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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 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. pororus*, 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 Toyoto 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		Group 3	
Blyth-Cadell	Figs. 20, 21	Prince Regent	Fig. 43
Liverpool-Tomkinson	Figs. 22-24	Roe	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, Finniss, 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 he 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 ≥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 Wenlocw.(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 ≥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 ≥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.

ACKNOWLEDGEMENTS

We wish to thank the University of Sydney and the Science Foundation for Physics for their great support over the past 16 years. Special thanks are due to Ray Fryer of Urapunga Station, where the University's Crocodile Research Base is presently established. We also wish to thank the station managers of Roper Valley (Mark Boulton) and Elsey (Barry Gunson) Stations for allowing us to camp on their properties and Jerry Coleman, the helicopter pilot, for his excellent cooperation and skilled flying during our aerial surveys. Kim Rayfield (formerly Mawhinnew), many thanks for your help. If only you could have taken the word processor into the field!

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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	
HATCHLING								
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								
TOTAL	31	—	—	—	—	30	1	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 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	
HATCHLING								
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								
TOTAL	58	—	—	3	—	54	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 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 IV	IVIW	OM	IM	SWOE	MS	OBSERVED FEEDING
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 IV	IVIW	OM	IM	SWOE	MS	OBSERVED FEEDING
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.

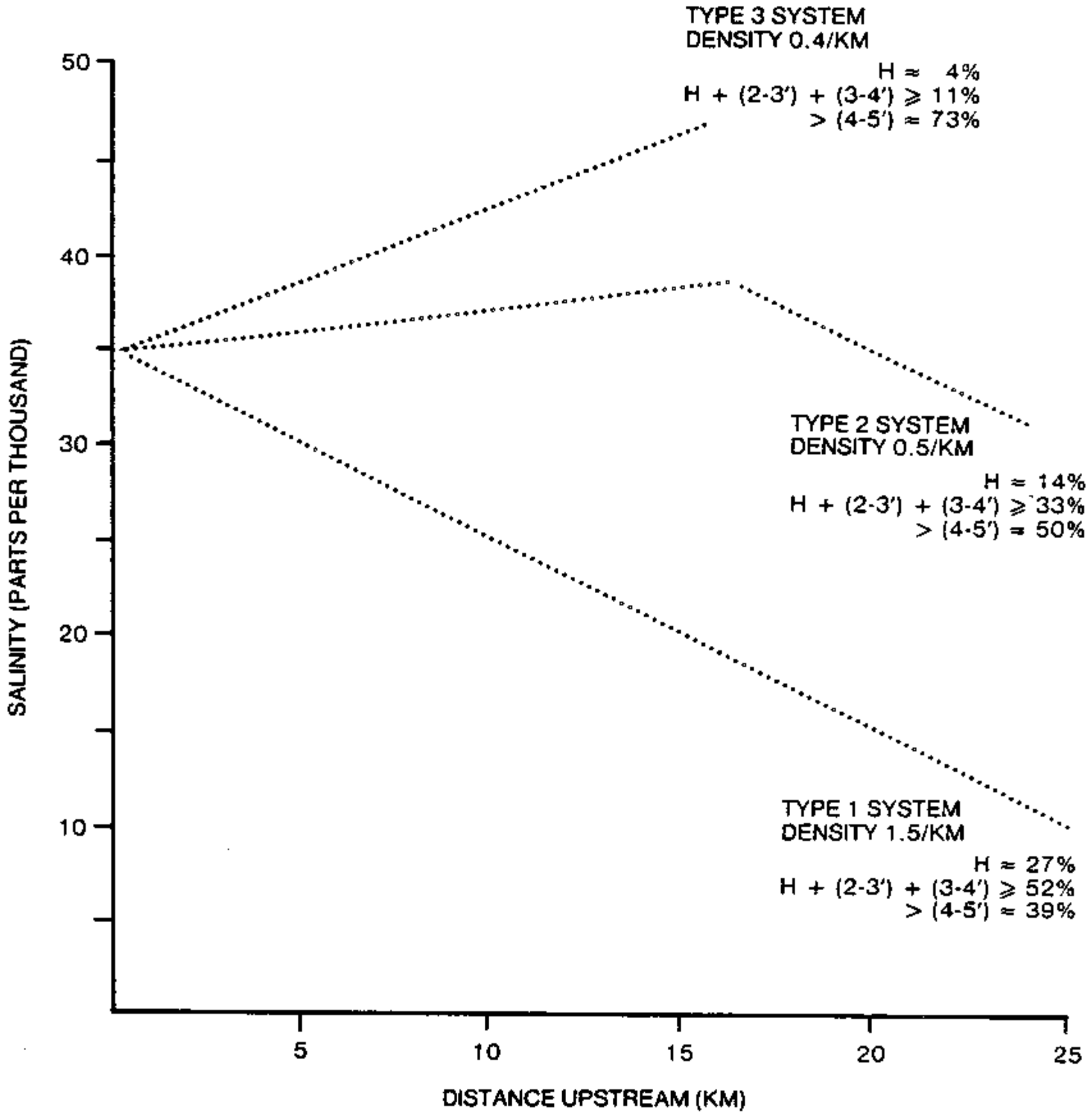

Figure 1. Typical dry season salinity profiles for the three types of tidal river systems occurring in the model's classification scheme. In a Type 1 system the salinity decreases steadily as one progresses upstream from that of seawater measured at the mouth of the waterway (-35°/oo). In contast, in 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).

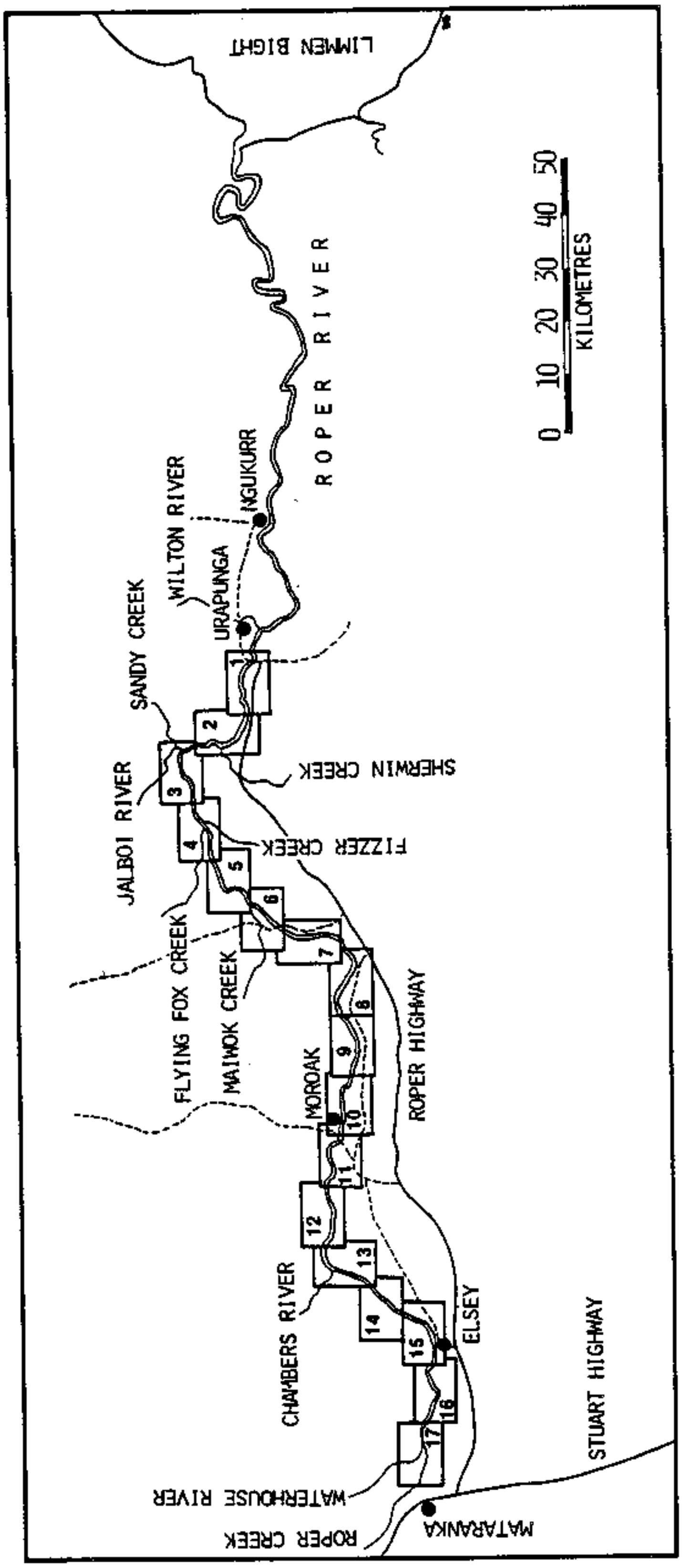

Figure 2. Legend to the river work maps of the upstream Roper River.

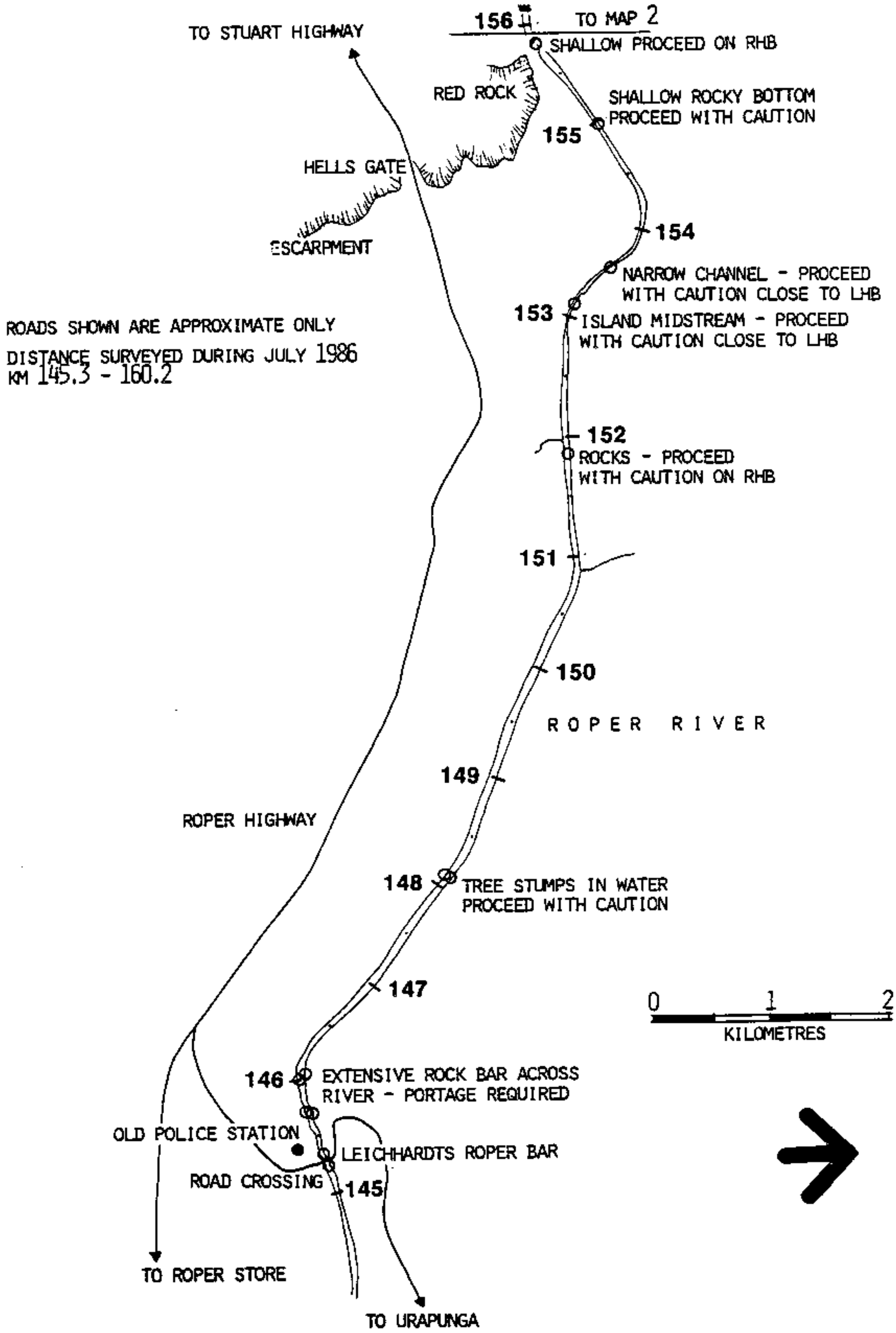

Figure 3. Upstream Roper River 1.

