicobars (India).

Areas like Sabah and Sarawak on the island of Borneo would seem to be likely repositories of some of the old saltwater crocodile population densities but unfortunately it is not so. World Wildlife Fund sponsored surveys carried out in 1983 by Rom Whitaker and in 1985 by Jack Cox have turned up low density figures of about 0.05 crocodiles per kilometer of river surveyed by night. Much of the area surveyed was uninhabited and still forested and contained habitat capable of supporting much higher densities of crocodiles. Hunting for skins is obviously the most important recent factor for the continued decline of crocodiles here, but as early as 1881 the British Government had been paying rewards for killing crocodiles "to encourage destruction of a pest".

Recommendations for the rehabilitation and management of the saltwater crocodile have been officially made to the governments of Sabah and Sarawak (East Malaysia) and Indonesia. Project proposals based on crocodile ranching and farming have been made in the hopes that aid agencies such as FAO/UNDP and USAID will provide funding and expertise. Major elements in the proposals include detailed surveys, establishment of reserves, crocodile farming, research, and population monitoring programmes. In specific cases, such as Sarawak, any hope of bringing crocodiles back to areas in which they have long been extinct is linked to public relations and the forming of an effective crocodile control team to deal with the occasional nuisance crocodile.

#### *Crocodylus mindorensis* -- Philippine crocodile

Recent surveys and studies by C.A. Ross and A.O. Alcala demonstrate the extremely depleted status of the Philippine crocodile. Hide hiding and now loss of habitat to agricultural development are the main reasons for the decline. It is still found scattered in small numbers in remaining suitable inland habitats, mainly on Mindanao and the Sulu Archipelago. It is estimated, perhaps optimistically, that there are 500 to 1000 left in the world.

As Ross (1982a) noted, "conservation of non-essential wildlife resources is not given high priority in the Philippines; any conservation program which offers some possibility of ultimate utilization is more likely to win support from the government." At present the Philippine program for *C. mindorensis* consists of a World Wildlife Fund aided project of the Silliman University where a small captive group at Dumaguete City are being bred to provide young for release in protected areas.

#### *Crocodylus novaeguineae* -- New Guinea crocodile

A four month survey of the New Guinea crocodile was carried out (October 1984 to February 1985) and over 1500 kilometers covered by boat in the interior of Irian Jaya by Rom Whitaker and his assistants, Paul Sukran of Indonesian Environmental Forum (WALHI) and Chadiz Hartono of Directorate of Forest Protection (PHPA).

During the day villages were visited to interview the people about crocodile natural history, status and the skin industry. At night spotlight surveys were carried out to assess relative numbers of crocodiles and capture of a sample for measuring, marking and release. Visits were made to mission stations and discussions were held with people responsible for rural development in Irian Jaya. Visits were made to the main crocodile rearing farms and skins exporters. A survey of the trash fish resources was also carried out to determine feed availability for crocodile farms. The main crocodile habitats that were visited and surveyed were:

- a) Bian Lakes, Merauke District
- b) Asmat Area, Merauke District
- c) Rouffaer River (Upper Mamberamo), Paniai District
- d) Bintuni Bay, Manokwari District

In addition, the main towns and other areas visited were:

- |             |              |           |
|-------------|--------------|-----------|
| a) Jayapura | d) Kaimana   | g) Sorong |
| b) Merakue  | e) Manokwari |           |
| c) Fak Fak  | f) Nabire    |           |

It was found that crocodile populations have been heavily reduced in the accessible river areas due to overhunting for skins. However, deep inland crocodile populations are more stable.

Some illegal killing of crocodiles and export of their skins continues. In general it was found that the local hunters will respect laws but are induced by the skin traders to organize periodic crocodile hunts. Most of the crocodile farms seen were of a mediocre standard and only one (Skyline in Jayapura) had significant numbers (1500-2000). So far very few skins of farmed animals are being exported.

Village hunters and rural developers all expressed a keen interest in participating in a proposed crocodile project. It was found that there is no other viable long-term alternative to help swamp-dwelling people (about 100,000 of them) to earn a living with cash income. For example, the small-scale timber industry in the Asmat area provides only a small remuneration (Rp. 5000 (US \$5) per cubic meter or about Rp. 10,000 for a large tree) for the hard work of felling and hauling logs along the river. The necessity of extracting timber near the river (in the absence of hauling machines) is causing rapid degradation to the riverbanks. A managed crocodile industry could provide the Asmat villagers with Rp. 10,000 for one baby crocodile, a wiser use of the forest than removal of its timber!

It was found that there are sufficient trash fish resources (the by-catch of the shrimp trawlers) to feed 20,000 crocodiles or more in the towns of Sorong, Jayapura and Merauke.

It was recommended that a project proposal be drafted to initiate a crocodile project in Irian Jaya consisting of three basic components:

- a) large commercial farms at Sorong, Jayapura and Merauke
- b) a network of village collection farms and appropriate rural extension work and
- c) a crocodile population monitoring and research program to assure the sustainability of the industry and conservation of the species.

It was recommended that aid agencies be approached for technical and financial assistance in implementing this project. It was also recommended that the protection of wild adult crocodiles in

Irian Jaya be given priority. The New Guinea crocodile will have a safe future in Irian Jaya if it can become a managed resource upon which a large number of economically depressed people are dependent.

*Tomistoma schlegelii* -- Malayan (or false) gharial

One of the least known of all the crocodilians, *Tomistoma* is rarely seen in the wild anymore and has only been bred in captivity at the Samut Prakan Crocodile Farm, Thailand. *Tomistoma* ranges from southern Thailand across to Borneo and down into Sumatra.

Today *Tomistoma* is apparently absent from southern Thailand and only a few live on peninsular Malaysia. On Borneo the situation may be little better. On a recent crocodile survey in Sarawak for WWF-Malaysia, consultant Jack Cox saw three *Tomistoma* at only one location, the Ensengai swamp system near Kuching. Rom Whitaker found no evidence that *Tomistoma* ever existed in Sabah; *Tomistoma* habitats in Kalimantan and Sarawak are cut off from Sabah by fairly high hill and mountain ranges. It is probable that there are viable populations of *Tomistoma* in Kalimantan (Indonesia) but no surveys have yet been made.

Small numbers of juvenile live *Tomistoma* still appear at Singapore crocodile "farms" and it is likely that their origin is nearby Sumatra which has never been surveyed.

*Gavialis gangeticus* -- Gharial

The gharial is one crocodilian that people acknowledge as harmless to humans. But being a fisheater it is treated as a competitor. In 1974 the world gharial population, captive and wild, was estimated to be under 250. Now, in 1986 it is over 2500 due mainly to the efforts of several State Forest Departments (see Table 2). The Government crocodilian rehabilitation program, initially aided by FAO/UNDP, initially concentrated its efforts on saving the gharial which looked like it was on its way out. Even today there are apparently fewer than twenty adult male gharial both captive and wild.

The only large area of protected habitat for the gharial in India is the National Chambal Sanctuary, covering 600 river kilometers and running through three states, Uttar Pradesh, Madhya Pradesh and Rajasthan. The other gharial areas in India such as Katarniaghat in Uttar Pradesh, Sathkoshia Gorge in Orissa and bits of the Son, Ken (Madhya Pradesh) and other rivers are very small and in the long run, very vulnerable. There is a small population in Corbett National Park (Uttar Pradesh). Besides the Chambal in India, the other major gharial population that is reasonably secure is that of about 20 adults in Chitwan National Park (Rapti-Narayani River) in Nepal.

Although it has been so far bred at only one center, (in 1985 six nests were laid at Nandankanan Biological Park, Orissa) the gharial responds well to captive rearing and growth rates make it acceptable for commercial farming or ranching. Considering the large quantities of fish gharial consume, it is critical that the ecological/economic advantages of having gharial back in the river ecosystems outweigh the disadvantages.

Table 2. Juvenile Gharial Released for Restocking Protected Habitat (1977-1984).

Place	State/Country	Number released
National Chambal Sanctuary	Madhya Pradesh, Uttar Pradesh, Rajasthan	912
Sathkoshia Gorge Sanctuary	Orissa	150
Katerniaghat Sanctuary	Uttar Pradesh	83
Chitawan National Park	Nepal	50
Ken Sanctuary	Madhya Pradesh	3
Son Sanctuary	Madhya Pradesh	2

*Alligator sinensis* -- Chinese alligator

This small (under 2 m) alligator was once widespread throughout the eastern portion of the Yangzi River basin. There is now little or no wild habitat left for the Chinese alligator and it survives precariously in the midst of human agriculture. Concentrated in the Xuancheng region, the center of the alligator's current range, smaller populations are found in Zhejiang and Jiangsu Province. Watanabe and Chu-chien (1984) estimate that there are about 300-500 wild alligators in the Xuancheng region and a total of 1500-2000 (both on farms and in the wild) in the country.

Chinese alligators depend on being able to dig extensive dens to hide in and to hibernate in over winter months. Being docile and fairly small they are frequently disturbed and nests destroyed by children and farmers.

The Chinese alligator is the subject of several ongoing studies and captive breeding has been achieved at the Chinese Alligator Breeding Center, Anhui Province (where 300 hatchlings were produced in 1983), Shanghai Zoo and Rockefeller Wildlife Refuge in the U.S. Emphasis on captive breeding is important to ensure the survival of adequate genetic stocks of the species. The establishment and maintenance of wild reserves for the Chinese alligator has very limited scope, but unless these efforts are made this interesting reptile will no longer be able to survive in the wild.

## SUMMARY

The outlook for the Asian crocodilians is bleak indeed. Table 3, which is made up in many cases of very approximate data, dramatizes their plight. The Chinese alligator, gharial and Siamese crocodile are all more numerous in captivity than in the wild. The New Guinea crocodile is the only species that still exists in anything resembling "safe" numbers and only because of its original swamp habitat remains difficult of access and unaltered.

Conservation and management approaches range all the way from India's preservation/rehabilitation program to Papua New Guinea's managed ranching scheme. Ranching, (that is, the collection of eggs and/or young for captive rearing and culling) can be a most effective method of guaranteeing attention to habitat protection. As long as it is profitable to take crocodiles from a swamp, that swamp will be protected with everything in it.

In general, two activities are needed in each of the Asian countries where crocodiles are found: (a) public education and reassurance (which includes an effective, mobile nuisance crocodile catching squad); and (b) the setting up of management programs, if necessary with outside help. Indonesia has a special responsibility since three of the eight Asian species--Malayan gharial, saltwater crocodile, and New Guinea crocodile--are found mainly in the Indonesian archipelago and Kalimantan. India is particularly responsible for the continued survival of the gharial, China the Chinese alligator, and Thailand the Siamese crocodile.

Demonstrating that (a) crocodile farming is a logical form of land use, (b) crocodiles are needed in aquatic ecosystem, (c) crocodiles are rarely dangerous to man, and (d) crocodiles are edible and produce the most valuable and durable leather in the world will help people accept that we cannot dismiss crocodiles. These reptiles have been denizens of the earth for 100 million years. Each country and indeed each set of circumstances may demand a novel approach to the problems of accepting and living with crocodiles. But it is worth the effort. The various Asian crocodile

Table 3. Status of Asian Crocodilians.

Species	Distribution	Wild population	Captive population	Conservation management efforts	Legal Status	CITES	IUCN Red Data Book
VIETNAM AND KAMPUCHEA							
<i>Crocodylus palustris</i>	Iran Pakistan India Nepal Bangladesh Sri Lanka	50-100 30-50 2-3000 30-50 5 2-3000	Few Few 3000+ Few Few	? Moderate Active Moderate Nil		I	Vulnerable
<i>Crocodylus siamensis</i>	Thailand Vietnam Kampuchea	50-100 ? ?	20,000 Few Few	Private farm ? ?		I	Endangered
<i>Crocodylus porosus</i>	India to Irian Jaya	25-50,000	10,000**	Nil to active in various countries		I	Endangered
<i>Crocodylus mindorensis</i>	Philippines	500-1000		Moderate		I	Endangered
<i>Crocodylus novagvineae</i>	Irian Jaya	100-200,000	3000	Surveys		II	Vulnerable
<i>Tomistoma schlegelii</i>	Malaysia (Sarawak) Indonesia (Kalimantan, Sumatra)	500-1000 1000-3000	100+ 200+	Surveys Nil		I	Endangered
<i>Gavialis gangeticus</i>	Pakistan Nepal India Bangladesh	30 30-120 1000+ 25-35	Few 100+ 2000+ Few	Little Active Active Little		I	Endangered
<i>Alligator sinensis</i>	China	500+	800+	Active		I	Endangered

\* excluding first year hatchlings

\*\*excluding *C. porosus* in Papua New Guinea and Australia

Table 4. Breeding results--Madras Crocodile Bank.

Year	Mugger hatchlings	Saltwater crocodile hatchlings	Caiman hatchlings
1976	30	--	--
1977	50	--	--
1978	399	--	--
1979	164	--	--
1980	236	--	--
1981	289	--	--
1982	228	--	37
1983	240	74	34
1984	252	30	60
1985	235	45	36
TOTAL	1813	92	167

programs are forerunners to what will hopefully become an accepted profitable form of land use. Man's first domestic reptile is the crocodile.

#### LITERATURE CITED

- Ross, C.A. 1982a. Philippine Crocodile Project (Smithsonian/World Wildlife Fund) Final Report, p. 1-34.
- Ross, C.A. 1982b. The crocodile must stay. *Habitat (Philippines)* 3(1):13-19.
- Watanabe, M. E., and H. Chu-chien. 1984. Status of the Chinese alligator in the People's Republic of China. Pages 216-219 in *Proceedings of the 6th working meeting of the IUCN/SSC*, 1982.



## **CROCODILES**

**Supplement to the Proceedings of the 8th Working Meeting of the Crocodile Specialist Group  
of the Species Survival Commission of the International Union for  
Conservation of Nature and Natural Resources**

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International Union for Conservation of Nature and Natural Resources

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## FOREWORD

This volume is a supplement to the Proceedings of the 8th Working Meeting of the Crocodile Specialist Group (CSG) in Quito, Ecuador, 13 to 18 October 1986. It contains two papers that were presented at that meeting, but were not published in the Proceedings volume (IUCN Publications New Series, 1989, ISBN 2-88032-968-X).

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The International Union for Conservation of Nature and Natural Resources (IUCN) was founded in 1948, and has its headquarters in Gland, Switzerland; it is an independent international body whose membership comprises states, irrespective of their political and social systems, government departments, and private institutions as well as international organizations. It represents those who are concerned at man's modification of the natural environment through the rapidity of urban and industrial development and the excessive exploitation of the earth's natural resources, upon which rest the foundations of his survival. IUCN's main purpose is to promote or support action which will ensure the perpetuation of wild nature and natural resources on a world-wide basis, not only for their intrinsic cultural or scientific values but also for the long-term economic and social welfare of mankind.

This objective can be achieved through active conservation programs for the wise use of natural resources in areas where the flora and fauna are of particular importance and where the landscape is especially beautiful or striking, or of historical, cultural, or scientific significance. IUCN believes that its aims can be achieved most effectively by international effort in cooperation with other international agencies, such as UNESCO, FAO, and UNEP, and international organizations, such as World Wild Fund for Nature (WWF).

The mission of IUCN's Species Survival Commission (SSC) is to prevent the extinction of species, subspecies, and discrete populations of fauna and flora, thereby maintaining the genetic diversity of the living resources of the planet. To carry out its mission, the SSC relies on a network of over 2,000 volunteer professionals working through 100 Specialist Groups and a large number of affiliate organizations, regional representatives, and consultants, scattered through nearly every country in the world.



**THE DISTRIBUTION OF *CROCODYLUS POROSUS* AND  
*CROCODYLUS JOHNSTONI* ALONG TYPE 1 TIDAL WATERWAYS  
IN NORTHERN AUSTRALIA  
AND  
SURVEY OF THE UPSTREAM NON-TIDAL SECTIONS OF THE ROPER  
RIVER, 1986**

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**ABSTRACT**

This paper discusses in general terms the distribution of *Crocodylus porosus* and *C. johnstoni* along Type 1 tidal water ways in northern Australia. The important Type 1 tidal waterways are classified into four broad groups on the basis of their distributional diagrams, and each group is explained in terms of the model of *C. porosus* population dynamics developed in previous publications. Alternative habitat, crocodile interactions, exclusion, and losses are the key features to the understanding of the distribution.

Results are also presented for the first survey carried out on the non-tidal sections of the Roper River upstream from the Roper Bar at km 145.3. On 77 km of waterway surveyed, 307 *C. johnstoni* were sighted and only one *C. porosus*, which was just 0.7 km up from the Roper River.

**INTRODUCTION**

In Monographs 1 to 19 and the two Western Australia Reports listed in the present publication, we documented, analyzed, and discussed the detailed results of the first systematic survey, since settlement of the continent of some 100 northern Australian tidal waterways and their crocodile populations. In this paper we assemble for the first time and discuss generally sample distributional diagrams for all the more important Type 1 tidal systems surveyed. We also present the results of a 1986 survey of the extreme upstream, non-tidal sections of the Roper River System (Monographs 12 and 19).

In the introduction to Monograph 20 we emphasized (also see Monographs 1, 18, and 19) that the analysis of the number, distribution, and size structure of crocodiles sighted during the general surveys of northern Australian tidal systems indicates that one of the most important parameters characterizing a tidal waterway is its salinity profile and that the profile and habitat type image one another. They appear to largely determine the suitability or otherwise of the tidal waterway for breeding, nesting, and rearing. We also gave a detailed description of the model that we developed

for the dynamics of *C. porosus* populations and which enabled us to account in a consistent fashion for the results we obtained for some 1100 tidal systems in northern Australia. In this model, we pointed out that the tidal waterways of northern Australia have been classified according to their salinity signatures into Type 1, Type 2, and Type 3 systems as shown in Figure 1 (see pages 100-105, Monograph 1). Type 1 systems are the main breeding ones, and non-Type 1 systems are usually poor non-breeding systems. It is the Type 1 systems and the freshwater billabongs and semipermanent and permanent freshwater swamps associated with them which account for the major recruitment of *C. porosus*; the other systems contribute to a lesser degree, and they must usually depend largely upon Type 1 systems and their associated freshwater complexes for the provision of their crocodiles. Non-Type 1 systems also sometimes have freshwater complexes associated with them but these are normally quite minor.

The information summarized in Figure 1 is of great importance for the understanding of the dynamics of *C. porosus* populations. In Type 1 systems some 27% of the crocodiles are hatchlings, whereas in Type 2-3 systems this figure falls to 14% and in Type 3 systems down to 4%, showing a much decreased hatchling recruitment in non-Type 1 systems. In Type 3 systems the percentage of crocodiles in the hatchling, 2-3', and 3-4' size classes combined is some 11%, whereas in Type 1 systems it is at least 52%. On the other hand the percentage of crocodiles in the  $\geq 4-5'$  size classes is some 39% in Type 1 systems and 73% on Type 3 systems. Some 79% of the non-hatchling crocodiles are sighted on Type 1 waterways and 21% on non-Type 1 waterways.

However, as mentioned above, we concern ourselves, in this paper, with the distribution of crocodiles in the more important Type 1 systems only and refer the reader to the series of Monographs for a complete treatment of all tidal waterways surveyed. Though the results for every Type 1 system surveyed were analyzed, discussed, and accounted for on the basis of our population model in the relevant Monographs, at no stage have we brought together sample distributional diagrams for each of the more important Type 1 tidal waterways surveyed in northern Australia, so that they could be compared easily and to see what salient features they have in common. We do so in this paper.

On page 440 of Monograph 1 we stated that the establishment of a University of Sydney field station at Urapunga on the Roper River would not only allow us to monitor the river (see Monographs 12 and 19 for the results) but would also permit us to carry out land-based studies of its long non-tidal freshwater section above Leichhardt's Roper Bar. The Roper River System is one of the largest and best Type 1 tidal waterways in northern Australia. It not only has a long navigable freshwater section, from about km 70 to Roper Bar at km 145.3, but also has a number of sections between km 145.3 and km 353.0 which are surveyable by small boat and which can be reached by bush track. These sections of the river are beyond the tidal limit and consist of intermittent waterholes. Between them the many branches of the river are usually dry during the dry season. Sporadic *C. porosus* were believed to occur and the more plentiful *C. johnstoni* were known to occur in the permanent waterholes, but no systematic night spotlight survey had been carried out of them. Many wild claims (pers. comm.) have been made about the 'hundreds' of *C. porosus* in them. Thus we decided to survey the larger upstream waterholes and obtain direct and quantitative evidence for the relative abundances of the two species on the non-tidal sections of this long and important waterway.

Work maps for the Roper System, from its mouth to Roper Bar at km 145.3, are given in Monograph 15. The additional 18 work maps covering the sections between km 145.3 and km 375 are presented in Figures 2 to 19. A helicopter was used to verify and increase the accuracy of the maps prepared from aerial photographs (see Introduction to Monograph 15) and to find the best tracks into the waterholes to be surveyed. Two Toyota Land Cruisers, a 12 foot dinghy with a 9.9



hp outboard motor, and our standard survey and camping gear were used for the surveys which were carried out during the period 7-15 July 1986.

## RESULTS

Sample distributional diagrams for 20 of the more important Type 1 tidal systems surveyed are taken directly from the relevant Monographs and are shown in Figures 20 to 50. Small Type 1 systems, such as the Goomadeer (Monograph 5), and systems with only a few crocodiles remaining in them have been omitted. An example of the latter is the McArthur River System (Monographs 13 and 19).

We surveyed six lagoons on the upstream non-tidal section of the Roper River as follows: km 145.3-160.2, km 207.0-228.1, km 236.2-241.5, km 252.5-267.0, km 318.5-335.8, plus a sidecreek of 0.6 km and km 349.2-352.5. These sections are shown on the work maps, Figures 2 to 19. In Tables 1 to 7 we give the results for the night spotlight surveys of the individual lagoons and show the size structure, situation, and number of *C. johnstoni* sighted. *C. porosus* are not shown in the Tables as only one animal was sighted during the course of the surveys, and this was a 5-6' animal, at km 146.0, only 0.7 km above Roper Bar.

## DISCUSSION

### Distributional Diagrams

In northern Australia, Type 1 tidal systems normally meander through coastal floodplains, often have large drainage basins, and have a heavy freshwater input during the wet season. The inflow decreases but remains sufficient as the dry season progresses to prevent the salinity upstream (though moving upstream gradually) from rising above the sea water values measured at the mouth of the system (see pages 100-105 Monograph 1). There are exceptions, however, for the Type 1 systems in the north-west Kimberley usually run through rugged gorges and fault lines. It is also to be noted that major Type 1 systems often contain non-Type 1 waterways as well. The Adelaide (Monographs 3 and 19), Liverpool (Monographs 7 and 18), and Roper (Monographs 12 and 19) Systems are excellent examples of such systems. Such matters were discussed in Chapter 9 of Monograph 1, where all the tidal system mainstreams were classified according to their salinity signatures.

One might be tempted into believing that the distributional pattern of *C. porosus* along all Type 1 tidal waterway mainstreams should be essentially similar. As will be seen by inspection of the distributional diagrams in Figures 20 to 50, this is not the case. There can be considerable variation from one Type 1 system to another; however, the shapes of the various distributional patterns appear to fall into four rather broad groups, with considerable overlap between them. We have grouped the 20 major Type 1 systems as follows:

#### Group 1

Blyth-Cadell  
Liverpool-Tomkinson

Figs. 20, 21  
Figs. 22-24

#### Group 3

Prince Regent  
Roe

Fig. 43  
Fig. 44

Ducie	Fig. 25	Mitchell	Fig. 45
Roper	Figs. 26-29	Glenelg-Gairdner	Fig. 46
Daly	Fig. 30	Wenlock	Fig. 47
Adelaide	Figs. 31-33	Goromuru	Fig. 48
Victoria	Figs. 34, 35		
Group 2		Group 4	
Murgenella	Fig. 36	Ord	Fig. 49
East Alligator	Figs. 37, 38	Glyde	Fig. 50
South Alligator	Figs. 39, 40		
West Alligator	Fig. 41		
Wildman	Fig. 42		

An acceptable model for the dynamics of populations of *C. porosus* must be able to account for the salient features of the distributional pattern of the animals sighted, as summarized in the distributional diagrams for each river system. In fact our model, as described in Monographs 1, 18, 19, and in the Introduction to Monograph 20, grew out of our endeavors to explain the important features of an ever increasing database, summarized by the distributional diagrams for the tidal river systems surveyed. It is thus not surprising that our model can explain the main features of the distributional diagrams not only for Type 1, but for non-Type 1 tidal systems as well.

The first critical break-through towards deriving our model was achieved when we found that we could classify the tidal river systems in northern Australia by their salinity profiles and, surprisingly, that the size structure of the animals sighted in them varied as shown in Figure 1. Almost concurrently with that came the start of even more surprising results concerning the missing crocodiles, now summarized and developed in our model as follows:

1. It appears that the populating of non-Type 1 systems (hypersaline or partially hypersaline coastal and non-coastal waterways) results mostly from the exclusion of a large fraction of the sub-adult crocodiles from Type 1 systems and any freshwater complexes associated with them. Adult crocodiles appear generally to tolerate hatchling, 2-3', and sometimes even 3-4' sized crocodiles in their vicinity (but not always--they sometimes eat them, page 43 Monograph 14--or kill them, page 334 Monograph 1), but not larger crocodiles. Thus once a crocodile reaches the 3-4' and 4-5' size classes, it is likely to be challenged increasingly not only by crocodiles near or in its own size class (pages 454-458 Monograph 1) but by crocodiles in the larger size classes and to be excluded from the area it was able to occupy when it was smaller. A very dynamic situation prevails with both adults and subadults being forced to move between various components of a system and between systems. Crocodile interactions or aggressiveness between crocodiles in all size classes increases around October--during the breeding season (page 445 Monograph 1 and page 109 Monograph 18)--and exclusions, if any, normally occur around this period. A substantial fraction (~80%) of the subadults, mostly in the 3-6' size classes but also including immature larger crocodiles, are eventually excluded from the river proper or are predated upon by larger crocodiles.
2. Of those crocodiles that have been excluded, some may take refuge in freshwater swamp areas and billabongs associated with the waterway from which they were

excluded or in the waterways' non-Type 1 creeks if it has any. Others may travel along the coast until by chance (?) they find a non-Type 1 or another Type 1 waterway; however, in this latter case they may again be excluded from it. Others may go out to sea and possibly perish, perhaps because of lack of food, as they are largely shallow water on edge feeders, or they may be taken by sharks. Those finding non-Type 1 systems, or associated freshwater complexes, frequent these areas, which act as rearing stockyards, for varying periods until they reach sexual maturity, at which time they endeavor to return to a Type 1 breeding system. Since a large fraction of the crocodiles sighted in non-Type 1 systems must be derived from Type 1 systems and their associated freshwater complexes, they are, as seen in (1) above, predominantly subadults in the  $\geq 3'$  size classes or just mature adults (page 431 Monograph 1). Both subadults and just mature adults might attempt to return and to be forced out of a system many times before finally being successful in establishing a territory in a Type 1 system or in its associated freshwater complex. Crocodiles may have a homing instinct (this important point requires further study), and even though a fraction of crocodiles may finally return to and remain in a Type 1 system or in its associated freshwater complex, the overall sub-adult numbers missing-presumed dead remain high and appear to be at least 60-70%.

3. Normally, the freshwater complexes (swamps and/or billabongs) associated with tidal systems are found at the terminal sections of small and large creeks running into the main waterway, or at the terminal sections of the mainstream(s). Though this alternative habitat is usually very limited in extent, sporadic (and sometimes extensive yearly) nesting does take place on it. There are, however, several fairly extensive freshwater complexes associated with Type 1 tidal systems, and these are important as they may act both as rearing stockyards and as breeding systems, just as the Type 1 waterway does itself. Examples of these are the Glyde River with the Arafura Swamp (Monograph 9), the Alligator Region Rivers with their wetlands (Monographs 4, 14, and 19), and the Daly, Finnis, Reynolds, and Moyle Rivers with their wetlands (Monograph 3). Not only can the loss factor, which appears to occur during the exclusion stage, be expected to be lower for movements into and out of swamp areas associated with a Type 1 waterway, than for movement into and out of coastal non-Type 1 systems, but the loss of nests due to flooding can also be expected to be less. We have observed nests made of floating grass cane mats in the Daly River Aboriginal Reserve area. Thus recovery of the *C. porosus* population on Type 1 tidal waterways, with substantial associated freshwater complexes, can be expected to be faster than on other systems (page 445 Monograph 1, page 98 Monograph 14, and also see important results for the 1984 resurvey of Alligator Region and Adelaide River systems appearing in Monograph 19 where we verified this prediction).
4. Though there are wide fluctuations, especially after "dry wet" seasons when the animals are concentrated into the tidal waterways, it appears that as the number of large crocodiles in a tidal waterway increases, there is a tendency for the number of subadults in the 3-6' size classes to decrease or increase marginally only. This density dependent behavior has an important bearing on the rate of population growth and on the size structure of the population.
5. An important and remarkable fact becomes evident in Type 1 tidal systems if one excludes the 3-4' size class and focuses on the 4-5' and 5-6' size classes only. Regardless of how large the recruitment may be, the number of animals sighted

in the 4-5' and 5-6' size classes seems to remain essentially constant or increases slowly only. Thus a major bottleneck occurs for these size classes. It is as if there are a definite number of slots for these animals on a given river system, and that the number of these slots increases slowly only--if at all (note especially the results for the Blyth-Cadell and Liverpool-Tomkinson waterways in Monographs 1 and 18 and the 1984 results for the Alligator Region and Adelaide River systems appearing in Monograph 19). The crocodiles themselves appear to be primarily responsible for the very heavy losses of about 70 % that occur in the process of trying to secure these slots or to increase them in number.

6. If one considers a group of 100 of the sub-adult crocodiles in a Type 1 tidal system without a substantial freshwater complex associated with it, one can expect some 80 to be excluded from it, at least 60-70 of the original 100 to end up missing-presumed dead, less than 15-20 to successfully establish territories on the system without having to leave it, and the remainder might eventually also return and establish a territory, especially after becoming sexually mature. The very nature of this matter is such as to preclude precise figures, and they must be looked upon as broad estimates only; however, detailed study of our results (Monograph 18) now indicates that the missing-presumed dead figure is likely to be in excess of 70. For systems with substantial freshwater complexes associated with them, this figure is likely to be considerably less.
7. When there is an exclusion from Type 1 systems of sub-adult animals, mostly 3-6' in size but also including immature larger animals, this takes place mainly in the breeding season, normally commencing around September-October and apparently lasting throughout the wet season. Any influx of animals in the 3-6' and/or large size classes appears to occur mainly in the early dry season and to be completed in the June-early September period, but may in some years be earlier.
8. After a single "dry wet" season there is a substantial influx of large and sometimes 3-6' animals, forced out of freshwater complexes, into the tidal waterways and these are sighted during June-July surveys. Surveys made in October-November of the same year usually reveal a substantial decrease in the number of 3-6' and/or large animals sighted; however, the number of large animals sighted sometimes remains higher than previously, and hence a number of the new large animals do not return from whence they came. These animals appear successful in establishing a territory on the waterway, and it could be the waterway from which they had originally been excluded. The "dry wet" variation in the number of animals sighted appears to be superimposed upon the variations normally found during surveys following usual wet seasons--which generally result in extensive flooding on the upstream sections of the tidal waterways. Hatchling recruitment on the tidal waterways is generally greatly enhanced during "dry wet" seasons but appears to be greatly reduced in major swamp habitat. The reverse appears to be true during normal or heavy wet seasons.

The key to the understanding of the distributional diagrams--the where, the how, the why, and the when--is contained essentially in the eight points of the model River above, all centered in one way or another, around the matter of crocodile habitat, interactions, exclusions, and losses. Consider the essentially "bell shaped" distributions of the tidal systems shown in Group 1 (Figs. 20 to 26, 30, 32, and 34). In the case of each of these waterways, nesting appears to occur largely on the midsections of the waterway--either on the brackish and/or early freshwater sections. The

position of the peak of the distribution, that is the mean distance upstream (page 333 Monograph 1), varies for each size class and is roughly inversely proportional to size: the mean distance upstream of the hatchling peak is greater than that for 2-3' sized crocodiles; in turn, the mean distance of 2-3' sized crocodiles is greater than that for (3-4') crocodiles. The peak is usually still quite distinct for the 4-5' size class, but sometimes is not so evident for the 5-6' size class and specially not for larger crocodiles, which, for the Group 1 systems, appear to be more evenly distributed along the river. On the basis of the interactions and exclusions discussed in (1) above, these distributional diagrams are easily understandable. The gradual shifting of the distributional peak downstream, of crocodiles in the 2-3', 4-5' and 5-6' size classes, may be understood, at least in part, on the basis of these crocodiles being on their way out of the river system, as they are forced gradually downstream by the larger crocodiles, which are more evenly distributed along the river system (page 334 Monograph 1). However, there are modifying features imposed upon this general picture, the most important of which is the availability of alternative habitat to which the 3-6' animals may be excluded rather than being forced out of the river system totally. This alternative habitat for the Group 1 systems may consist of small freshwater swamps, as on the Adelaide and Roper Systems, or of non-Type 1 creeks, as in the case of the Adelaide (Fig. 33), Roper (Fig. 27), Liverpool (Figs. 22 and 23), and Ducie (Fig. 25); or the limited extreme upstream tidal and non-tidal sections as on the Liverpool-Tomkinson (note specially the Tomkinson) and Blyth-Cadell Systems. For both of these latter systems we have shown the distributional diagrams for July and October-November surveys in order to highlight the fact that exclusions of animals in the 3-6' size classes appears to set in with the onset of the breeding season around October (see [7] above). Note particularly in Figure 20, for the June 1982 survey of the Blyth, the  $\geq 4-5'$  animals on the river mouth section, apparently on their way into the river system.

The surveyable length of the tidal freshwater section of each of the Group 1 systems varies. It can be small as in the cases of the Blyth-Cadell (about 25 km), Liverpool-Tomkinson (about 15 km), and Ducie (nil) or large as in the cases of the Roper (some 70 km) and Adelaide (some 70 km). On a map, the non-tidal freshwater section can appear to be very long, in fact usually much longer than the tidal section. However, great caution is needed when studying river systems on Australian maps. Beyond the tidal limit, the rivers usually consist of intermittent waterholes with sections in between which are dry during the dry season. We discuss a survey of the upstream non-tidal section of the Roper System later in this paper. Examination of the distributional diagrams for the Group 1 systems shows the drop in *C. porosus* numbers past the midsection of the mainstreams. This decrease in *C. porosus* numbers is particularly striking in the cases of the long Group 1 tidal systems--the Roper, the Daly, the Victoria, and to a lesser degree for the Adelaide.

If one is able to proceed beyond the tidal limit (as we did on the Roper), the sighting of *C. porosus* becomes sporadic only, and the sighting of *C. johnstoni* becomes common. It was on the Adelaide River in 1977 (pages 39 and 40 Monograph 3), that the surprising sightings of *C. johnstoni* on the tidal saltwater sections were recorded for the first time by us and was then to be repeated many times over by other tidal systems (see page 459 Monograph 1; pages 19 and 20 Monograph page 16 Monograph 8; pages 25, 58, 59, and 79 Monograph 12; pages 20, 30, 61, 72, and 80 Monograph 13; pages 30, 45, 71, and 110 Monograph 16; pages 56, 57, 71, 72, 75, and 80 Monograph 19). This evidence supports the second point in the hypothesis we first put forward in 1978 (page 20 Monograph 2):

"Could it be that all stages of *C. johnstoni* can indeed tolerate salinities higher than those in which they have heretofore been found? Is it then the case that the scarce observations of *C. johnstoni* in tidal rivers reflect exclusion by *C. porosus* rather than an intrinsic intolerance of saline conditions?"

Our prediction about *C. johnstoni* being able to tolerate salinities greater than those of freshwater was also proven correct when Taplin and Grigg (Science 1981, 212:1045-1047) discovered lingual salt glands both in *C. porosus* and *C. johnstoni*.

The shape of the distributional diagrams for the tidal systems shown in Group 2 (Figs. 36 to 42) are strikingly different from those for Group 1. Unlike the generally bell-shaped distributions for the Group 1 systems, those for Group 2 are skewed heavily towards the upstream freshwater sections of the waterways. These waterways are all in the Alligator Region and have one thing in common—excellent alternative habitat on their upstream sections, in the form of substantial freshwater swamps (see point [3] above in our model). The distributions show, to varying degrees, signs that the mean distance downstream of the peak of the distribution varies for each size class, roughly inversely proportional to size, and hence indicate that some of the animals are being forced downstream and probably out of the waterways. However one can plainly see the input of animals in size classes  $\geq 4.5'$  on the extreme upstream sections of the East Alligator (Fig. 37) and the South Alligator (Fig. 39)—note especially Nourlangie Creek. One can see a similar occurrence for all size classes on the Wildman System. These animals can only come from the upstream swamps that act both as breeding and rearing areas.