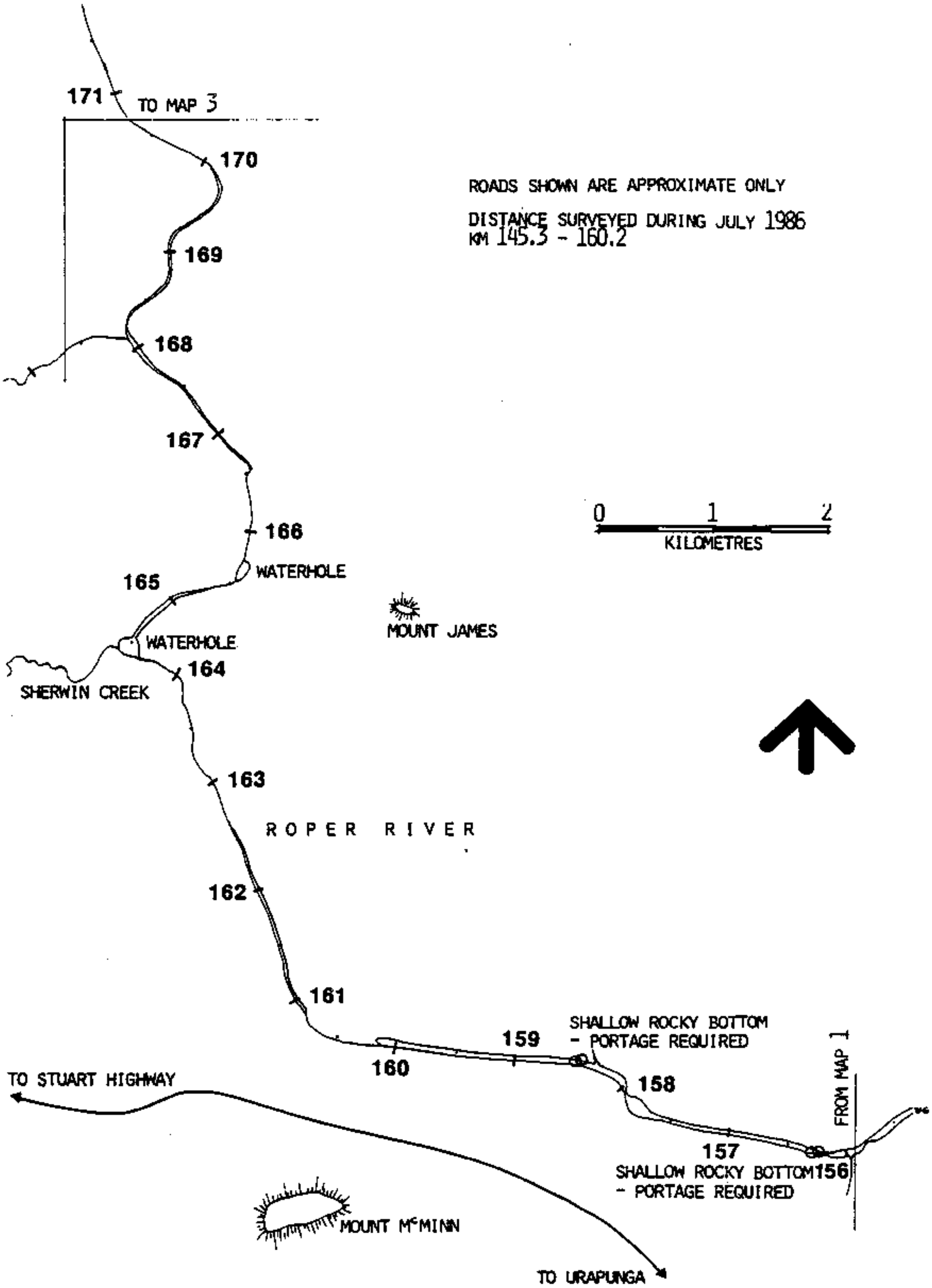

Figure 4. Upstream Roper River 2.

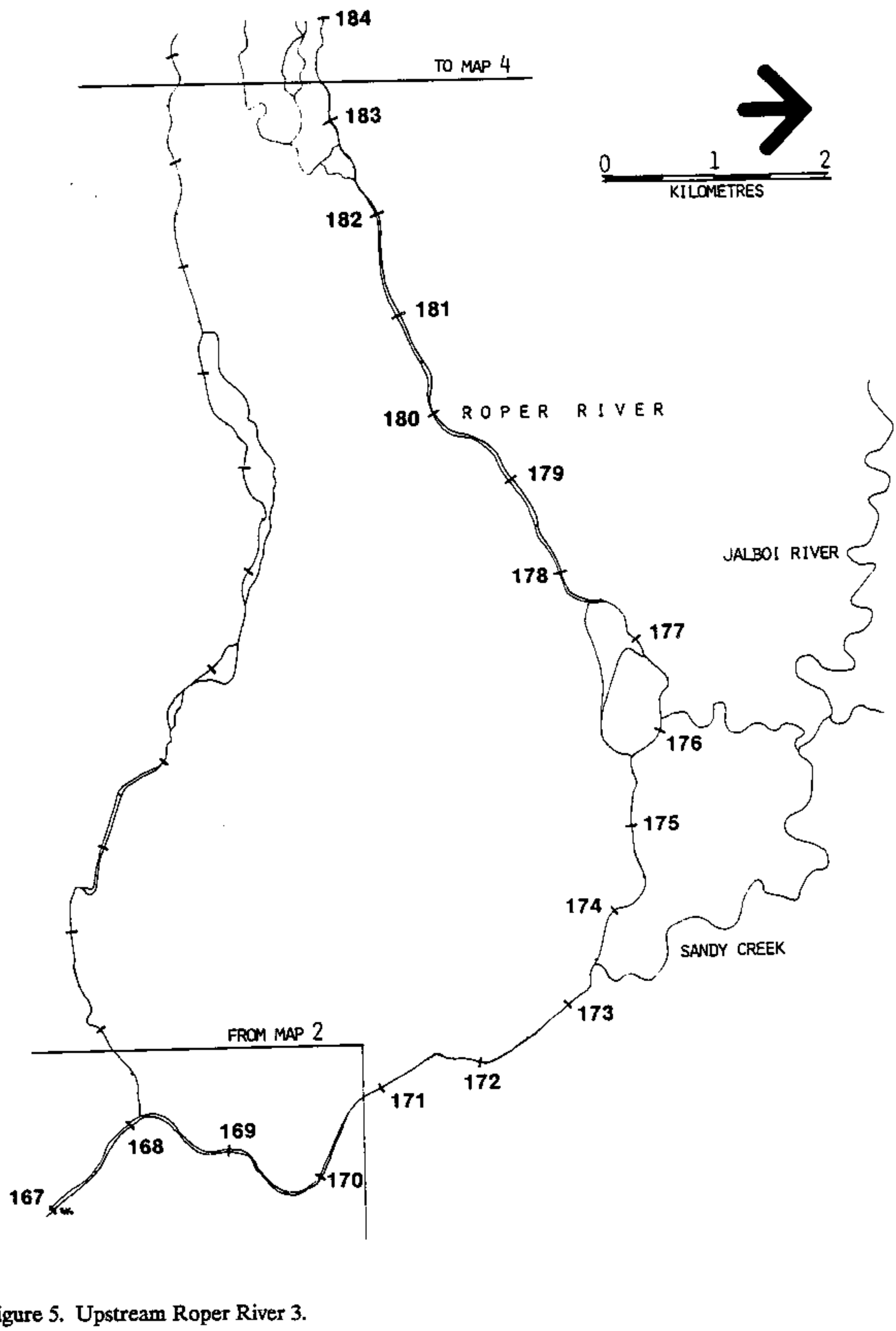

Figure 5. Upstream Roper River 3.

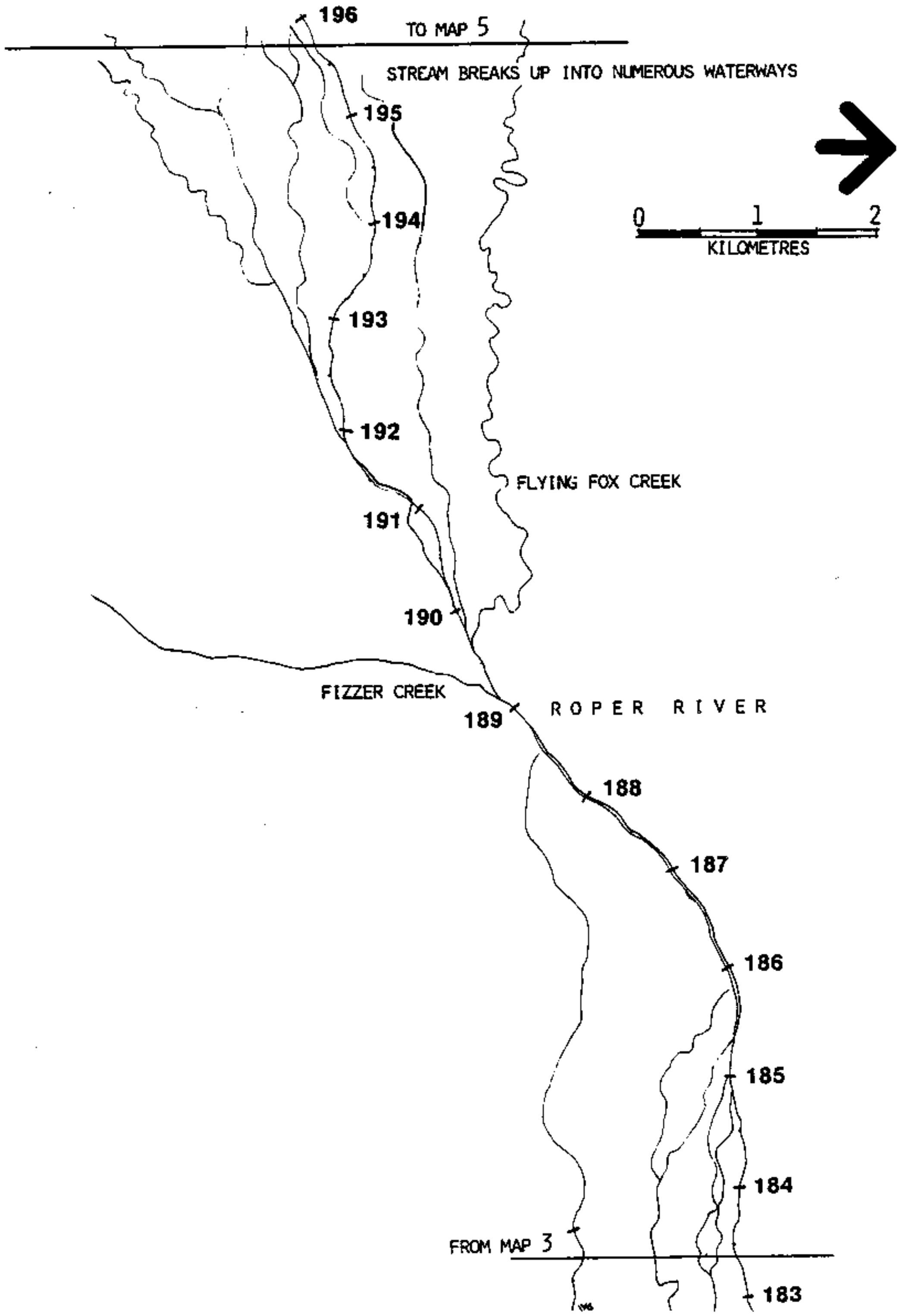

Figure 6. Upstream Roper River 4.