The shapes of the distributional diagrams for the tidal systems in Group 3 (Figs. 43 to 48) are quite similar to those of Group 2, but the reasons for them being so are quite different. None of these systems, with the exception of the Wenlock (Fig. 47) has freshwater swamps of any import upstream. The Wenlock does have some freshwater swamp (see page 85 Monograph 16) and perhaps could be included in Group 2 as easily as in Group 3. In the cases of the Prince Regent (Fig. 43), the Roe (Fig. 44), the Mitchell (Fig. 45), the Glenelg (Fig. 46), and the Goromuru (Fig. 48), the distributions are all skewed upstream because suitable nesting habitat is essentially all located on the upstream sections. For the exception of the Wenlock and Goromuru, the downstream sections of the Group 3 waterways have either wide bays, rocky gorges, and/or turbulent waters. One should note that for the waterways in Group 3, one again sees the shifting downstream of the distributional peak with increasing size class. Excellent examples of the important role that alternative habitat can play for excluded animals in the  $\geq 4.5'$  size classes can be seen in Figures 43 and 44 for the Prince Regent and Roe Systems respectively. The North and South Arms at the mouth of the Prince Regent show that some 95 such animals were sighted in them and that Creeks A to F at the mouth of the Roe System held a number of excluded animals as well.

We grouped the Ord and Glyde Systems separately into Group 4 (Figs. 49 and 50), because they do not quite fit any of the other groups, though their distributional diagrams are interpreted easily. Inspection of the work maps for the Ord System (page 321-328 Monograph 15) shows that the Ord System is not quite like any other that we surveyed. Its zero point is to the north of Adolphus Island in the East Arm of Cambridge Gulf and it retains its gulf-like features until km 40; thereafter the river begins to meander. Between km 12 and 20, to the east of Mount Connection, there are three creeks which provide alternative habitat for  $\geq 3-4'$  animals excluded from the upstream breeding sections of the Ord. Move the crocodiles of the three creeks to the right on the distributional diagram, and you could be looking at the diagram for the Blyth System with similar reasoning pertaining to the distribution.

The Glyde River (see pages 108 and 141-145 Monograph 18) drains the Arafura Swamp, and the Goyder River runs into the swamp. It is a unique system and one of the most important for the understanding of the dynamics of the population of *C. porosus* on the northern Arnhem Land coast. The Swamp acts both as a breeding and rearing area and appears to hold animals excluded from Type 1 systems to the west of it, such as the Blyth-Cadell, Liverpool-Tomkinson, and Goomadeer Systems (see pages 100-158 Monograph 18). There appears to be continuing

movement of these animals to and from these systems, and the Glyde River is the conduit into and out of the Arafura Swamp. The distributional diagram (Fig. 50) reflects this beautifully, where one notes a peak for the animals at the mouth of the Glyde and a peak at the upstream swamp end. Minor nesting takes place on the Glyde, but the majority of animals sighted on it are likely to come from the swamp or elsewhere. Note the large number of EO animals, probably new animals entering the system.

### Survey of Non-tidal Sections of the Roper River

The 77 km of upstream lagoons surveyed and spotlighted on the Roper River between km 145.3 and km 353 constitutes 37% of the total upstream distance; the remainder is largely numerous dry watercourses. Tables 1 to 7 reveal a healthy population of *C. johnstoni* on the upstream non-tidal sections of the Roper River. Our surveys of the Roper in 1979 revealed the first *C. johnstoni*, on the km 80-85 section of the mainstream (page 66 Monograph 12) and between this and the Roper Bar at km 145.3, at least an additional 34 *C. johnstoni* as well as 27 *C. porosus* were sighted. During the 1985 survey of the Roper, the first *C. johnstoni* was sighted on the km 95-100 section, and thereafter at least a further 41 *C. johnstoni* were sighted on the tidal section to Roper Bar (an isolated *C. johnstoni* was in fact sighted on the km 45-50 section). Nineteen *C. porosus* were sighted on the same sections of the mainstream inhabited by the *C. johnstoni*.

The dramatic change in the relative abundance of *C. porosus* and *C. johnstoni* between the tidal section of the mainstream immediately below Roper Bar and the non-tidal section above it is seen by examining Tables 1 and 7. On the 14.9 km section immediately above Roper Bar, 73 *C. johnstoni* were sighted and only one *C. porosus*; between km 145.3 and km 353 on the 77 km surveyed above the Bar only that one *C. porosus* was sighted, whereas 307 *C. johnstoni* were counted.

On page 57 of Monograph 12 we made the statement that throughout our surveys of the northern Australian rivers we invariably have found that the density of *C. porosus* plummets as soon as the freshwater sections of rivers are reached. We intimated similarly on pages 334-335 of Monograph 1. As we have seen, this is essentially so in the case of the Group 1 tidal systems, but in the case of the non-Group 1 systems it certainly is not so. What one can say is that for those tidal systems not terminating in freshwater swamps but becoming a series of intermittent waterholes, the density of *C. porosus* is essentially zero on the non-tidal sections of the waterway.

A word of caution should be interpolated here. The fact that no *C. porosus* are at present found on the upstream Roper does not necessarily mean that there never were significant numbers of *C. porosus* on such sections. We are looking today at a depleted population, and one hundred years ago, when the population was much higher on the tidal sections, it is possible many more *C. porosus* were pushed up into the non-tidal sections. The same warning applies to the interpretation of the distributions on most other systems as well. They reflect severely depleted populations in many cases.

The density of *C. johnstoni* sighted in the six waterholes (sections) surveyed varied considerably, from 2.1/km on the km 207.0-228.1 section (Table 2) to 7.0/km on the km 349.2-352.5 one. The overall density for the six waterholes was 4.0/km. The waterholes on the upstream Roper River are coming under increasing tourist pressure, and we found definite evidence of poaching for *C. johnstoni*, using baited hooks, on the km 207.0-228.1 waterhole.

Food supply, in the way of small fish and specially freshwater turtles, appeared plentiful in the waterholes surveyed. Barramundi were nowhere to be seen and not a single tourist that we met had been successful in catching one. One wonders at the resource planning that allows the destruction of such an extremely valuable tourism asset as barramundi when only a few individuals benefit from this destruction. The waterholes do not appear to provide very suitable habitat for *C. porosus*; however, there is one exception, and that is the downstream portion of Red Lily Lagoon, km 318.5-335.8. At km 318.5 there is substantial freshwater swamp which appeared to provide excellent habitat for *C. porosus*. We were convinced that if *C. porosus* was to be found on the extreme upstream sections of the Roper River, then this was the area. On 15 July 1986 we chartered a helicopter so we could carry out careful low level surveys of the swamps, looking for signs of *C. porosus* and specially for old nests. None was found.

THIS WAS, AFTER 16 YEARS OF SURVEYING, OUR FINAL CROCODILE SURVEY IN THE NORTHERN TERRITORY.

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#### MONOGRAPH SERIES

##### Surveys of Tidal Waterways in Northern Australia and Their Crocodile Populations

A series of monographs covering the navigable portions of the tidal rivers and creeks of northern Australia. Published by Pergamon Press, Sydney, Australia, 1979-1987.

1. The Blyth-Cadell Rivers System Study and the Status of *Crocodylus porosus* in Tidal Waterways of Northern Australia. Methods for analysis, and dynamics of a population of *C. porosus*. Messel, H.; Vorlicek, G. C.; Wells, A. G. and Green, W. J.
2. The Victoria and Fitzmaurice River Systems. Messel, H.; Gans, C.; Wells, A. G.; Green, W. J.; Vorlicek, G. C. and Brennan, K. G.
3. The Adelaide, Daly and Moyle Rivers. Messel, H.; Gans, C.; Wells, A. G. and Green, W. J.
4. The Alligator Region River Systems. Murgarella and Coopers Creeks; East, South and West Alligator Rivers and Wildman River. Messel, H.; Wells, A. G. and Green, W. J.
5. The Goomadeer and King River Systems and Majarie, Wurugoi and All Night Creeks. Messel, H.; Wells, A. G. and Green, W. J.



6. Some River and Creek Systems on Melville and Grant Islands Johnston River, Andranangoo, Bath, Dongau and Tinganoo Creeks and Pulloloo and Brenton Bay Lagoons on Melville Island; North and South Creeks on Grant Island. Messel, H.; Wells, A. G. and Green, W. J.
7. The Liverpool-Tomkinson Rivers Systems and Nungbulgarri Creek. Messel, H.; Wells, A. G. and Green, W. J.
8. Some Rivers and Creeks on the East Coast of Arnhem Land, in the Gulf of Carpentaria, Rose River, Muntak Creek, Hart River, Walker River and Koolatong River. Messel, H.; Elliott, M., Wells, A. G., Green, W. J. and Brennan, K. G.
9. Tidal Waterways of Castlereagh Bay and Hutchinson and Cadell Straits. Bennett, Darbitla, Djigagila, Djabura, Ngandadauda Creeks and the Glyde and Woolen Rivers.
10. Waterways of Buckingham and Ulundurwi Bays, Buckingham, Kalarwoi, Warawuruwoi and Kurala Rivers and Slippery Creek. Messel, H.; Vorlicek, G. C.; Wells, A. G. and Green, W. J.
11. Tidal Waterways of Arnhem Bay. Darwarunga, Habgood, Baralminar, Gobalpa, Goromuru, Cato, Peter John and Burungbirinung Rivers. Messel, H.; Vorlicek, G. C.; Wells, A. G. and Green, W. J.
12. Tidal Waterways on the South-Western Coast of the Gulf of Carpentaria. Limmen Bight, Towns, Roper, Phelp and Wilton Rivers; Nayarnpi, Wungguliyanga, Painnyilatya, Mangkurdurrungku and Yiwapa Creeks. Messel, H.; Vorlicek, G. C.; Wells, A. G., Green, W. J. and Johnson, A.
13. Tidal Systems on the Southern Coast of the Gulf of Carpentaria. Calvert, Robinson, Wearyan, McArthur Rivers and some intervening Creeks. Messel, H.; Vorlicek, G. C.; Wells, A. G.; Green, W. J. and Johnson, A.
14. Tidal Waterways of Van Diemen Gulf. Ilamaryi, Iwalg, Saltwater and Minimini Creeks and Coastal Arms on Cobourg Peninsula. Resurveys of the Alligator Region Rivers. Messel, H.; Vorlicek, G. C.; Wells, A. G. and Green, W. J.
15. Work maps of Tidal Waterways in Northern Australia. Messel, H.; Green, W. J.; Wells, A. G. and Vorlicek, G. C.
16. Surveys of Tidal Waterways on Cape York Peninsula, Queensland, Australia, and their Crocodile Populations. Messel, H.; Vorlicek, G. C.; Wells, A. G.; Green, W. J.; Curtis, H. S.; Roff, C. R. R.; Weaver, C. M. and Johnson, A.
17. Darwin and Bynoe Harbours and their Tidal Waterways. Messel, H.; Vorlicek, G. C.; Elliott, M.; Wells, A. G. and Green, W. J.
18. Population Dynamics of *Crocodylus porosus* and Status, Management and Recovery Update 1979-1983. Messel, H.; Vorlicek, G.C.; Green, W.J. and Onley, I.C.

19. Resurveys of the Tiday Waterways of Van Diemen Gulf and the Southern Gulf of Carpentaria, 1984 and 1985. Messel, H.; Vorlicek, G.C.; Green, W.J.; Onley, I.C.; and King, F. W.
20. Tidal Waterways of the Kimberley Surveyed during 1977, 1978 and 1986. Messel, H.; Burbidge, A.A.; Vorlicek, G.C.; Wells, A.G.; Green, W.J.; Onley, I.C. and Fuller, P.J.

Appearing in the same series and published by the Western Australian Government:

1. The status of the salt-water crocodile in some river systems of the north-west Kimberley, Western Australia. Dept. Fish. Wildl., West, Aust. Rept. No. 24:1-50(1977). Messel, H.; Burbidge, A. A.; Wells, A. G. and Green, W. J.
2. The status of the salt-water crocodile in the Glenelg, Prince Regent and Ord River Systems, Kimberley, Western Australia, Dept. Fish. Wildl. West. Aust. Rept. No. 34:1-38(1979). Burbidge, A. A. and Messel, H.

TABLE 1  
ROPER RIVER, KM145.3-160.2, JULY 7, 1986

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
HATCHLING	1					1		
2-3 (0.6-0.9)	8					8		1
3-4 (0.9-1.2)	24					24		
4-5 (1.2-1.5)	19			1		18		
5-6 (1.5-1.8)	5					5		
6-7 (1.8-2.1)	1					1		
>7 (>2.1)								
EO<6 (<1.8)	8					8		
EO>6 (>1.8)								
EO	7					5	2	
TOTAL	73	—	—	1	—	70	2	1

## ABBREVIATIONS:

IV — IN VEGETATION IVIW — IN VEGETATION IN WATER OM — ON MUD IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE MS — MIDSTREAM EO — EYES ONLY

## Table 1

Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River. One (5-6') *C. porosus* sighted at km146.0 not included in Table. Non-hatchling density is 4.8/km.

TABLE 2  
ROPER RIVER, KM207.0-228.1, JULY 8-9, 1986

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
HATCHLING								
2-3 (0.6-0.9)	2					2		
3-4 (0.9-1.2)	17					17		
4-5 (1.2-1.5)	15					15		
5-6 (1.5-1.8)	4			1		3		
6-7 (1.8-2.1)								
>7 (>2.1)								
EO<6 (<1.8)	5					4	1	
EO>6 (>1.8)								
EO	1					1		
TOTAL	44	—	—	1	—	42	1	—

## ABBREVIATIONS:

IV — IN VEGETATION IVIW — IN VEGETATION IN WATER OM — ON MUD IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE MS — MIDSTREAM EO — EYES ONLY

## Table 2

Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River. Non-hatchling density is 2.1/km.

**TABLE 3**  
**ROPER RIVER, KM236.2-241.5, JULY 10, 1986**

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
<b>HATCHLING</b>								
2-3 (0.6-0.9)	1					1		
3-4 (0.9-1.2)	8					8		
4-5 (1.2-1.5)	13					13		1
5-6 (1.5-1.8)	4					4		
6-7 (1.8-2.1)	1					1		
>7 (>2.1)								
EO<6 (<1.8)	4					3	1	
EO>6 (>1.8)								
EO								
<b>TOTAL</b>	31	—	—	—	—	30	1	1

## ABBREVIATIONS:

IV — IN VEGETATION IVIW — IN VEGETATION IN WATER OM — ON MUD IM — IN MUO  
SWOE — SHALLOW WATER ON EDGE MS — MIDSTREAM EO — EYES ONLY

## Table 3

Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River. Non-hatchling density is 5.8/km.

**TABLE 4**  
**ROPER RIVER, KM252.5-267.0, JULY 11, 1986**

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
<b>HATCHLING</b>								
2-3 (0.6-0.9)	1					1		
3-4 (0.9-1.2)	11					11		
4-5 (1.2-1.5)	19					18	1	
5-6 (1.5-1.8)	7			2		5		
6-7 (1.8-2.1)	1					1		
>7 (>2.1)	1			1				
EO<6 (<1.8)	18					18		
EO>6 (>1.8)								
EO								
<b>TOTAL</b>	58	—	—	3	—	54	1	—

## ABBREVIATIONS:

IV — IN VEGETATION IVIW — IN VEGETATION IN WATER OM — ON MUO IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE MS — MIDSTREAM EO — EYES ONLY

## Table 4

Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River. Non-hatchling density is 4.0/km.

**TABLE 5**  
**ROPER RIVER, KM318.5-335.8, JULY 13-14, 1986**

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
<b>HATCHLING</b>								
2-3 (0.6-0.9)								
3-4 (0.9-1.2)	11					11		
4-5 (1.2-1.5)	25					25		
5-6 (1.5-1.8)	12					12		
6-7 (1.8-2.1)	2					2		
>7 (>2.1)								
EO<6 (<1.8)	27					27		
EO>6 (>1.8)								
EO	1					1		
<b>TOTAL</b>	<b>78</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>—</b>	<b>78</b>	<b>—</b>	<b>—</b>

ABBREVIATIONS:  
IV — IN VEGETATION IVIW — IN VEGETATION IN WATER OM — ON MUD IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE MS — MIDSTREAM EO — EYES ONLY

Table 5  
Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River. A sidecreek of 0.6 km was surveyed making a total distance of 17.9 km. Non-hatchling density is 4.4/km.

**TABLE 6**  
**ROPER RIVER, KM349.2-352.5, JULY 12, 1986**

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
<b>HATCHLING</b>								
2-3 (0.6-0.9)								
3-4 (0.9-1.2)	11			1		10		
4-5 (1.2-1.5)	4					4		
5-6 (1.5-1.8)	1					1		
6-7 (1.8-2.1)								
>7 (>2.1)								
EO<6 (<1.8)	7					7		
EO>6 (>1.8)								
EO								
<b>TOTAL</b>	<b>23</b>	<b>—</b>	<b>—</b>	<b>1</b>	<b>—</b>	<b>22</b>	<b>—</b>	<b>—</b>

ABBREVIATIONS:  
IV — IN VEGETATION IVIW — IN VEGETATION IN WATER OM — ON MUD IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE MS — MIDSTREAM EO — EYES ONLY

Table 6  
Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River. Non-hatchling density is 7.0/km.

TABLE 7  
OVERALL UPSTREAM ROPER RIVER, JULY 7-14, 1986

SIZE IN FEET (metres)	NUMBER OF CROCS	SITUATION						OBSERVED FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
HATCHLING	1					1		
2-3 (0.6-0.9)	12					12		1
3-4 (0.9-1.2)	82			1		81		
4-5 (1.2-1.5)	95			1		93	1	1
5-6 (1.5-1.8)	33			3		30		
6-7 (1.8-2.1)	5					5		
>7 (>2.1)	1			1				
EO<6 (<1.8)	69					67	2	
EO>6 (>1.8)								
EO	9					7	2	
TOTAL	307	—	—	6	—	296	5	2

## ABBREVIATIONS:

IV — IN VEGETATION IVIW — IN VEGETATION IN WATER OM — ON MUD IM — IN MUD  
SWOE — SHALLOW WATER ON EDGE MS — MIDSTREAM EO — EYES ONLY

## Table 7

Number of *C. johnstoni* spotted in each size class and situation on upstream Roper River from km145.3. One (5-6) *C. porosus* sighted at km146.0 not included in table. Total distance surveyed was 77 km, yielding a non-hatchling density of 4.0/km.

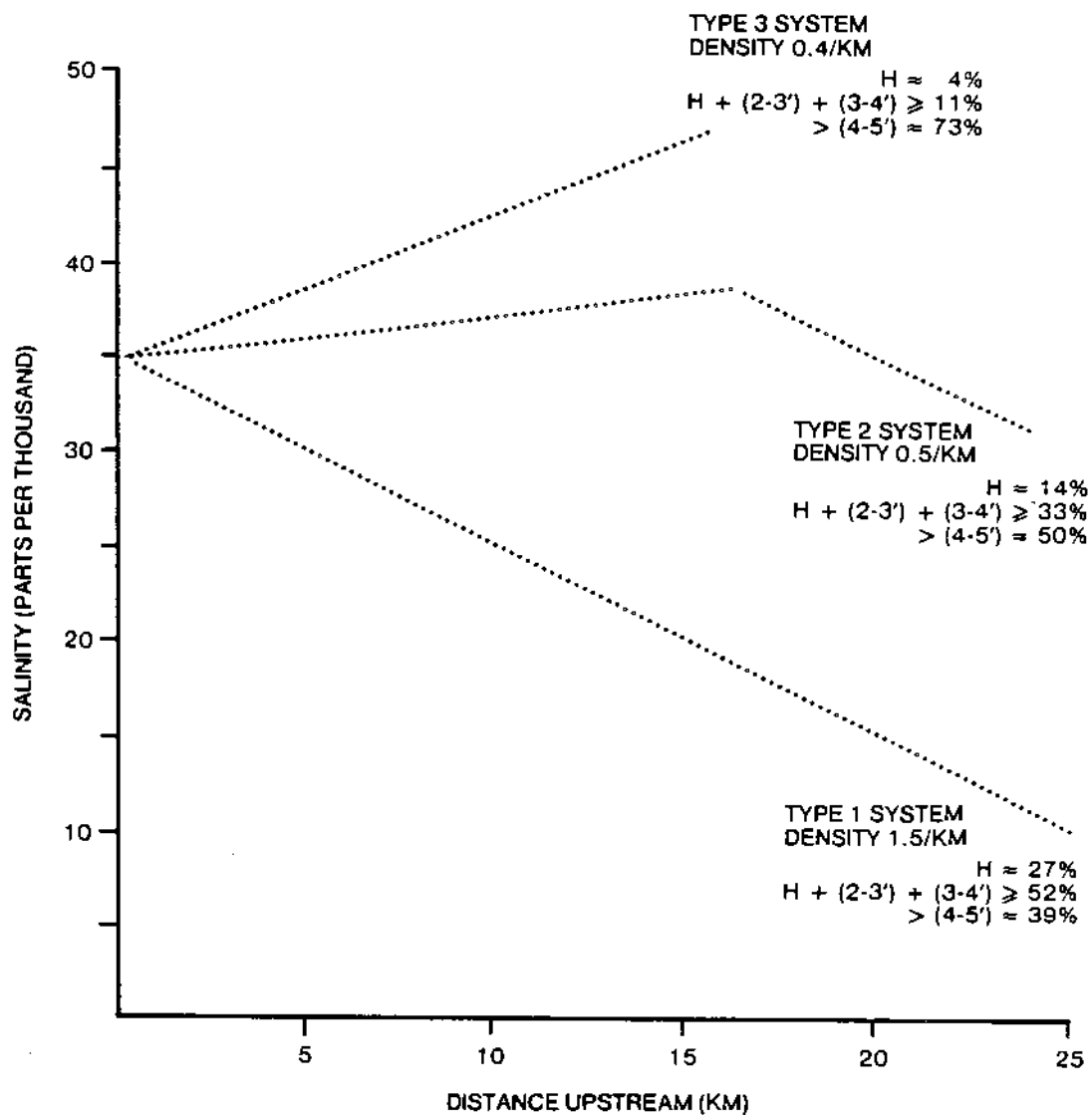


Figure 1. Typical dry season salinity profiles for the three types of tidal river systems occurring in the model's classification scheme. In a Type 1 system the salinity decreases steadily as one progresses upstream from that of seawater measured at the mouth of the waterway ( $\sim 35^0/\text{oo}$ ). In contrast, in a Type 3 system the salinity increases steadily as one progresses upstream. Type 2 systems fall somewhere between Type 1 and Type 3 systems and tend to show hypersaline tendencies as the dry season progresses (pages 100 and 101 Monograph 1). As shown above, the non-hatchling density and size structure of the crocodiles sighted in the three kinds of systems differ strikingly (Table 9.2.1, page 419 Monograph 1).

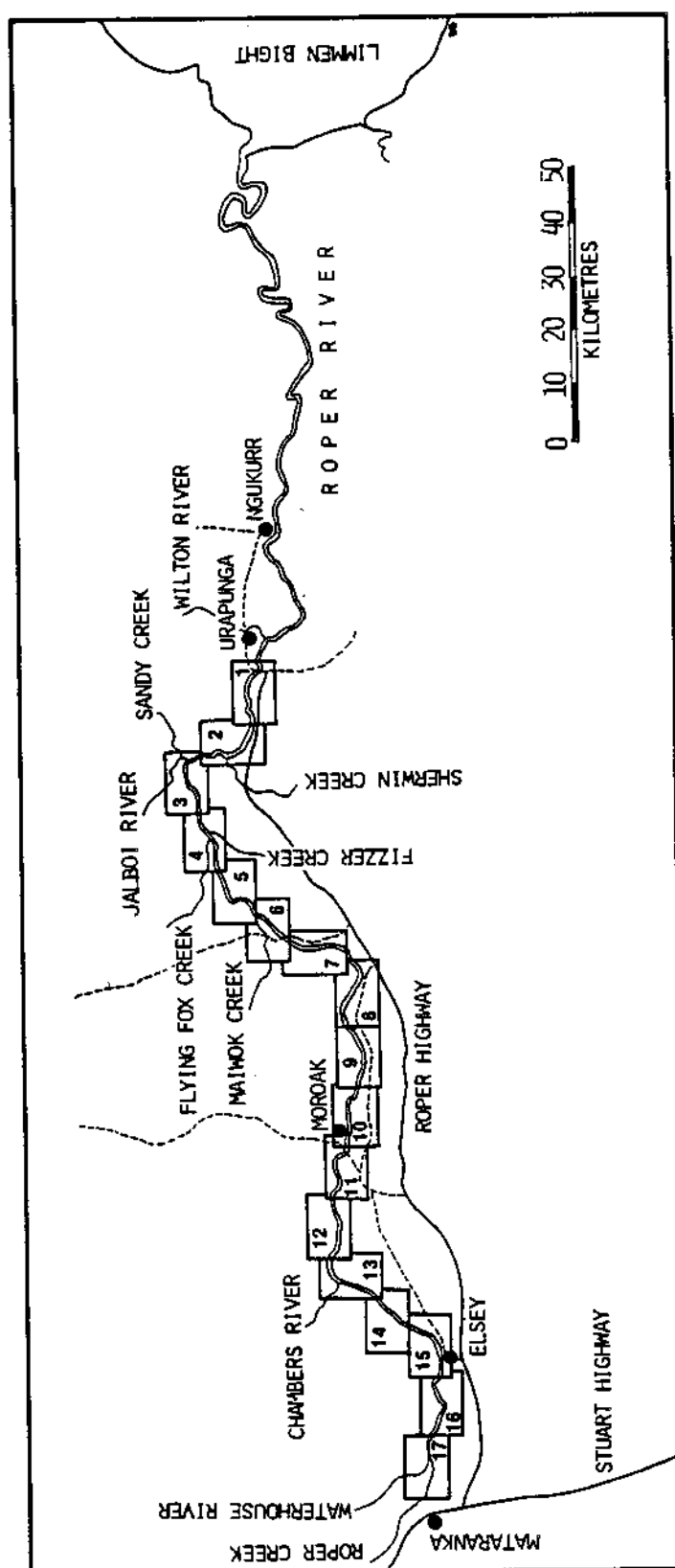


Figure 2. Legend to the river work maps of the upstream Roper River.



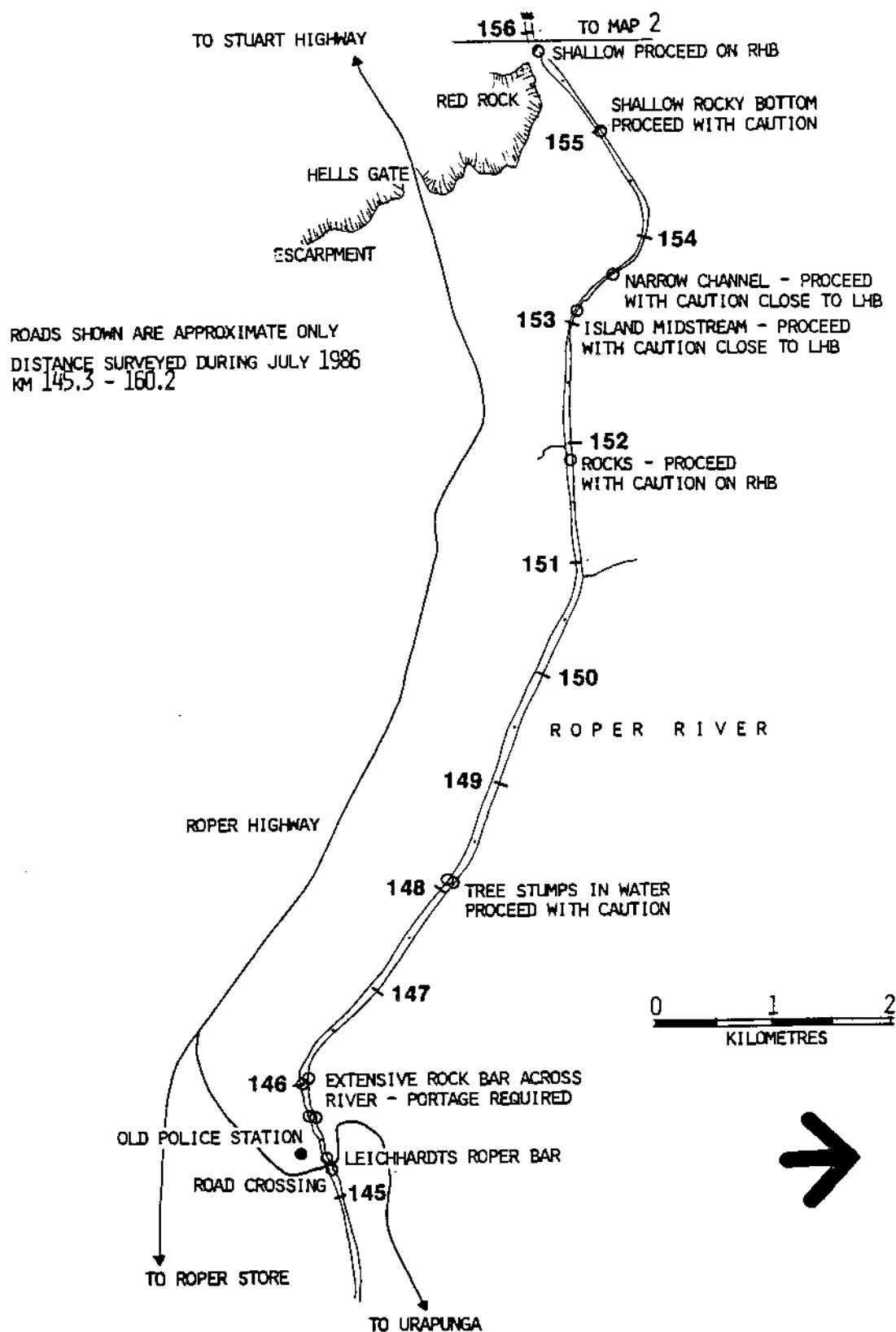


Figure 3. Upstream Roper River 1.

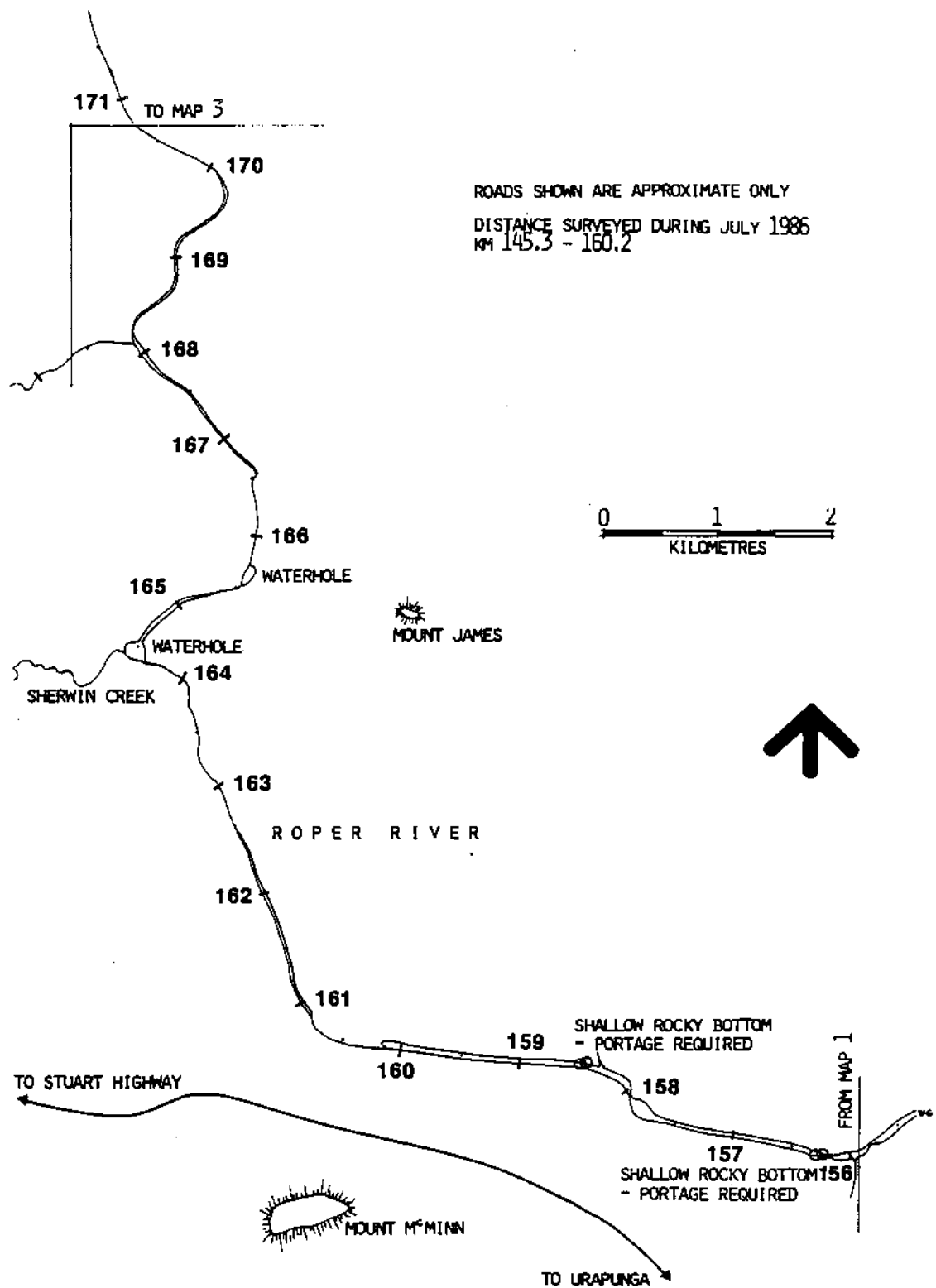


Figure 4. Upstream Roper River 2.

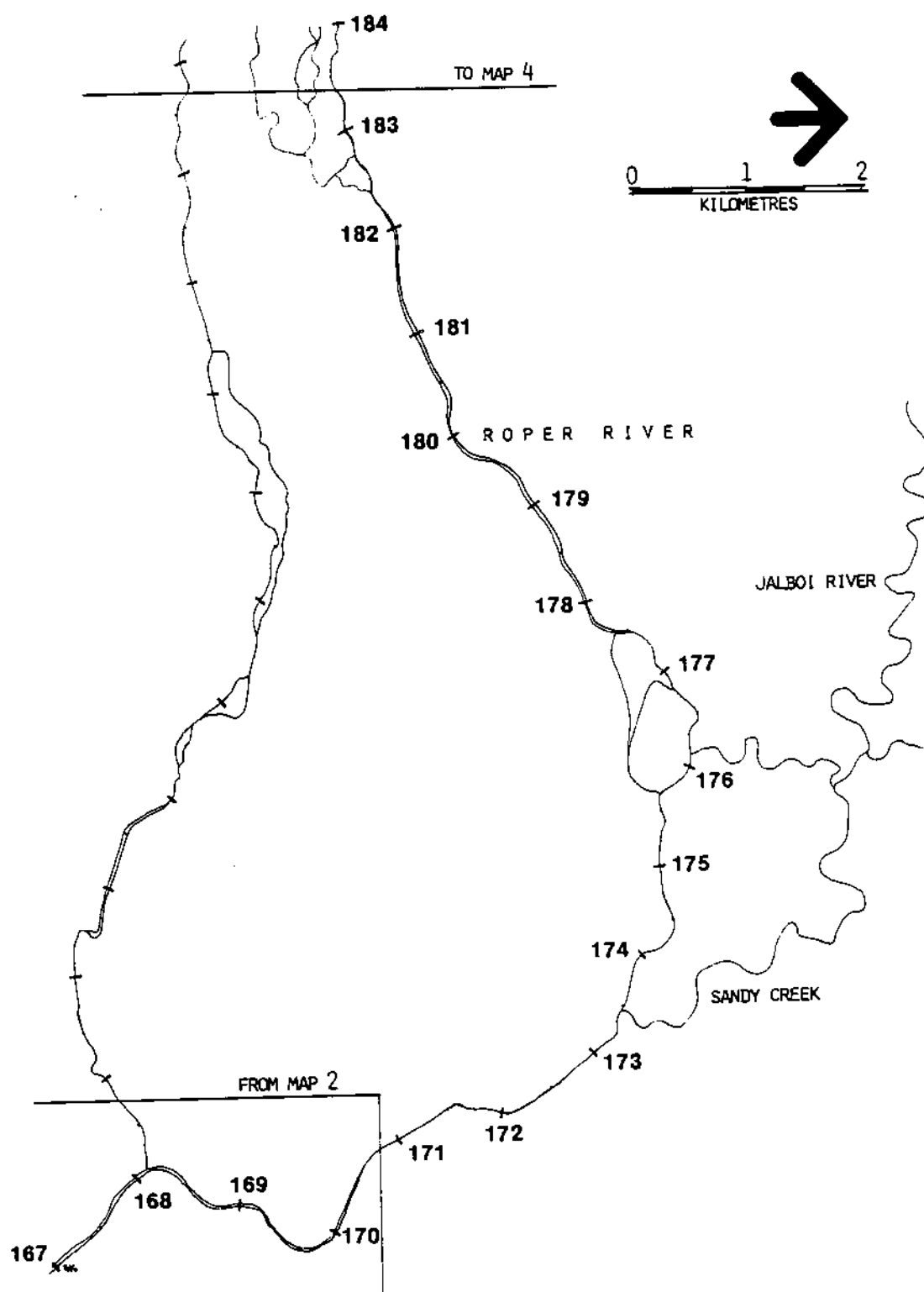


Figure 5. Upstream Roper River 3.

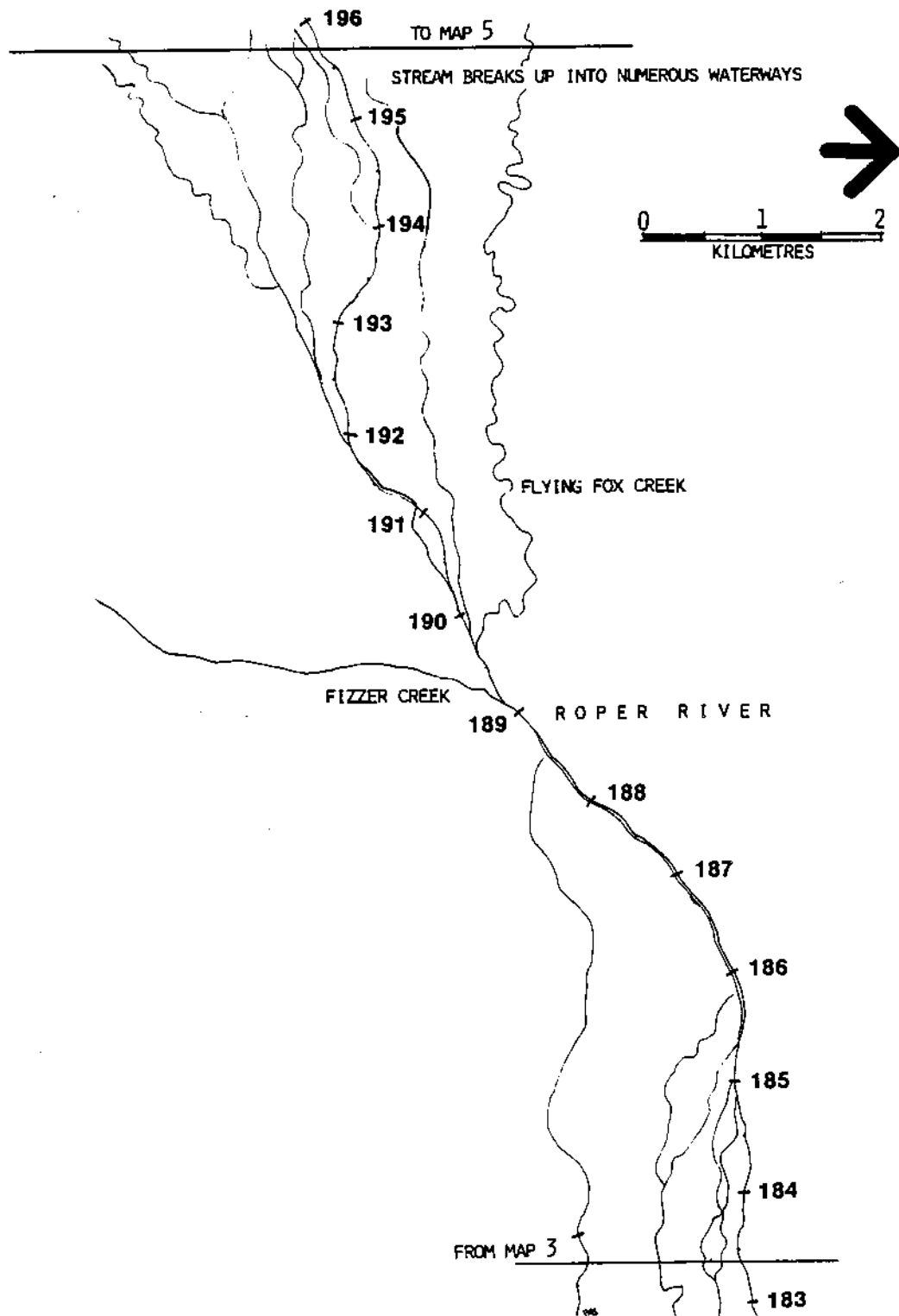


Figure 6. Upstream Roper River 4.

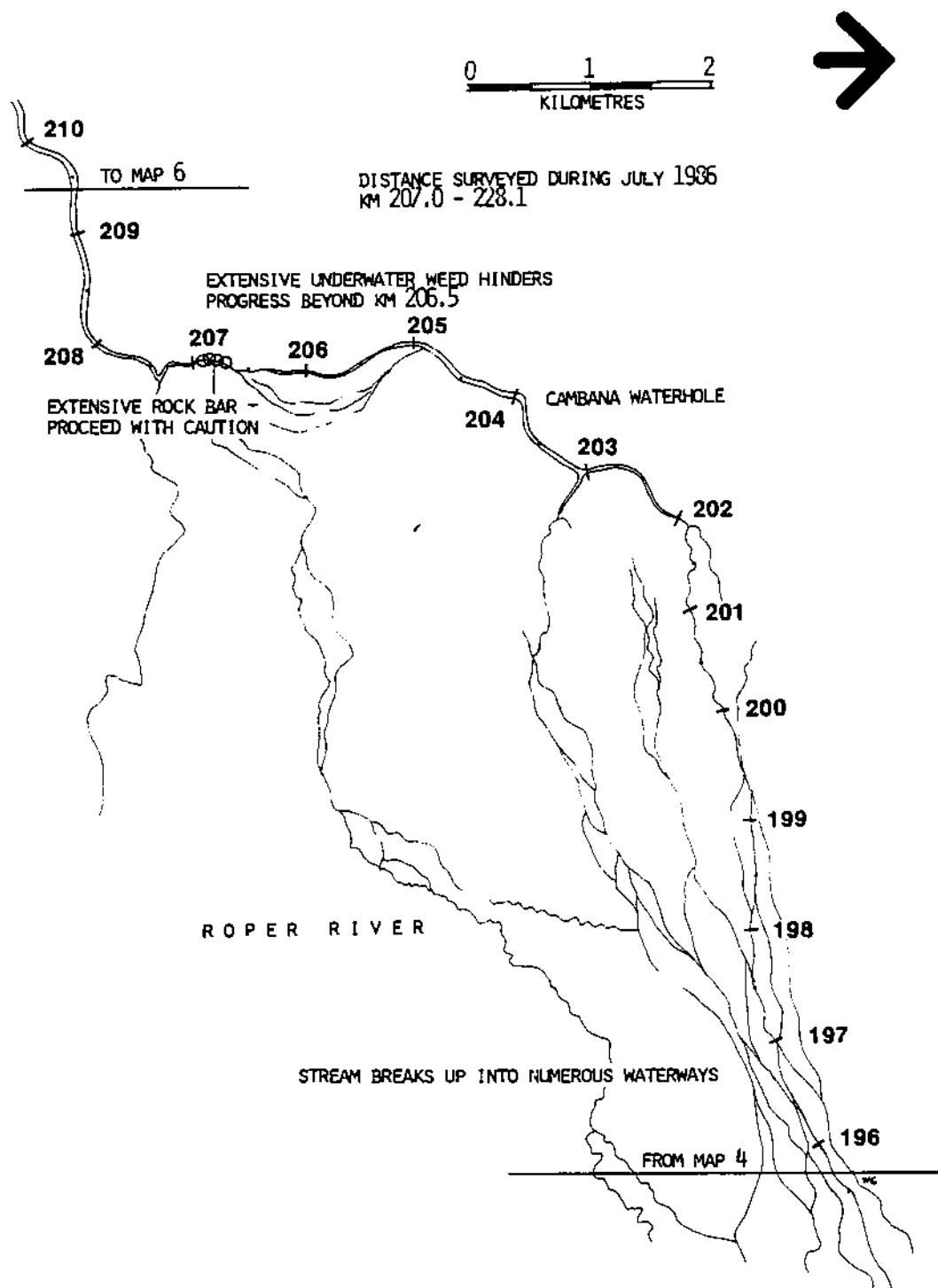


Figure 7. Upstream Roper River 5.

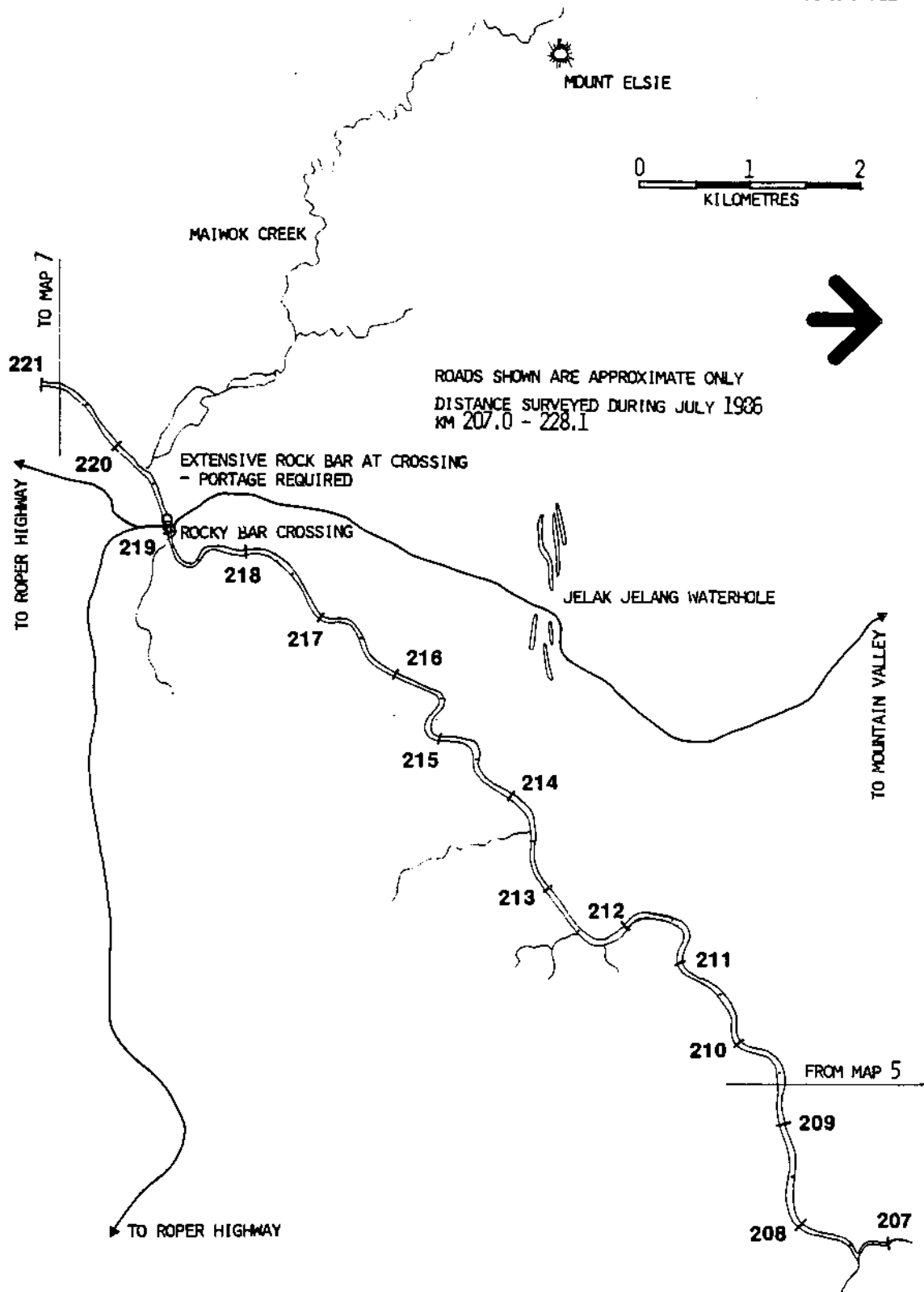


Figure 8. Upstream Roper River 6.

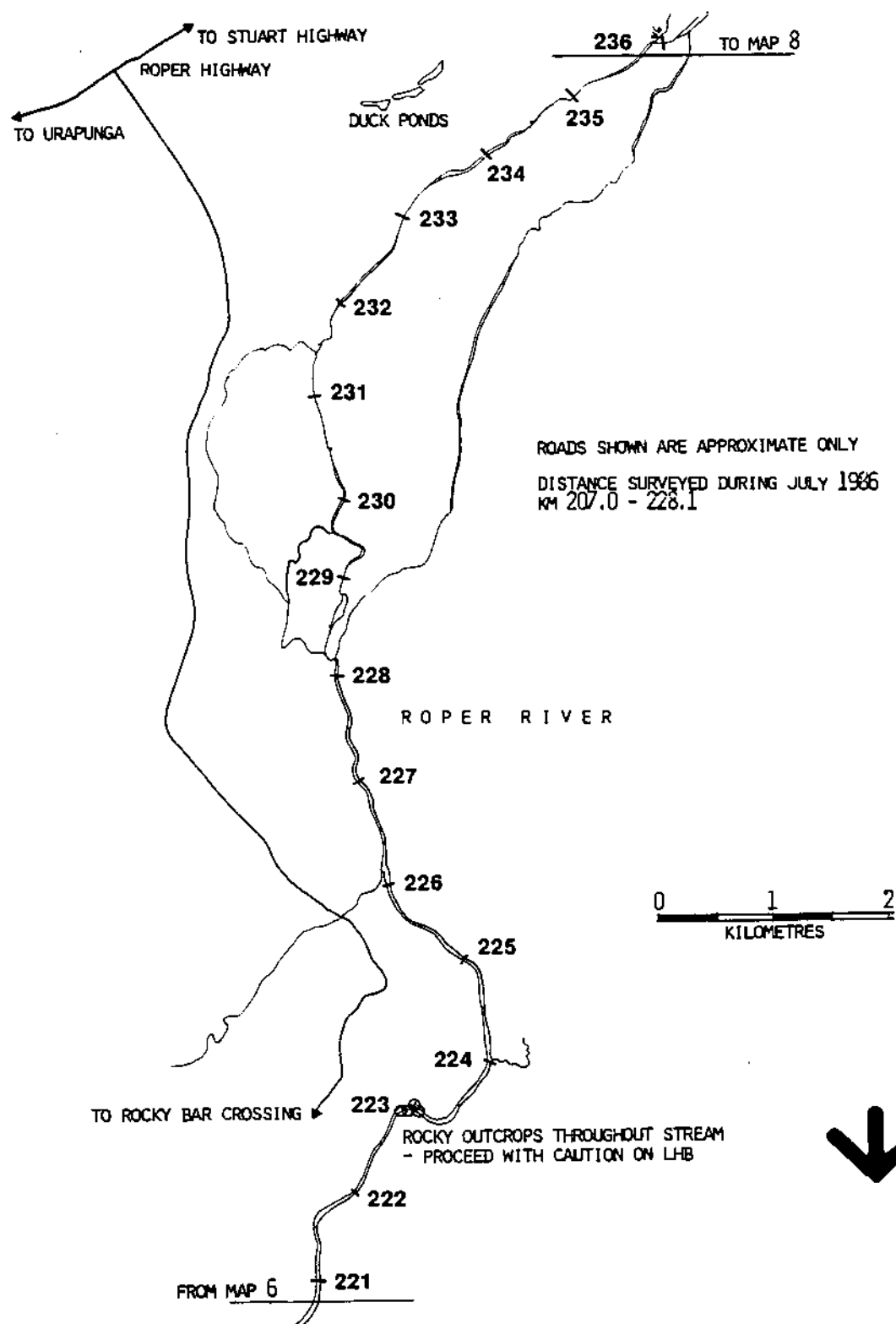


Figure 9. Upstream Roper River 7.

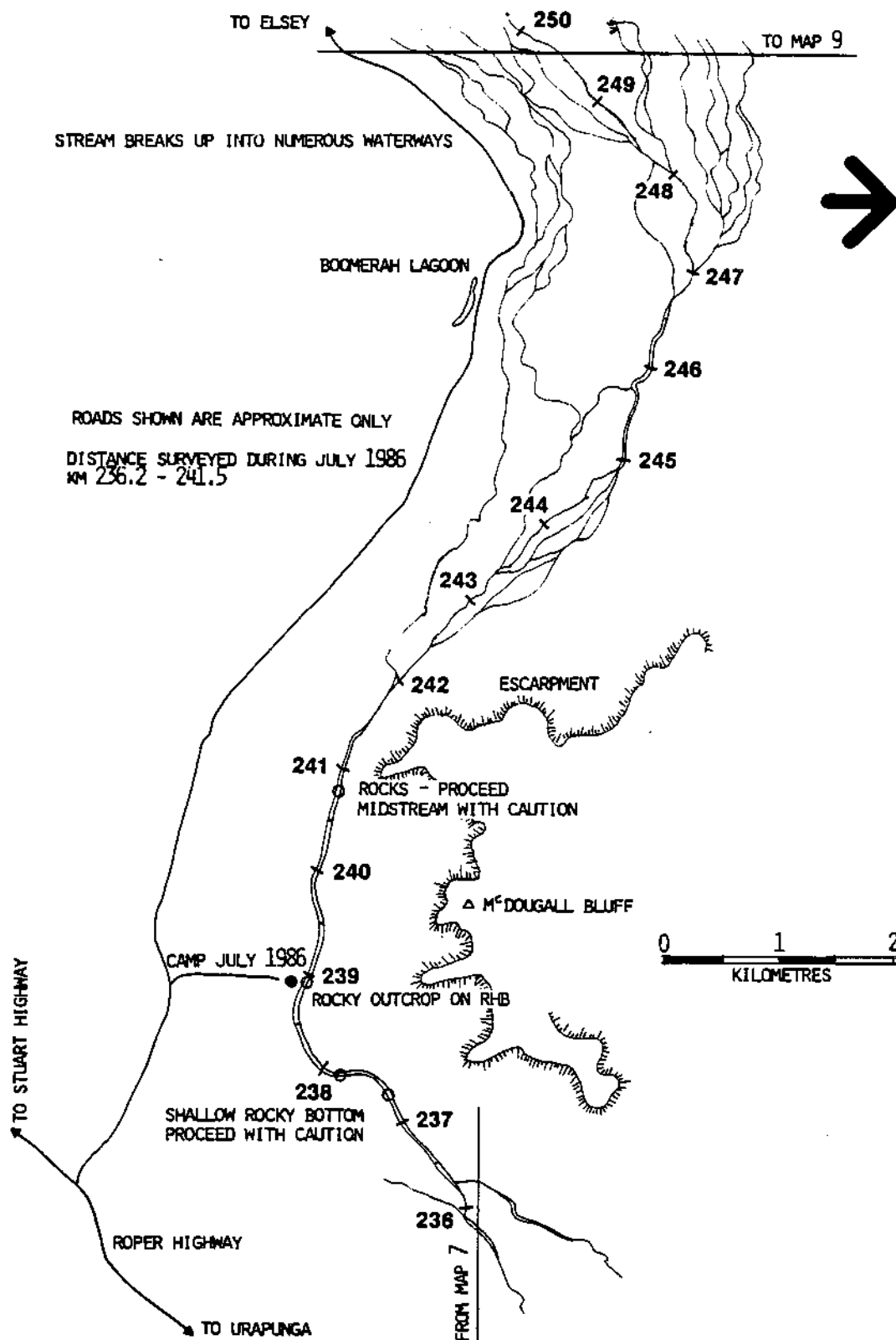


Figure 10. Upstream Roper River 8.



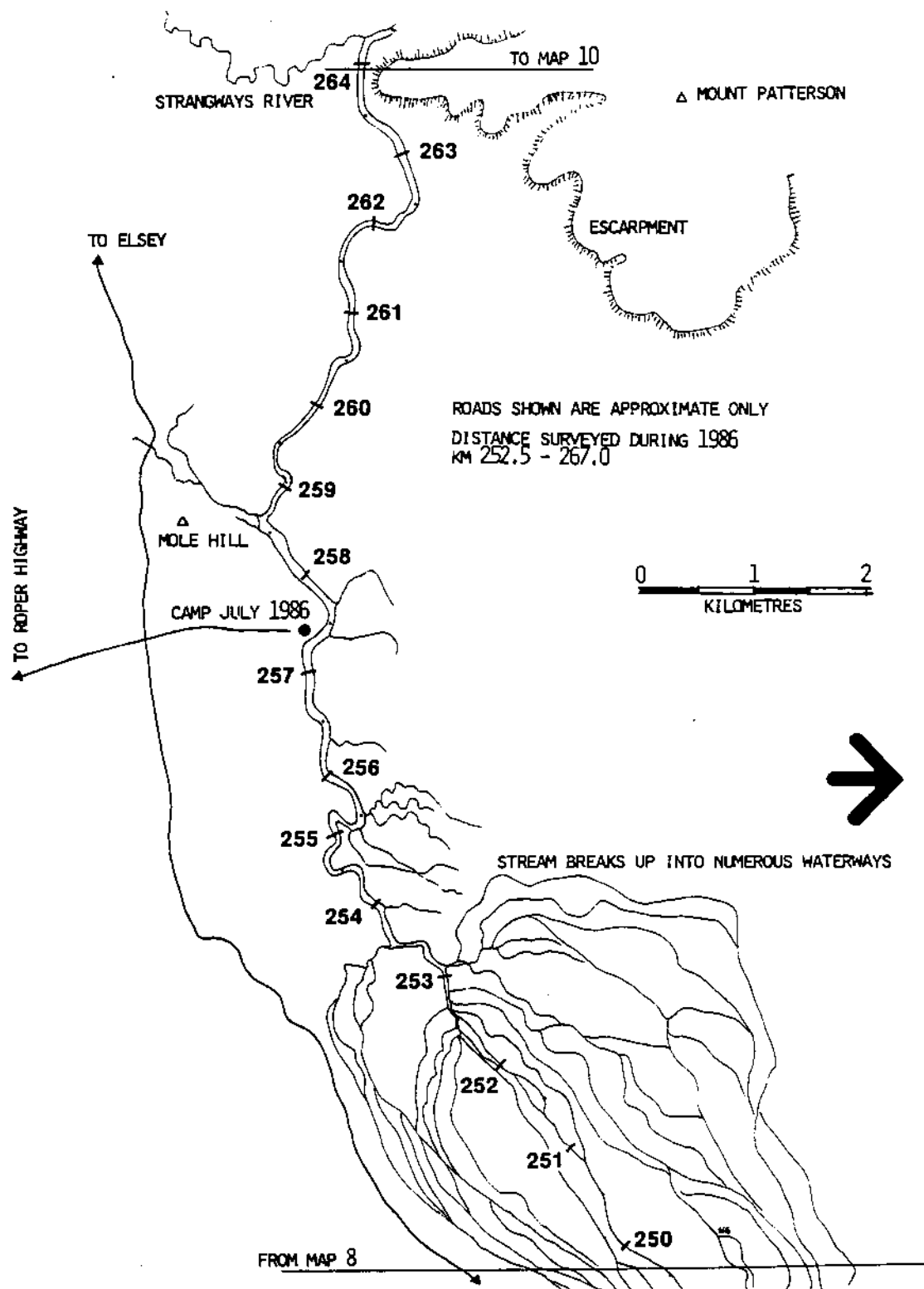


Figure 11. Upstream Roper River 9.

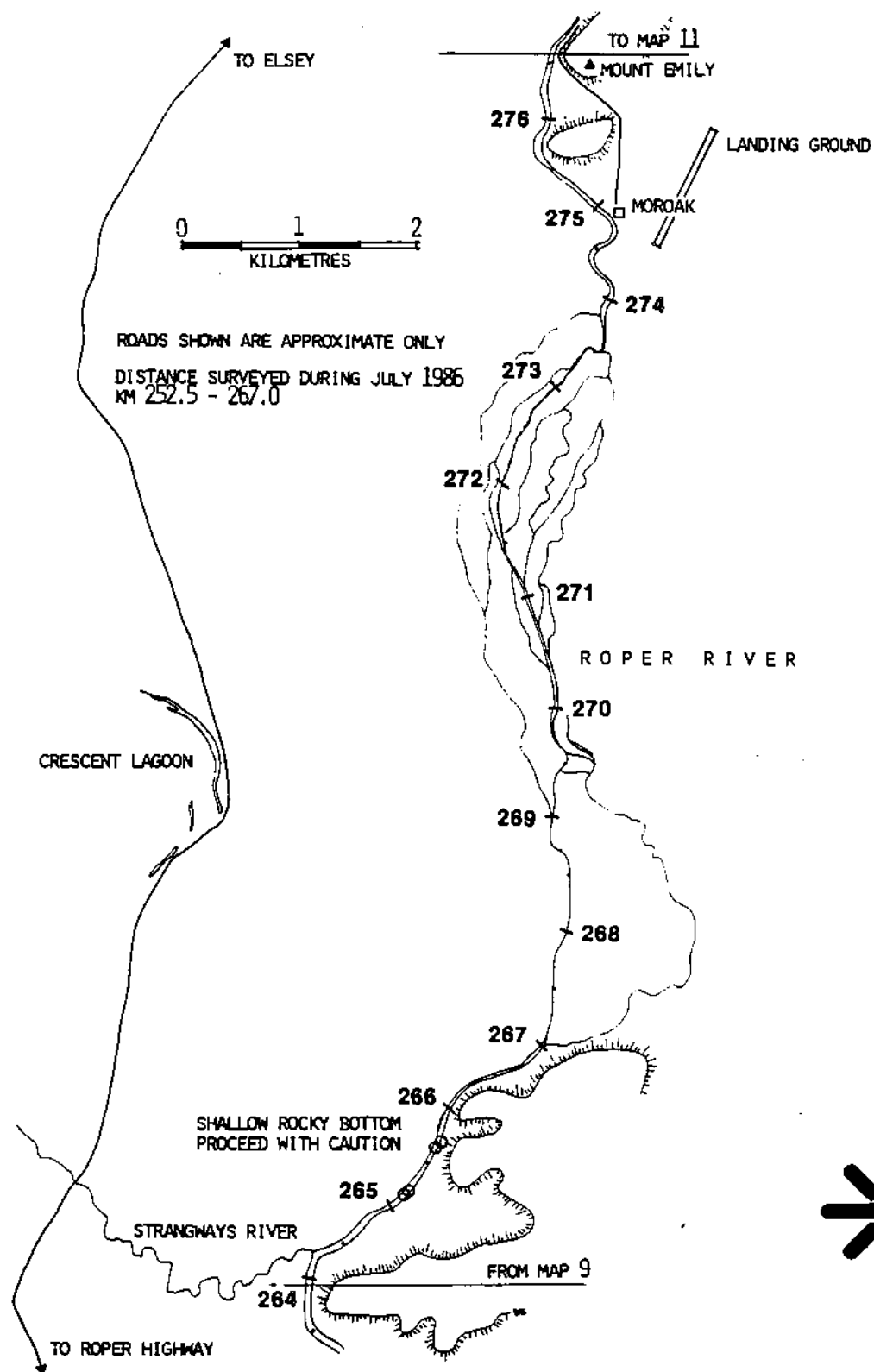


Figure 12. Upstream Roper River 10.

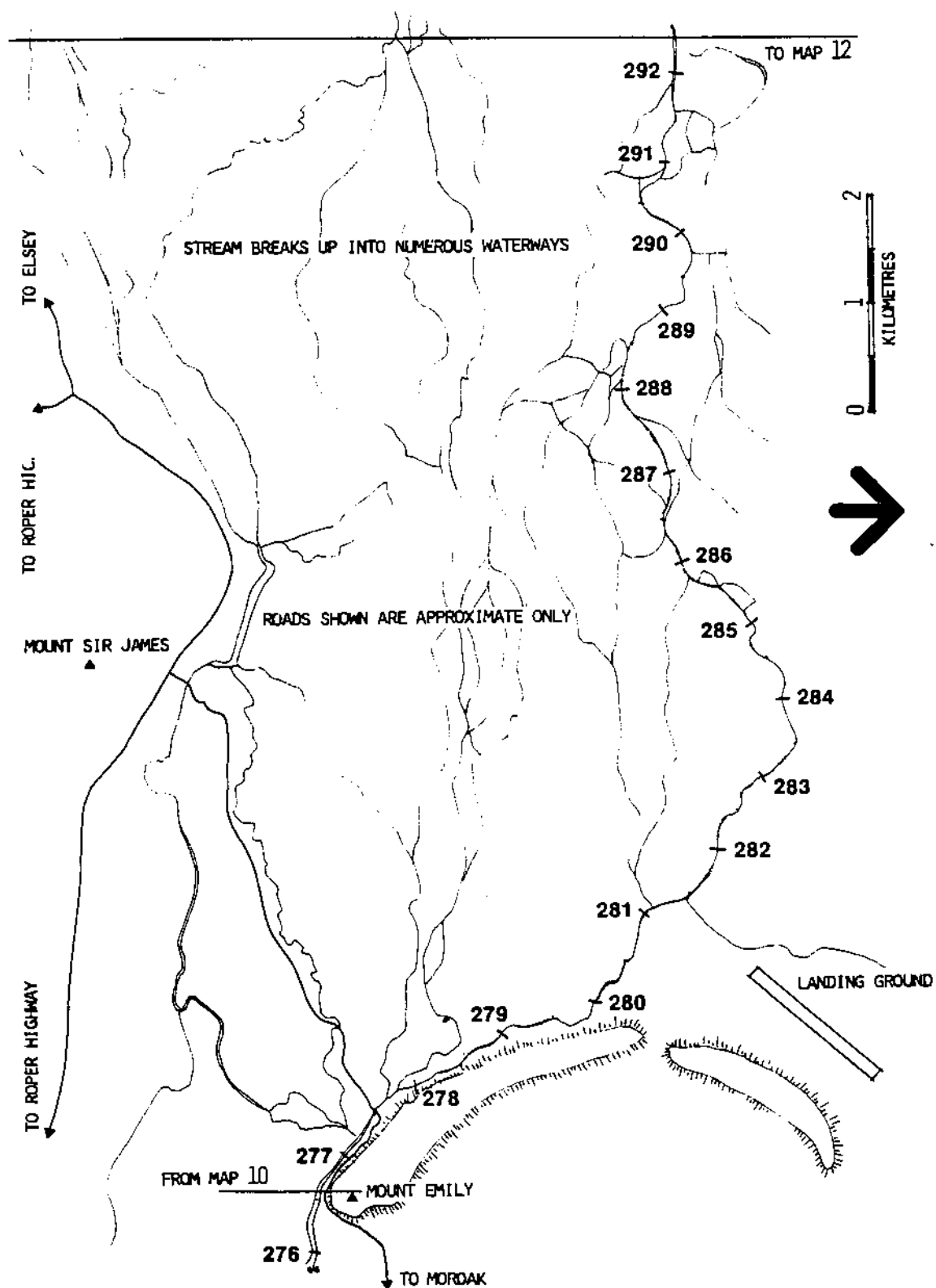


Figure 13. Upstream Roper River 11.

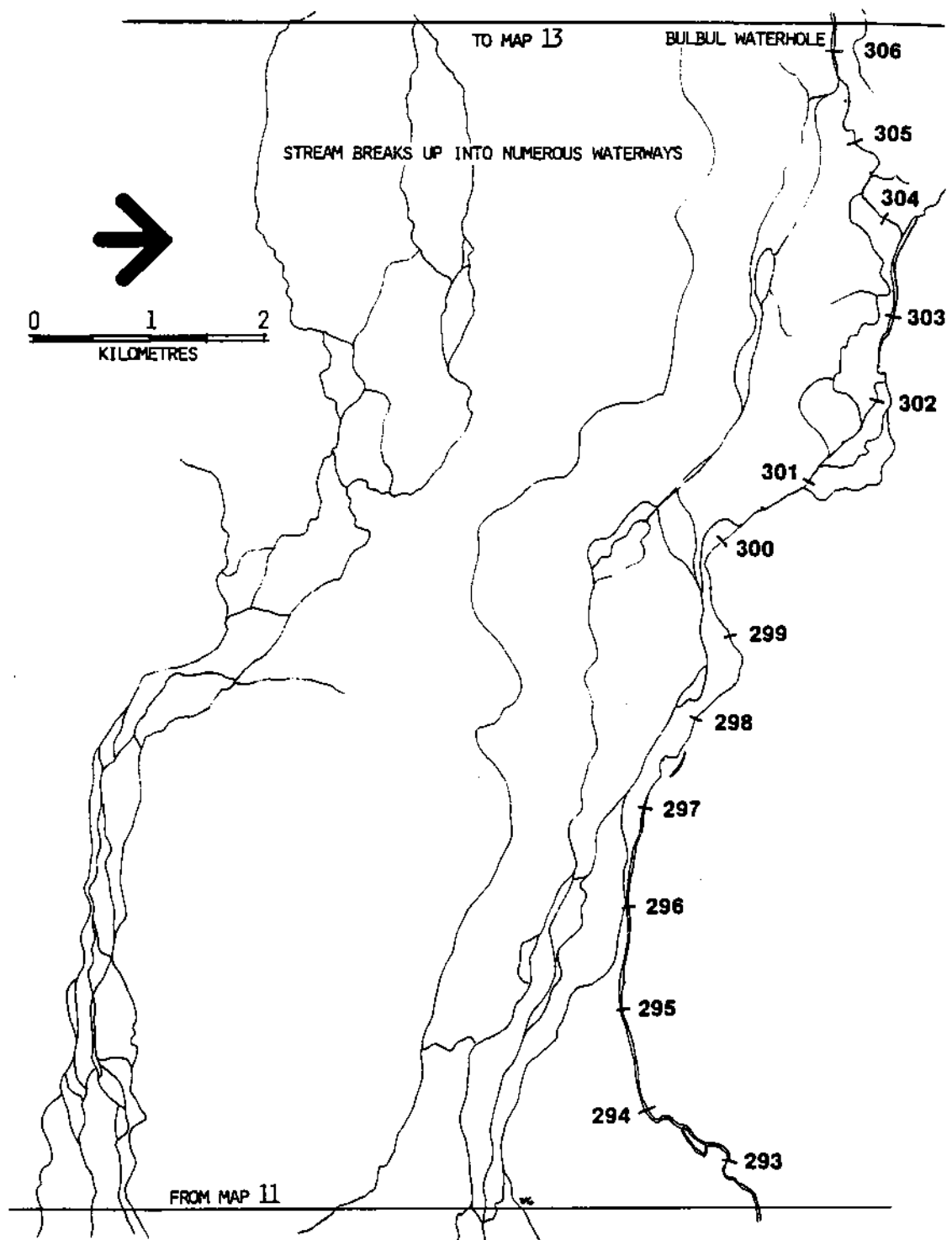


Figure 14. Upstream Roper River 12.