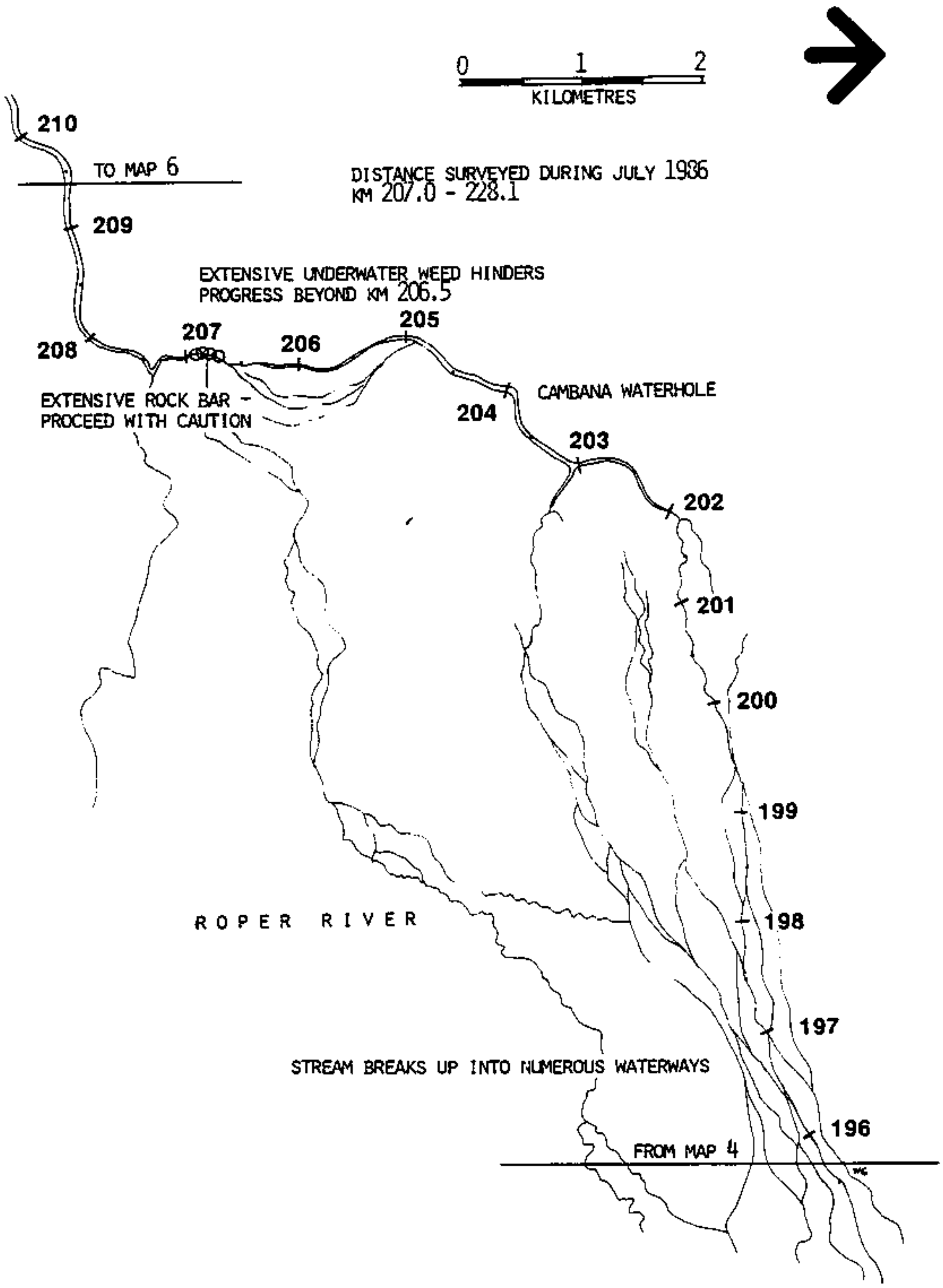

Figure 7. Upstream Roper River 5.

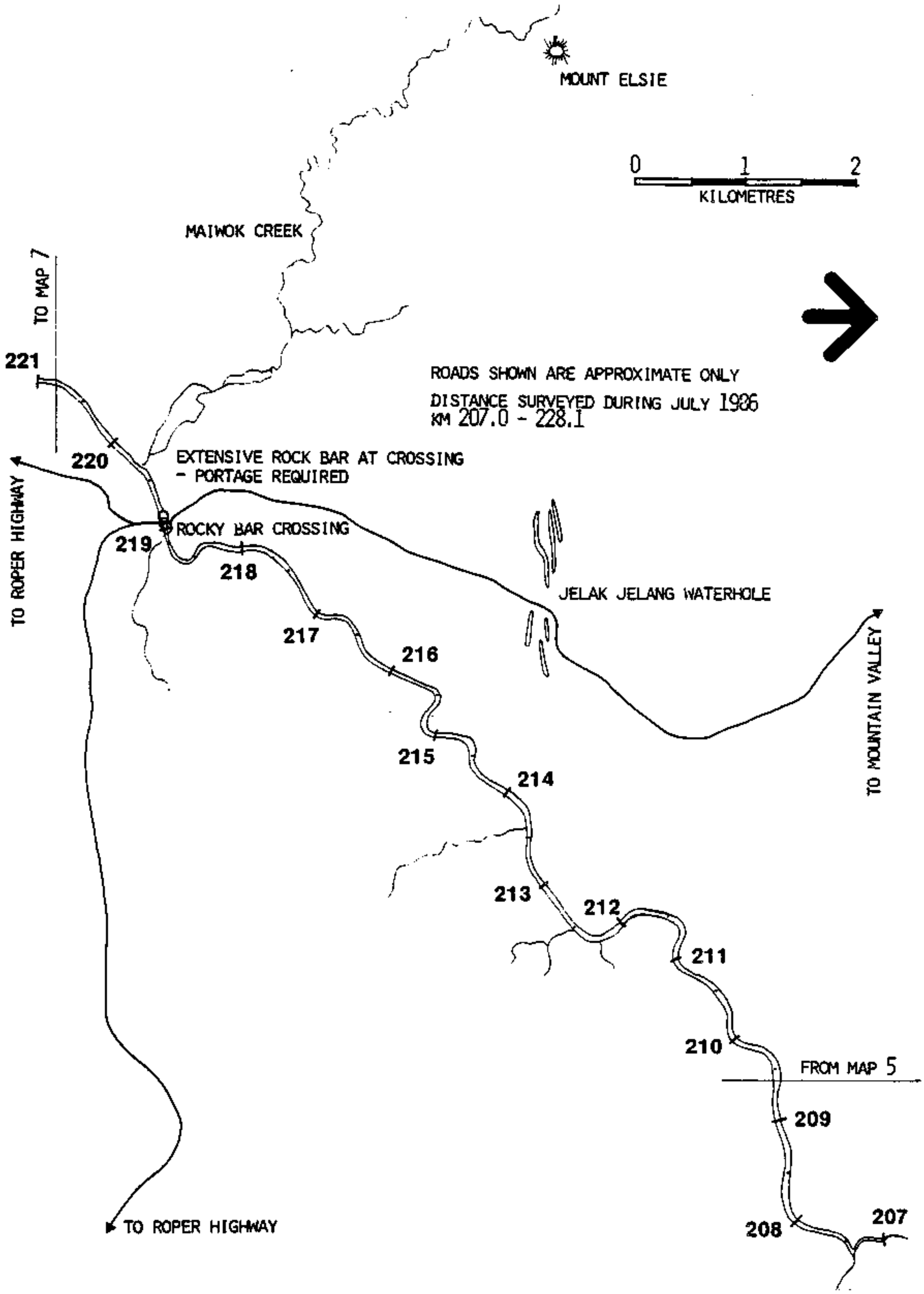

Figure 8. Upstream Roper River 6.

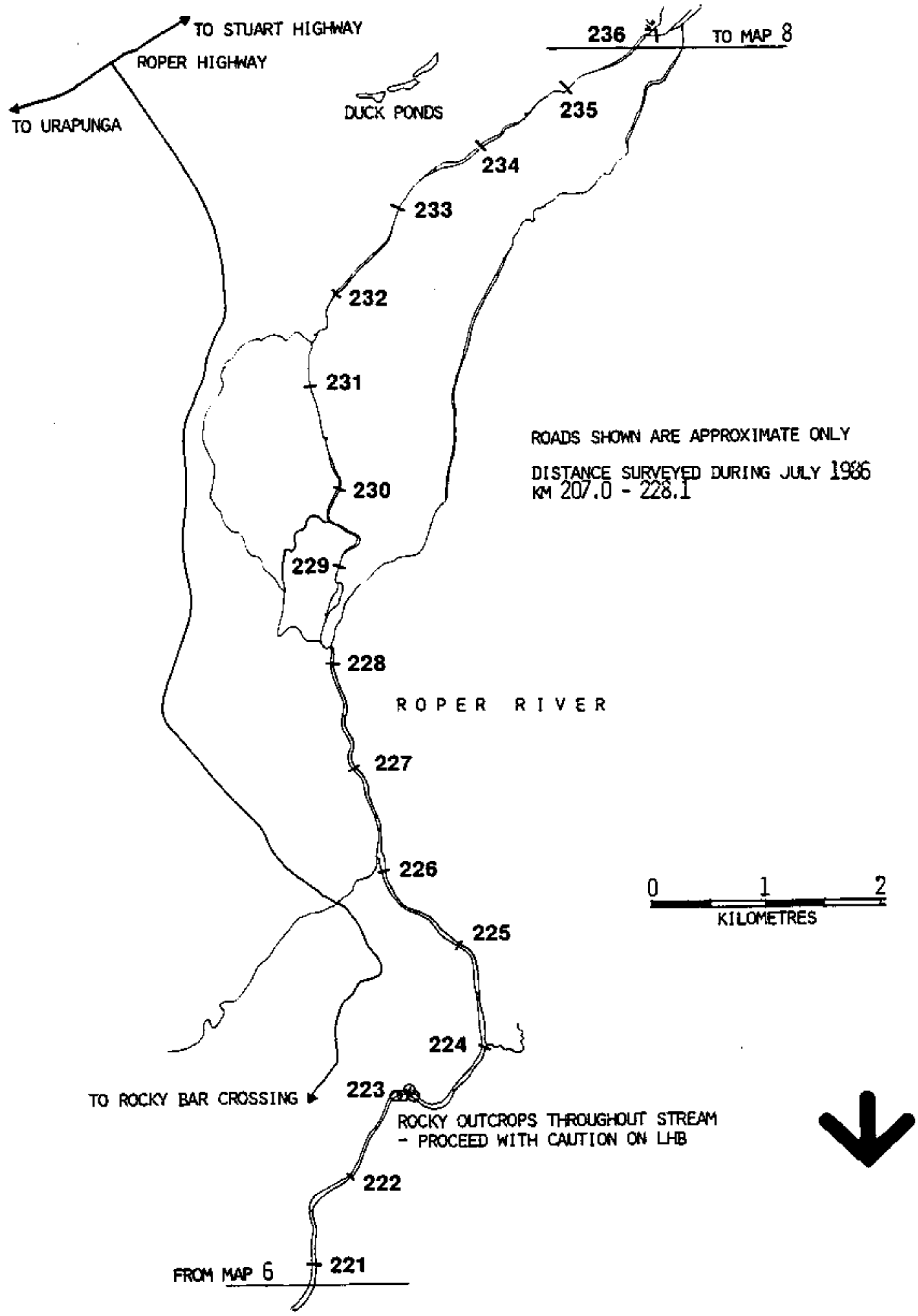

Figure 9. Upstream Roper River 7.

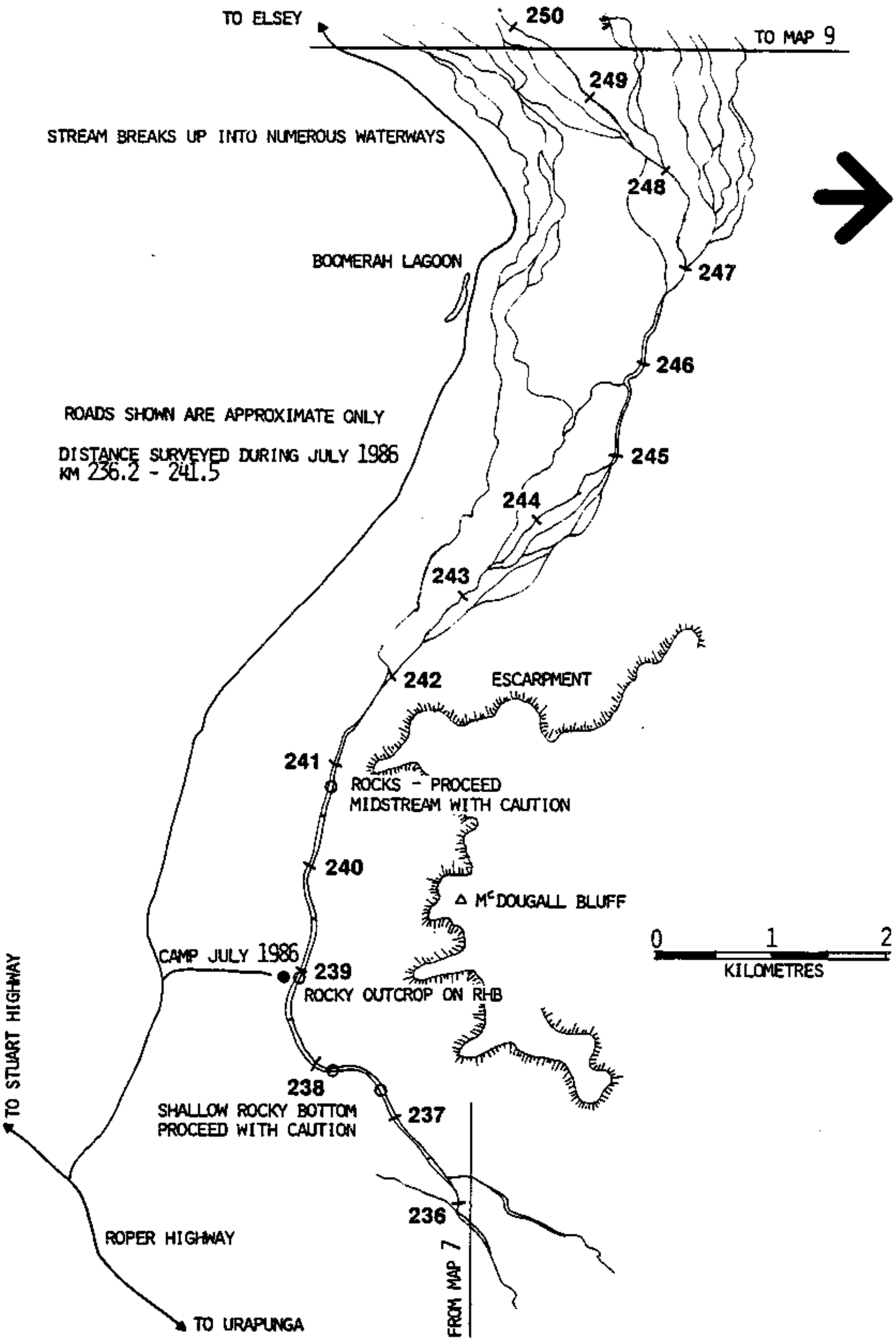

Figure 10. Upstream Roper River 8.