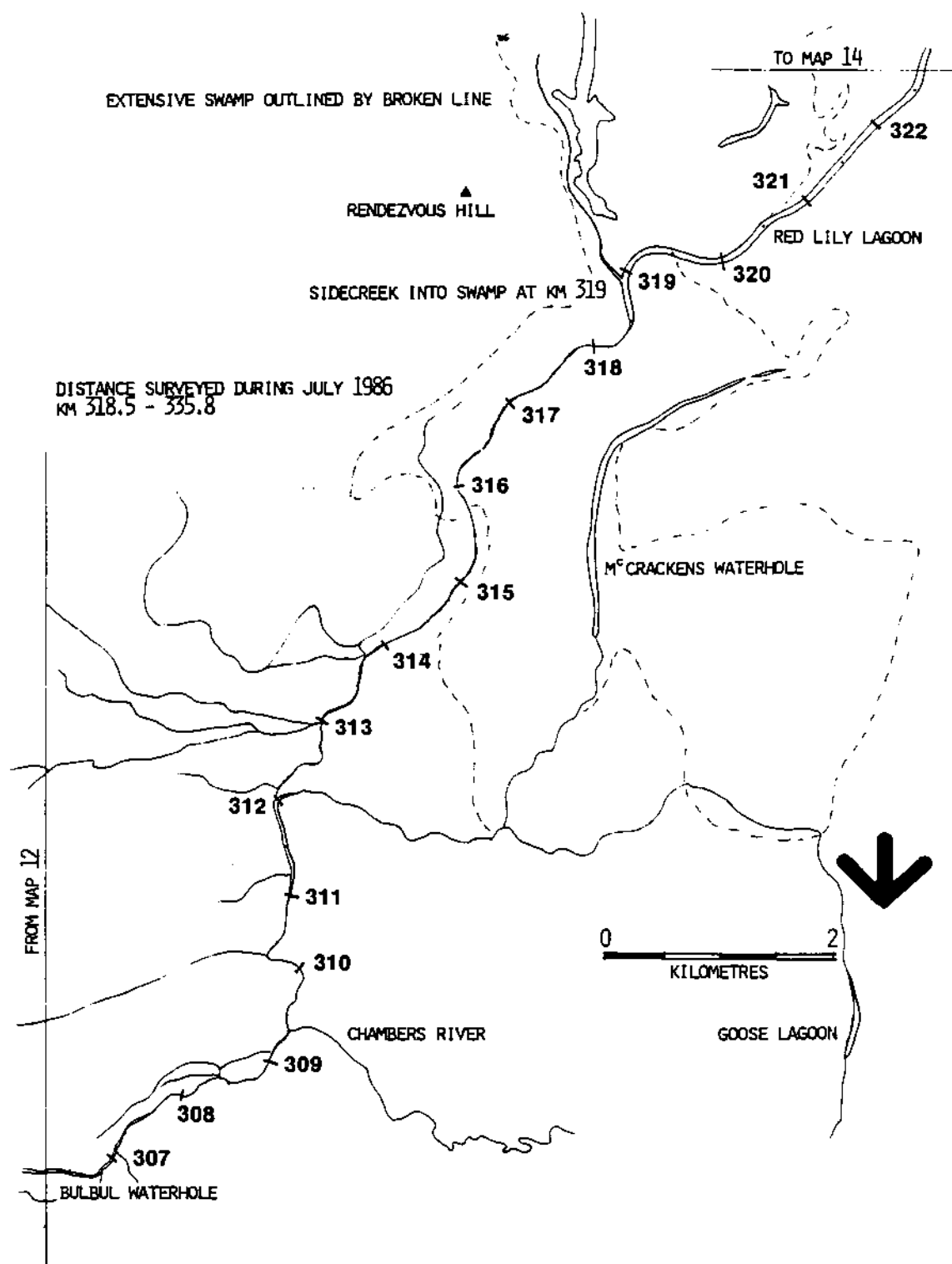


Figure 15. Upstream Roper River 13.

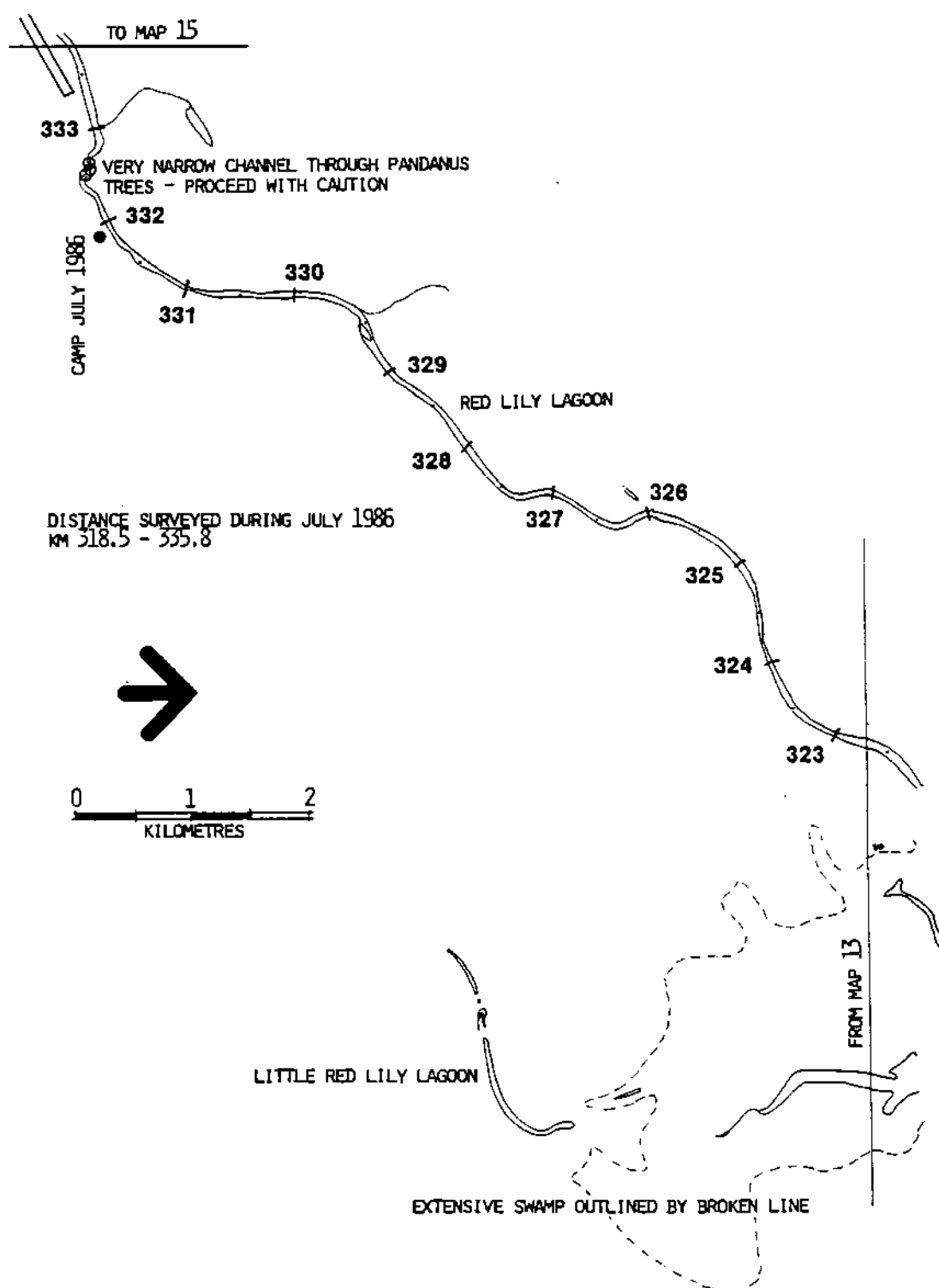


Figure 16. Upstream Roper River 14.

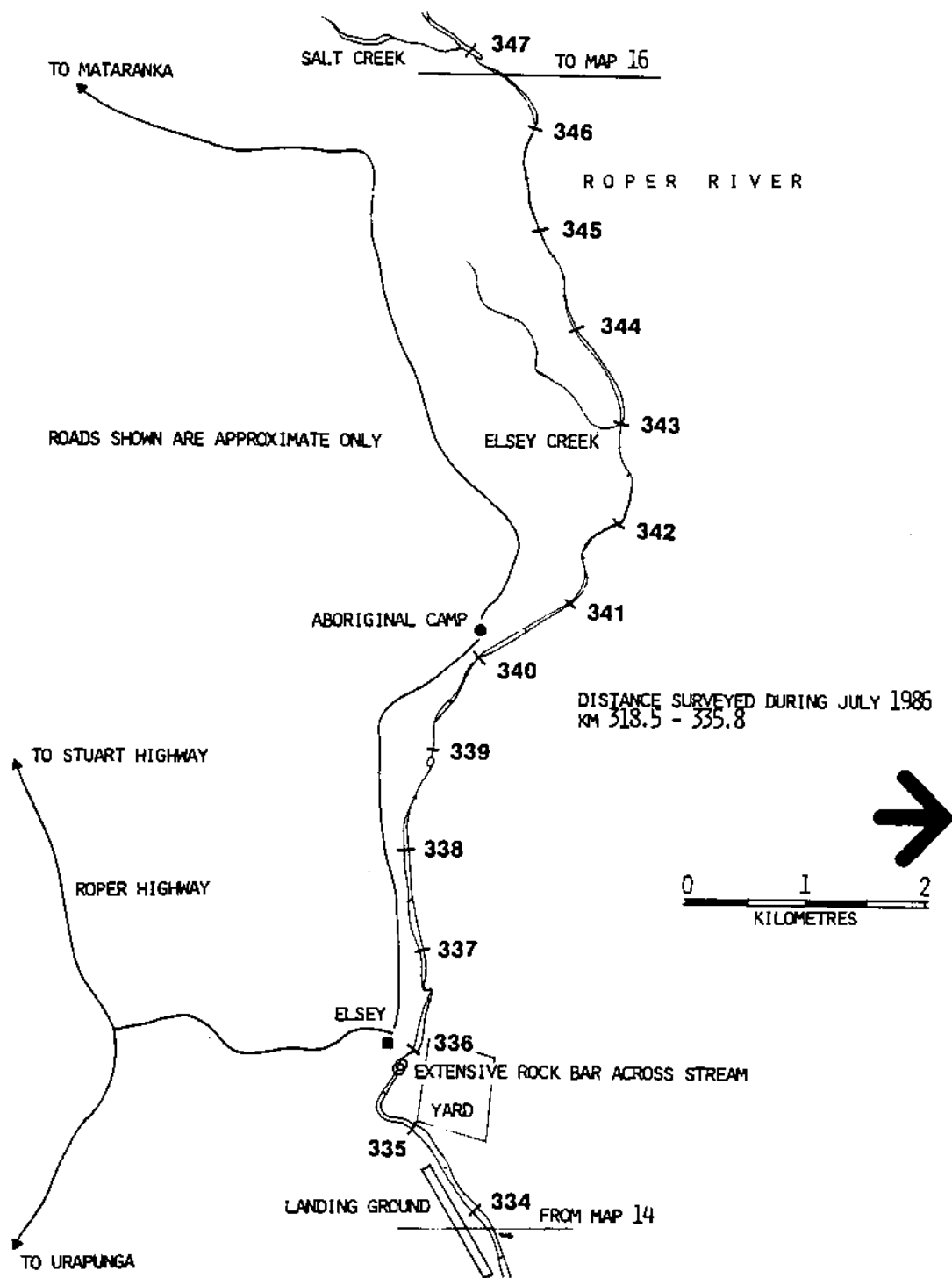


Figure 17. Upstream Roper River 15.

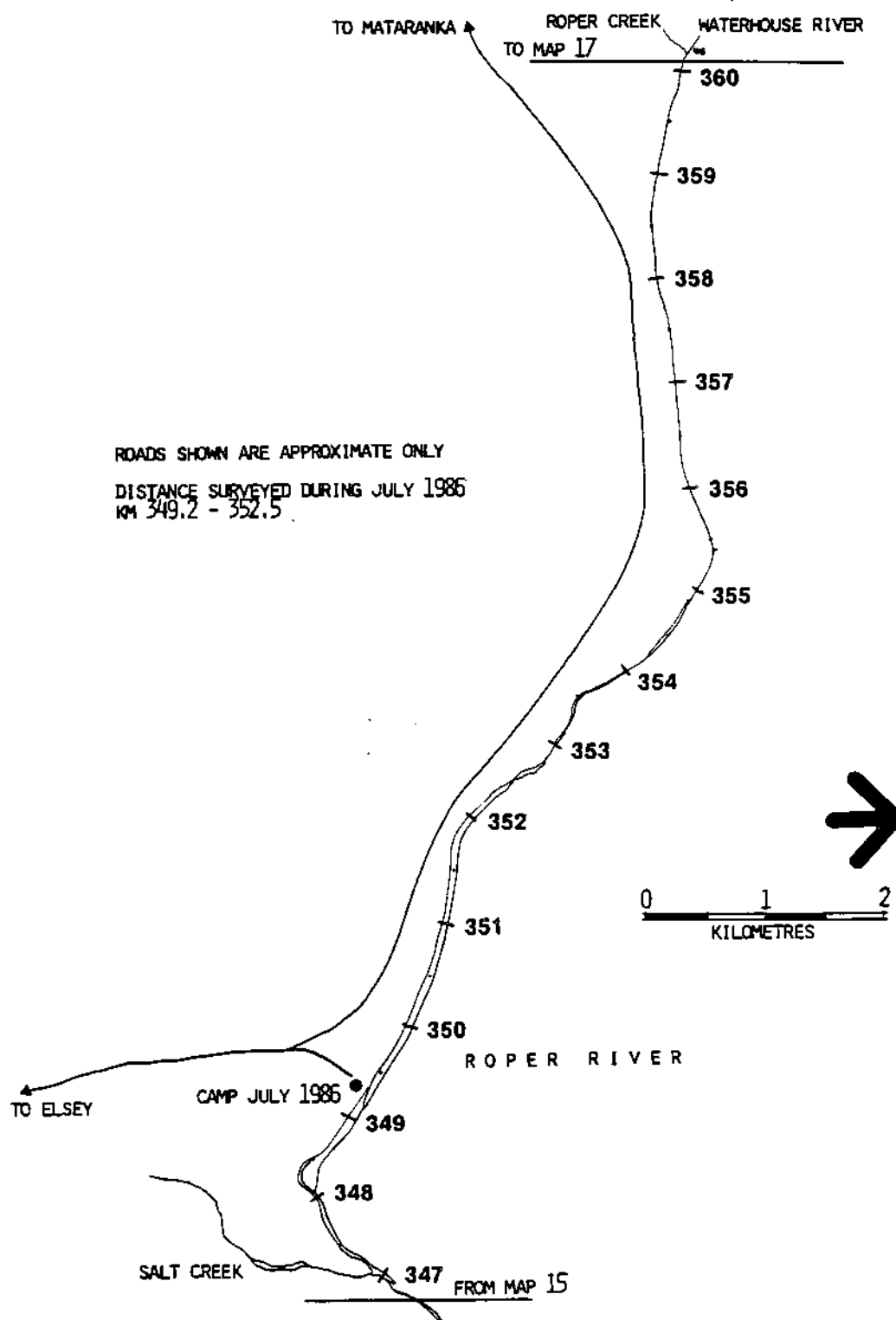


Figure 18. Upstream Roper River 16.



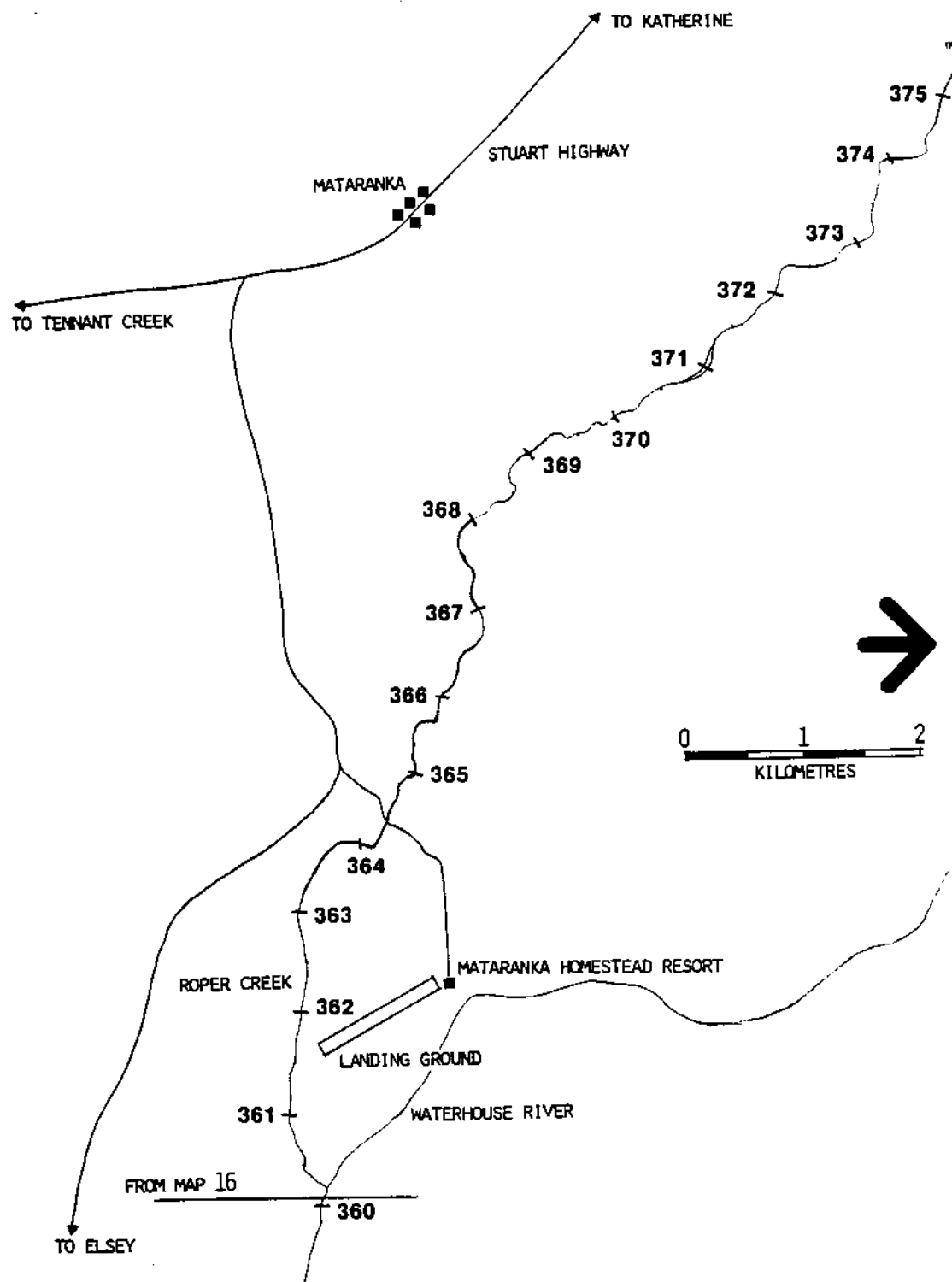


Figure 19. Upstream Roper River 17.

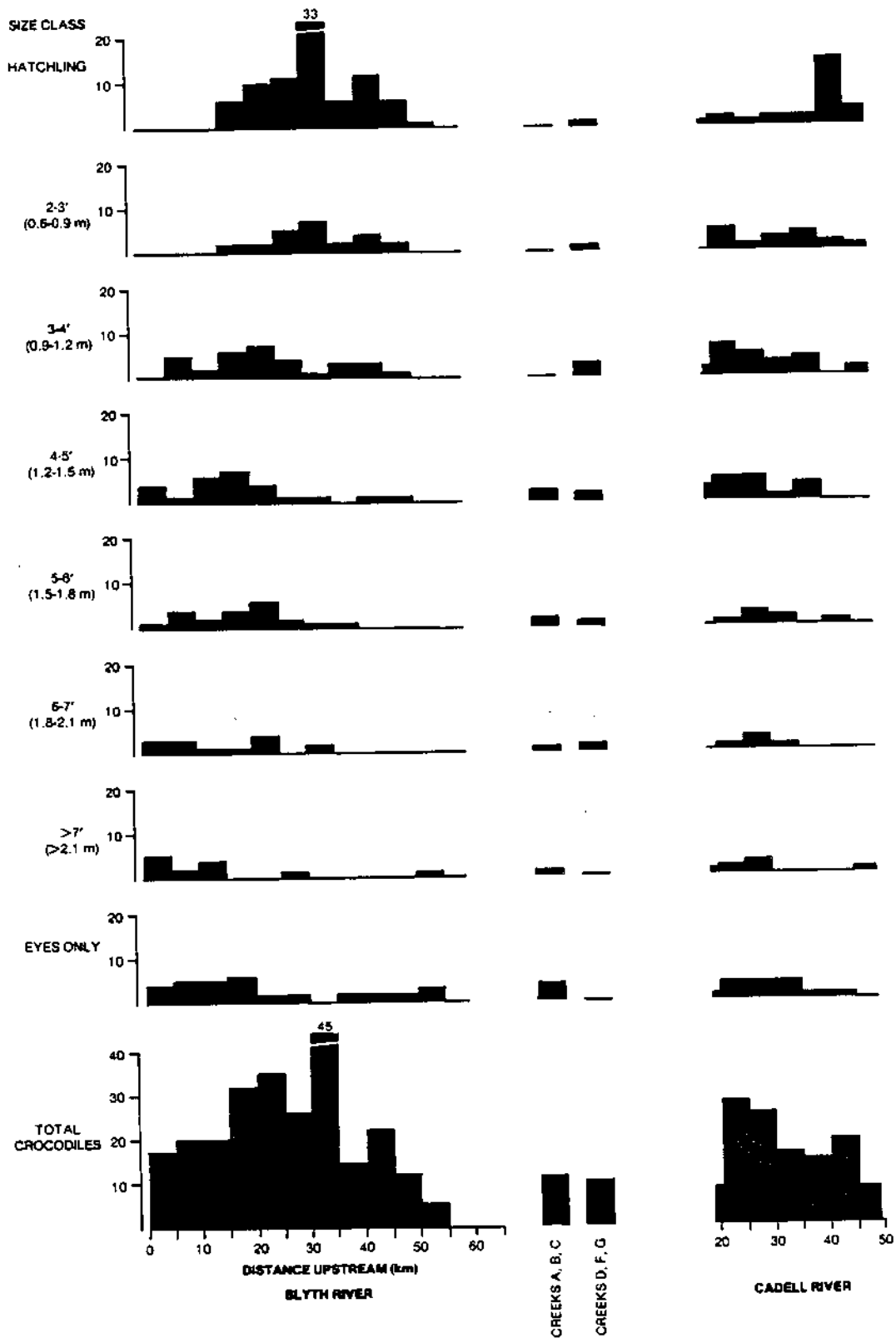


Figure 20. Distributional pattern of *Crocodylus porosus* in the Blyth-Cadell Rivers System during 25-28 June 1982 (from p. 175 Monograph 18).

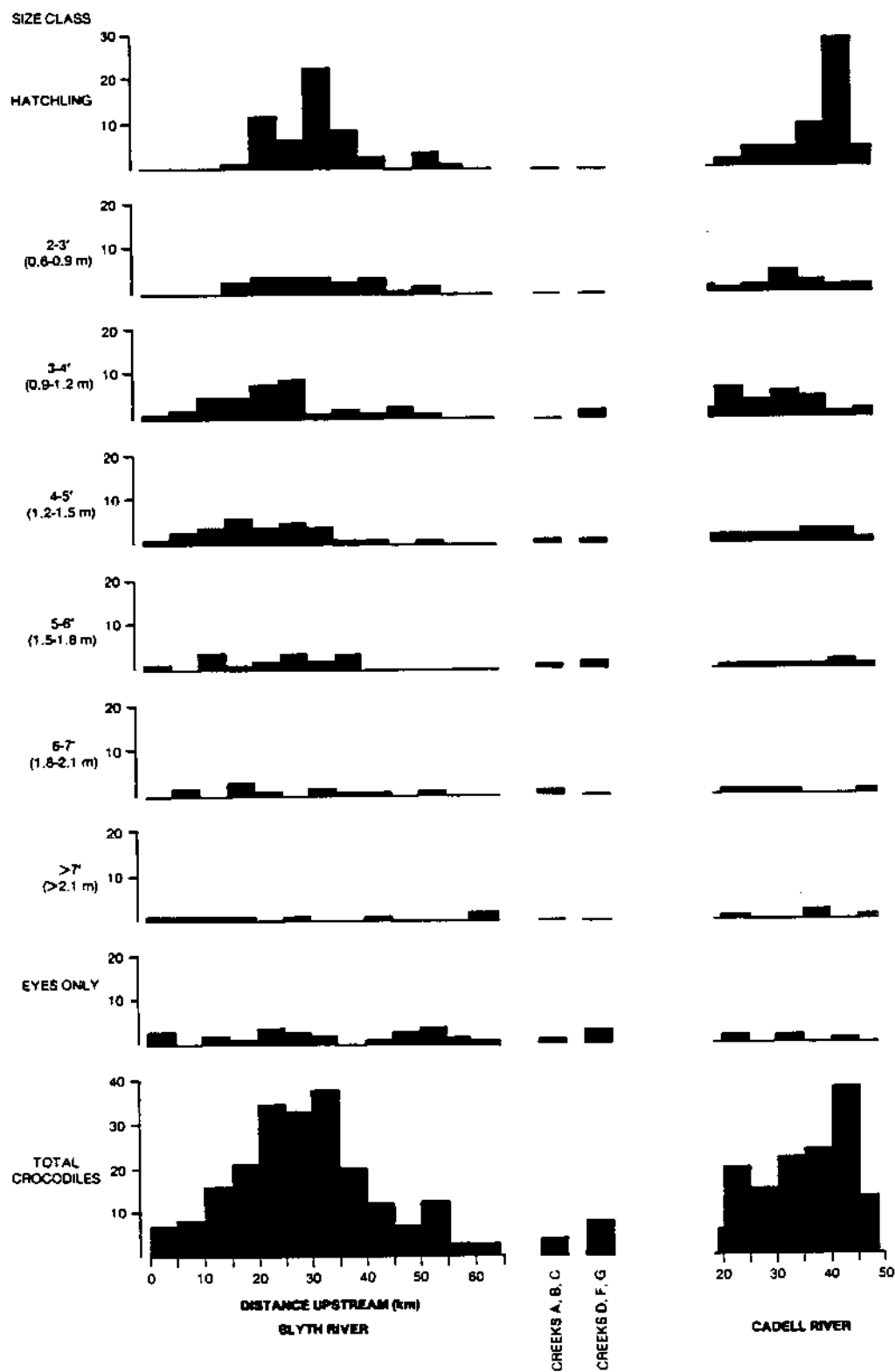


Figure 21. Distributional pattern of *Crocodylus porosus* in the Blyth-Cadell Rivers System during 6-8 November 1982 (from p. 176 Monograph 18).

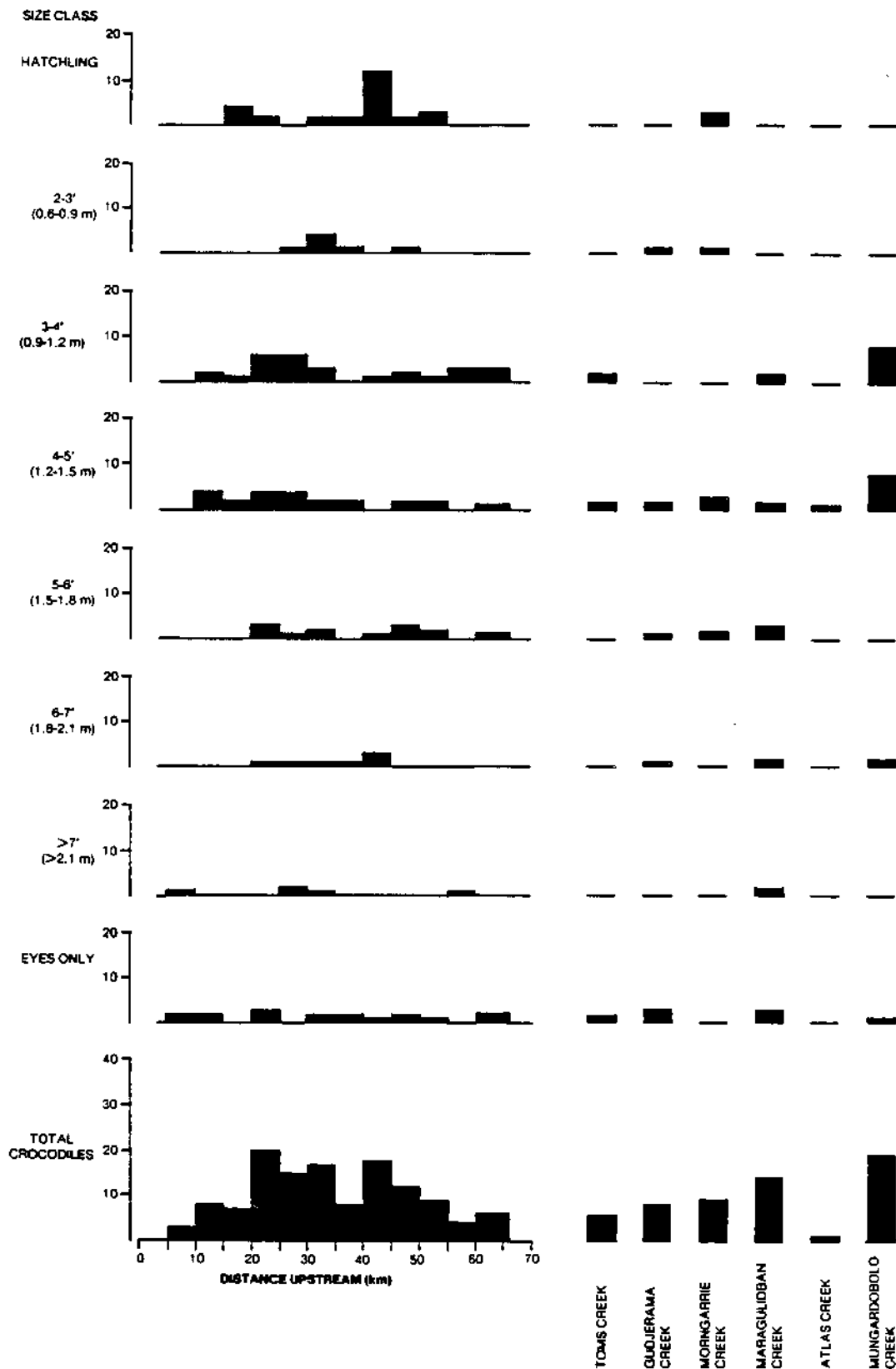


Figure 22. Distributional pattern of *Crocodylus porosus* on the Liverpool River and its creeks in July 1983 (from p. 286 Monograph 18); the distance scale has been corrected here as it was shown incorrectly in Monograph 18.

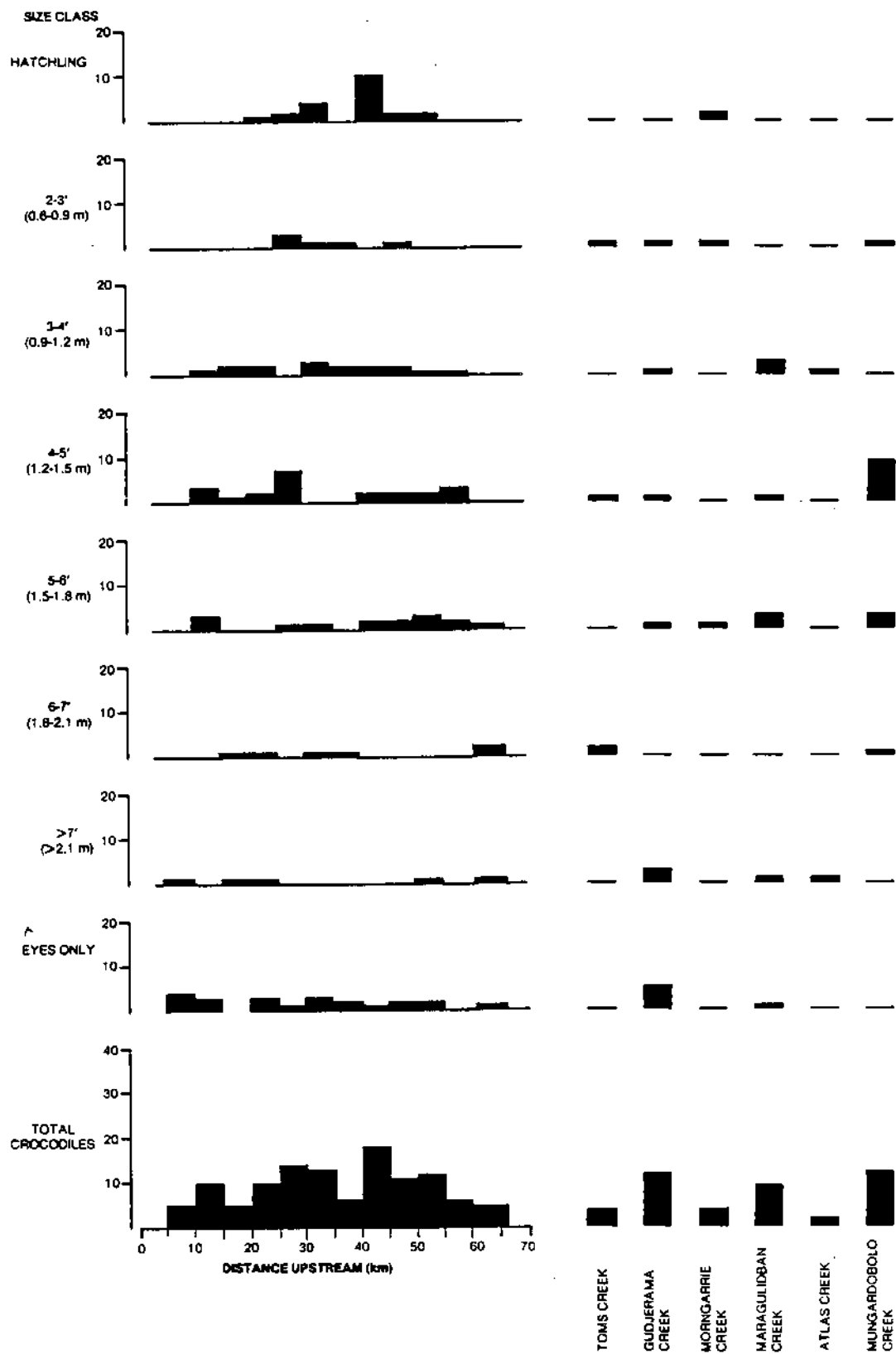


Figure 23. Distributional pattern of *Crocodylus porosus* on the Liverpool River and its creeks in October 1983 (from p. 287 Monograph 18).

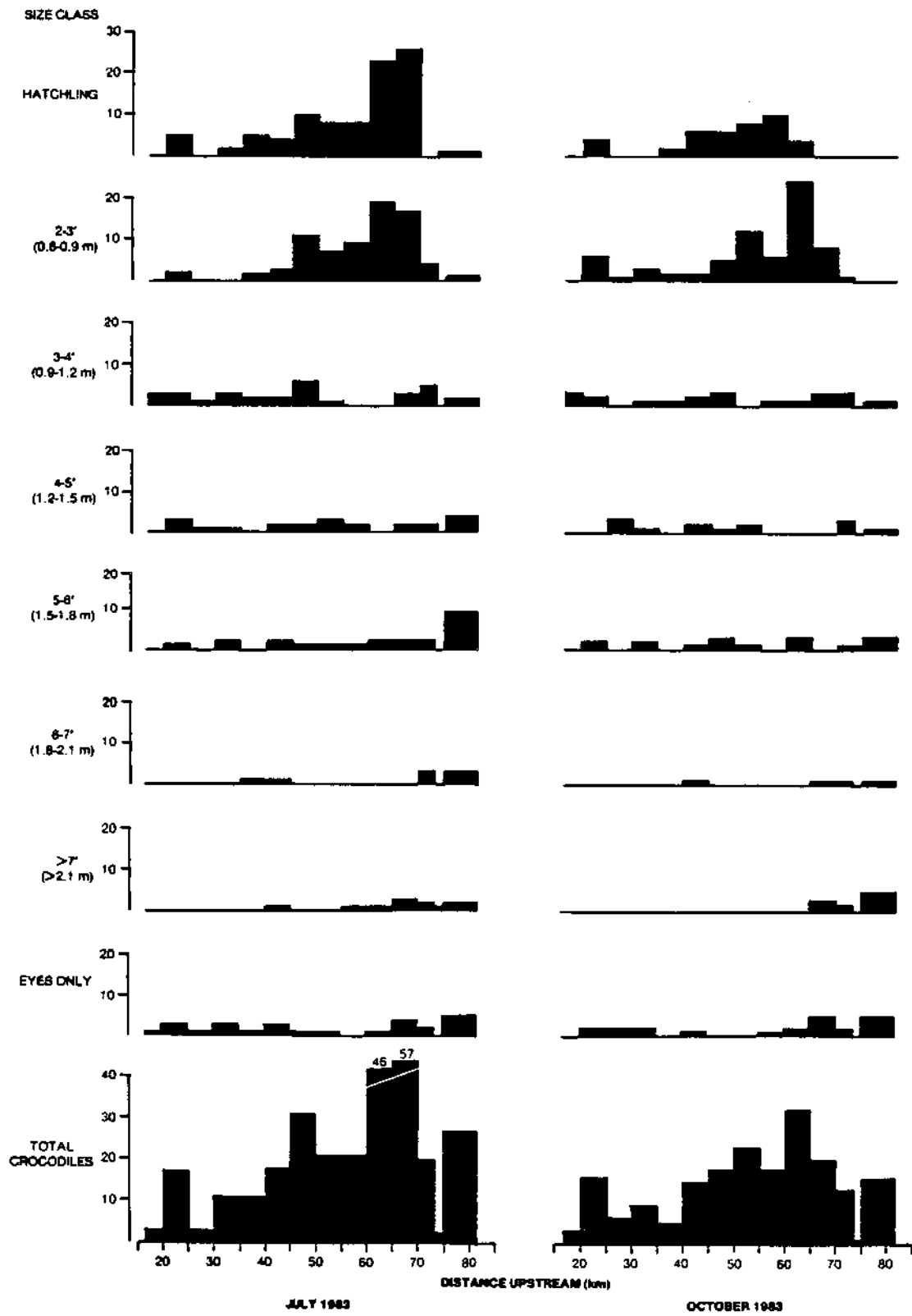


Figure 24. Distributional pattern of *Crocodylus porosus* on the Tomkinson River in July and October 1983 (from p. 288 Monograph 18).

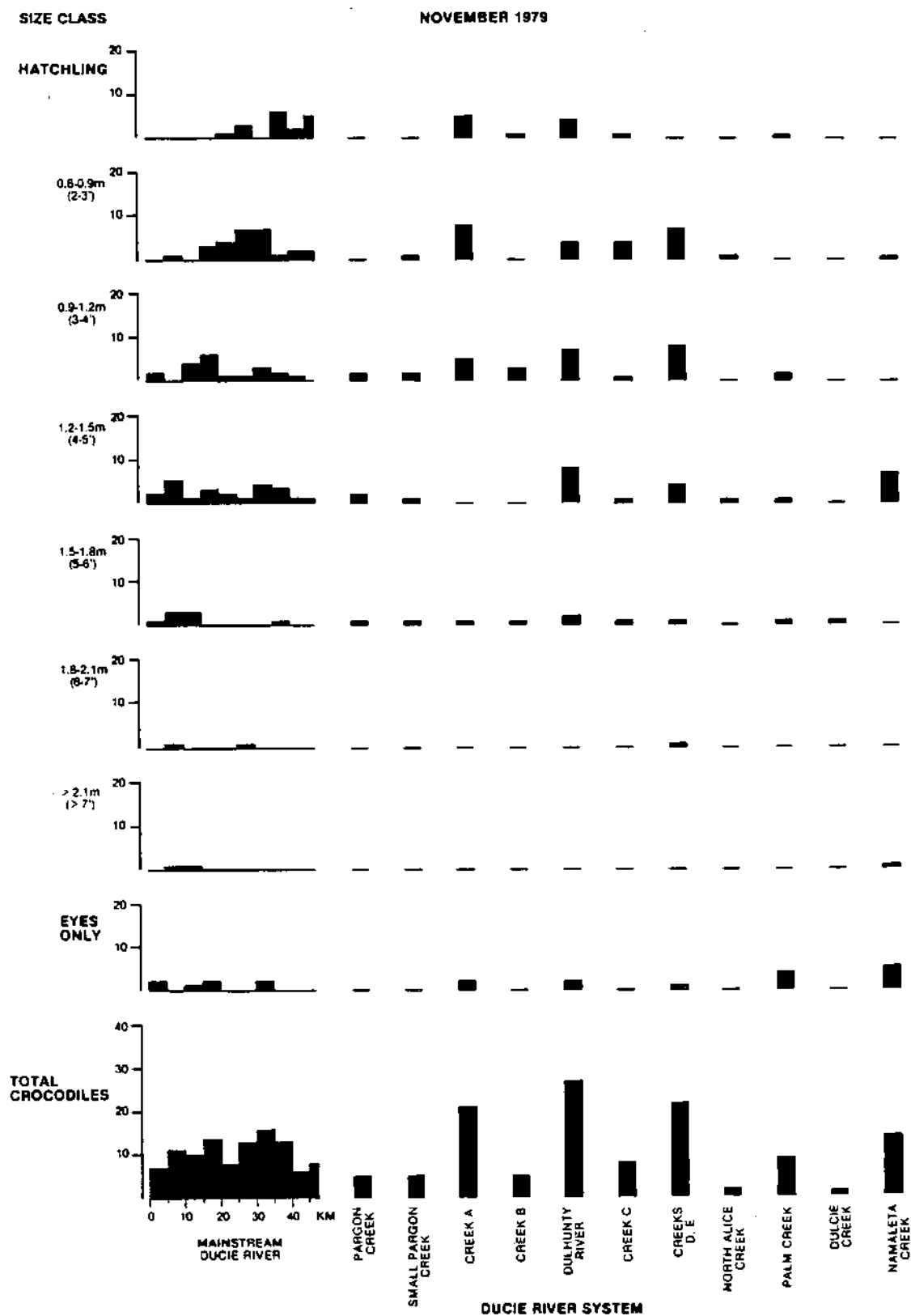


Figure 25. Distributional pattern of *Crocodylus porosus* on the Ducie River System and Palm, Dulcie, and Namaleta Creeks in Port Musgrave in November 1979 (from p. 90 Monograph 16).

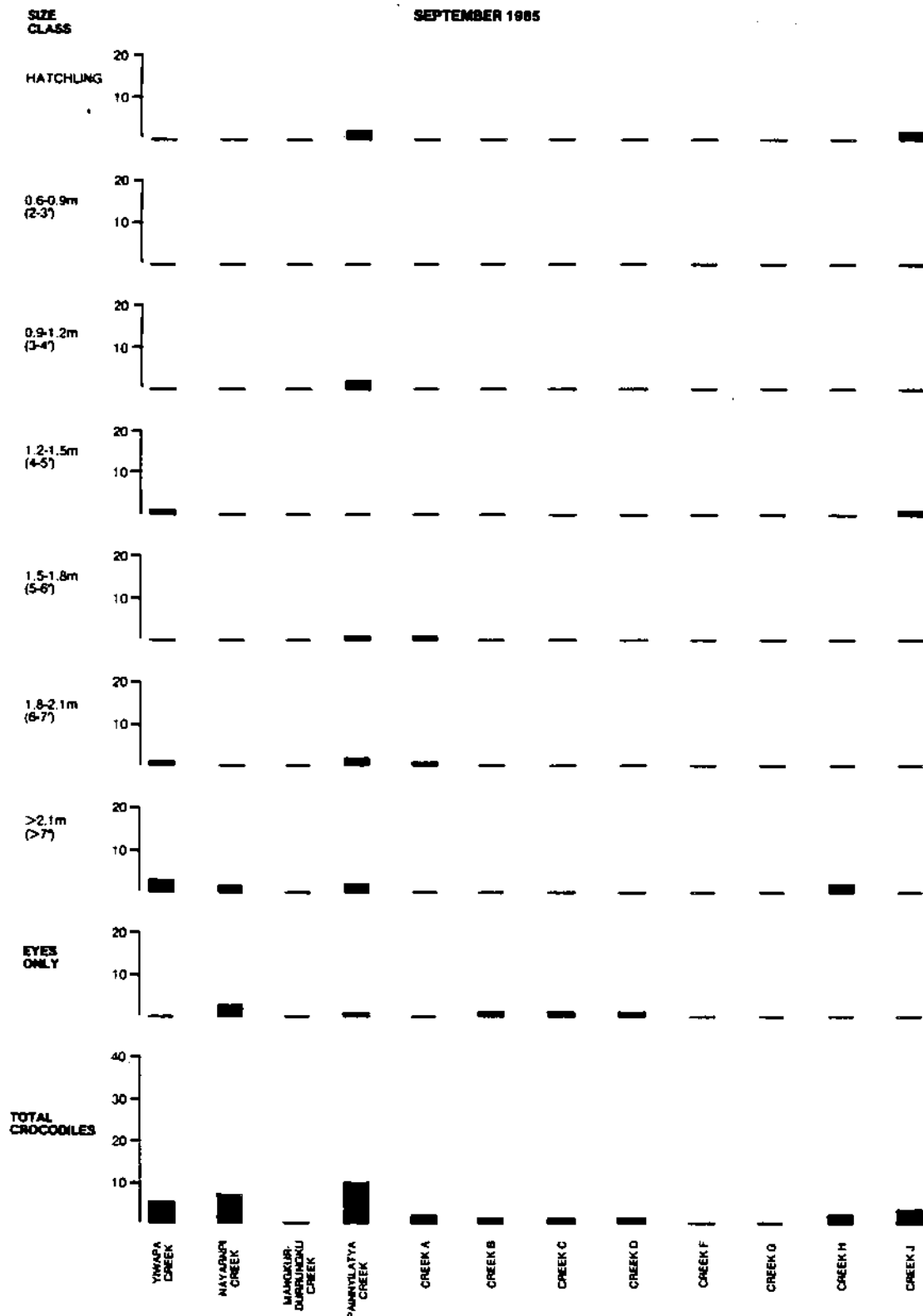


Figure 26. Distributional pattern of *Crocodylus porosus* on the coastal saltwater creeks and on the small creeks of the Roper River mainstream, downstream of km 25.0, in September 1985 (from p. 117 Monograph 19).



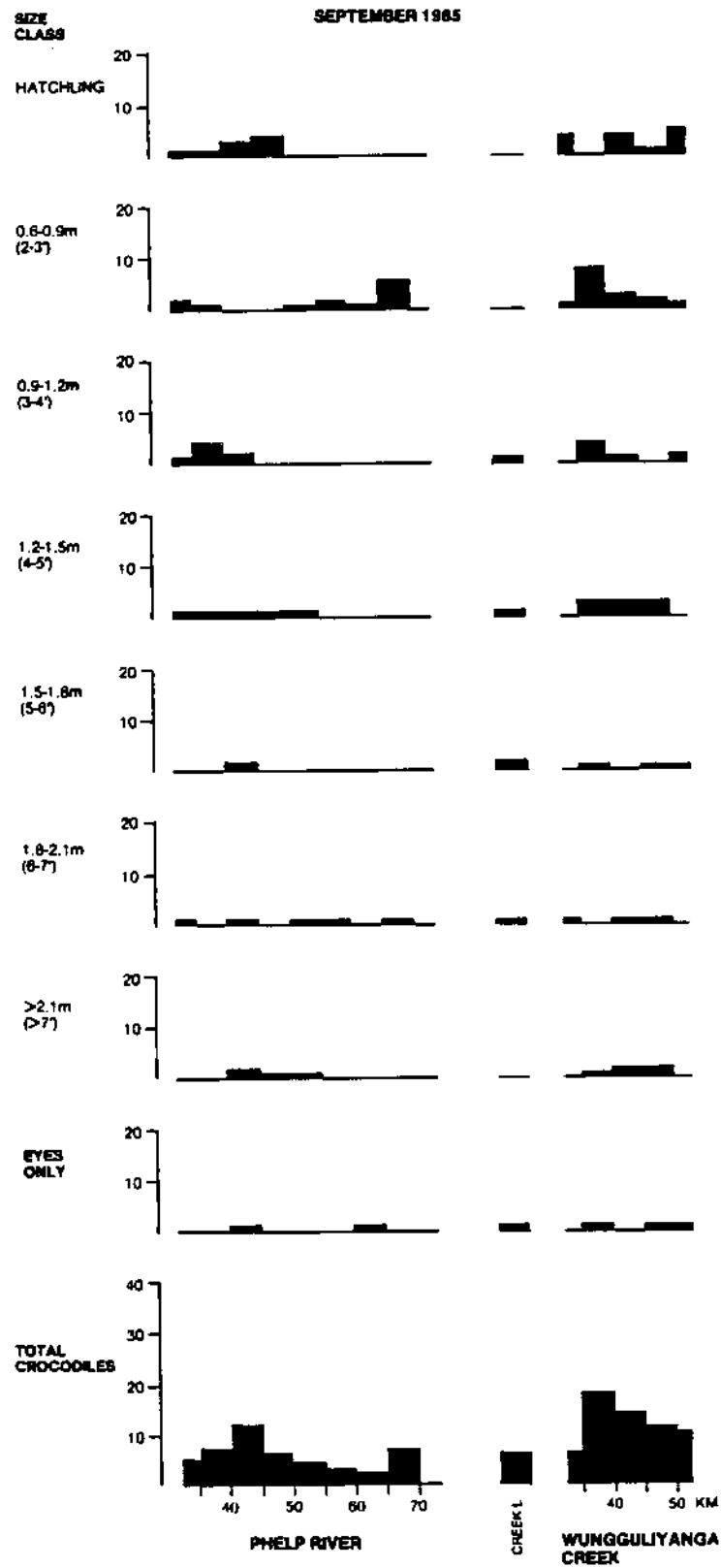


Figure 27. Distributional pattern of *Crocodylus porosus* on the Phelp River and Wungguliyanga Creek in September 1985 (from p. 118 Monograph 19).

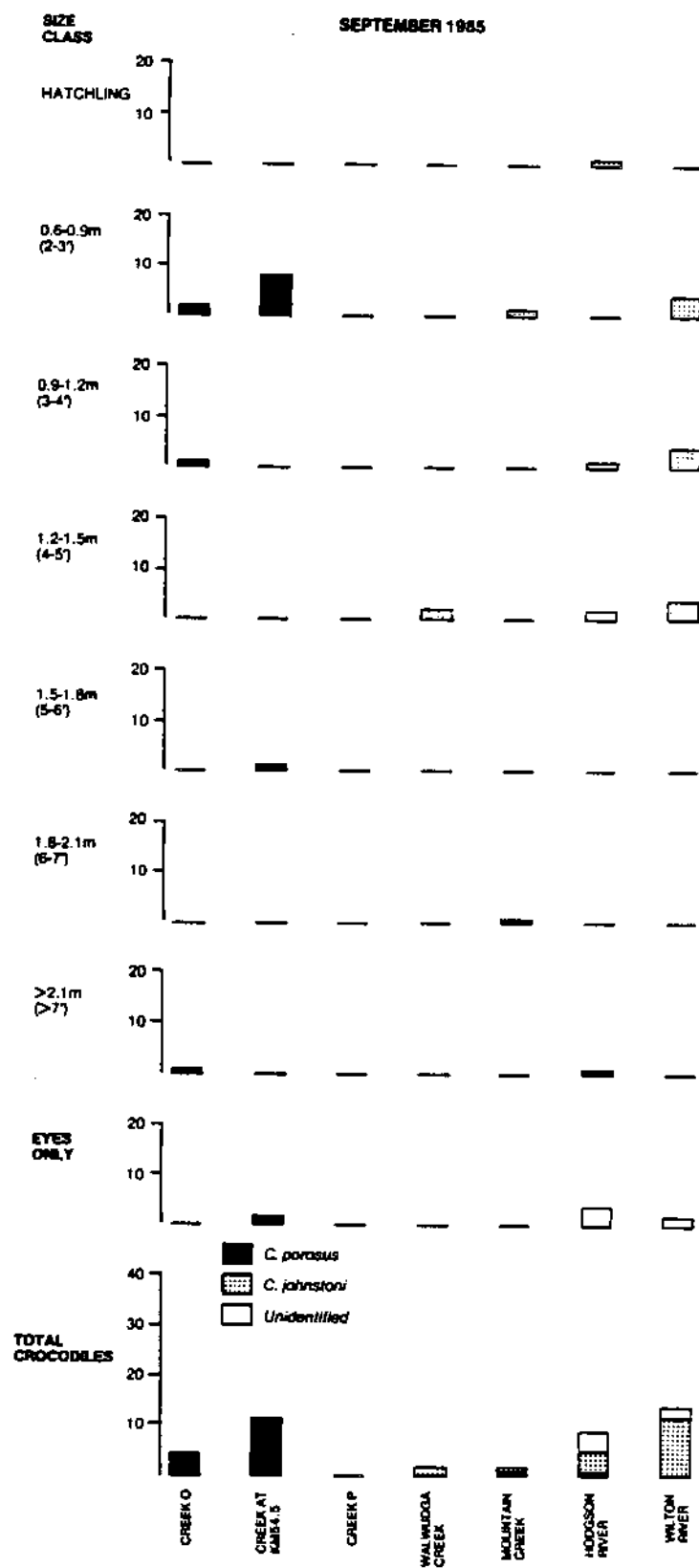


Figure 28. Distributional pattern of *Crocodylus porosus* and *C. johnstoni* on the Wilton and Hodgson Rivers and on the small creeks of the Roper River mainstream, upstream of km 25.0, in September 1985 (from p. 119 Monograph 19).

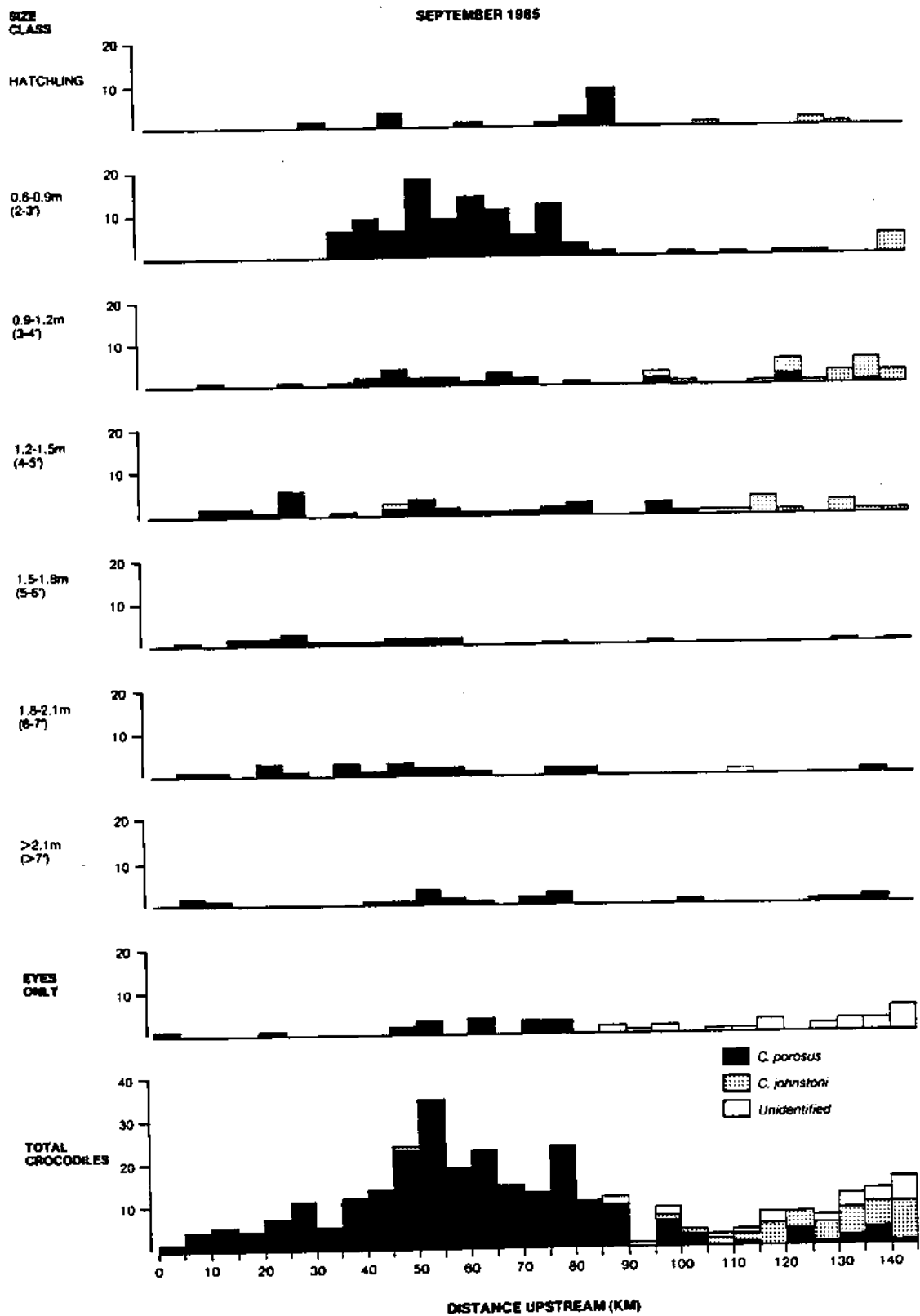


Figure 29. Distributional pattern of *Crocodylus porosus* and *C. johnstoni* on the Roper River mainstream in September 1985 (from p. 116 Monograph 19).

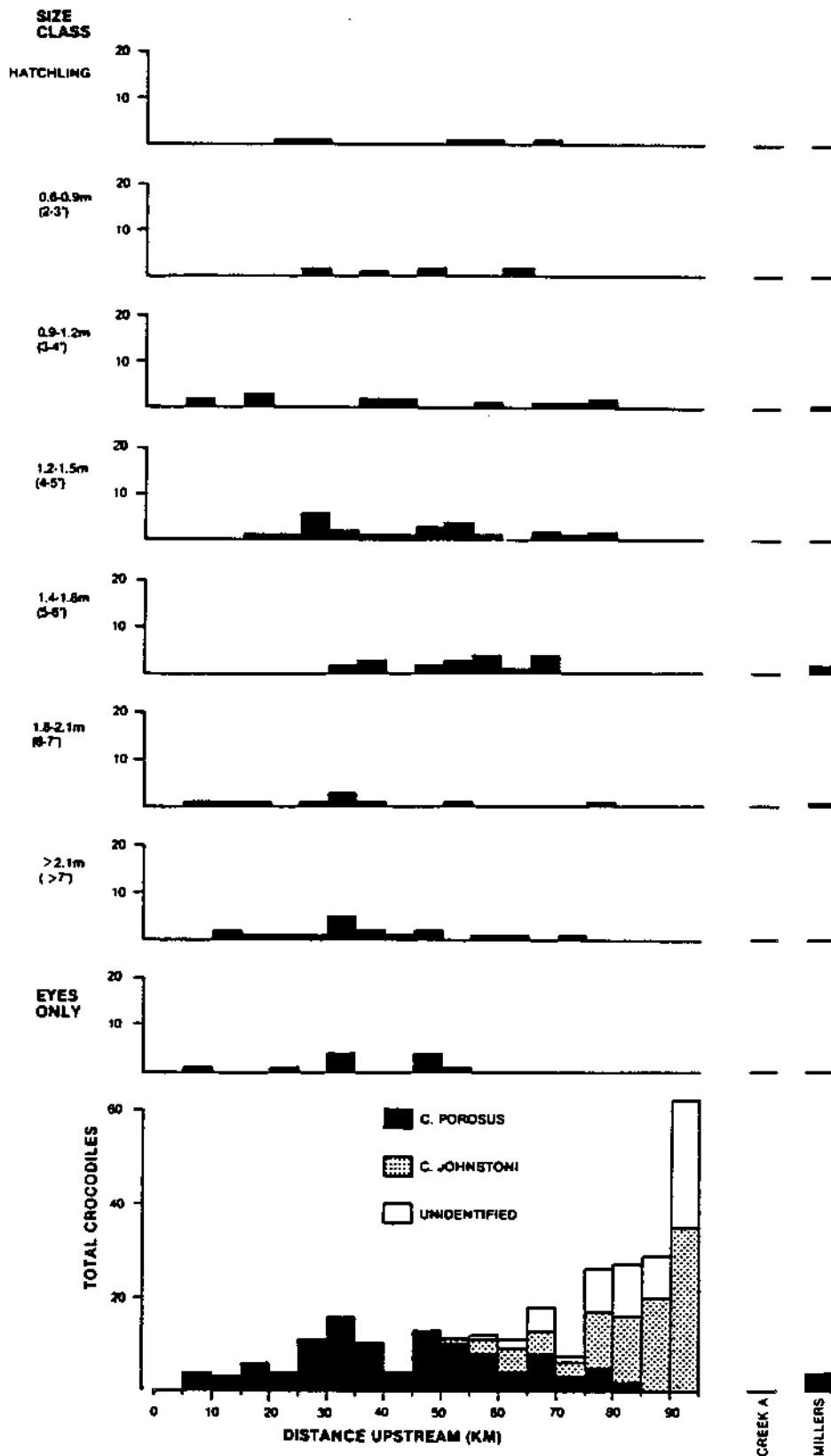


Figure 30. Distributional pattern of crocodiles on the Daly River System in August 1978 (from p. 51 Monograph 3).

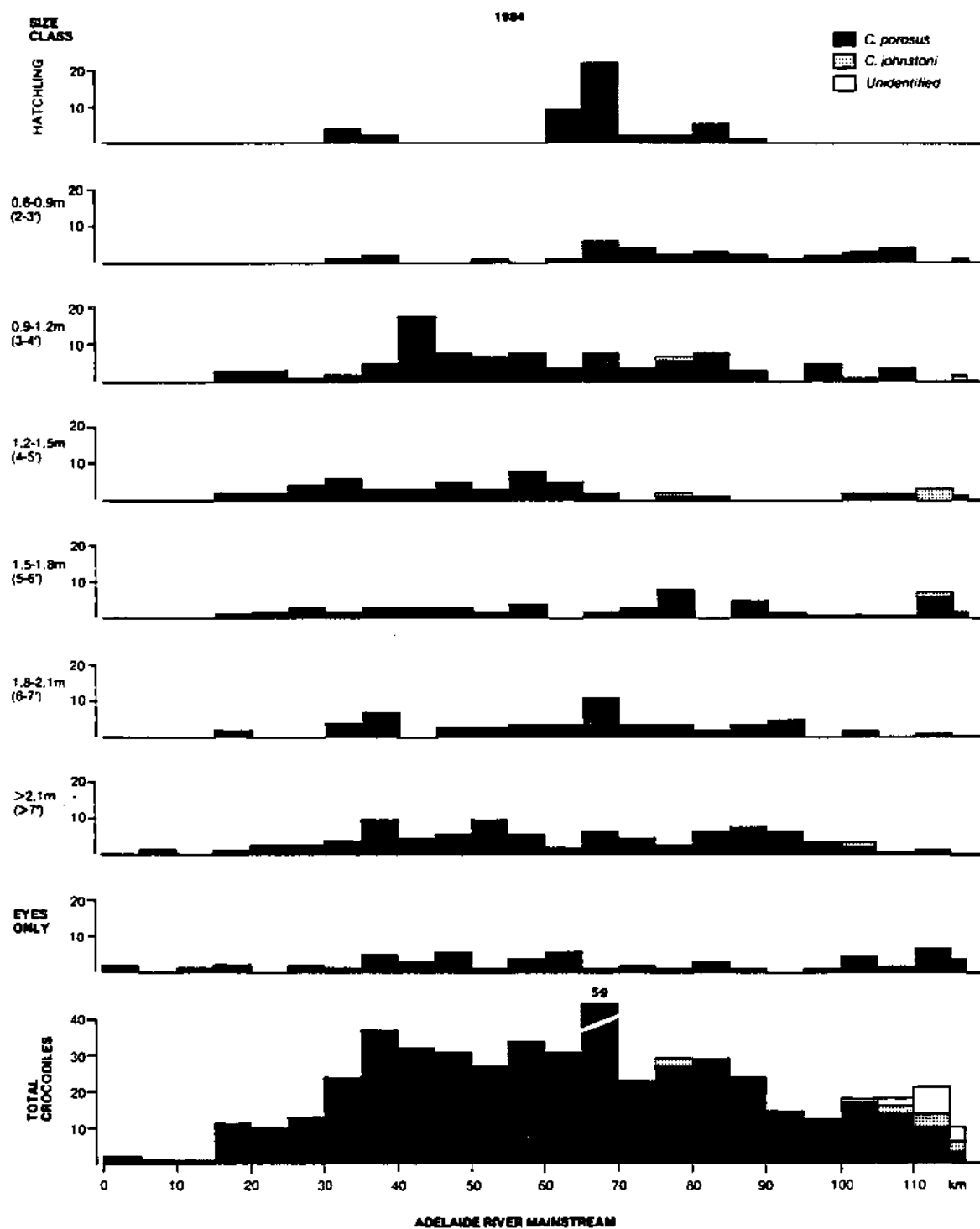


Figure 31. Distributional pattern of crocodiles on the mainstream of the Adelaide River in July 1984 (from p. 98 Monograph 19).

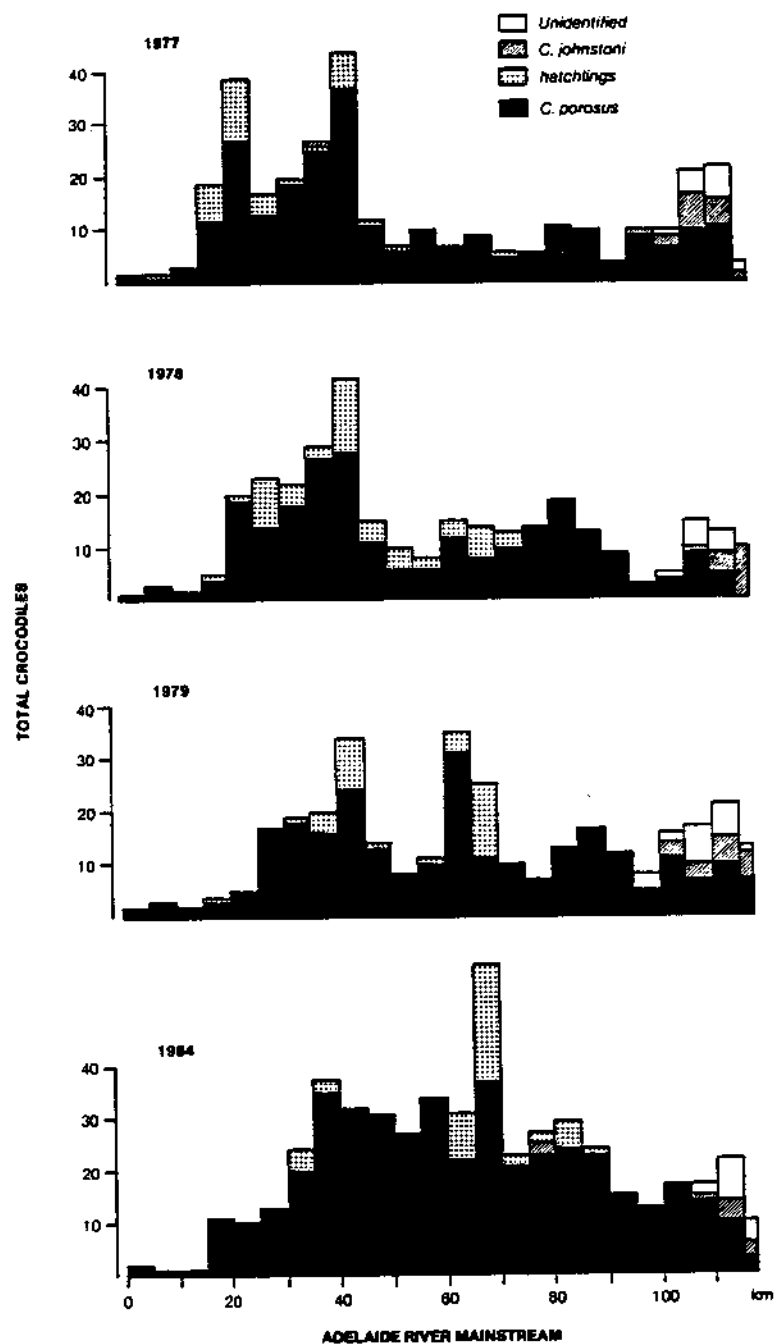


Figure 32. Distributional pattern of *Crocodylus porosus* on the Adelaide in July 1977, September 1978, September 1979, and July 1984 (from p. 100 Monograph 19).

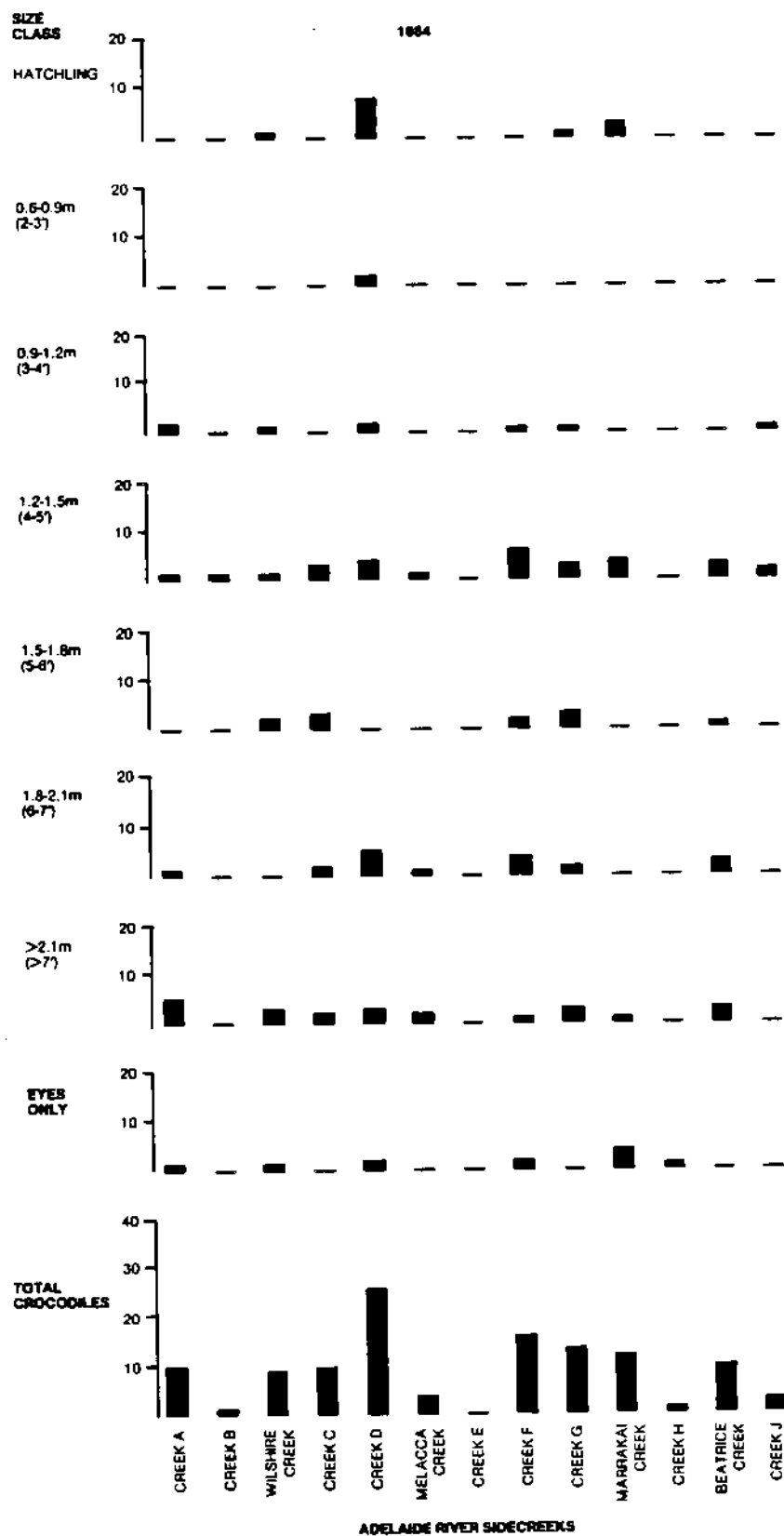


Figure 33. Distributional pattern of *Crocodylus porosus* on the sidecreeks of the Adelaide River in July 1984 (from p. 99 Monograph 19).