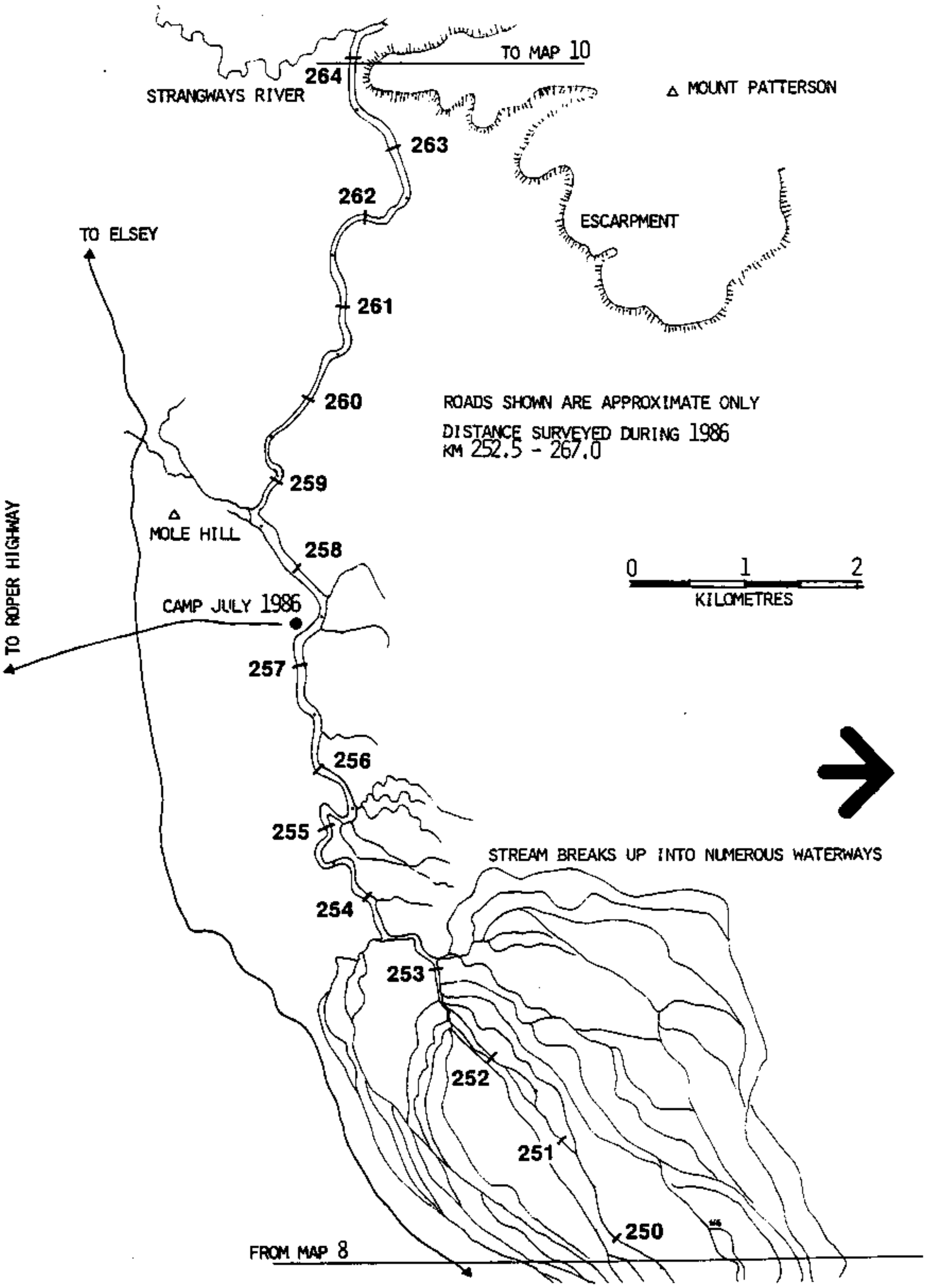

Figure 11. Upstream Roper River 9.

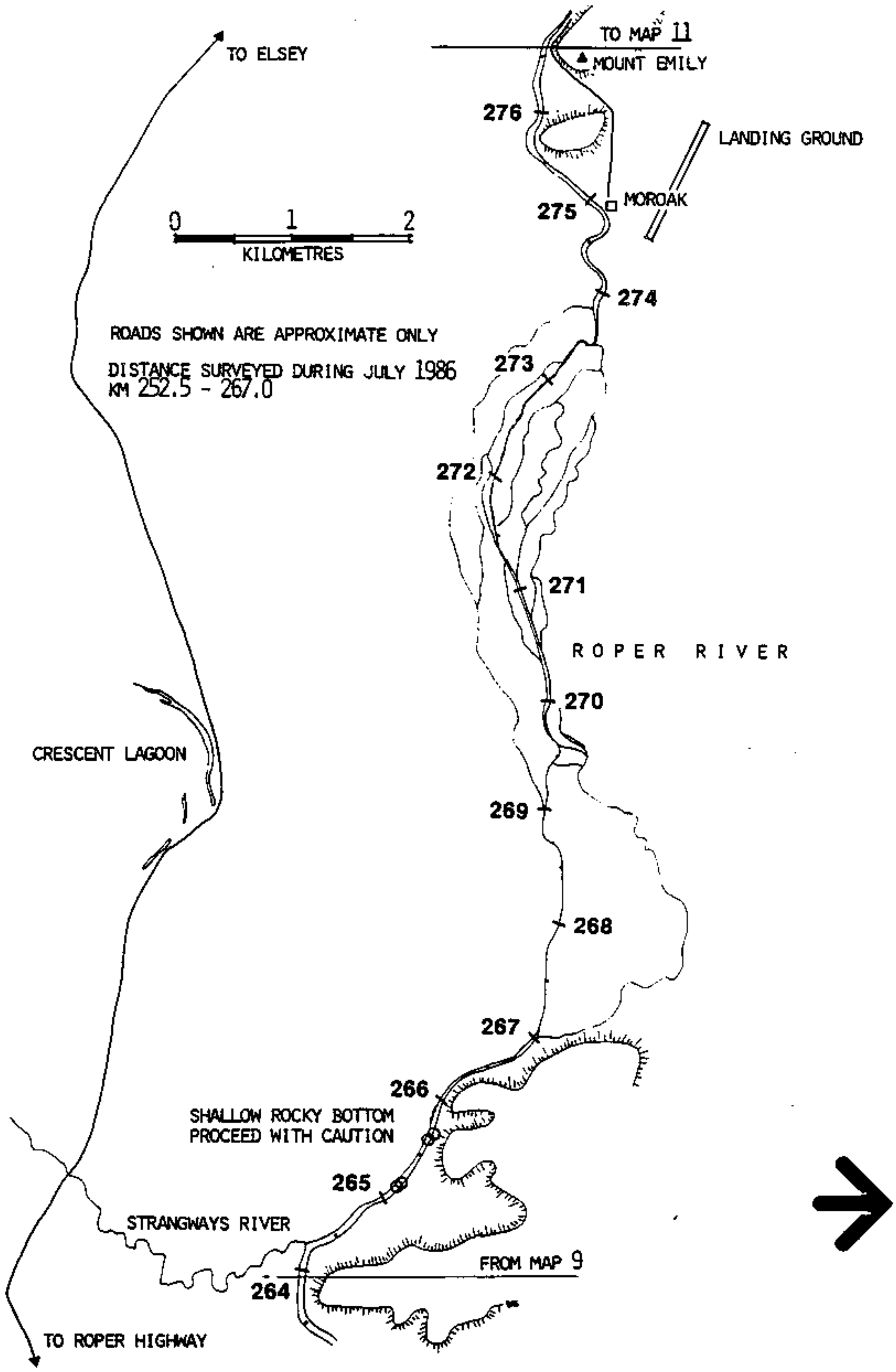

Figure 12. Upstream Roper River 10.

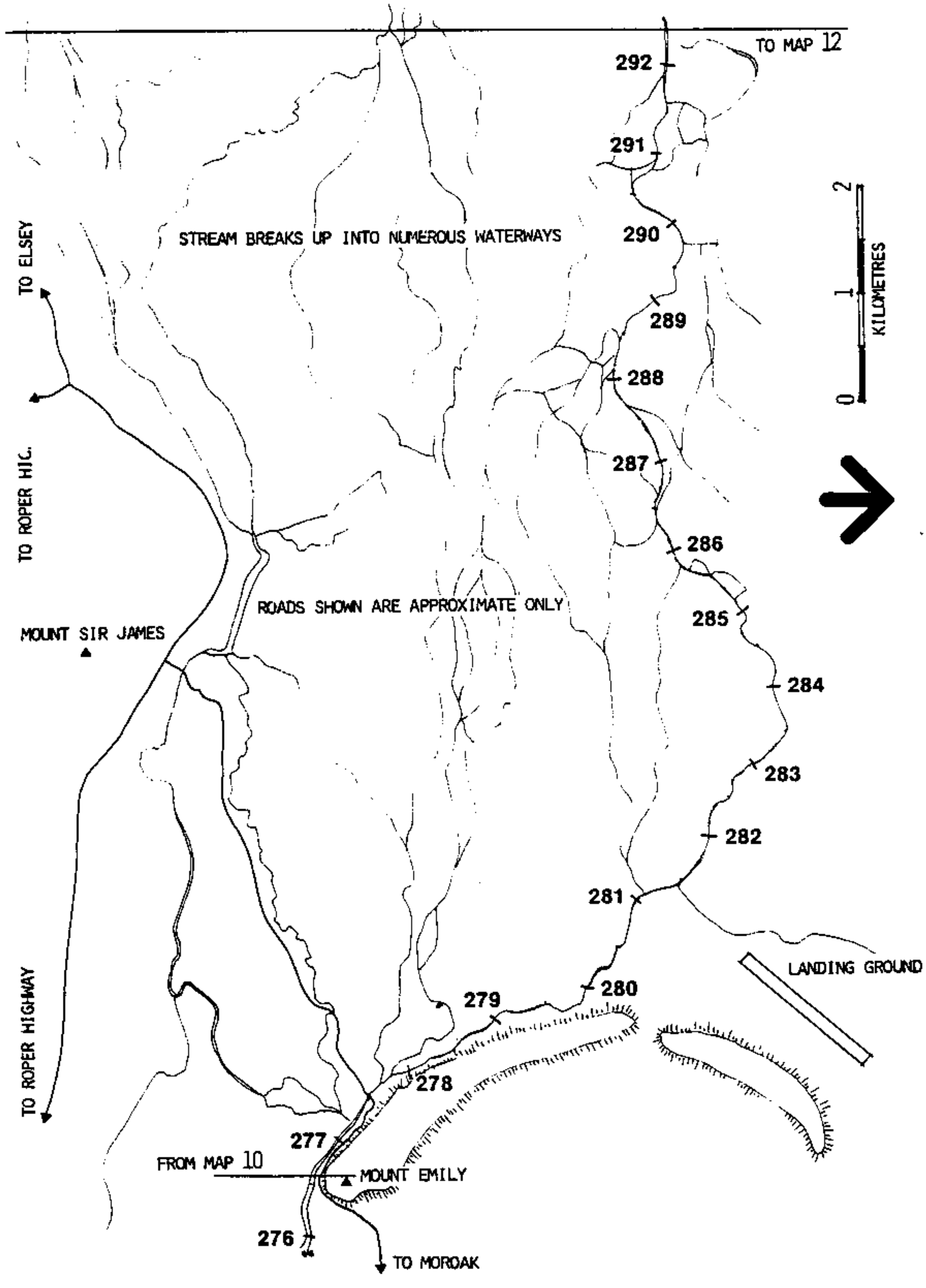

Figure 13. Upstream Roper River 11.