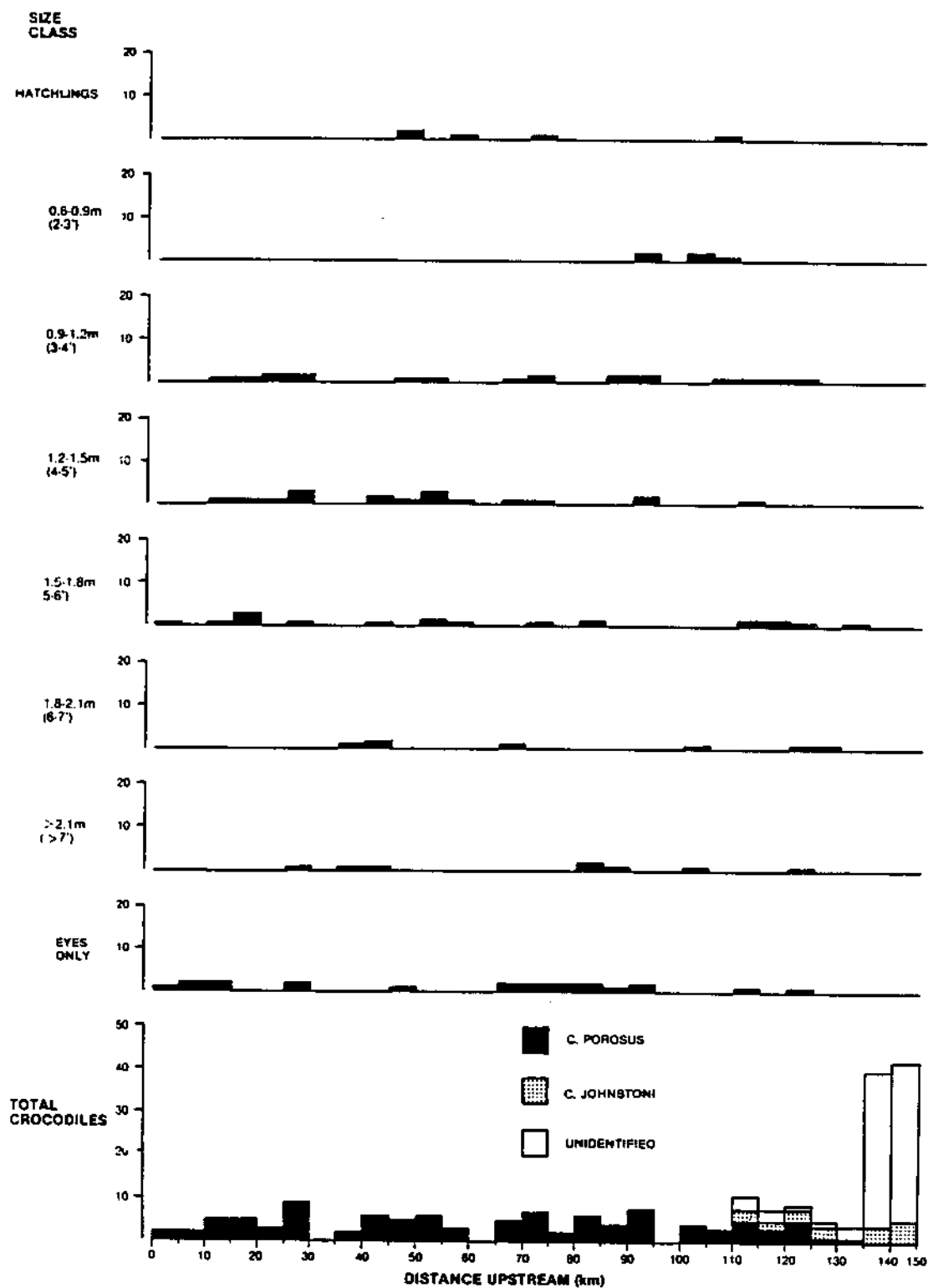


Figure 34. Distributional pattern of crocodiles on the mainstream of the Victoria River System in August 1978 (from p. 34 Monograph 2).



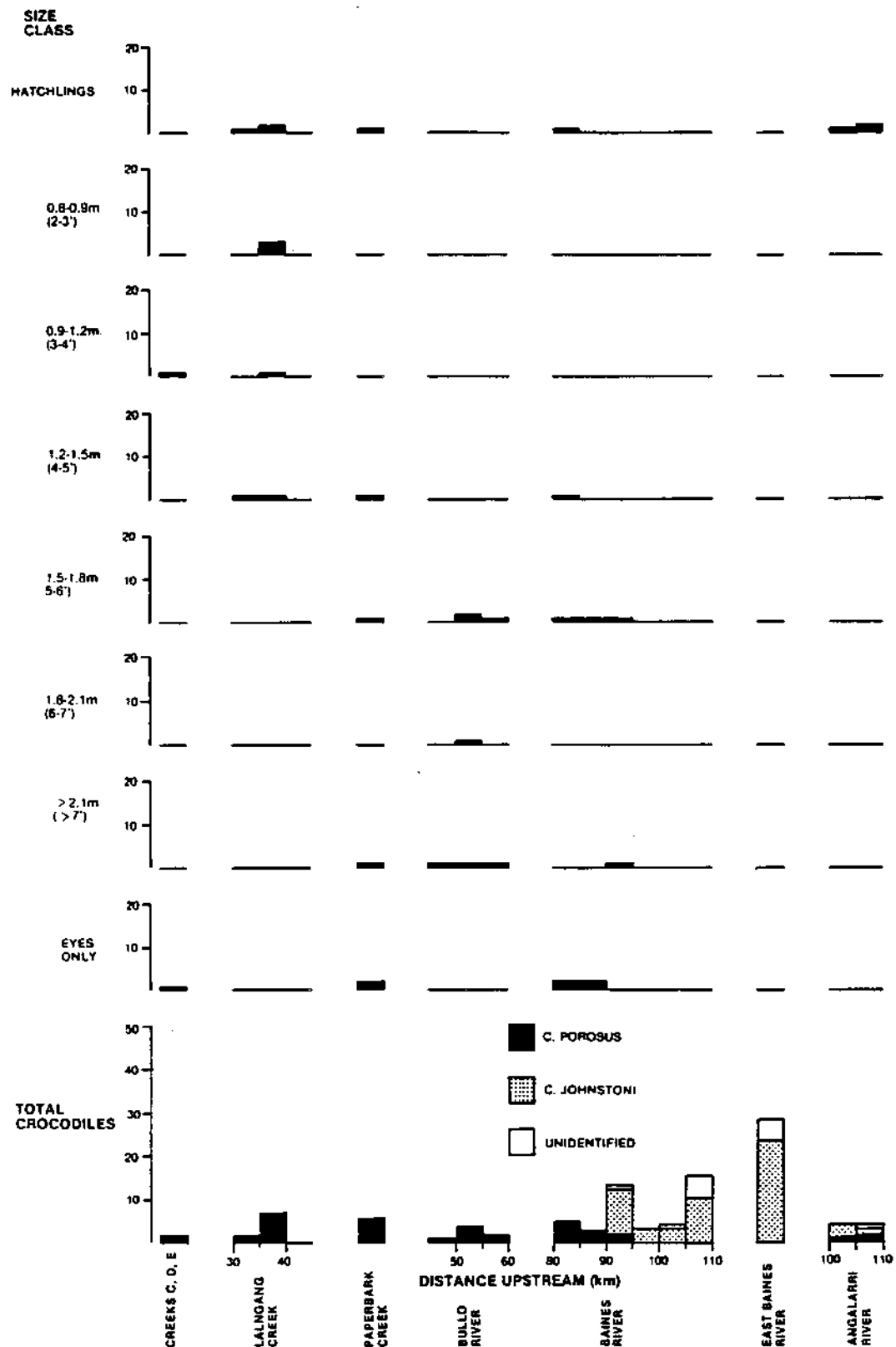


Figure 35. Distributional pattern of crocodiles on the sidecreeks and/or rivers of the Victoria River System in August 1978 (from p. 33 Monograph 2).

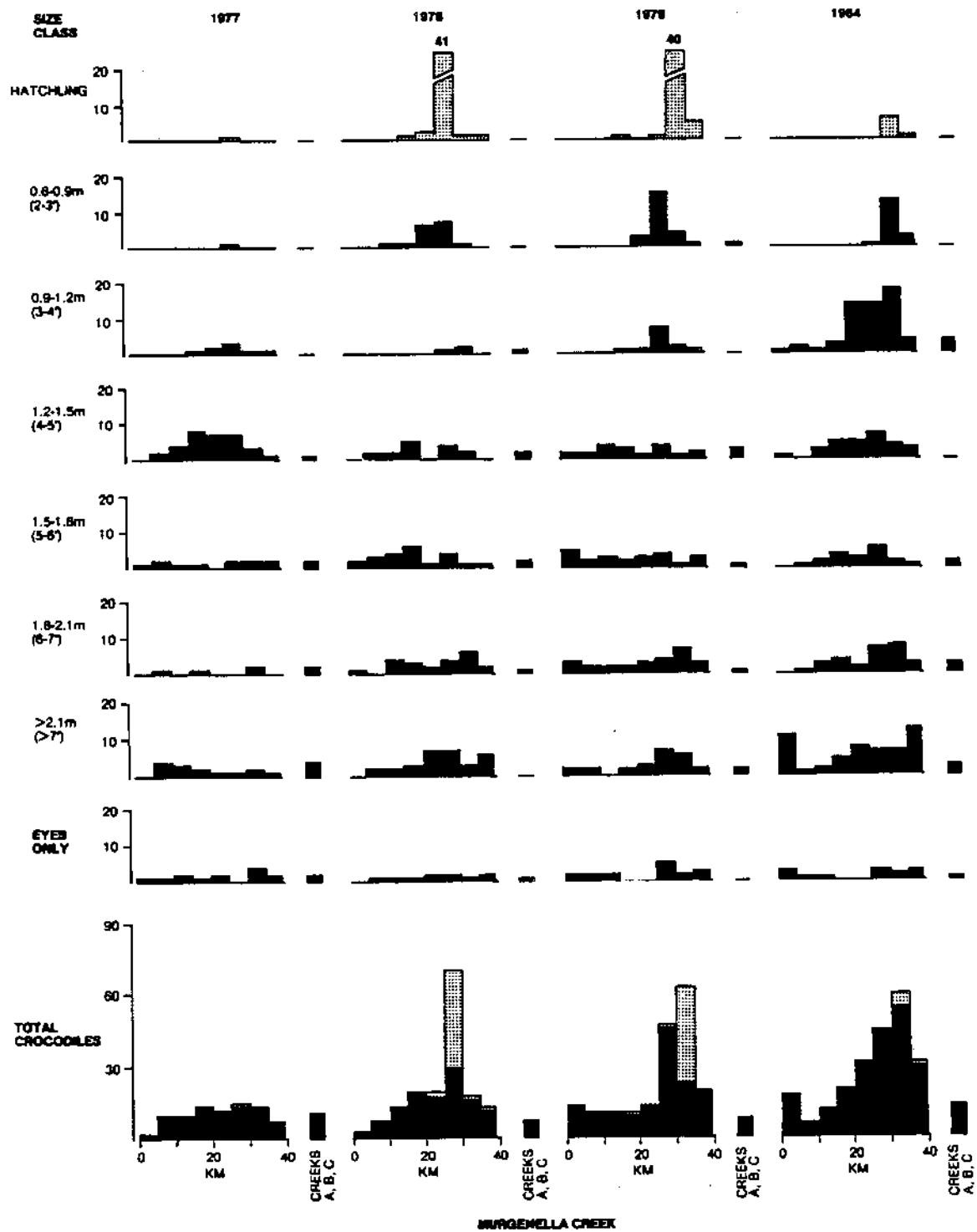


Figure 36. Distributional pattern of *Crocodylus porosus* on Murgarella Creek in October 1977, June 1978, August 1979, and July 1984 (from p. 177 Monograph 19).

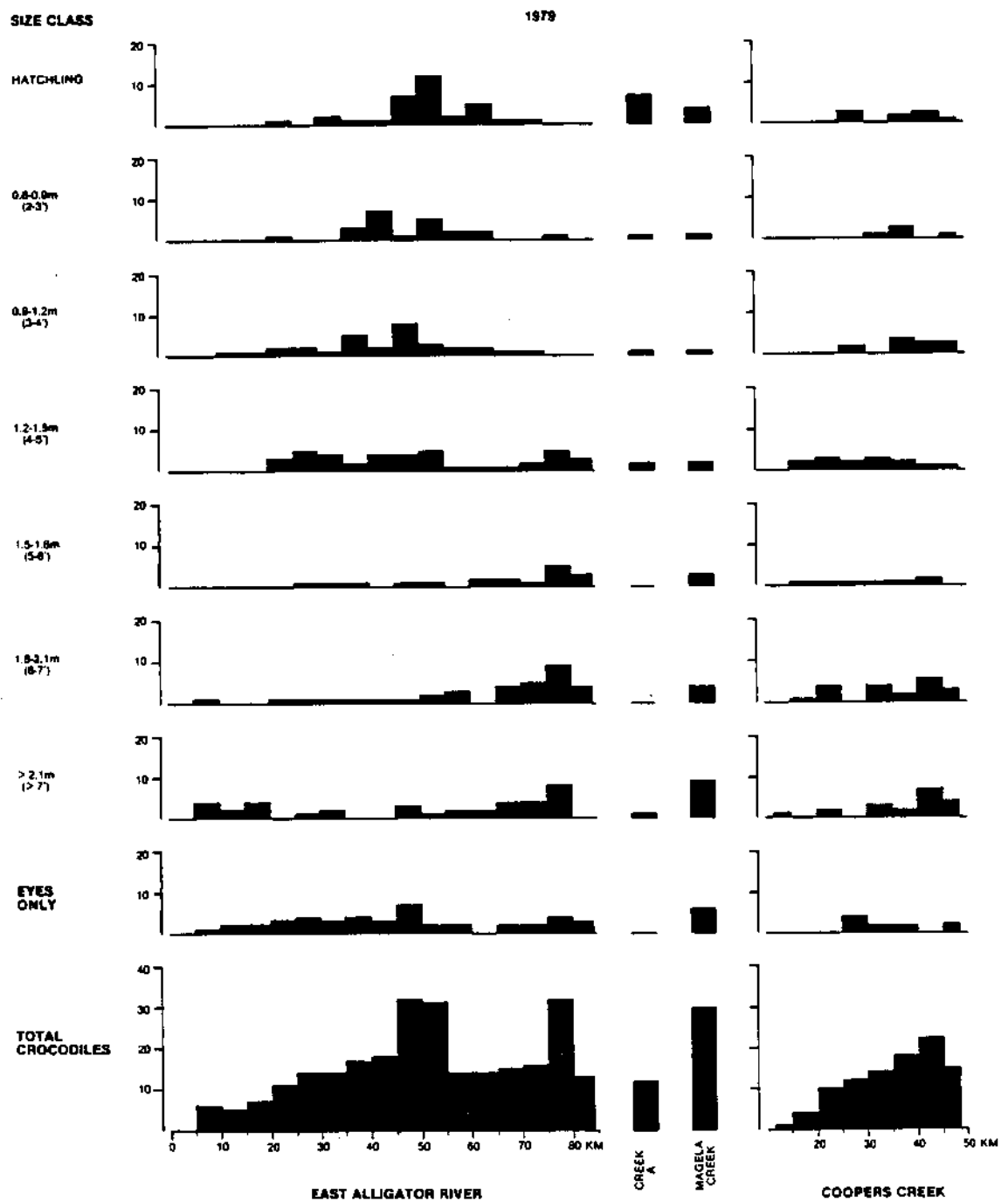


Figure 37. Distributional pattern of *Crocodylus porosus* on the East Alligator River System in August 1979 (from p. 87 Monograph 14).

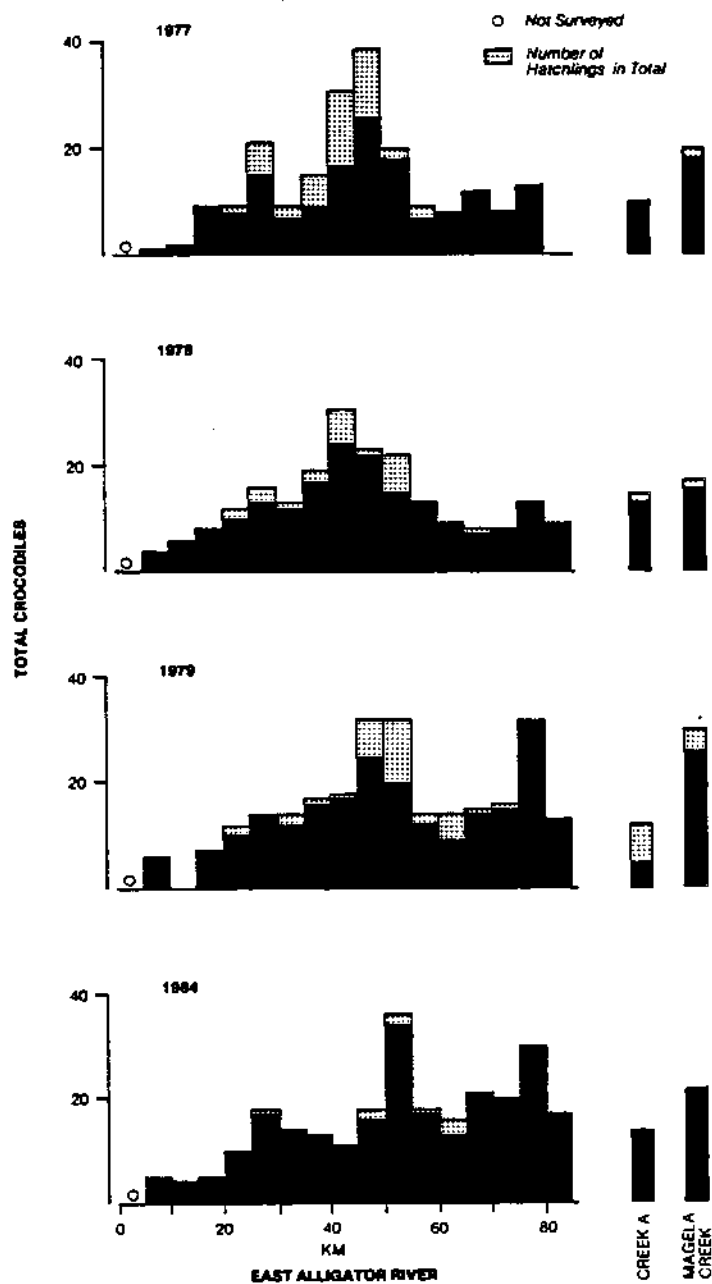


Figure 38. Distributional pattern of *Crocodylus porosus* on the East Alligator River in October 1977, June 1978, August 1979, and July 1984 (from p. 179 Monograph 19).

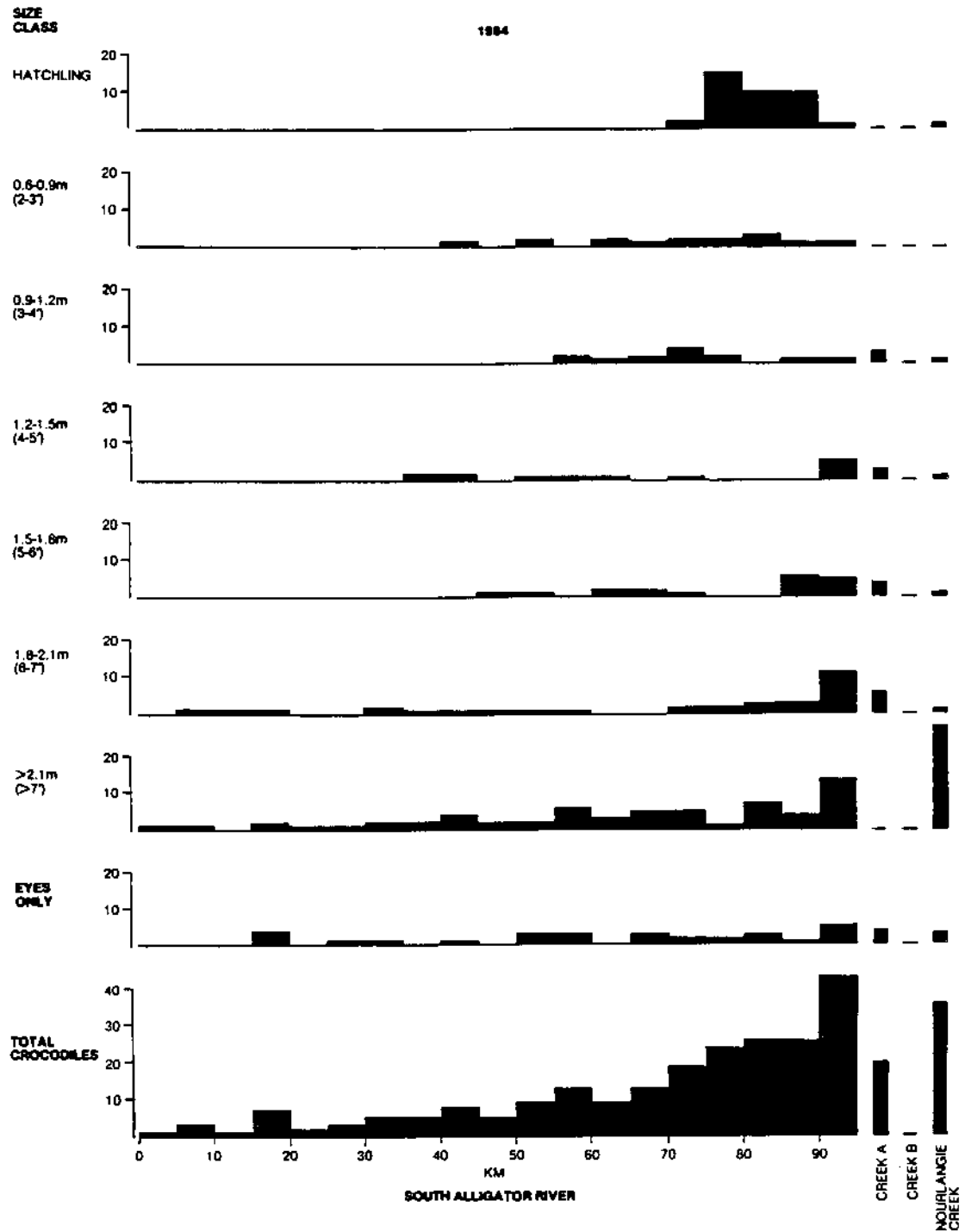


Figure 39. Distributional pattern of *Crocodylus porosus* on the South Alligator River in July 1984 (from p. 180 Monograph 19).

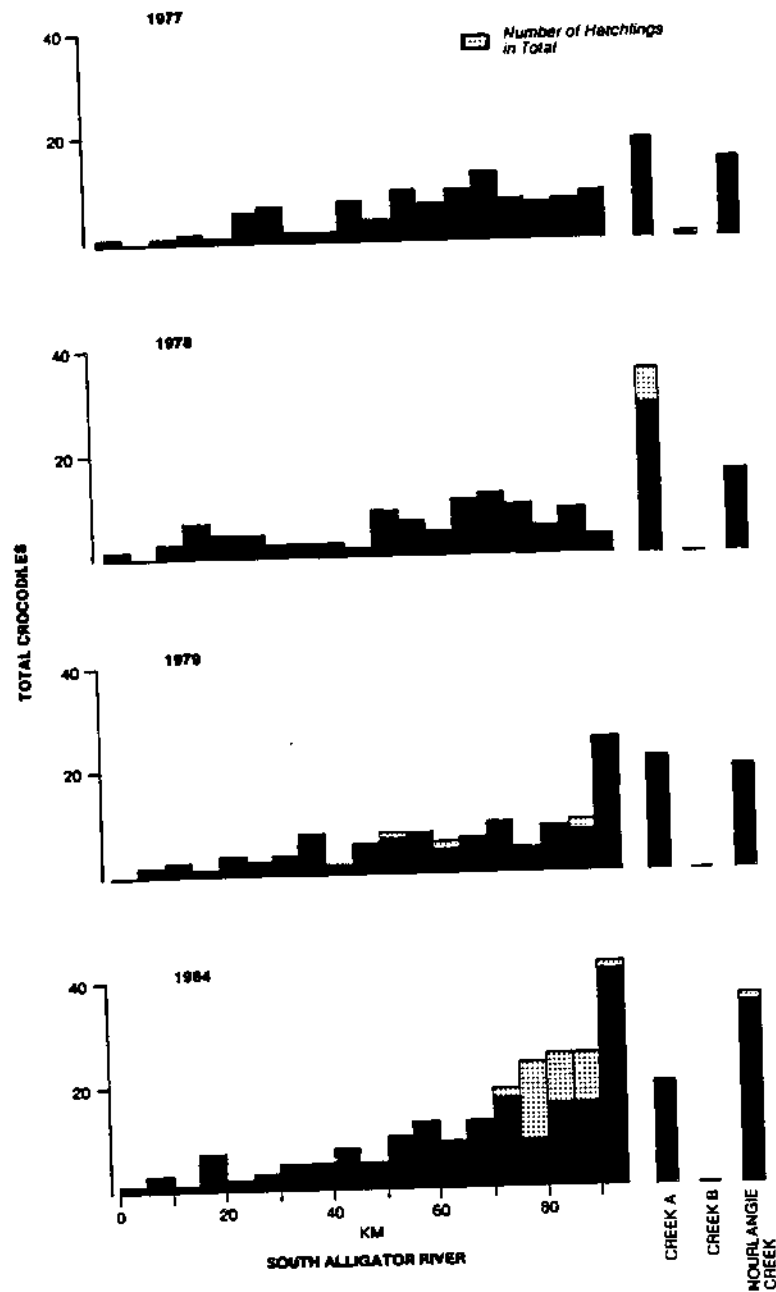


Figure 40. Distributional pattern of *Crocodylus porosus* on the South Alligator River in October 1977, July 1978, August 1979, and July 1984 (from p. 181 Monograph 19).

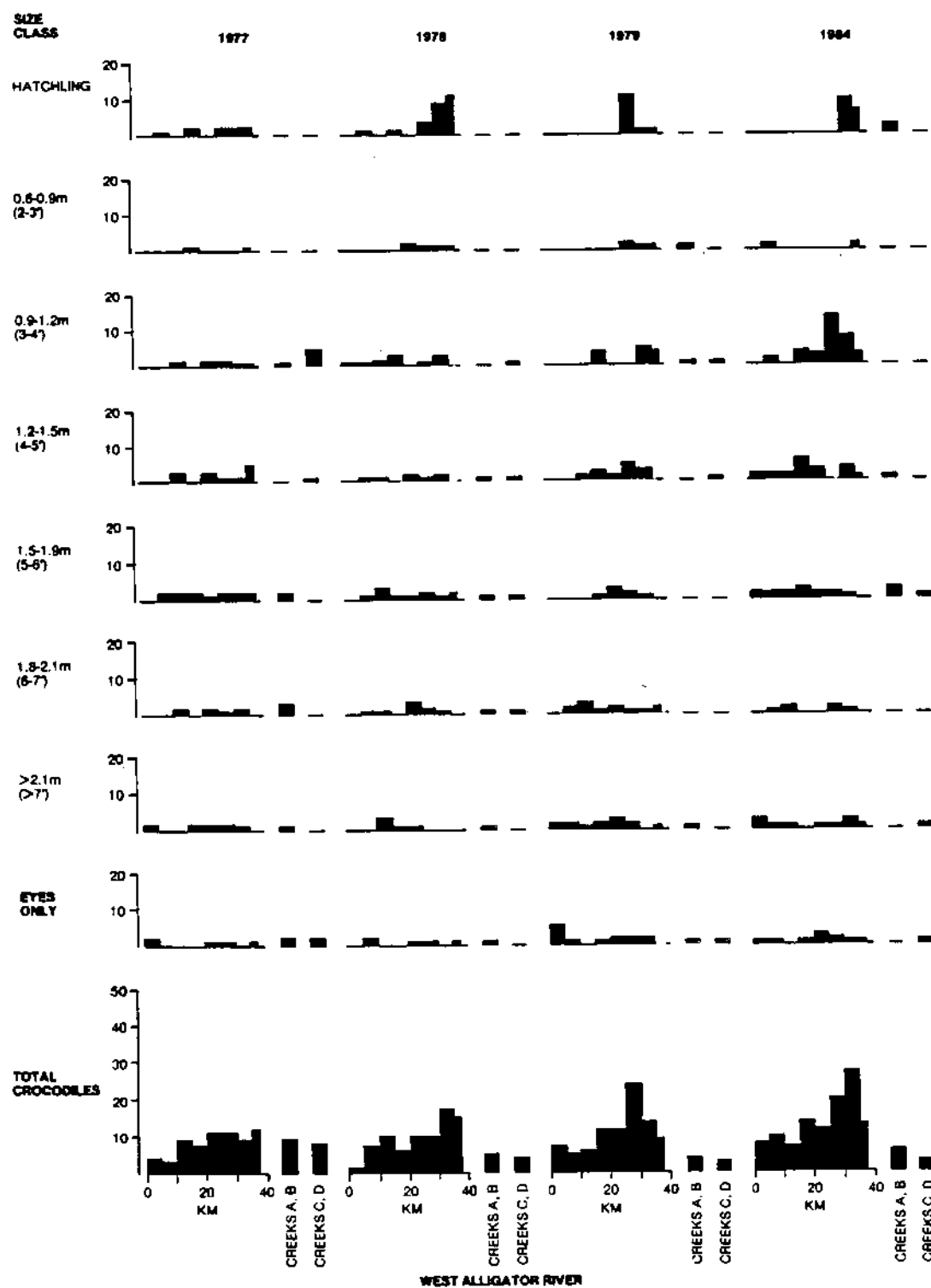


Figure 41. Distributional pattern of *Crocodylus porosus* on the West Alligator River in October 1977, July 1978, August 1979, and June 1984 (from p. 182 Monograph 19).

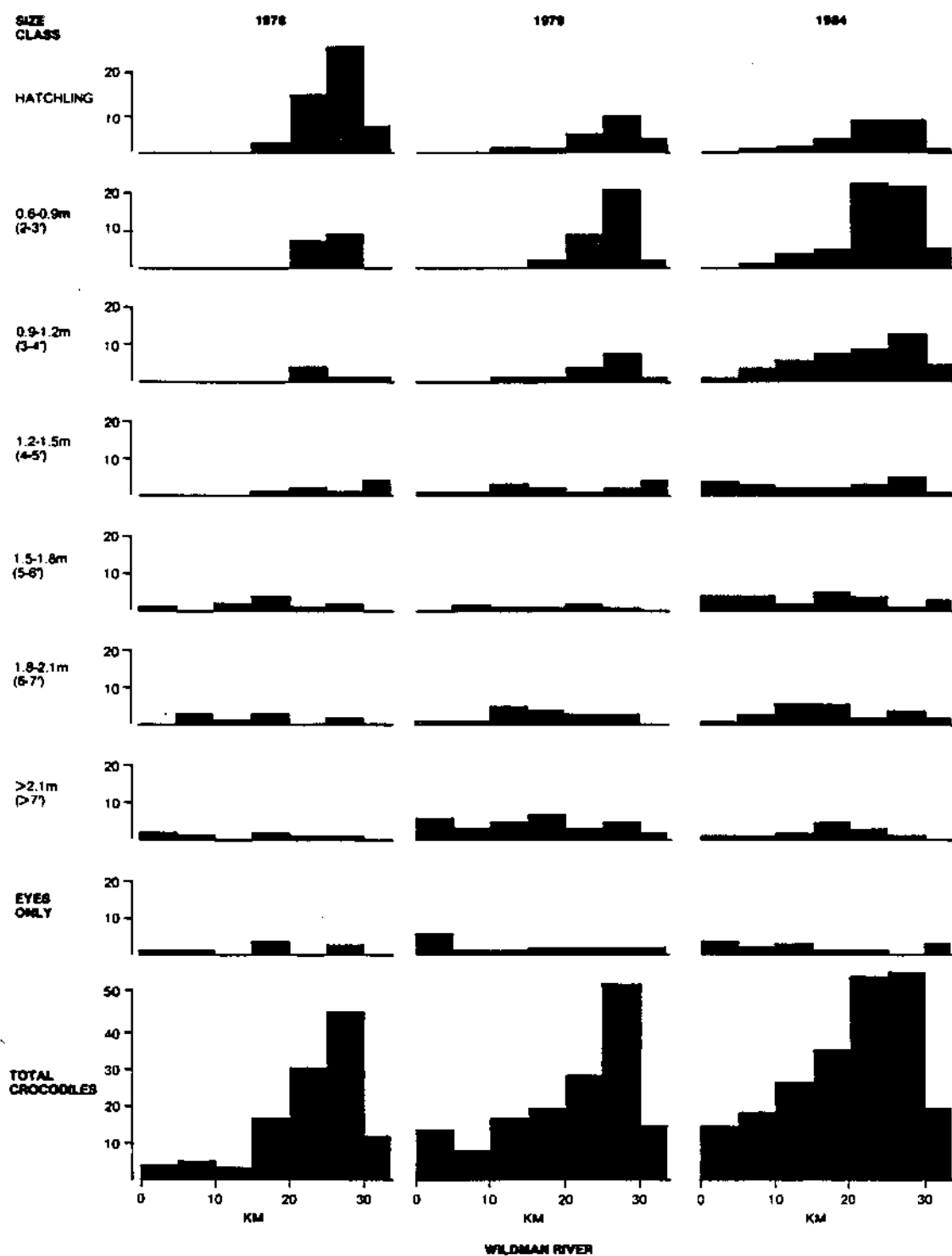


Figure 42. Distributional pattern of *Crocodylus porosus* on the Wildman River in September 1978, August 1979, and June 1984 (from p. 183 Monograph 19).



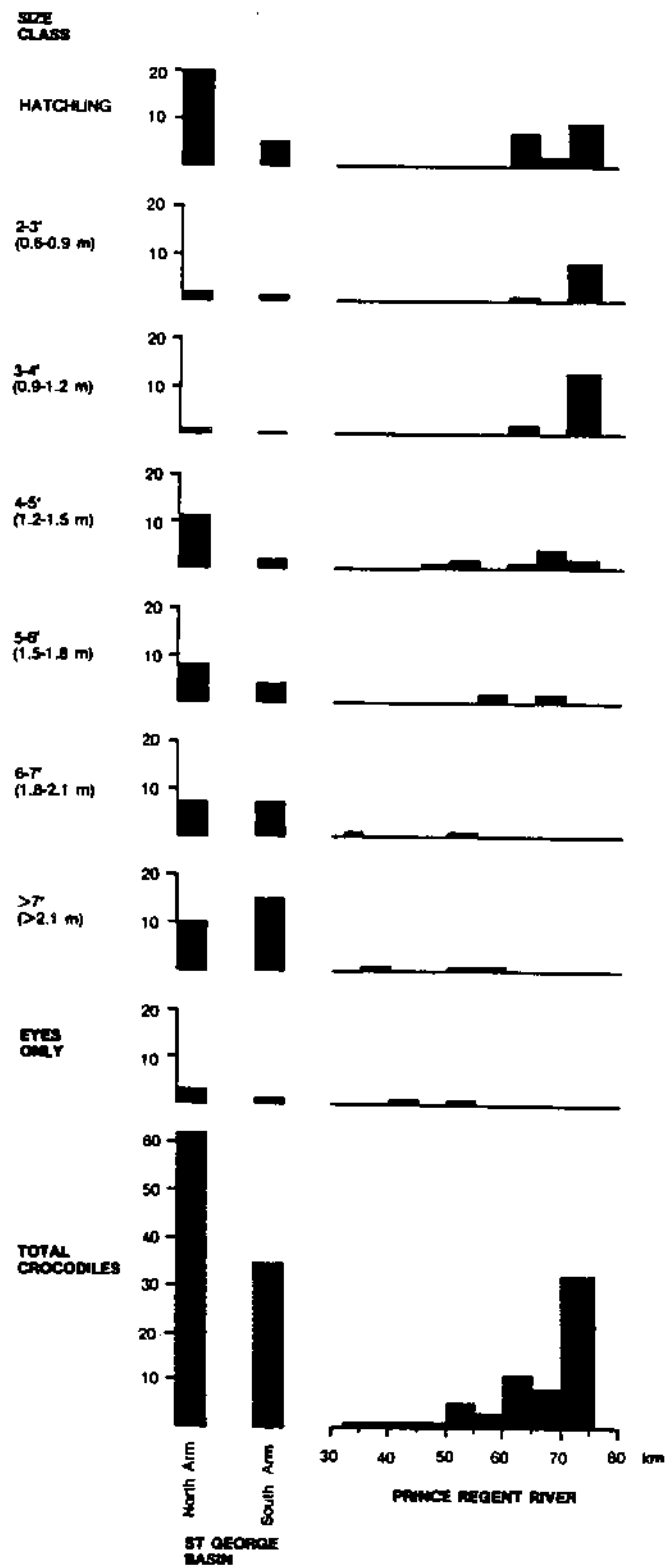


Figure 43. Crocodile distribution on the Prince Regent River and the St. George Basin in July 1978 (from p. 24, W.A. Report No. 34).

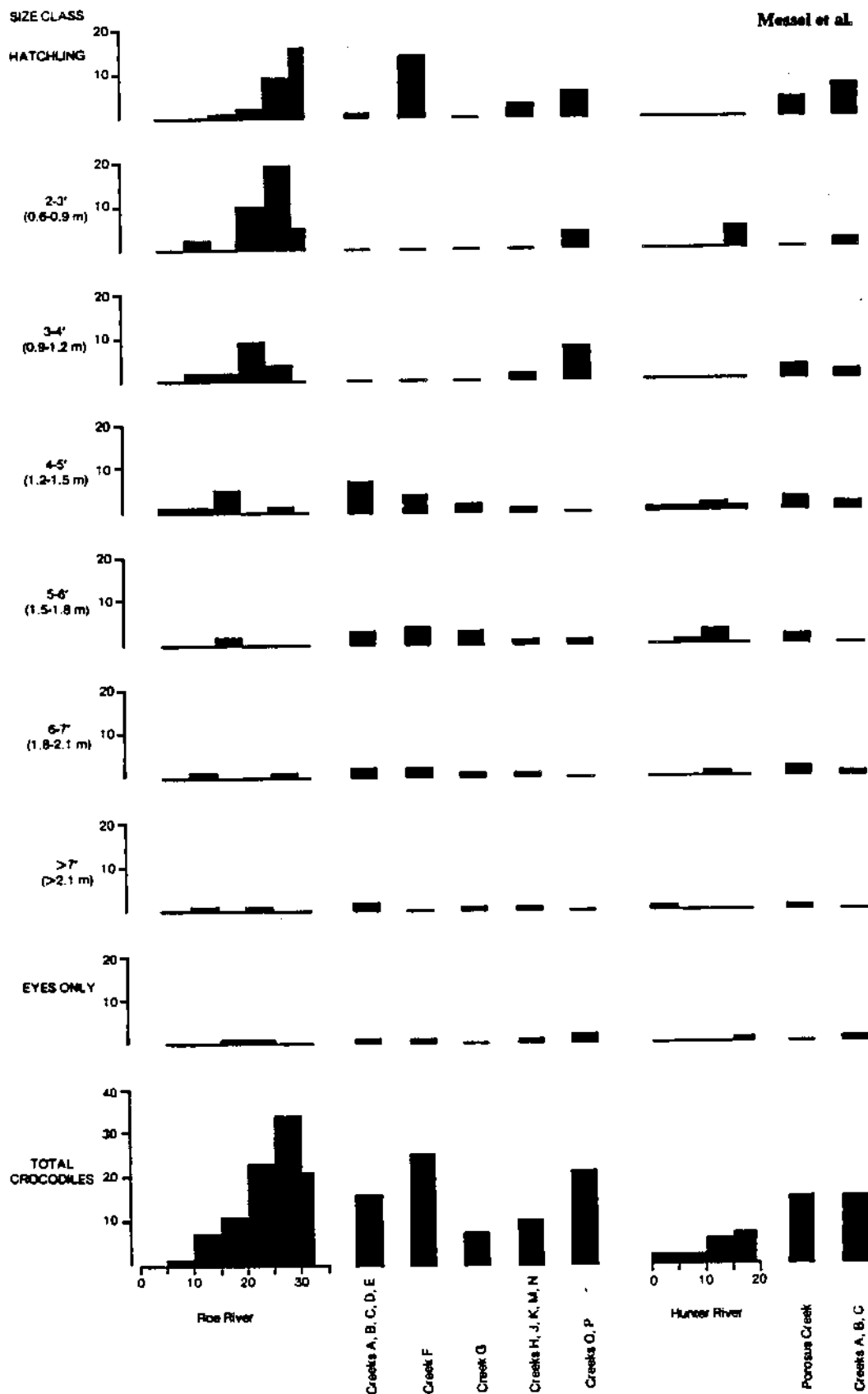


Figure 44. Crocodile distribution on the Roe River System in July 1977 (from p. 33 W.A. Report No. 24).

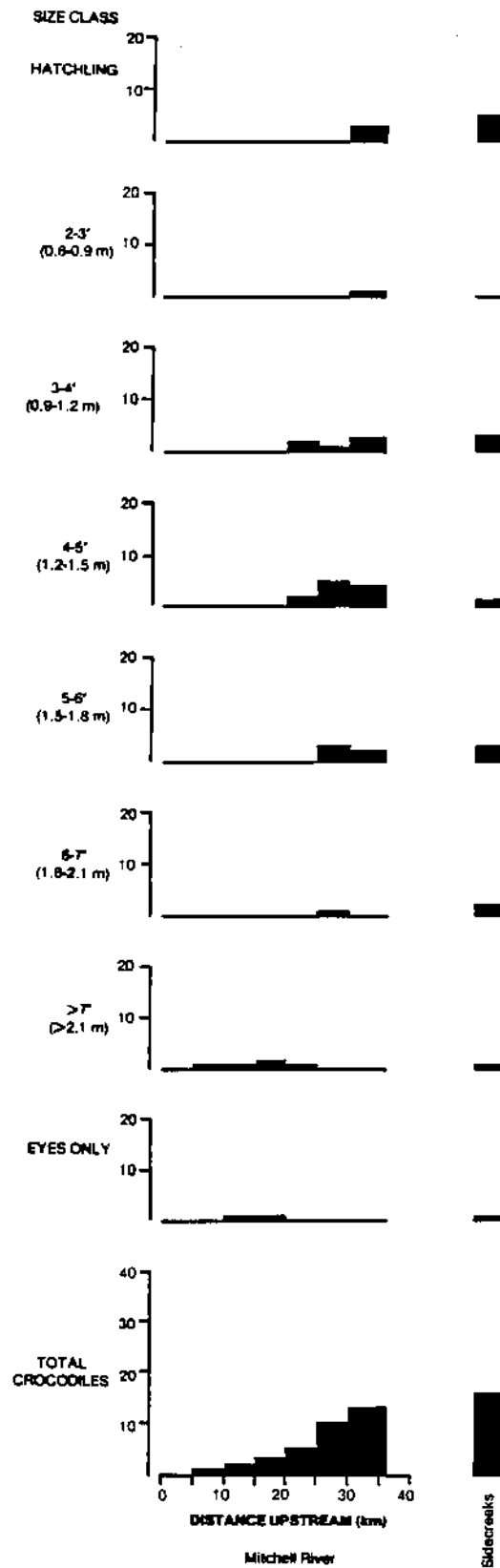
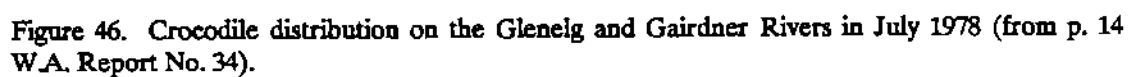


Figure 45. Crocodile distribution on the Mitchell River in July 1977 (from p. 28 W.A. Report No. 24).



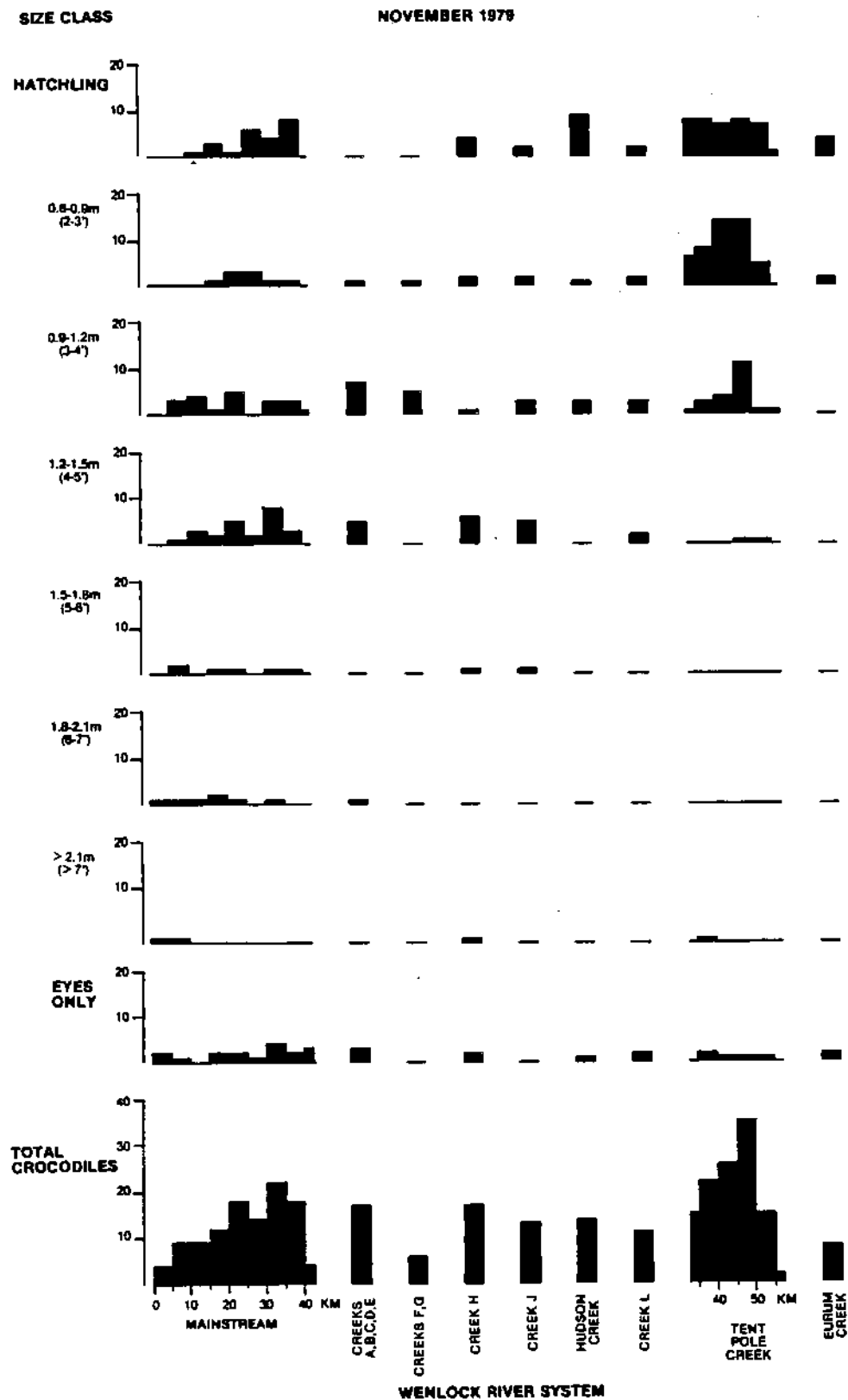


Figure 47. Distributional pattern of *Crocodylus porosus* on the Wenlock River System in November 1979 (from p. 89 Monograph 16).



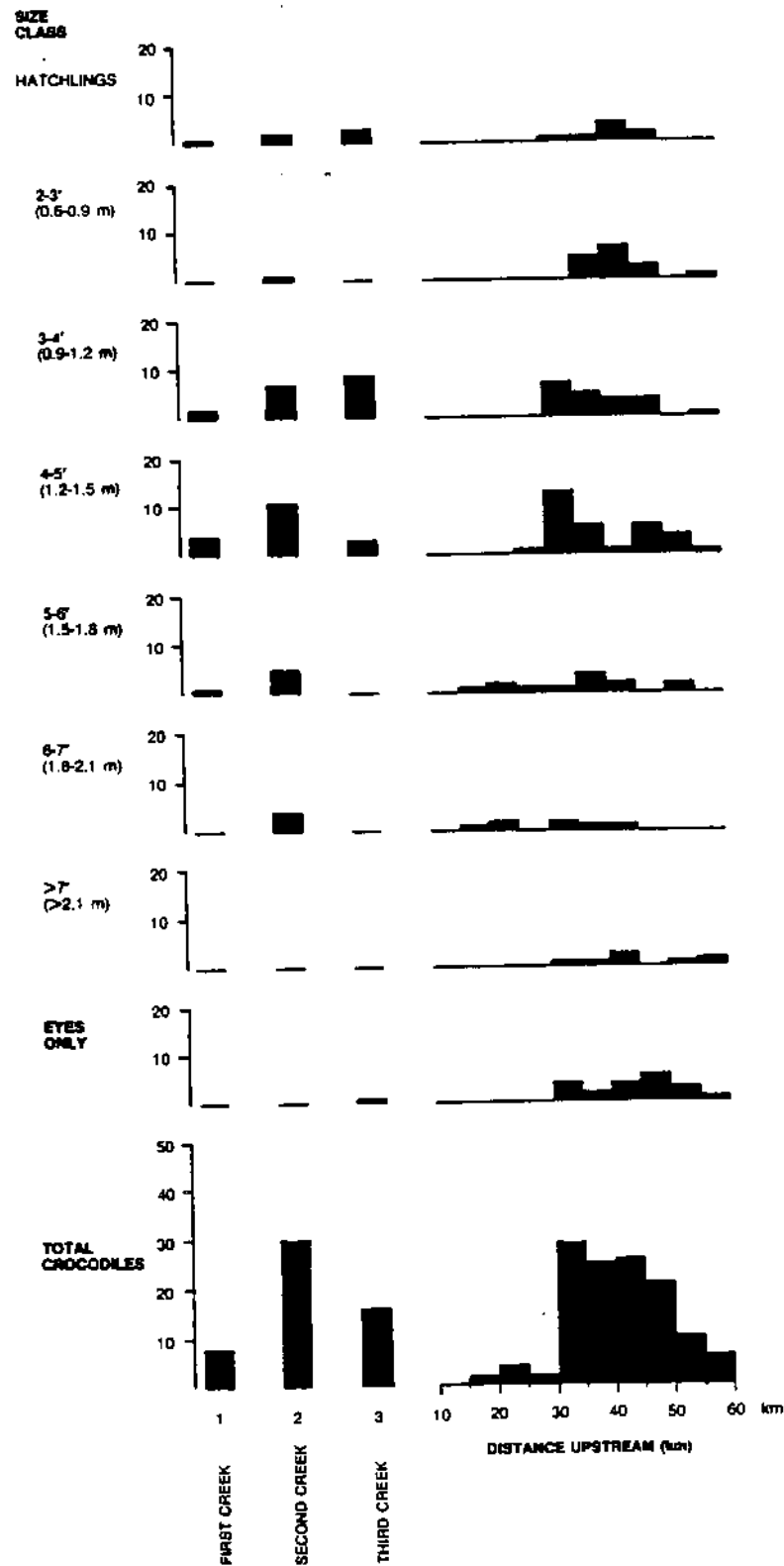


Figure 49. Crocodile distribution on the Ord River System in July 1978 (from p. 32 W.A. Report No. 34).

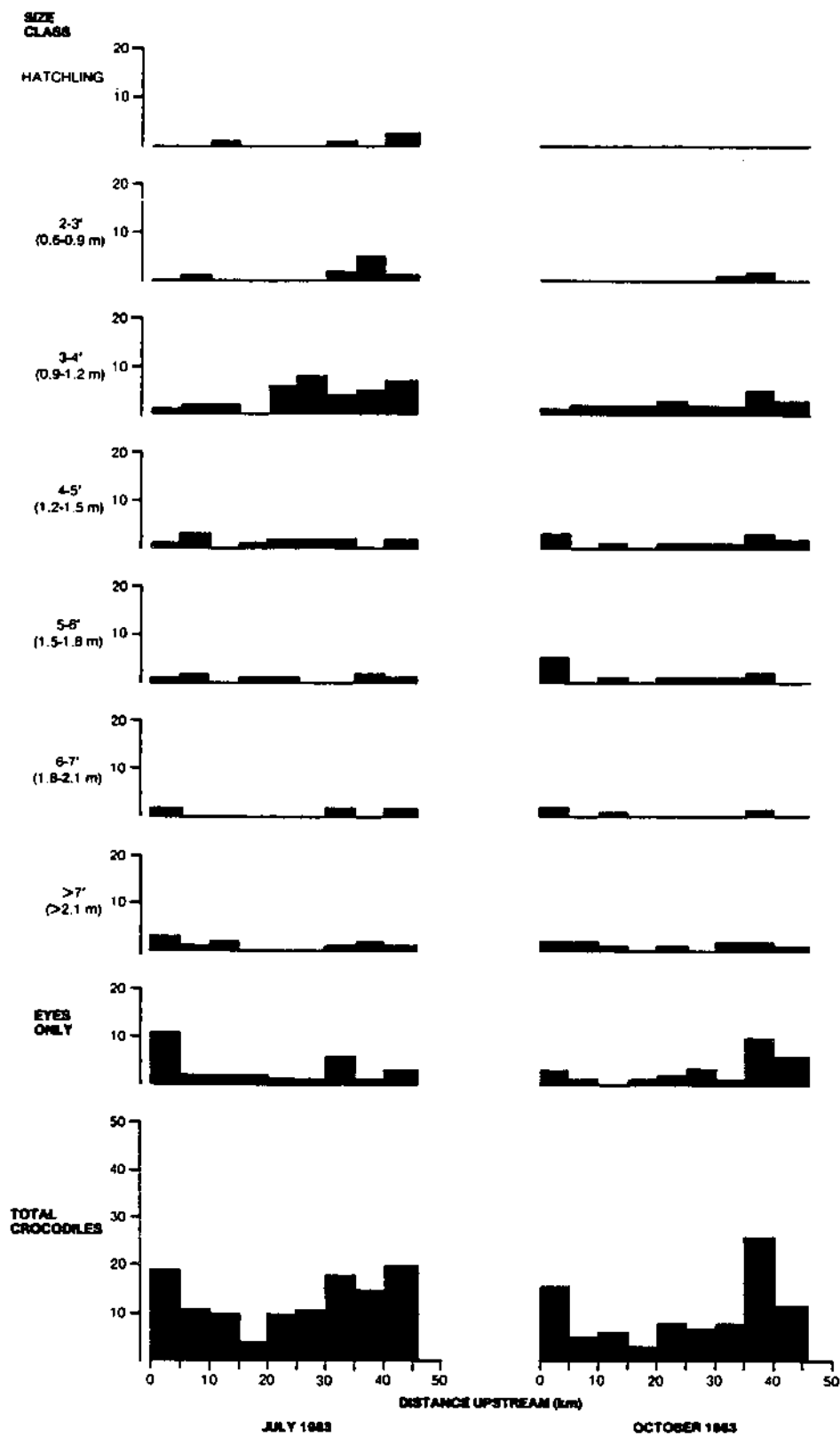


Figure 50. Distributional pattern of *Crocodylus porosus* on the Glyde River in July and October 1983 (from p. 307 Monograph 18).



**SUMMARY RESULTS OF SURVEYS OF THE TIDAL WATERWAYS  
IN THE KIMBERLEY OF WESTERN AUSTRALIA  
DURING THE YEARS 1977, 1978 AND 1986**

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**ABSTRACT**

Some 50% of the important *Crocodylus porosus* habitat in the Kimberley of Western Australia was surveyed for the first time during the years 1977 and 1978. In 1986 we resurveyed most of the tidal systems first surveyed in 1977 and 1978, and in addition surveyed the 203 km of tidal systems in the West Arm of Cambridge Gulf. A slow but important recovery appears to be on the way on the still remote tidal waterways of the Kimberley.

The recovery on the Ord and Glenelg Systems mimics that of the tidal waterways on the northern Arnhem Land coast and is understood on the basis of our population dynamics model for *C. porosus* but a number of intriguing questions remain. After an interval of 8 years, both of the Systems end up with a non-hatchling density less than what was found when the Systems were first surveyed by us in 1978. The number of (3-6') animals sighted remained closely the same or decreased, however the number of large animals sighted essentially doubled in both cases. The ratio of (3-6')/large animals decreased as predicted.

The Prince Frederick Harbor and Prince Regent Systems show a slow but important recovery. On these systems, with their non-Type rearing stockyards near the mouth of the mainstream, not only has the density of non-hatchlings increased but the number of large animals has almost trebled. The ratio of (3-6')/large animals also fell as predicted. Our population dynamics model is able to account for the results and in fact predicted such a finding.

In 1978 we gave an estimate for the number of non-hatchling *C. porosus* remaining in the tidal waterways of the Kimberley in Western Australia. Our estimate then was that a maximum of 2,000 non-hatchlings remained. What about our estimate now? A total of 978 non-hatchlings were sighted on the 790.4 km of tidal waterways surveyed. This yields an estimate for the actual number of non-hatchlings of between 1,541 and 1,667, at the 95% confidence level. We estimate that we have now surveyed some 67% of the important crocodile habitat in the Kimberley. This being the

case, the estimate for the total non-hatchling *C. porosus* population in Western Australia is between 2,300 and 2,488 animals. It is to be compared with the some 3,000 animals reportedly taken for their skins around the Admiralty Gulf area alone, during the period 1963-1965. Protection for *C. porosus* should continue, for it is now apparent that recovery of the population must be measured in decades.

Our results pose a number of interesting questions, especially about the paucity of hatchlings and crocodiles in the (2-3') size class sighted during the 1986 survey. The number of large crocodiles sighted increased by a factor of about 3. Could cannibalism by these animals be one of the reasons for the small hatchlings and (2-3') numbers sighted?

## INTRODUCTION

During the years 1977 and 1978 we systematically surveyed and charted the majority of the large Kimberley tidal river systems (Figs. 1 and 2) and inventoried *Crocodylus porosus* in them. The only significant areas not surveyed in those years were the Walcott Inlet-Secure Bay area and the West Arm of Cambridge Gulf—with their associated tidal rivers. During 1986 we resurveyed most of the systems we had done in 1977 and 1978 and surveyed the tidal systems of the West Arm of Cambridge Gulf for the first time.

The following tidal systems of the Kimberley in Western Australia were surveyed by us:

	Latitude	Longitude
Cambridge Gulf		
Ord River System (East Arm)	15°03'S	128°10'E
West Arm	15°11'S	128°06'E
Sellers Creek at km 12.5	15°17'S	128°08'E
Forrest River at km 15.0	15°18'S	128°04'E
Canal Creek at km 16.0	15°18'S	128°04'E
Parry Creek at km 18.0	15°20'S	128°08'E
King River at km 35.0	15°30'S	128°05'E
Durack River at km 61.0	15°36'S	127°50'E
Pentecost River at km 62.0	15°37'S	127°51'E
Port Warrender		
Lawley River System	14°33'S	125°53'E
Walmesly Bay		
Mitchell River System	14°24'S	125°42'E
Prince Frederick Harbor		
Hunter River System	15°02'S	125°23'E
Roe River System	15°08'S	125°21'E
St. George Basin		
Prince Regent River System	15°13'S	124°49'E
George Water		
Sale River	15°58'S	124°36'E
Glenelg River System	15°48'S	124°42'E

The coordinates shown are those for the km 0 point of the work maps given in Monographs 15 and 20.

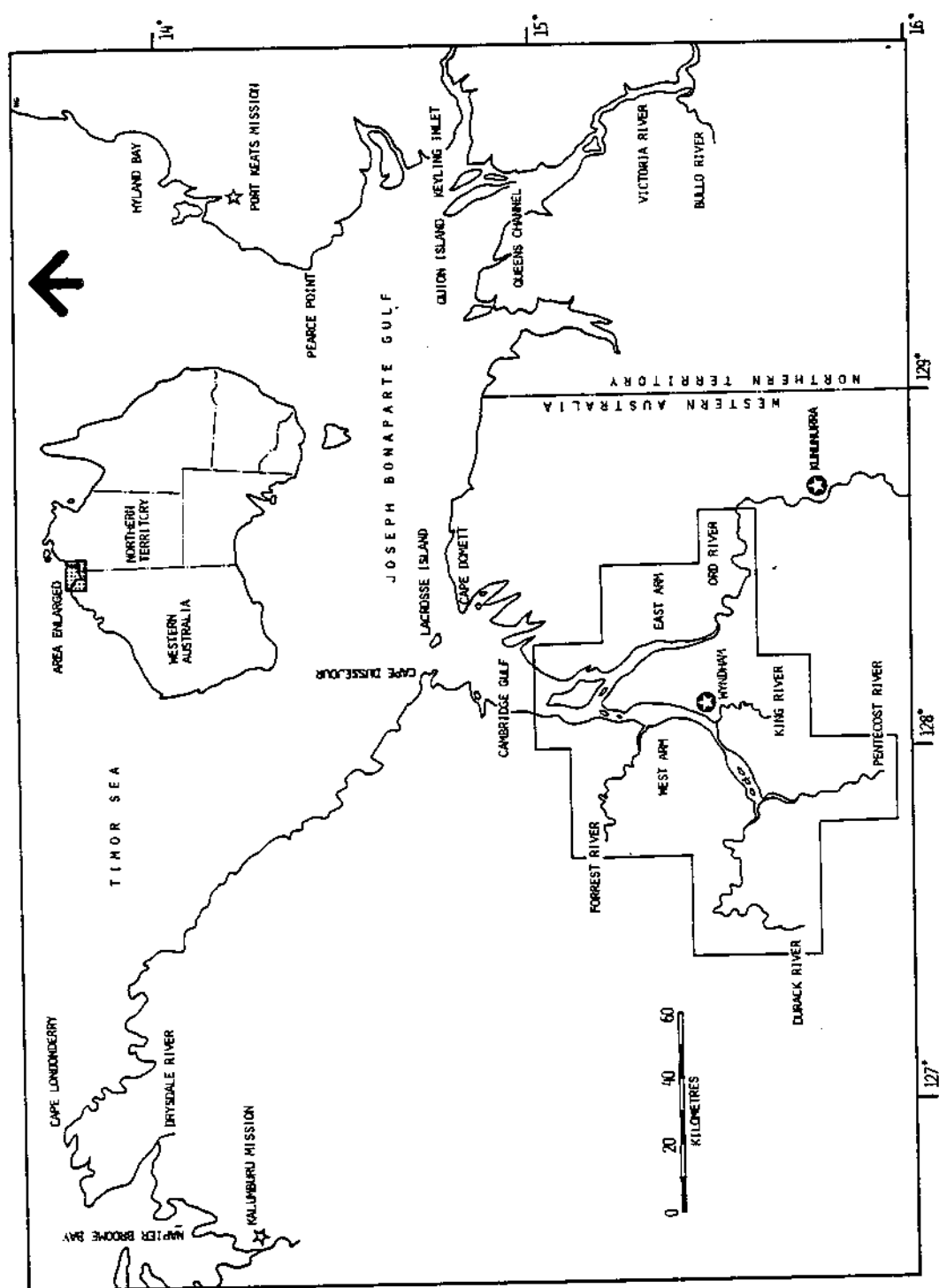


Figure 1. General area map 1: East Kimberley, Western Australia.

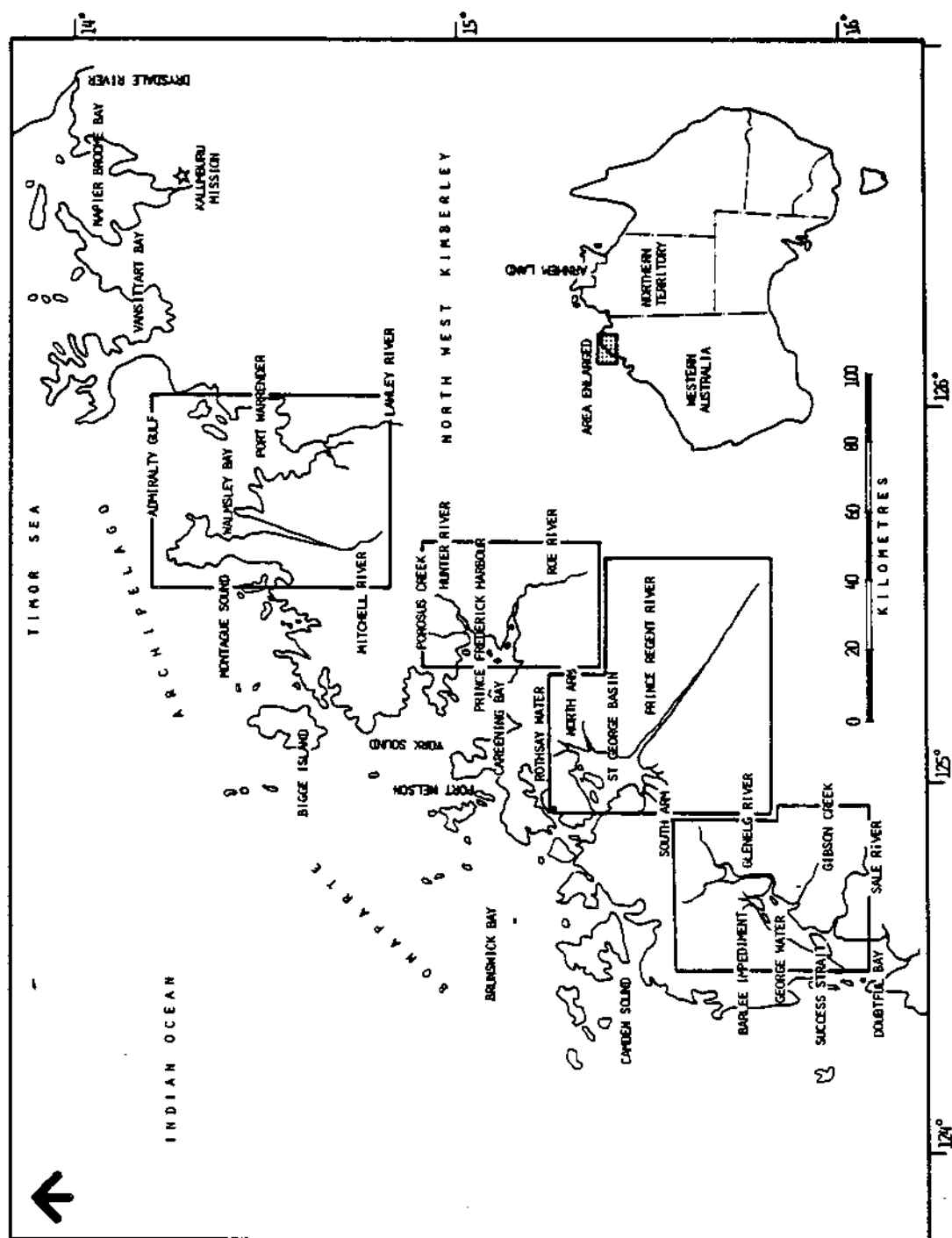


Figure 2. General area map 2: North West Kimberley, Western Australia.

The surveys of 1986 essentially wind up our 15 year program of systematically surveying and charting over 100 tidal systems in northern Australia and studying and inventorying their crocodile populations. The results of this work have appeared in a series of 19 Monographs published by Pergamon Press (and two reports published by the Western Australian Government on the 1977 and 1978 surveys).

The work summarized very briefly in the present paper covers the surveys of 1977, 1978 and 1986 and will appear in detail in Monograph 20, a special volume devoted mainly to tidal systems in the Kimberley of Western Australia.

The surveys of the major tidal systems in the Kimberley carried out in 1977 and 1978 were important not just because we were able to ascertain the status of *C. porosus* in those systems, but even more importantly, it was results from these surveys that provided a number of the basic ideas about the dynamics of *C. porosus* populations.

When the 1977 and 1978 surveys were carried out in the Kimberley, we still did not have a model for the dynamics of *C. porosus* populations; in fact data from the 1977 survey of the Prince Regent River System provided us with one of the first clues for our model. On page 47 of Report 24 we stated:

"The distribution of crocodiles in the larger size classes in the main River and its creeks is similar to that of a badly depleted population, except for the almost complete absence of larger crocodiles near the mouth of the River (Table 8).

The distribution of the size classes in St. George Basin (Table 7) is in striking contrast. Here the majority of crocodiles seen were greater than 1.2 m long, including 28 over 1.8 m."

Our resurvey of Prince Regent in 1978 then led us to make the following statements on pages 27 and 28 of Report 34:

"If one compares the number of crocodiles seen in 1977 and 1978 for those creeks surveyed in both years, then the 72 including 10 hatchlings, are to be compared with 75 including 25 hatchlings. The ten 1977 hatchlings would, if they survived, be in the non-hatchlings would, if they survived, be in the non-hatchling class by 1978 so the 72 crocodiles of 1977 are now to be compared with  $75-25=50$  crocodiles remaining in 1978. Thus, there is evidence for considerable mortality and/or emigration in this population. Comparison of the number in each size class indicates that this occurs not only in the hatchling but in the 3 to 4, 4 to 5 and 5 to 6 foot size classes as well. The decrease amounts to 31% and is similar to that found by one of us (HM) in many other river systems in northern Australia."...

"Examination of the size structure of the crocodiles observed in each of the north and south arm creeks (Table 4) provides evidence for a major input of small (2 to 6 feet, 0.6 to 1.8 m) and large (>6 feet or 1.8 m) crocodiles from the Prince Regent mainstream and its creeks. The small crocodiles which appear to have moved into the Basin creek complexes are in the 4 to 5 feet (1.2 to 1.5 m) and 5 to 6 feet (1.5 to 1.8 m) classes and appear to be almost evenly distributed among the Basin creeks, with perhaps some indication of a lower density further away from the River mouth."....

"The Prince Regent River and St. George Basin, as a whole, yielded 189 crocodiles, 133 of which were non-hatchlings. The combination of a river which provides nesting habitat upstream and large mangrove blocks at its mouth is unique, and further study of the system may lead to a better understanding of movement patterns in the Salt-water Crocodile."

"It is undoubtedly the existence of these arms which leads to the unusually high proportion of large (>6 foot or 1.8 m) compared to small (2 to 6 feet, 0.6 to 1.8 m) crocodiles in the Prince Regent River system. The ratio is 54/78, equivalent to 69%, whereas the mean ratio for all rivers counted in Australia is 27% (Messel et al. 1978b). It is possible that in other river systems where similar mangrove blocks do not exist the large crocodiles move out to sea and a proportion perish."

And on page 36 of the same report:

"One interesting difference between some Kimberley river systems and those in Arnhem Land has emerged from our studies. Some Kimberley rivers have extensive areas of mangrove-lined tidal creeks near the mouth of the main "breeding" river. This is especially evident in the Prince Regent River, and to a somewhat lesser extent, in the Glenelg River, but they also occur in the Ord, Roe and Lawley River systems. Except in the case of the Lawley these mangrove blocks have numbers of larger crocodiles living in them which have moved from the main river where they hatched. Further study of the relationships between these "holding areas" and their breeding rivers may give clues to the movement patterns of *C. porosus*, since in most Arnhem Land rivers there are not such "holding areas" and many crocodiles moving downstream apparently leave the river system entirely."

These remarks are to be compared with a number of the major points of our model given later in this section and will be seen to be very much in keeping with them. But more of this anon.

Analysis of the number, distribution and size structure of crocodiles sighted during the general surveys of northern Australian tidal systems indicates that one of the most important parameters characterizing a tidal waterway is its salinity profile. The profile and habitat type image one another and appear to largely determine the suitability or otherwise of the tidal waterway for breeding, nesting and rearing. It was in Monograph 5, on the Goomadeer and King River Systems, that we first classified the tidal rivers and creeks on the northern Arnhem Land coastline roughly into three different types of waterways (also see pages 100-105 of Monograph 1). This classification played a critical role in the unravelling of the dynamics of populations of *C. porosus* (especially see Monographs 1, 5, 9, 10 and 11) and is given by (see Fig. 3):

#### TYPE 1

Normally, these are tidal river systems meandering through coastal floodplains and having a major freshwater input during the wet season. However, in the Kimberley the rivers often run through rugged gorges and fault lines. The freshwater inflow decreases but remain sufficient, as the dry season progresses, to prevent the salinity upstream (though progressing upstream gradually) from rising above the sea water values measured at the mouth of the system. Systems usually running through coastal floodplains have good to excellent nesting habitat and could be expected to have good recruitment potential. The Blyth-Cadell Rivers System (Monograph 1) is one of the best examples of the Type 1 systems of the Kimberley is usually more limited and thus

the recruitment potential of these systems is decreased accordingly. The Ord, Roe, Prince Regent and Glenelg river Systems are examples of Type 1 waterways in the Kimberley.

### TYPE 3

Tidal waterways which also have a large freshwater input during the height of the wet season, but in which the freshwater input drops rapidly with the onset of the dry season. These waterways, which usually have short surveyable lengths and often have direct openings to the sea, are typified by salinities that, during the dry season, are above those measured at their mouths and that increase with increasing distance upstream--they are hypersaline and become increasingly so as the dry season progresses. Nesting habitat in such systems is minimal or non-existent. All Night Creek (Monograph 5) was given as an example of such a system; most of the coastal creeks surveyed on the southern coast of the Gulf of Carpentaria also fall into this category (Monograph 13). In the Kimberley "Porosus Creek" (Prince Frederick Harbor) is a Type 3 system.