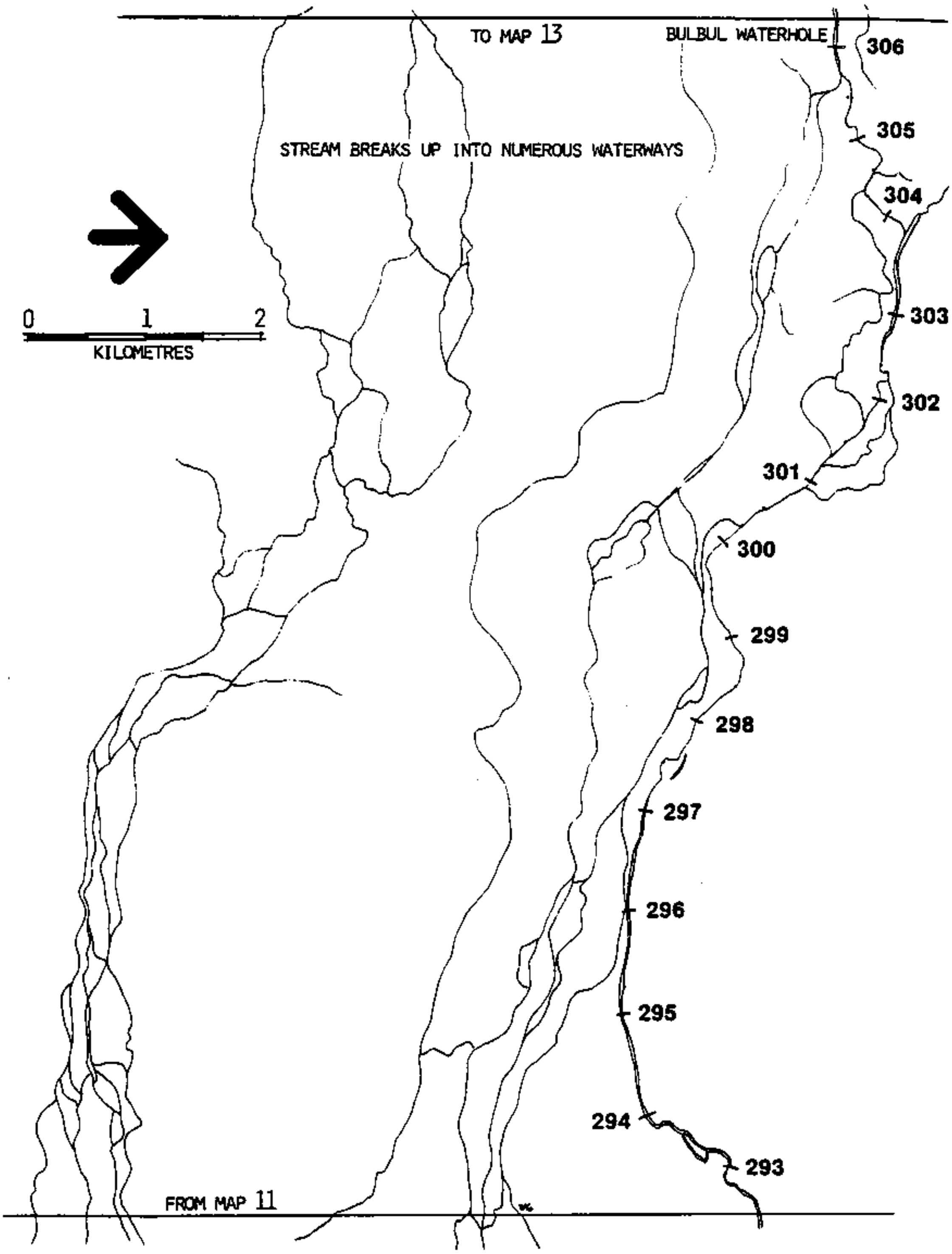

Figure 14. Upstream Roper River 12.

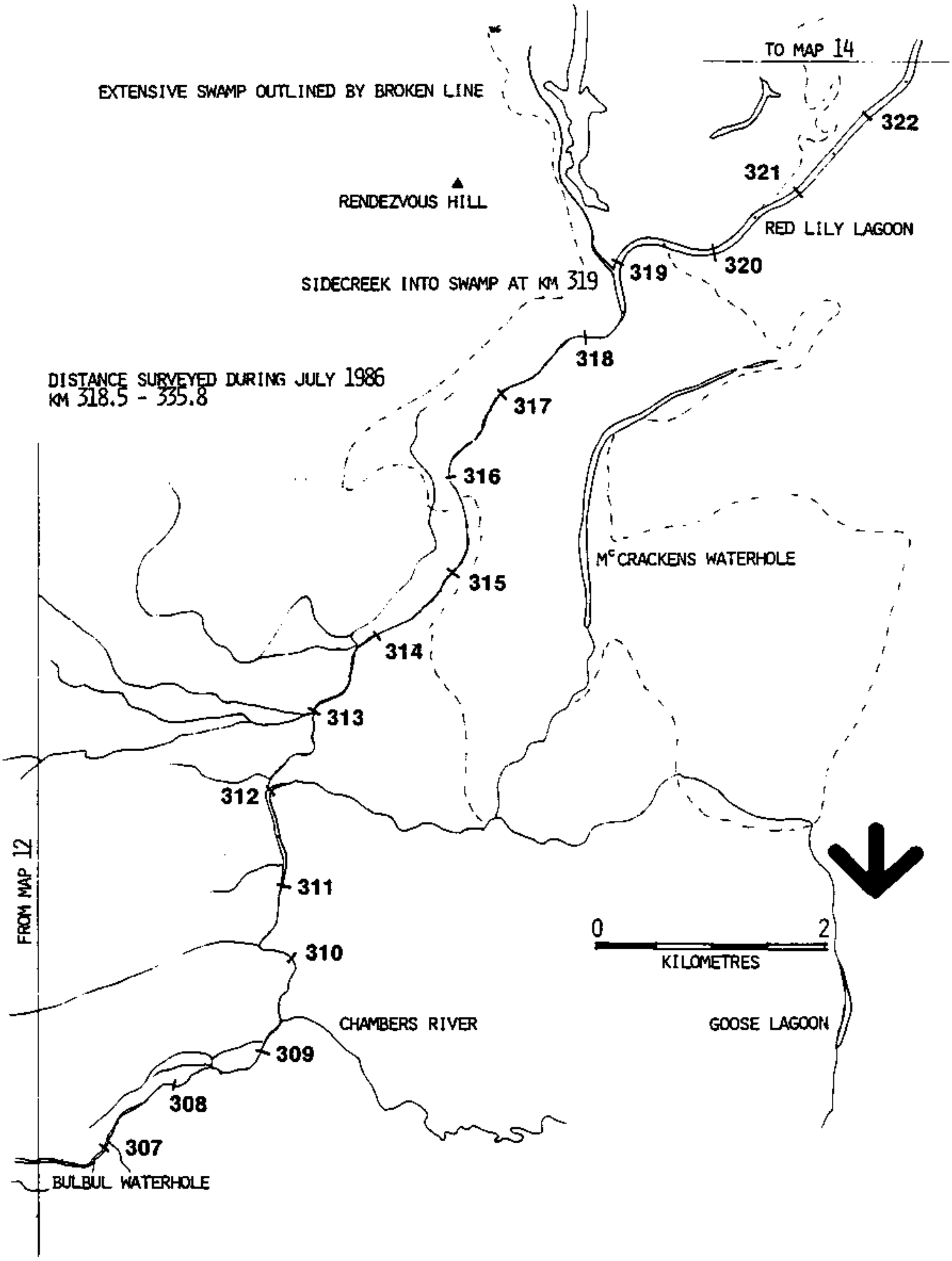

Figure 15. Upstream Roper River 13.

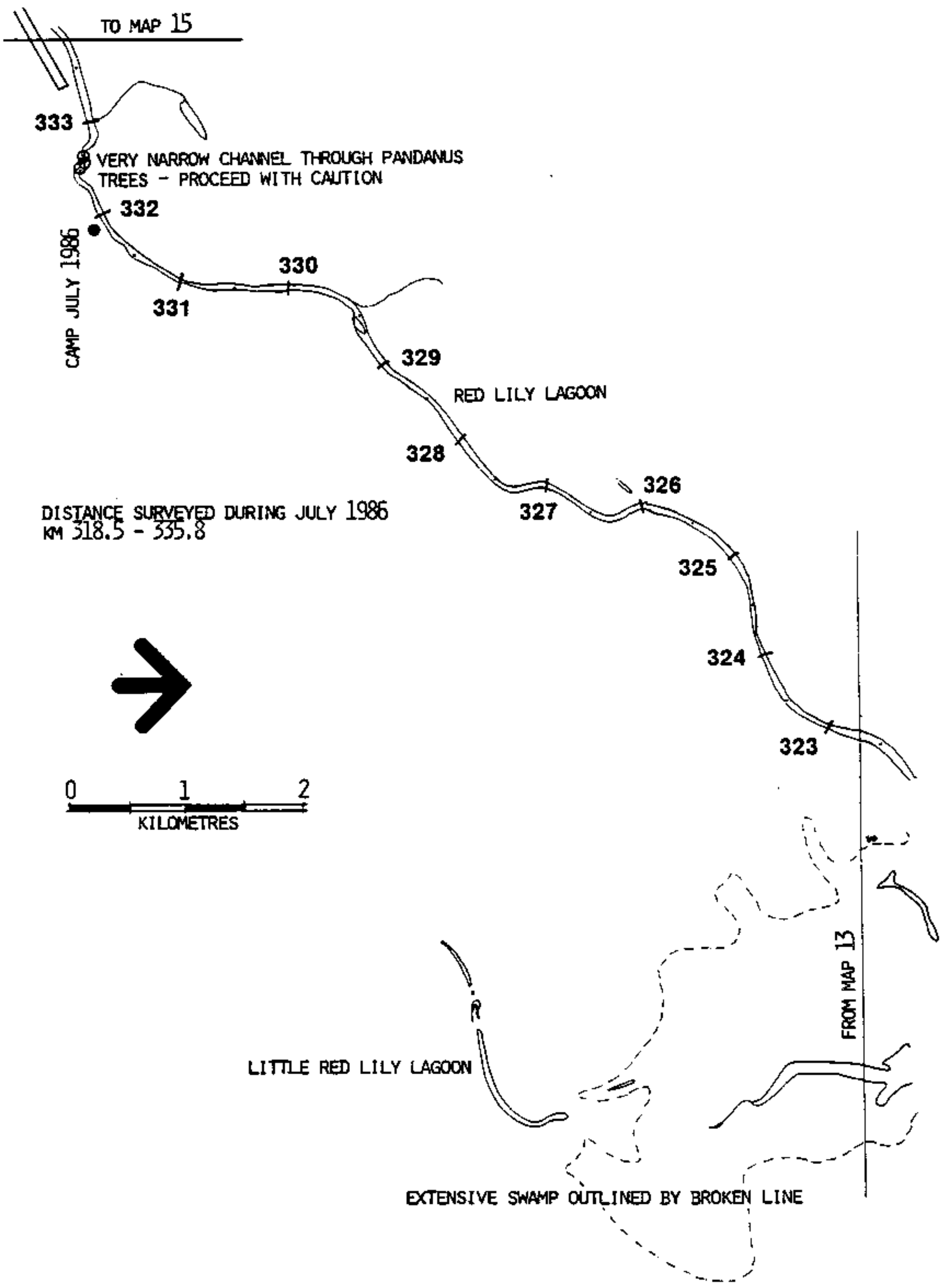

Figure 16. Upstream Roper River 14.

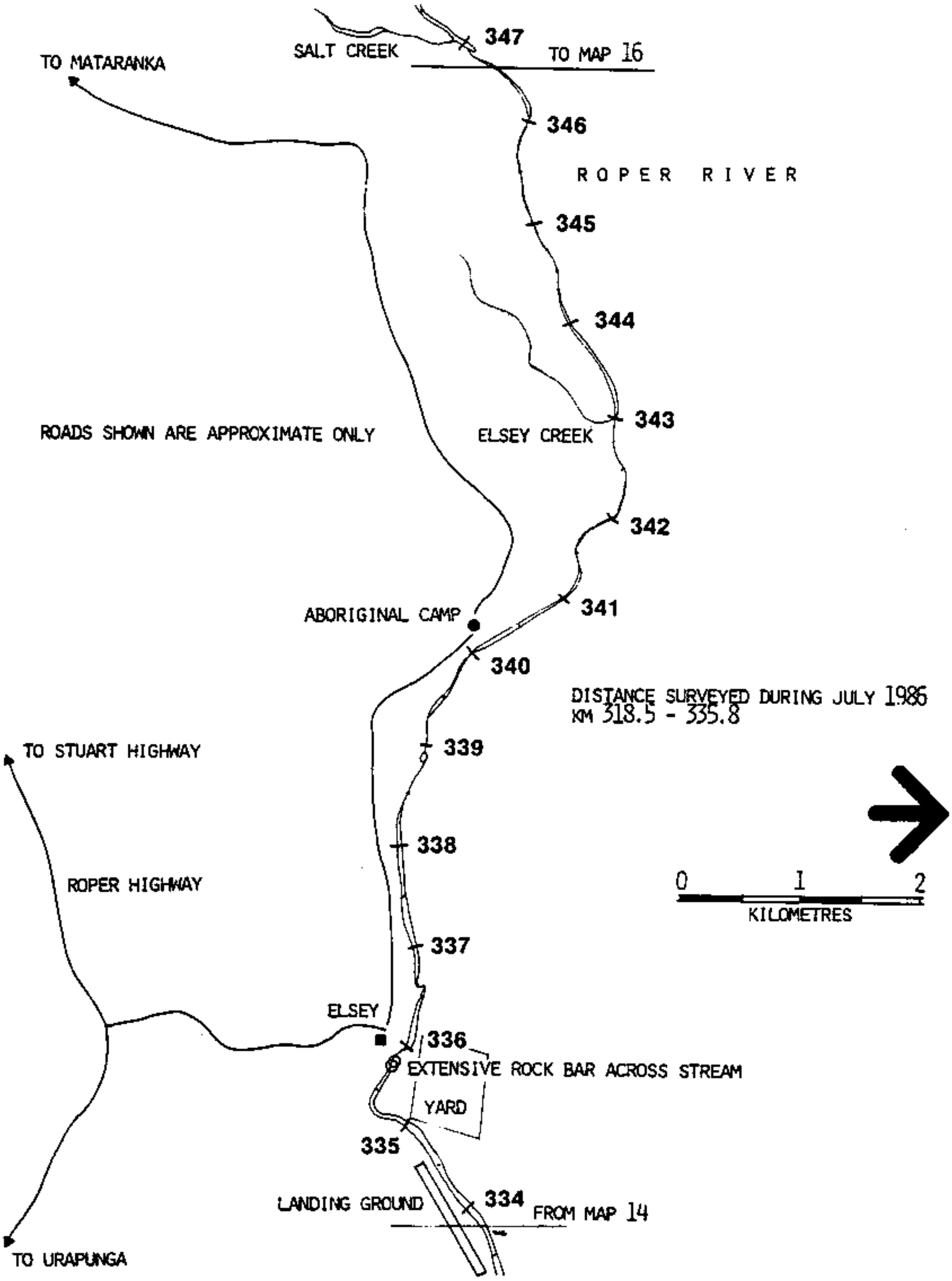

Figure 17. Upstream Roper River 15.

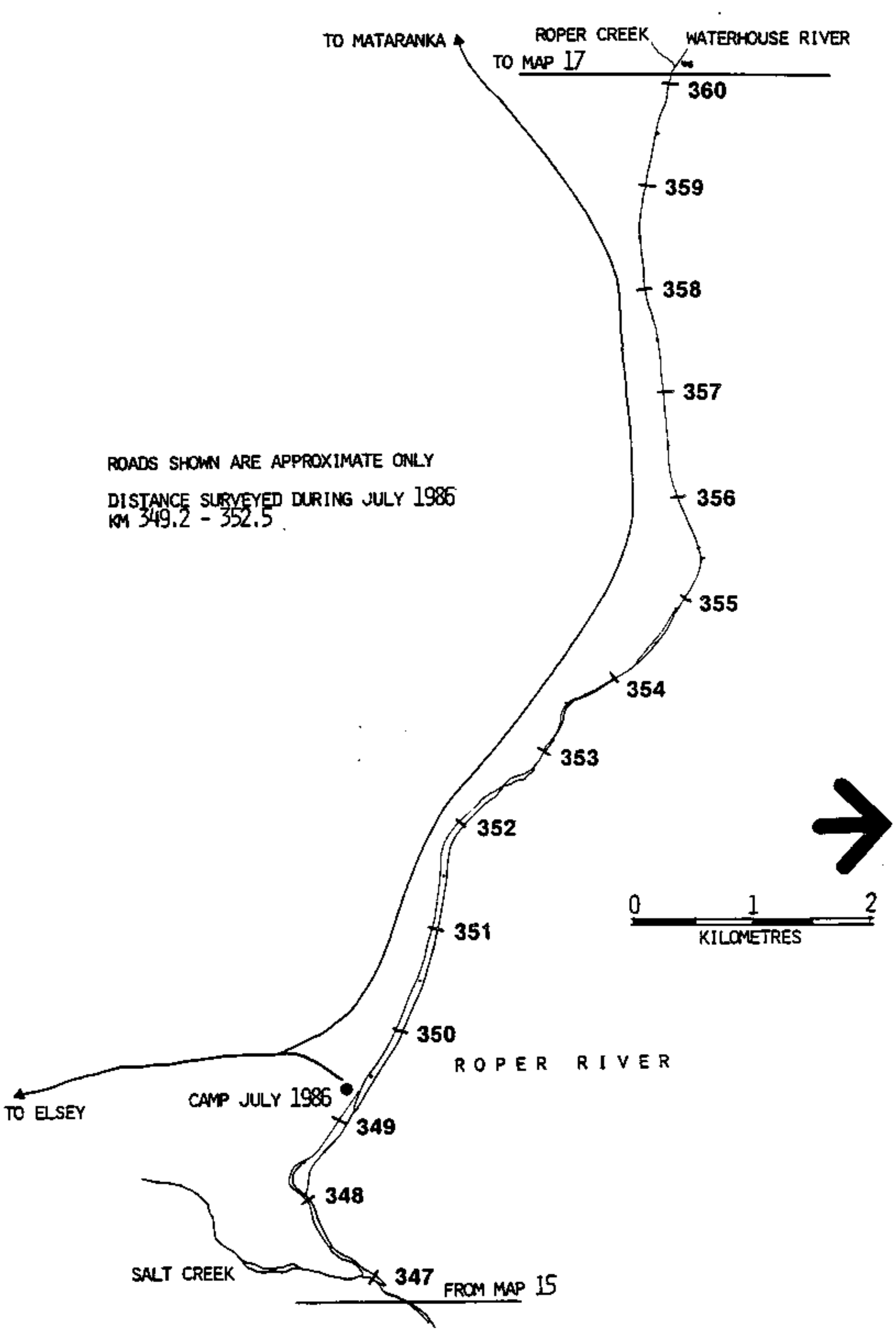

Figure 18. Upstream Roper River 16.

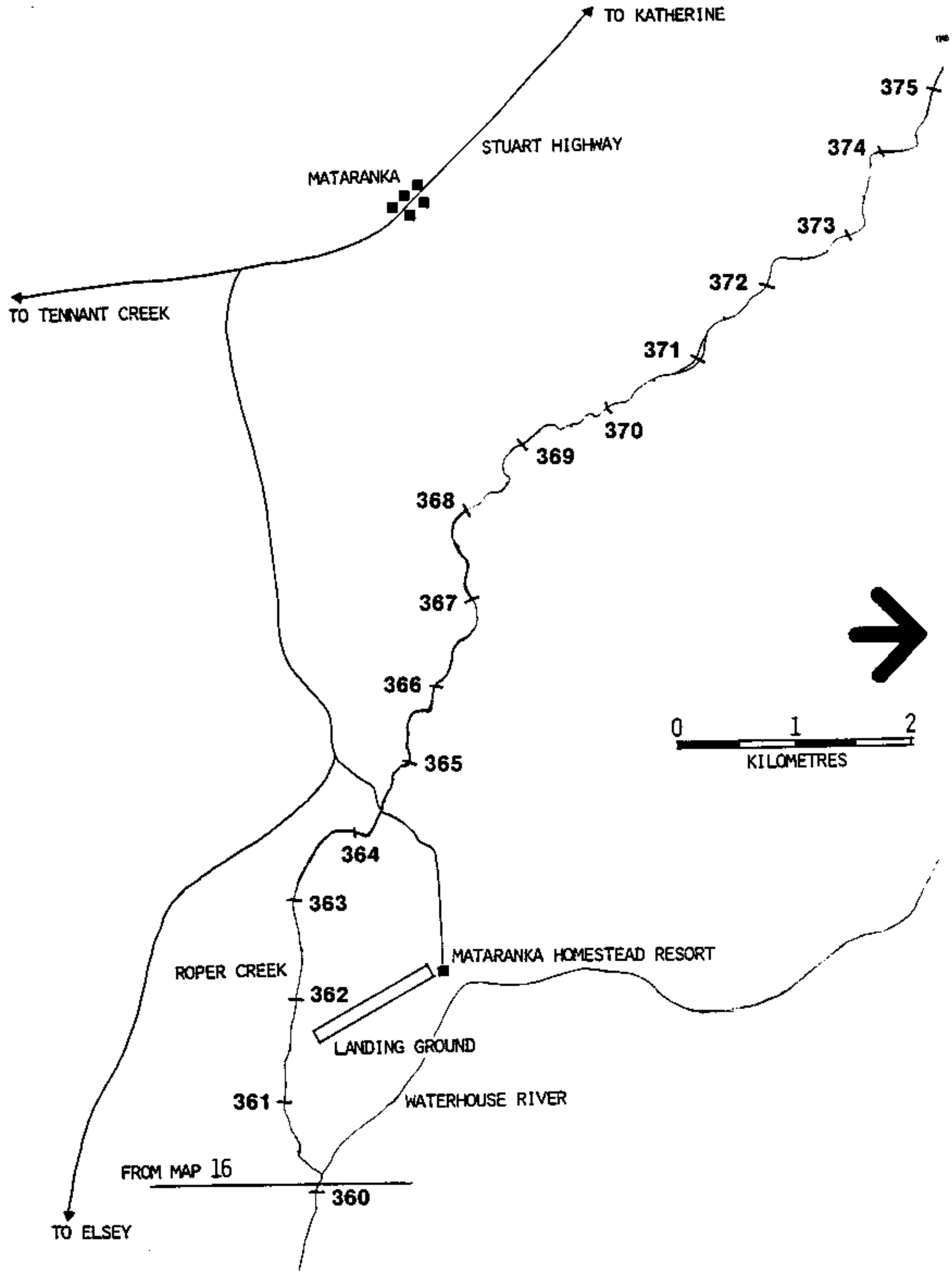

Figure 19. Upstream Roper River 17.

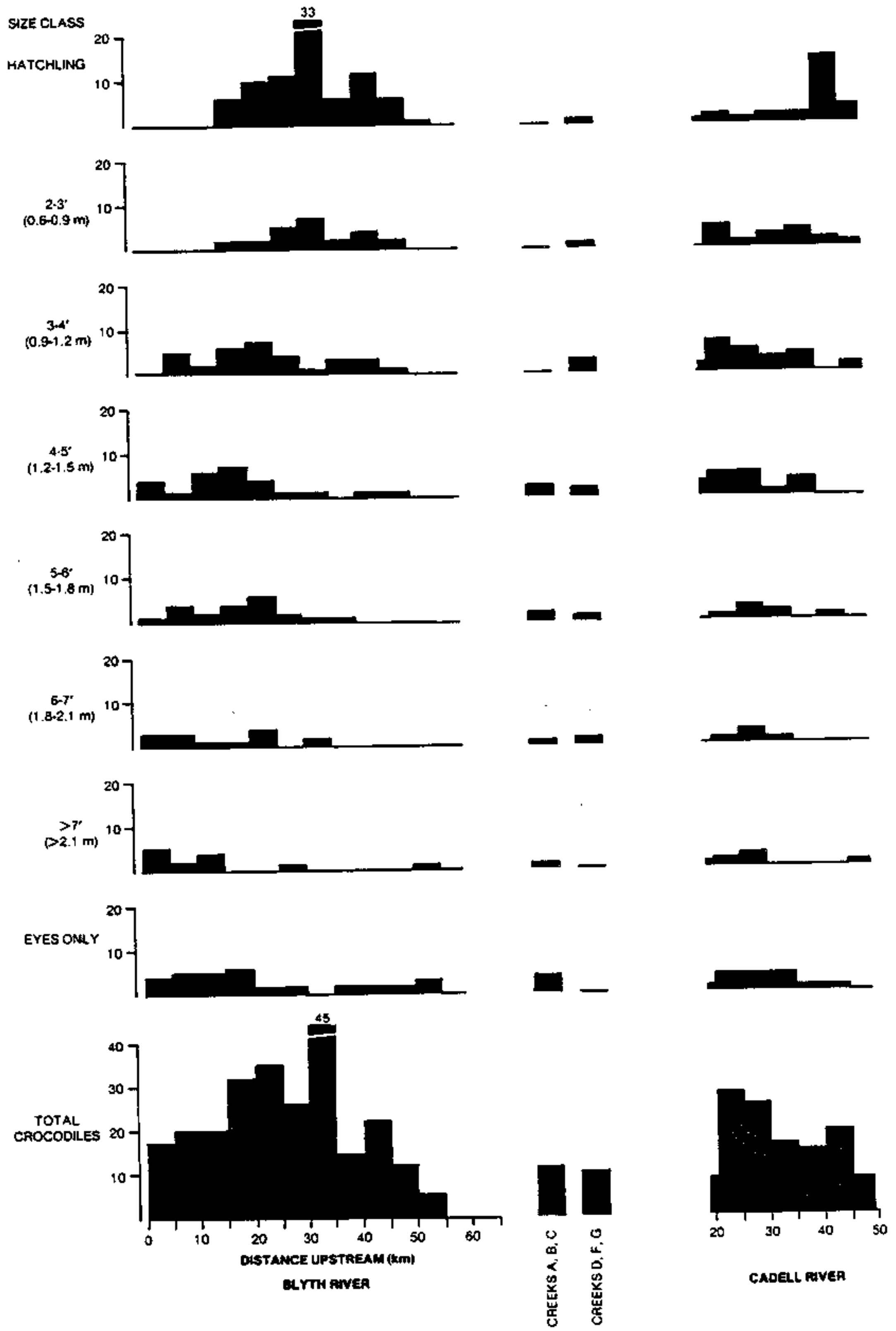

Figure 20. Distributional pattern of *Crocodylus porosus* in the Blyth-Cadell Rivers System during 25-28 June 1982 (from p. 175 Monograph 18).