### TYPE 2

Tidal systems which fall somewhere between Type 1 and Type 3 above and that tend to show hypersaline characteristics as the dry season progresses. Such systems usually have good to poor nesting habitat and equivalent recruitment potential depending upon how close they are to Type 1 or 3 above. The Hunter River in Prince Frederick Harbor is a Type 2 system.

It will be seen (see Fig. 3) that each of these three system types has its own characteristic type of salinity variation, both in respect of time of year and distance upstream, and that the salinity characteristics largely determine the nature of the system. The salinity profile of a system may be said to be its own unique signature. A river system may have multiple signatures, one for its mainstream and then other different signatures for the creeks and side creeks.

The model which we have built up and have been refining (see especially Monographs 1 and 18), as more data are obtained, not only enables us to account in a consistent fashion for the vast store of field observations and results we have accumulated for some 100 tidal waterways in northern Australia, but also enables us to predict successfully results expected on future individual surveys. The model runs as follows:

1. The tidal waterways of northern Australia have been classified according to their salinity signatures into Type 1, Type 2 and Type 3 systems shown in Fig. 3. Type 1 systems are the main breeding ones and non-Type 1 systems are usually poor or non-breeding systems. It is the Type 1 systems the freshwater billabongs and semipermanent and permanent freshwater swamps associated with them that account for the major recruitment of *C. porosus*; the other systems contribute to a lesser degree and they must usually depend largely upon Type 1 systems and their associated freshwater complexes for the provision of their crocodiles. Non-Type 1 system also sometimes have freshwater complexes associated with them but these are normally quite minor.
2. As indicated in Fig. 3, our results show that in Type 1 systems some 27% of the crocodiles sighted are hatchlings (of which some 50% are normally lost between June of one year and June of the next, page 394 Monograph 1), whereas in Type 3 systems down to 4%, showing a much decreased hatchling recruitment in non-Type 1 systems it is at least 52%. On the other hand the percentage of crocodiles in the  $\geq(4-5')$  size classes is some 39% in Type 1 systems and 73% on Type 3

systems. Some 79% of the non-hatchling crocodiles are sighted on Type 1 waterways and 21% on non-Type 1 waterways (page 419, Monograph 1).

3. The relatively few large, and more frequent small freshwater billabongs and semipermanent and permanent freshwater swamps associated with tidal waterways are known to contain *C. porosus* but have not been inventoried systematically, except in a few cases. The accurate extent of their non-hatchling *C. porosus* populations is unknown. Based upon the fact that the number of large freshwater swamp areas, with substantial perennial water (normally bordering old river channels), in northern Australia is very limited--perhaps 400 km<sup>2</sup> maximum--and upon limited observations, we estimated that in 1979 the non-hatchling *C. porosus* population was less than 20% of the non-hatchling population sighted in tidal systems. We now believe that the 20% figure was an overestimate for 1979--an unusual year associated with one of the "driest wet" seasons on record. In the Kimberley there are very few freshwater swamps or billabongs.
4. It appears that the populating of non-Type 1 systems (hypersaline or partially hypersaline coastal and non-coastal waterways) results mostly from the exclusion of a large fraction of the sub-adult crocodiles from Type 1 systems and any freshwater complexes associated with them. Adult crocodiles appear generally to tolerate hatchlings, (2-3') and sometimes even (3-4') size crocodiles in their vicinity--but not always: they sometimes eat them (page 43, Monograph 14) or kill them (page 334, Monograph 1). Larger crocodiles are not tolerated. Thus once a crocodile reaches the (3-4') and (4-5') size classes, it is likely to be challenged increasingly not only by crocodiles near or in its own size class (pages 454-458, Monograph 1) but by crocodiles in the large size classes. It is thus likely to be excluded from the area it was able to occupy when it was smaller. A very dynamic situation prevails with both adults and sub-adults being forced to move between various components of a system and between systems. Crocodile interactions, or aggressiveness between crocodiles, in all size classes increases around October--during the breeding season (page 445, Monograph 1 and page 109, Monograph 18) and exclusions, if any, normally occur around this period. A substantial fraction (=80%) of the sub-adults, mostly in the (3-6') size classes but also including immature large crocodiles, is eventually excluded from the river proper or is predated upon by larger crocodiles.
5. Of those crocodiles that have been excluded, some may take refuge in freshwater swamp areas and billabongs associated with the waterway from which they were excluded or in the waterway's non-Type 1 creeks if it has any. Others may travel along the coast until by chance (?) they find a non-Type 1 or another Type 1 waterway, however in this latter case they may again be excluded from it; others may go out to sea and possibly perish, perhaps because of lack of food, as they are largely shallow water on edge feeders, or they may be taken by sharks. Those finding non-Type 1 systems, or associated freshwater complexes, frequent these areas, which act as rearing stockyards, for varying periods until they reach sexual maturity, at which time they endeavor to return to a Type 1 breeding system. Since a large fraction of the crocodiles sighted in non-Type 1 systems must be derived from Type 1 systems and their associated freshwater complexes, they are, as seen in (2) above, predominantly sub-adults in the ( $\geq 3'$ ) size just mature adults might attempt to return to and be forced out of a system many times before finally being successful in establishing a territory in a Type 1 system or in its associated freshwater complex. Crocodiles may have a homing instinct (this



important point requires further study) and even though a fraction of crocodiles may finally return to and remain in a Type 1 system or in its associated freshwater complex, the overall sub-adult numbers missing--presumed dead--remain high and appear to be at least 60-70%.

6. Normally, in the Northern Territory, the freshwater complexes (swamps and/or billabongs) associated with tidal systems, are found at the terminal sections or small and large creeks running into the main waterway, or at the terminal section of the mainstream(s). Though this alternative habitat is usually very limited in extent, sporadic (and sometimes extensive yearly) nesting does take place on it. There are, however, several fairly extensive freshwater complexes associated with Type 1 tidal systems and these are important as they may act both as rearing stockyards and as breeding systems, just as the Type 1 waterway does itself. Examples of these are the Glyde River with the Arafura Swamp (Monograph 9), the Alligator Region Rivers with their wetlands (Monographs 4, 14 and 19), and the Daly, Finnis, Reynolds and Moyle Rivers with their wetlands (Monograph 2). The loss factor, which appears to occur during the exclusions stage, can be expected to be lower for movements into and out of swamp areas associated with a Type 1 waterway, than for movement into and out of coastal non-Type 1 systems. The loss of nests due to flooding can also be expected to be less. We have observed nests made of floating grass cane mats in the Daly River Aboriginal Reserve area. Thus recovery of the *C. porosus* population and Type 1 tidal waterways, with substantial associated freshwater complexes (or with large non-Type 1 waterways associated with them), can be expected to be faster than on other systems (page 445, Monograph 1, page 98, Monograph 14 and also see important results for the 1984 resurvey of Alligator Region and Adelaide River systems, Monograph 19 where we verified this prediction). In the Kimberley, freshwater complexes are found only in the Cambridge Gulf area and do not occur to any extent on the north west coast.
7. Because of the ~80% exclusion and at least 60-70% losses of sub-adult crocodiles from Type 1 systems as they proceed toward sexual maturity, there appears to have been on significant sustained increase in the non-hatchling *C. porosus* population on the some 500 km of tidal waterways monitored in the Maningrida area of northern Australia since the commencement of our systematic surveys in 1974, a period of ten years (Monograph 18). With the exception of the Glyde River, these waterways have only freshwater complexes associated with them.
8. Though there appears to have been no sustained significant increase in the number of non-hatchling crocodiles sighted on the tidal waterways of the Maningrida area since our surveys started in 1974, the size structure of the animals sighted appears to have been changing slowly. Notwithstanding substantial fluctuations, the ratios of small (2-6') to large ( $\geq 6'$ ) and (3-6') to large animals were decreasing on the Blyth-Cadell; may have been decreasing on the Liverpool-Tomkinson; and were decreasing overall on the tidal waterways of the Maningrida monitoring area. Thus there was some indication of the commencement of a slow recovery phase.
9. For the 861 km of tidal waterways of the Alligator Region with their substantial freshwater complexes, and the Adelaide River System, there was strong evidence, as of July 1984, that an important and sustained recovery was underway, as predicted in (6) above.

10. Though there are wide fluctuations, especially after "dry wet" seasons when the animals are concentrated into the tidal waterways, it appears that as the number of large crocodiles in a Type 1 tidal waterway increases, there is a tendency for the number of sub-adults in the (3-6') size classes to decrease or increase marginally only. Thus the total number of (3-6') and large animals sighted appears generally to be holding steady or increasing slowly only. This density dependent recruitment has an important bearing on the rate of population growth and on the size structure of the population.
11. When a steady state is reached in a "recovered" population, the ratio of (3-6') to large animals might be considerably less than one.
12. An important and remarkable fact becomes evident in Type 1 tidal waterways (which are not overly exhausted and on the road to recovery) if one excludes the (3-4') size class and focuses on the (4-5') and (5-6') size classes only. Regardless of how large the recruitment may be, the number of animals sighted in the (4-5') and (5-6') size classes seems to remain essentially constant or increases slowly only. Thus a major bottleneck occurs for these size classes. It is as if there are a definite number of these slots increases slowly only--if at all (note especially the results for the Blyth-Cadell and Liverpool-Tomkinson waterways in Monographs 1 and 18 and the 1984 results for the Alligator Region and Adelaide River systems. Monograph 19). The crocodiles themselves appear to be primarily responsible for the very heavy losses of  $\approx 70\%$  that occur in the process of trying to secure these slots or to increase them in number.
13. If one considers a group of 100 of the sub-adult crocodiles in a Type 1 tidal system without a substantial freshwater complex associated with it, one can expect some 80 to be excluded from it, at least 60-70 of the original 100 to end up missing--presumed dead, less than 15-20 to successfully establish territories on the system without having to leave it and the remainder might eventually also return and establish a territory, especially after becoming sexually mature. The very nature of this matter is such as to preclude precise figures and they must be looked upon as broad estimates only. However, detailed study of our results (Monograph 18) now indicates that the missing--presumed dead figure is likely to be in excess of 70. For systems with substantial freshwater complexes or large non-Type 1 waterways associated with them, this figure is likely to be considerably less.
14. When there is an exclusion from Type 1 systems of sub-adult animals, mostly (3-6') in size but also including immature larger animals, this takes place mainly in the breeding season, normally commencing around September-October and apparently lasting throughout the wet season. Any influx of animals in the (3-6') and/or large size classes appears to occur mainly in the early dry season and to be completed in the June-early September period, but may be earlier in some years.
15. After a single "dry wet" season there is a substantial influx of large and sometimes (3-6') animals, forced out of freshwater complexes into the tidal waterways and these are sighted during June-July surveys. Surveys made in October-November of the same year usually reveal a substantial decrease in the number of (3-6') and/or large animals sighted. However the number of large animals sighted

sometimes remains higher than previously and hence a number of the new large animals do not return from whence they came. These animals appear successful in establishing a territory on the waterway; it could be the waterway from which they had been originally excluded. The "dry wet" variation in the number of animals sighted appears to be superimposed upon the variations normally found during surveys following usual wet seasons--which generally result in extensive flooding on the upstream sections of the tidal waterways. Hatchling recruitment on the tidal waterways is generally greatly enhanced during "dry wet" seasons but appears to be greatly reduced in major swamp habitat. The reverse appears to be true during normal or heavy wet seasons.

On the basis of the above model we made the following statement on page 61, Monograph 19:

"Furthermore, one would predict any recovery on many of the tidal waterways in the Kimberley of Western Australia to be similar to that found in the Maningrida area. The tidal waterways there are mostly devoid of freshwater complexes of any consequence, however the Glenelg and the Prince Regent Systems have extensive Type 3 systems--similar to the Cobourg Complex--at their mouths and these might help keep the exclusion and/or loss factor down. We surveyed these tidal waterways in 1977 and 1978 (W.A. Reports 24 and 34) and a resurvey in the near future could throw further light on our model and allow further refinement of it."

The 1986 surveys of the Kimberley tidal systems were carried out by the now "standard" University of Sydney Crocodile Research Team and staff from the Western-Australian Wildlife Research Center, Department of Conservation and Land Management. The charter vessel, the M.C. Piscean was used for the 1986 surveys and was crewed by Mr. Peter Satori (Master) and Glenice Munro. Mr. Warryn Braithwaite was their young and able assistant and also participated in the surveys. The University of Sydney research vessel, The Harry Messel was used for the 1977 and 1978 surveys. Details about staff and crew for these latter surveys are given in Monograph 20.

## RESULTS

Standard survey methods as laid down in detail in Chapter 2 of Monograph 1 were used for the spotlight surveys. Summary results for each of the tidal waterways surveyed in 1977, 1978 and 1986 are shown in Tables 1 and 2.

In order to obtain an estimate for the number of *C. porosus* there are in the systems we surveyed during 1977, 1978 and 1986, we have taken the results for the Lawley and Mitchell River Systems for 1977, added in the results for the Sale River surveyed in 1978 and then added in the results for all the systems we surveyed in 1986. The results are shown in Tables 1 and 2 under the heading "OVERALL KIMBERLEY--LATEST SURVEY".

Next, in order to see how great the recovery in the Kimberley has been since the 1977 and 1978 surveys, we took the latest of the 1977 or 1978 surveys for each of the systems resurveyed during 1986 and added the results for these together. We then added together the 1986 results for the same systems. The results for this are shown in Tables 1 and 2 under the heading "OVERALL KIMBERLEY--RESURVEYED SYSTEMS ONLY". The detailed results, including the distributional diagrams and much other relevant data and discussion are appearing in Monograph 20.

In Tables 1 and 2 we have also included results for some important tidal systems in the Northern Territory, so that the results found for the Kimberley systems could be compared with them. For comparison, we chose the Blyth-Cadell System, one of the best Type 1 systems on the northern Arnhem Land coast and a system which we understand in some detail (see Monograph 1 and 18). We show results for November 1975 and October 1983 surveys in order to demonstrate how in an excellent Type 1 system, not having substantial freshwater complexes or major non-Type 1 rearing stockyards associated with it, one can have good recruitment year after year (see Monographs 1 and 18 for more details) and yet not find the density of non-hatchling crocodiles increasing. After a period of 8 years only the size structure of the animals sighted appeared to change. As the number of large animals increased the number of animals in the (3-6') size classes decreased. We also show results for the Goomadeer System (Monographs 1, 5 and 18) whose size is close to that of the Glenelg.

The third waterway we chose to compare with was the Adelaide River System (Monographs 3 and 19). This large system is one which is showing a sustained and major recovery. We give results for the July 1977 and July 1984 surveys. One should note the big increase in the number of large animals sighted and the apparent constancy of the number of animals sighted in the (3-6') size classes. The Adelaide System has a number of small freshwater complexes associated with it, and importantly a number of large non-Type 1 creek systems on its mouth sections, which function as rearing stockyards.

The large McArthur River System is the fourth system chosen for comparison (Monographs 13 and 19). It is an example of a very large system in which the *C. porosus* population is nearing exhaustion with little hope of recovery as long as commercial net fishing for barramundi is permitted on much of the waterway. The depletion of *C. porosus* on that System continues through the drowning of crocodiles in barramundi nets.

We have also included results for tidal systems in two broad geographical areas so as to be able to compare the overall Kimberley results with these. Results are shown for the Adelaide plus Alligator Region (excluding the Wildman) for the years 1977 and 1984 (Monographs 3, 4, 14 and 19). It is in this large region, with its excellent Type 1 waterways and associated freshwater complexes, that one observes what appears to be a definite recovery. Results are also given for the Maningrida area, which includes the tidal systems on the northern Arnhem Land coast, from the Goomadeer in the west to the Blyth in the east (Monographs 1, 5 and 18). The recovery for the excellent Type 1 systems in this area is much less definite and is probably evidenced by the slow change in the size composition of the animals sighted rather than an increased density of non-hatchlings.

## DISCUSSION

What can we say about recovery on each of the Kimberley Systems surveyed? Both the Ord and Glenelg Systems demonstrated their ability to mimic the Type 1 tidal systems on the northern Arnhem Land coast (shown in Tables 1 and 2) even though they should not have, with their large non-Type 1 rearing stockyards. After an interval of eight years, both of these Systems end up with a non-hatchling density less than what was found when the Systems were first surveyed by us in 1978. The number of (3-6') animals sighted remained closely the same or decreased, however the number of large animals sighted essentially doubled in both cases. In Monograph 20, we ended up our discussion of the Ord System as follows:

We sum up our analysis of the overall results for the East Arm of Cambridge Gulf—the Ord River System, by stating that we remain baffled by a number of points. Why the almost negligible hatchling and (2-3') crocodile count during the 1986 survey? Is the doubling of the number of large animals on the System between 1978 and 1986 responsible for this, through the mechanism of cannibalism? And why is the excellent Type 1 Ord System behaving as if it was a Type 1 system on the northern Arnhem Land coast, but unlike those systems, the Ord has an excellent non-Type 1 creek system at its mouth, much like the Adelaide, to act as rearing stockyards for animals excluded from the mainstream. And then there is the very large non-Type 1 West Arm of Cambridge Gulf which is simple one large rearing stockyard for animals excluded from the Ord. Why then the large exclusion and/or loss factor of 73% on the Ord? We leave the search for answers to these fascinating questions to our successors. Perhaps 40 to 50 years hence they will find a non-hatchling density of 5.0/km on the Ord, consisting largely of animals in size classes (>6')?

And for the Glenelg we ended up with the statement\*

The Glenelg System with the Barlee Impediment is a small excellent system, which at first sight appears to have excellent recovery potential. However, as we have seen, this potential will take several decades to be realized, as in the cases of the tidal systems on the northern Arnhem Land coast.

After the 1978 survey, we believed that recovery on the Glenelg System would be much like that on the Prince Regent, with its North and South Arms. However, this was not to be. The North and South Arms acted as major rearing stockyards for animals excluded from the Prince Regent mainstream, and the number of animals sighted in them increased from 27(3-6') plus 42(>6') in 1978 to 55(3-6') plus 91(>6') animals in 1986. We thought that the equivalent of the North South Arms of the Prince Regent would be the Barlee Impediment for the Glenelg and that there would be a substantial increase of animals sighted on the Impediment. This did not occur and we do not know why. Fifteen crocodiles were sighted on the Impediment in 1978 and again 15 in 1986. The mystery deepens when one considers, in addition, the results for Prince Frederick Harbor with the Roe, and the Prince Frederick Harbor Creeks A to F. These Creeks have a surveyable length of 24.8 km. The Creeks have a surveyable length of 19.0 km. As we saw in the section on Prince Frederick Harbor, Creeks A to F act as rearing stockyards for animals excluded from the Roe and the number of non-hatchling crocodiles sighted in them increased from 26 in 1978 to 56 for the 1986 survey. Again, why didn't more of the crocodiles excluded from the Glenelg use the Barlee Impediment as a rearing stockyard?

The Prince Frederick Harbor System, with the Roe, Hunter and non-Type 1 Harbor Creeks A to F, behaved as one would have predicted. The density of the sighted non-hatchlings increased significantly from 1.5/km to 2.5/km for the overall System and there was a major change in the size composition of the animals sighted. The ratio (3-6')/large dropped from 3.5 for 1977 to 1.9 for 1986. This System with its rearing stockyards in Prince Frederick Harbor is functioning as predicted and is well on the road to recovery. Its recovery is akin to that for the Adelaide System shown in Tables 1 and 2.

Similar remarks apply to the excellent Prince Regent System which is close in size to the Adelaide System. Though the density of non-hatchling crocodiles sighted doubled between 1978

and 1986, it is still only 1.2/km and it must double again to approach the Adelaide for non-hatchling numbers. On the other hand, the size composition of the crocodiles is such that the (3-6')/large ratio fell from 1.2 to 0.7 between 1978 and 1986, whereas on the Adelaide this ratio was only down to 1.2 in July 1984. A few decades hence should see excellent numbers of large crocodiles on the Prince Regent System.

The remarks we made on page 154 of Monograph 18 for the tidal systems in the northern Arnhem Land coast apply with equal force for the tidal systems of the Kimberley. We remarked that a major sustained increase in the number of (3-6') and large crocodiles, and the change in population structure from a dominance in the number of (3-6') to a major dominance in the number of large animals present is inherently a slow and very long term process. During this period, there is an exceedingly severe sorting out process resulting in only a small fraction of highly successful animals surviving. Results for the "OVERALL KIMBERLEY--RESURVEYED SYSTEMS ONLY" support this view. Over an interval of 8 to 9 years, the density of the animals sighted increased from 1.2/km to 1.6/km only and the (3-6')/large ratio decreased from 2.7 to 1.3. It has been satisfying to note how successful our population dynamics model for *C. porosus* has been in helping to analyse the survey results for the Kimberley. It has allowed us to discuss meaningfully what has been observed, even though many 'why' questions still remain. One of the important ones relates to the paucity of hatchlings and (2-3') crocodiles sighted on the Kimberley System during the 1986 surveys. The matter is perhaps best summarized by our discussion of this matter for the Prince Frederick System in Monograph 20:

Our 1986 survey of the Prince Frederick Harbor System yielded a strange picture in relation to the number of hatchlings and (2-3') animals sighted. Nine hatchlings were observed on the Hunter River and only one on the remainder of the Prince Frederick Harbor System. A total of only 12(2-3') animals were observed. What happened? As shall be seen later in this Monograph, this observation parallels our survey results for the other tidal waterways which we surveyed in the Kimberley in July-August, 1986--a paucity of hatchlings and (2-3') animals on each of the major systems surveyed. Could this be related to the observation, which we shall discuss shortly, that the number of large animals sighted had increased considerably since 1977? Is it possible that hatchling recruitment was in fact much higher, but that the hatchling and (2-3') animals were cannibalized by the increasing number of large animals? Or, for some reason, had the two previous wet seasons on the Roe-Hunter Systems been poor nesting seasons? Some indirect support for this latter view may be provided by the 47(3-4') animals sighted (see Table 20.6.30). These animals would have resulted from nesting during the 1983-1984 wet season. However, note that the nesting success on the Hunter appears to have been about the same in 1986 as it was in 1977. Furthermore the wet season of 1985-1986 was "dry" until the very heavy rainfall at the end of January. This caused widespread and heavy flooding in the Kimberley. Most nests laid down in January were not likely to have survived. However, nests laid down after that should have been successful. The wet season of 1984-1985 was relatively dry and there was little flooding in the tidal waterways of the Kimberley. It should have been a very successful nesting season with little or no loss of nests due to flooding. Then why so few (2-3') animals sighted in 1986? Thus the overall mystery remains!

The results in Tables 1 and 1 demonstrate that when we first surveyed the tidal river systems in the Kimberley, during 1977 and 1978, we were dealing with badly depleted populations. In Western Australia hunting pressure on *C. porosus* was particularly high during the early 1960's and by 1969 the species had become rare. *C. porosus* was not protected until April 1970, by which time

commercial hunting had become uneconomic. Protection followed in the Northern Territory in 1972 and a total export-import ban on crocodile products was declared by the Commonwealth Government later the same year. It was this ban that effectively stopped hunting throughout Australia. The species has now had some 16 years to recover, but as we have seen, this recovery is now still only in its early phase and complete protection must continue to be accorded to the species.

In 1978, in Report 34, we gave as estimate for the number of non-hatchling *C. porosus* population in Western Australia is between 2,300 and 2,488 animals.

On page 433, Monograph 1 we also made estimates for the number of non-hatchling crocodiles remaining in the Kimberley in 1978. We stated the following:

"We believe that we examined more than half of the better *C. porosus* habitat in the Kimberley. In the 527.3 km surveyed, 898 crocodiles were sighted of which 227 were hatchlings. The 671 non-hatchling yield a density of 1.3/km and the estimate for the actual number of non-hatchlings present, at the 95% confidence level, is 1,048-1,152. Assuming that the number of non-hatchlings which would be sighted in the areas not surveyed is also 671 we obtain lower limits of 2,127-2,275 for the number of non-hatchlings remaining in the Kimberley as of July 1978. One can extend this estimate (of say 2,500) almost without limit if one cares to make what we feel would be unreasonable assumptions."

It is obvious that we were overly generous with this estimate of 2,500 and that the figure of 2,000 we gave in Report 34 was closer to the correct figure for 1978. The figure of 2,500 non-hatchling crocodiles is the figure for 1986. It is to be compared with the some 3,000 animals reportedly taken for their skins around the Admiralty Gulf area alone, during the period 1963-1965 (pers. comm. Father Sanz, formerly of Kalumburu Mission).

#### ACKNOWLEDGEMENTS

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20. Tidal Waterways of the Kimberley Surveyed during 1977, 1978 and 1986. Messel, H.; Burbidge, A.A.; Vorlicek, G.C.; Wells, A.G.; Green, W.J.; Onley, I.C. and Fuller, P.J.

Appearing in the same series and published by the Western Australian Government:

1. The status of the salt-water crocodile in some river systems of the north-west Kimberley, Western Australia. Dept. Fish. Wildl., West. Aust. Rept. No. 24:1-50(1977). Messel, H.; Burbidge, A. A.; Wells, A. G. and Green, W. J.
2. The status of the salt-water crocodile in the Glenelg, Prince Regent and Ord River Systems, Kimberley, Western Australia, Dept. Fish. Wildl. West. Aust. Rept. No. 34:1-38(1979). Burbidge, A. A. and Messel, H.

TABLE 1. Number of *C. porosus* sighted within each size class on the Kimberley tidal waterways shown during night-time spotlight surveys carried out during 1977, 1978 and 1986. The midstream distance surveyed and density of non-hatchling crocodiles sighted on each waterway is shown, as are the 95% confidence limits for the estimate of the actual number of non-hatchlings present. The TYPE classification of each waterway is given also. Results for the Blyth-Cadell and Goomadeer Systems for 1975 and 1983, for the Adelaide for 1977 and 1984 and for the McArthur for 1979 and 1985 are shown for comparison. Also shown are results for the geographical group of waterways of the Adelaide and Alligator Region for 1977 and 1984, and the Maningrida area for 1976 and 1983.

System	Totals	Numbers in size class							EO	km Surveyed	Density	95% Levels	TYPE
		H	2-3	3-4	4-5	5-6	6-7	>7					
CAMBRIDGE GULF EAST ARM - ORD													
July 78	179	14	17	39	50	19	11	8	21	98.8	1.7	245- 297	1
July 86	153	3	1	15	28	25	12	29	40	98.8	1.5	221- 271	
WEST ARM													
July 86	128		1	17	15	23	18	21	33	203.0	0.6	187- 233	2-3
EAST-WEST ARM													
July 86	281	3	2	32	43	48	30	50	73	301.8	0.9	422- 490	1 to 3
PORT WARRENDER-LAWLEY													
July 77	38	11	1	3	6	6	2	5	4	34.0	0.8	34- 54	2
July 77	44	13	1	4	6	8	5	3	4	34.0	0.9	40- 62	
WALMESLY BAY-MITCHELL													
July 77	50	8	1	9	12	8	3	6	3	47.7	0.9	56- 82	1
PRINCE FREDERICK HARBOR ROE MAINSTREAM AND CREEKS													
July 77	135	37	40	27	11	7	4	4	5	43.8	2.2	141- 181	1
August 86	158	1	9	35	33	27	23	7	23	43.8	3.6	232- 282	

TABLE 1. cont.

System	Totals	Numbers in size class								km Surveyed	Density	95% Levels	TYPE
		H	2-3	3-4	4-5	5-6	6-7	>7	EO				
PRINCE FREDERICK HARBOR CREEKS													
July 77	41	15			11	7	4	2	2	24.8	1.0	33- 53	1 to 3
August 86	56		1	1	15	10	9	12	8	24.8	2.3	77- 107	
ROE SYSTEM													
July 77	176	52	40	27	22	14	8	6	7	68.6	1.8	181- 225	1 to 3
August 86	214	1	10	36	48	37	32	19	31	68.6	3.1	320- 378	
HUNTER SYSTEM													
July 77	47	11	7	5	10	6	4	2	2	35.3	1.0	47- 71	2-3
August 86	59	9	2	11	8	5	7	9	8	35.3	1.4	68- 96	
OVERALL PRINCE FREDERICK SYSTEM													
July 77	223	63	47	32	32	20	12	8	9	103.9	1.5	237- 287	1 to 3
August 86	273	10	12	47	56	42	39	28	39	103.9	2.5	398- 464	
GEORGE WATER SYSTEMS SALE													
July 78	3				1			2		19.0	0.2	3	1
BARLEE IMPEDIMENT													
July 78	15	1		2	4	5	1	2		19.0	0.7	15- 31	2 to 3
August 86	15			2			2	3	8	20.5	0.7	17- 33	
GLENELG-GAIRDNER													
July 78	193	72	33	24	29	12	10	7	6	58.3	2.1	176- 220	1
August 86	124	20		30	24	14	16	8	12	57.5	1.8	151- 191	

TABLE 1. cont.

System	Totals	Numbers in size class							EO	km Surveyed	Density	95% Levels	TYPE
		H	2-3	3-4	4-5	5-6	6-7	>7					
OVERALL GLENELG AND BARLEE													
July 78	208	73	33	26	33	17	11	9	6	77.3	1.7	198-244	1 to 3
PRINCE REGENT MAINSTREAM AND CREEKS													
July 77	74	15	4	25	12	8	5	1	4	58.6	1.0	82-112	1
July 78	92	31	11	17	11	8	6	6	2	68.2	0.9	84-116	
August 86	87		3	19	12	8	16	20	9	68.2	1.3	124-162	
NORTH ARM													
July 77	39	6	1		8	7	9	8		36.8	0.9	42-66	2 to 3
July 78	62	20	2	1	11	8	7	10	3	63.5	0.7	56-82	
August 86	85	5	3	6	9	11	18	19	14	63.5	1.3	113-149	
SOUTH ARM													
July 77	33	4		2	9	4	6	5	3	39.6	0.7	37- 59	2 to 3
July 78	35	5	1		2	4	7	15	1	74.3	0.4	38- 60	
August 86	75		6	1	8	10	21	23	6	74.3	1.0	106- 140	
OVERALL SYSTEM													
July 77	146	25	5	27	29	19	20	14	7	135.0	0.9	176- 220	1 to 3
July 78	189	56	14	18	24	20	20	31	6	206.0	0.6	195- 241	
August 86	247	5	12	26	29	29	55	62	29	206.0	1.2	366- 428	
OVERALL KIMBERLEY-LATEST SURVEY													
77 or 78 & 76	1037	59	28	150	170	150	150	162	168	790.4	1.2	1541-1667	1 to 3

TABLE 1. cont.

System	Numbers in size class										km Surveyed	Density	95% Levels	TYPE
	Totals	H	2-3	3-4	4-5	5-6	6-7	>7	EO					
OVERALL KIMBERLEY-RESURVEYED SYSTEMS ONLY														
77 or 78	799	206	111	115	139	76	54	56	42		486.0	1.2	924-1022	1 to 3
1986	812	38	25	120	137	110	124	130	128		486.7	1.6	1213-1325	
BLYTH-CADELL - Monographs 1 and 18														
Nov. 75	353	50	106	81	72	23	4	2	15		94.9	3.2	462- 532	1
Oct. 83	354	73	95	69	45	24	11	10	27		92.8	3.0	427- 495	
GOOMADEER - Monographs 1, 5 and 18														
August 75	46		27	7	5	4			3		45.3	1.0	61- 89	1
June 83	63	24	5	6	8	3	3	4	10		45.3	0.9	53- 79	
ADELAIDE - Monographs 3 and 19														
July 77	417	48	24	88	116	47	35	33	26		226.3	1.6	566- 644	1
July 84	602	60	36	105	79	64	78	120	60		231.6	2.3	842- 936	
McARTHUR - Monographs 13 and 19														
May 79	28			2	3	6	4	5	8		232.6	0.1	35- 57	1
Sept. 85	48	2	14	1	3	1	5	9	13		232.6	0.2	61- 89	
ADELAIDE + ALLIGATOR REGION EXCL. WILDMAN - Monograph 19														
July & Oct. 77	1055	111	45	159	244	140	116	126	114		543.1	1.7	1486-1610	1
July 84	1648	145	121	288	181	152	200	340	221		552.6	2.7	2387-2543	
MANINGRIDA AREA - BLYTH TO GOOMADEER - Monographs 1 and 18														
July-Sept. 76	651	121	107	174	83	29	14	12	111		339.9	1.6	823- 915	1
June-July 83	1045	340	189	141	122	77	42	28	106		333.1	2.1	1103-1209	

TABLE 2. This Table was prepared using the results given in Table 1 and groups the crocodiles sighted into the important size classes shown. 50% of the EO size classes were distributed to the (3-6' size classes and the remaining 50% to the  $\geq 6'$ ) size classes. This weights the distribution heavily in favor of larger crocodiles, which are known to normally be the most wary. When the EO is an odd number, the bias is also given to the ( $\geq 6'$ ) size classes.

Survey	Totals	H	(2-3')	(3-6')	Large ( $> 6'$ )	(3-6') Large
CAMBRIDGE GULF EAST ARM - ORD						
July 78	179	14	17	118	30	3.9
July 86	153	3	1	88	61	1.4
WEST ARM						
July 86	128		1	71	56	1.3
EAST-WEST ARM						
July 86	281	3	2	159	117	1.4
PORT WARRENDER-LAWLEY						
July 77	38	11	1	17	9	1.9
July 77	44	13	1	20	10	2.0
WALMESLY BAY-MITCHELL						
July 77	50	8	1	30	11	2.7
PRINCE FREDERICK HARBOR ROE MAINSTREAM AND CREEKS						
July 77	135	37	40	47	11	4.3
August 86	158	1	9	106	42	2.5
PRINCE FREDERICK HARBOR CREEKS						
July 77	41	15		19	7	2.7
August 86	56		1	30	25	1.2
ROE SYSTEM						
July 77	176	52	40	66	18	3.7
August 86	214	1	10	136	67	2.0
HUNTER SYSTEM						
July 77	47	11	7	22	7	3.1
August 86	59	9	2	28	20	1.4

TABLE 2. cont.

Survey	Totals	H	(2-3')	(3-6')	Large (>6')	(3-6') Large
OVERALL PRINCE FREDERICK SYSTEM						
July 77	223	63	47	88	25	3.5
August 86	273	10	12	164	87	1.9
GEORGE WATER SYSTEMS SALE						
July 78	3			1	2	0.5
BARLEE IMPEDIMENT						
July 78	15	1		11	3	3.7
August 86	15			6	9	0.7
GLENELG-GAIRDNER						
July 78	193	72	33	68	20	3.4
August 86	124	20		74	30	2.5
OVERALL GLENELG AND BARLEE						
July 78	208	73	33	79	23	3.4
August 86	139	20		80	39	2.1
PRINCE REGENT SYSTEM MAINSTREAM AND CREEKS						
July 77	74	15	4	47	8	5.9
July 78	92	31	11	37	13	2.8
August 86	87		3	43	41	1.0
NORTH ARM						
July 77	39	6	1	15	17	0.9
July 78	62	20	2	21	19	1.1
August 86	85	5	3	33	44	0.8
SOUTH ARM						
July 77	33	4		16	13	1.2
July 78	35	5	1	6	23	0.3
August 86	75		6	22	47	0.5
OVERALL SYSTEM						
July 77	146	25	5	78	38	2.1
July 78	189	56	14	65	54	1.2
August 86	247	5	12	98	132	0.7

TABLE 2. cont.

Survey	Totals	H	(2-3')	(3-6')	Large (>6')	(3-6') Large
OVERALL KIMBERLEY - LATEST SURVEY						
77 or 78 & 86	1037	59	28	554	396	1.4
OVERALL KIMBERLEY - RESURVEYED SYSTEMS ONLY						
77 or 78	799	206	111	351	131	2.7
1986	812	38	25	430	319	1.3
BLYTH - CADELL - Monographs 1 and 18						
November 75	353	50	106	183	14	13.1
October 83	354	73	95	151	35	4.3
GOOMADEER - Monographs 1, 5 and 18						
August 75	46		27	17	2	8.5
June 83	63	24	5	22	12	1.8
ADELAIDE - Monographs 3 and 9						
July 77	417	48	24	264	81	3.3
July 84	602	60	36	278	228	1.2
McARTHUR - Monographs 13 and 19						
May 79	28			15	13	1.2
September 85	48	2	14	11	21	0.5
ADELAIDE + ALLGATOR REGION EXCL. WILDMAN - Monograph 19						
July & Oct. 77	1055	111	45	600	299	2.0
July 84	1648	145	121	731	651	1.1
MANINGRIDA AREA - BLYTH TO GOOMADEER - Monographs 1 and 18						
July-Sept. 76	651	121	107	341	82	4.2
June-July 83	1045	340	189	393	123	3.2