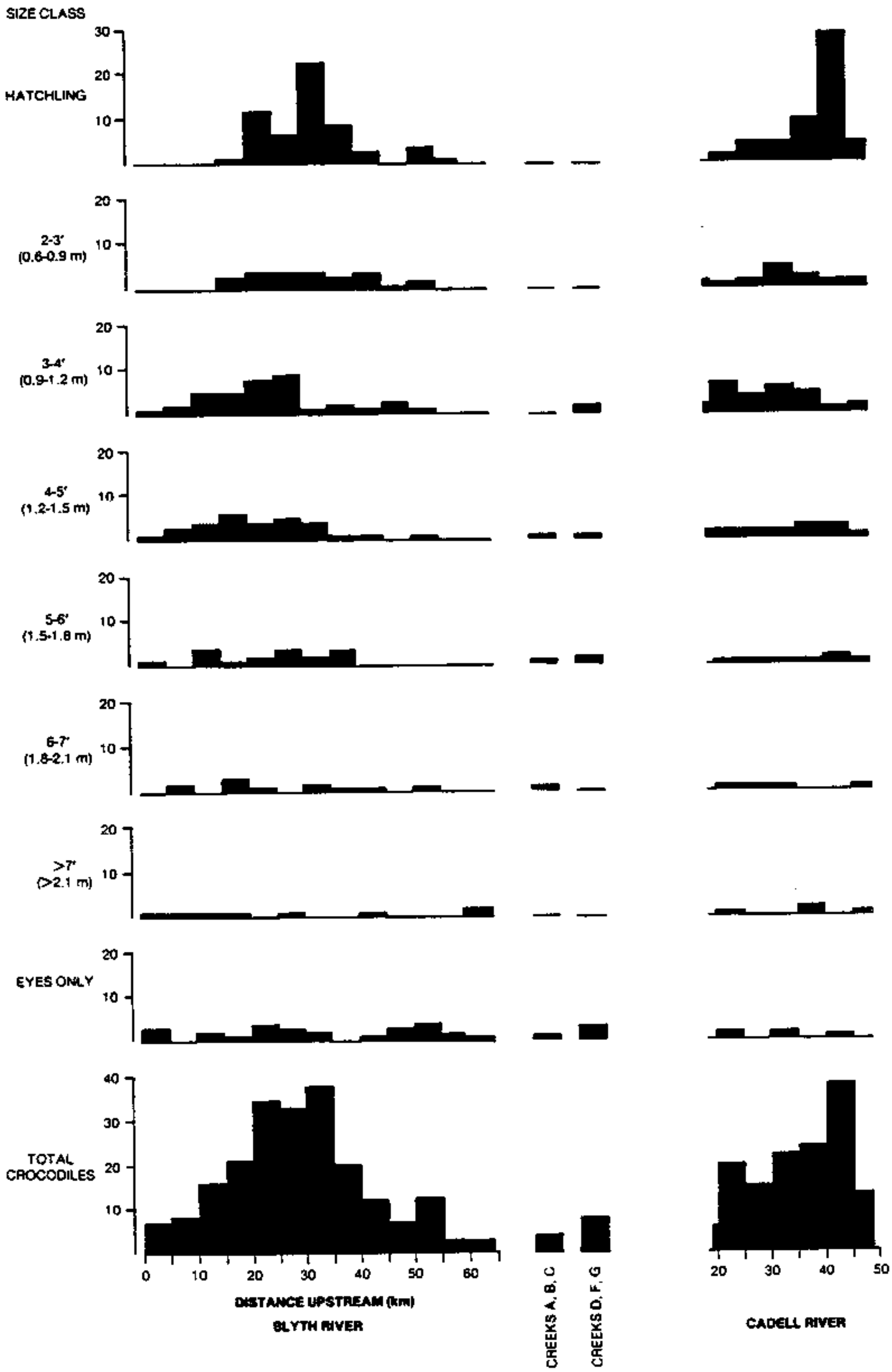

Figure 21. Distributional pattern of *Crocodylus porosus* in the Blyth-Cadell Rivers System during 6-8 November 1982 (from p. 176 Monograph 18).

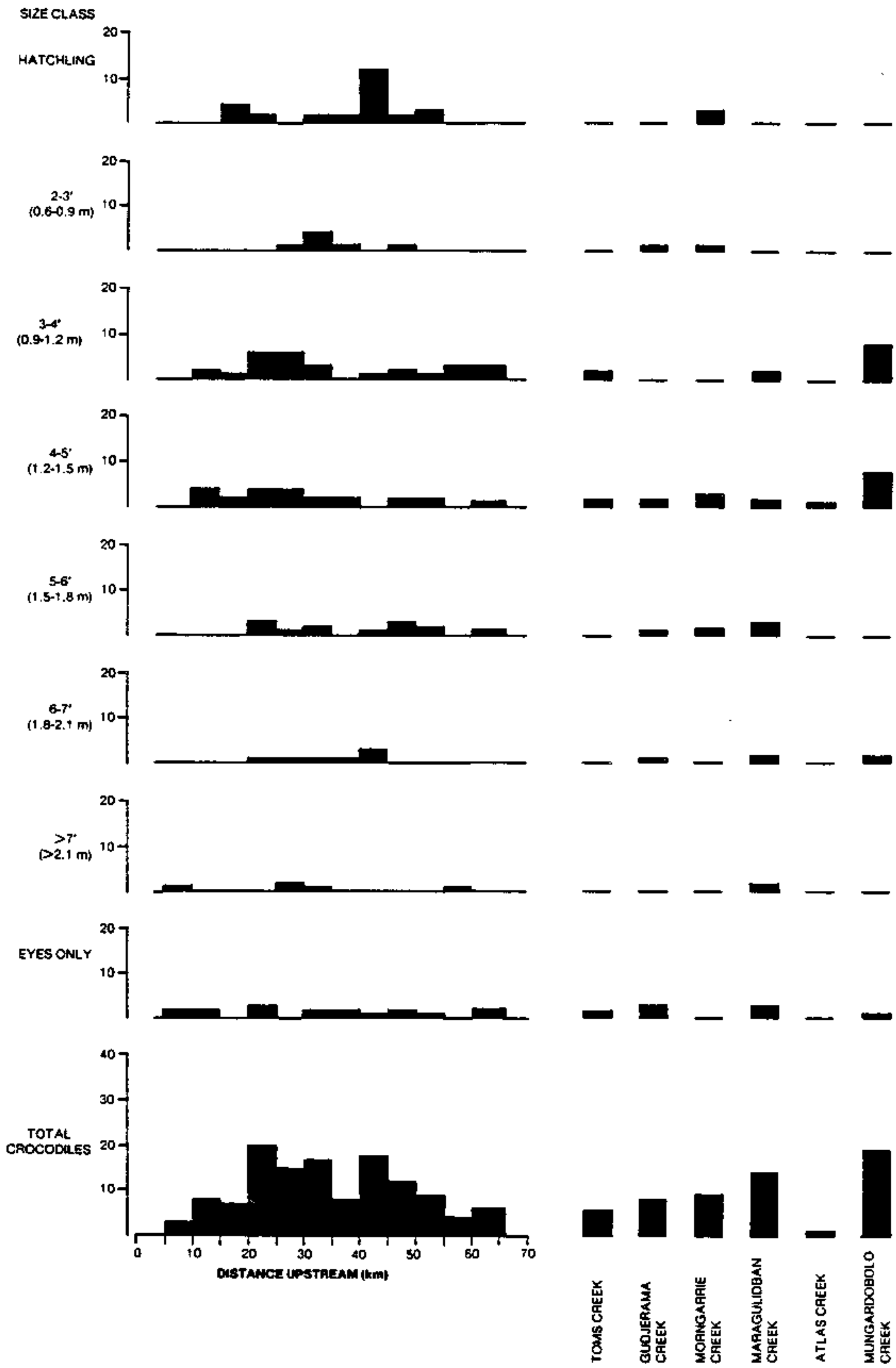

Figure 22. Distributional pattern of *Crocodylus porosus* on the Liverpool River and its creeks in July 1983 (from p. 286 Monograph 18); the distance scale has been corrected here as it was shown incorrectly in Monograph 18.

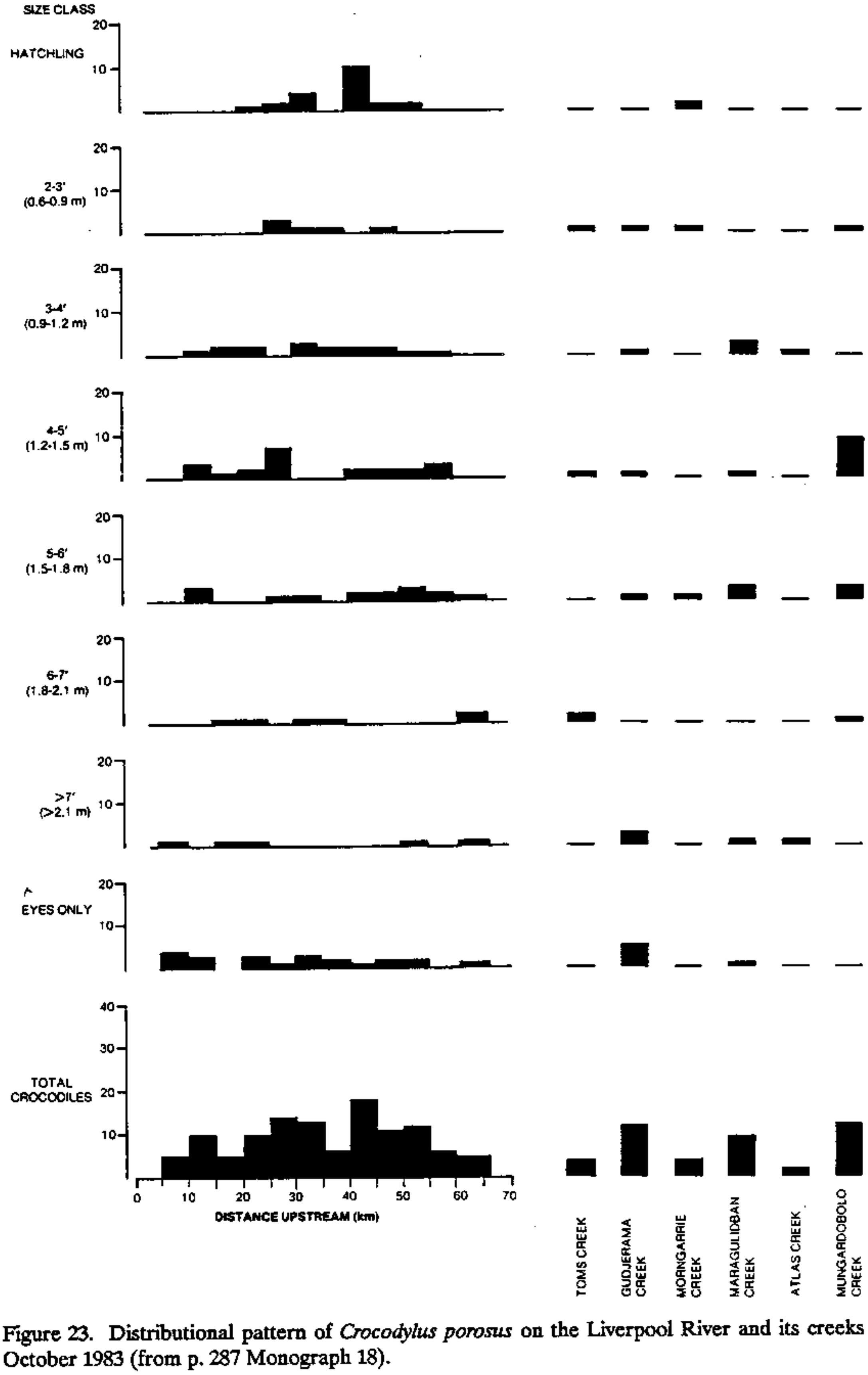

Figure 23. Distributional pattern of *Crocodylus porosus* on the Liverpool River and its creeks in October 1983 (from p. 287 Monograph 18).

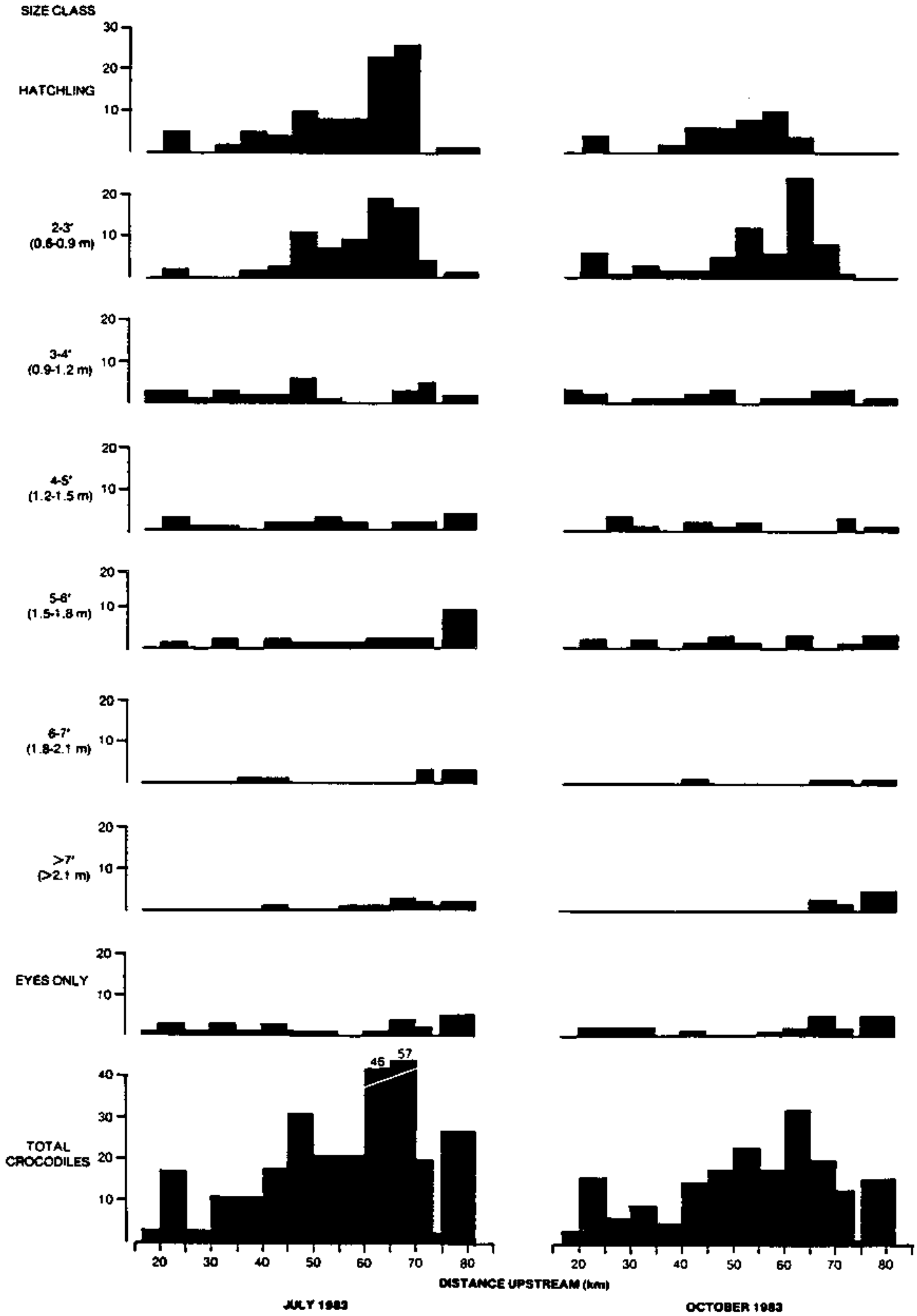

Figure 24. Distributional pattern of *Crocodylus porosus* on the Tomkinson River in July and October 1983 (from p. 288 Monograph 18).

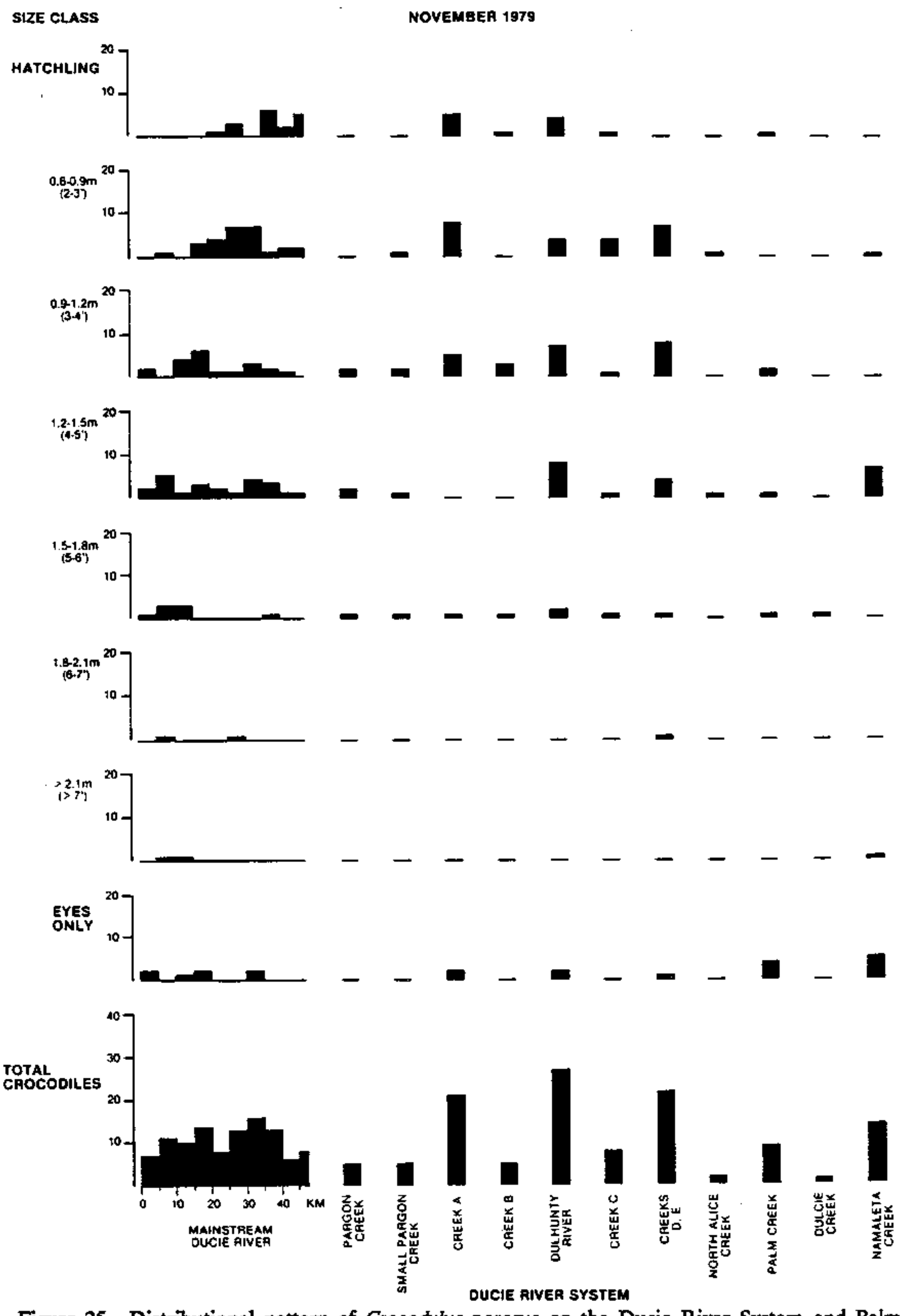

Figure 25. Distributional pattern of *Crocodylus porosus* on the Ducie River System and Palm, Dulcie, and Namaleta Creeks in Port Musgrave in November 1979 (from p. 90 Monograph 16).

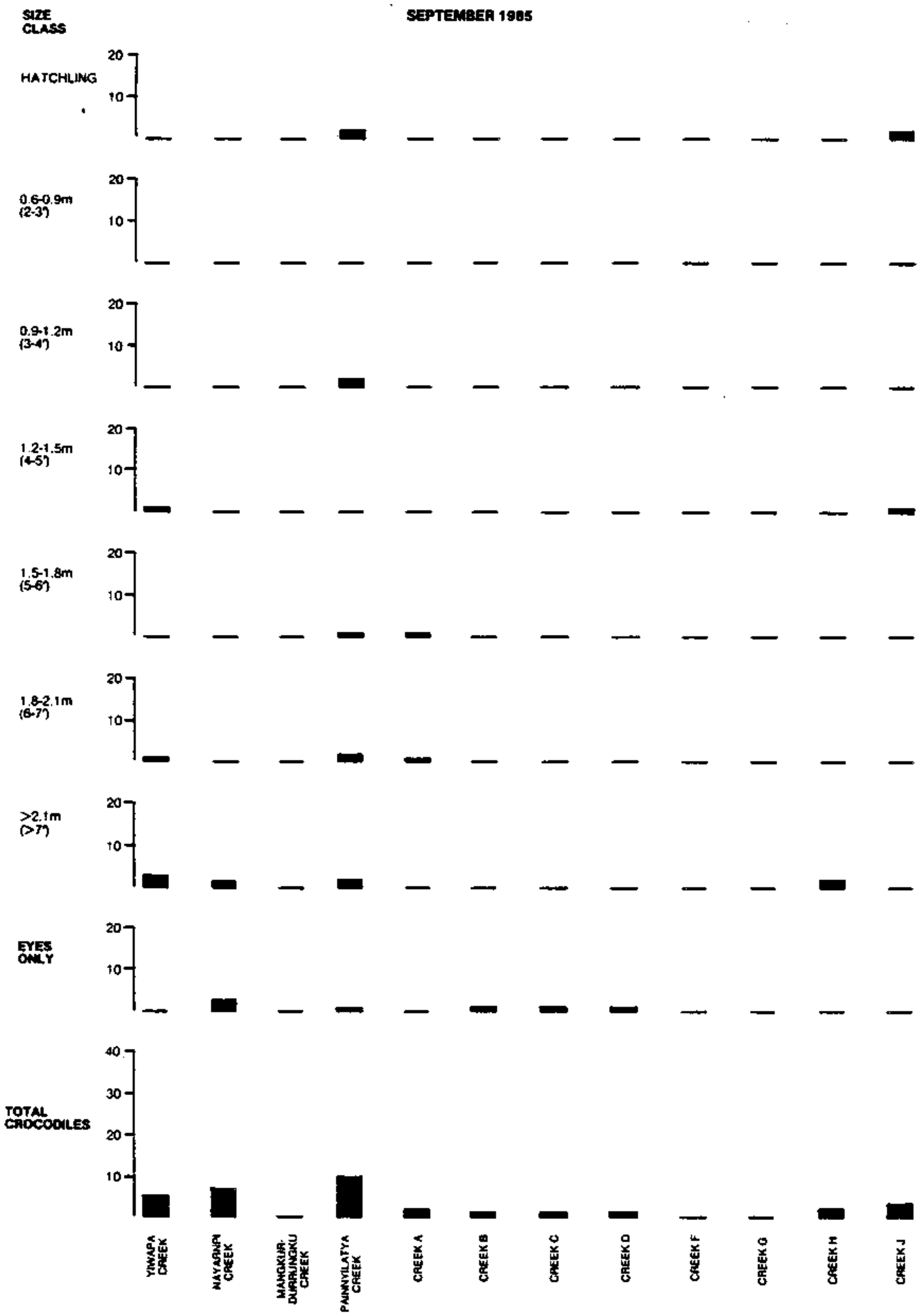

Figure 26. Distributional pattern of *Crocodylus porosus* on the coastal saltwater creeks and on the small creeks of the Roper River mainstream, downstream of km 25.0, in September 1985 (from p. 117 Monograph 19).

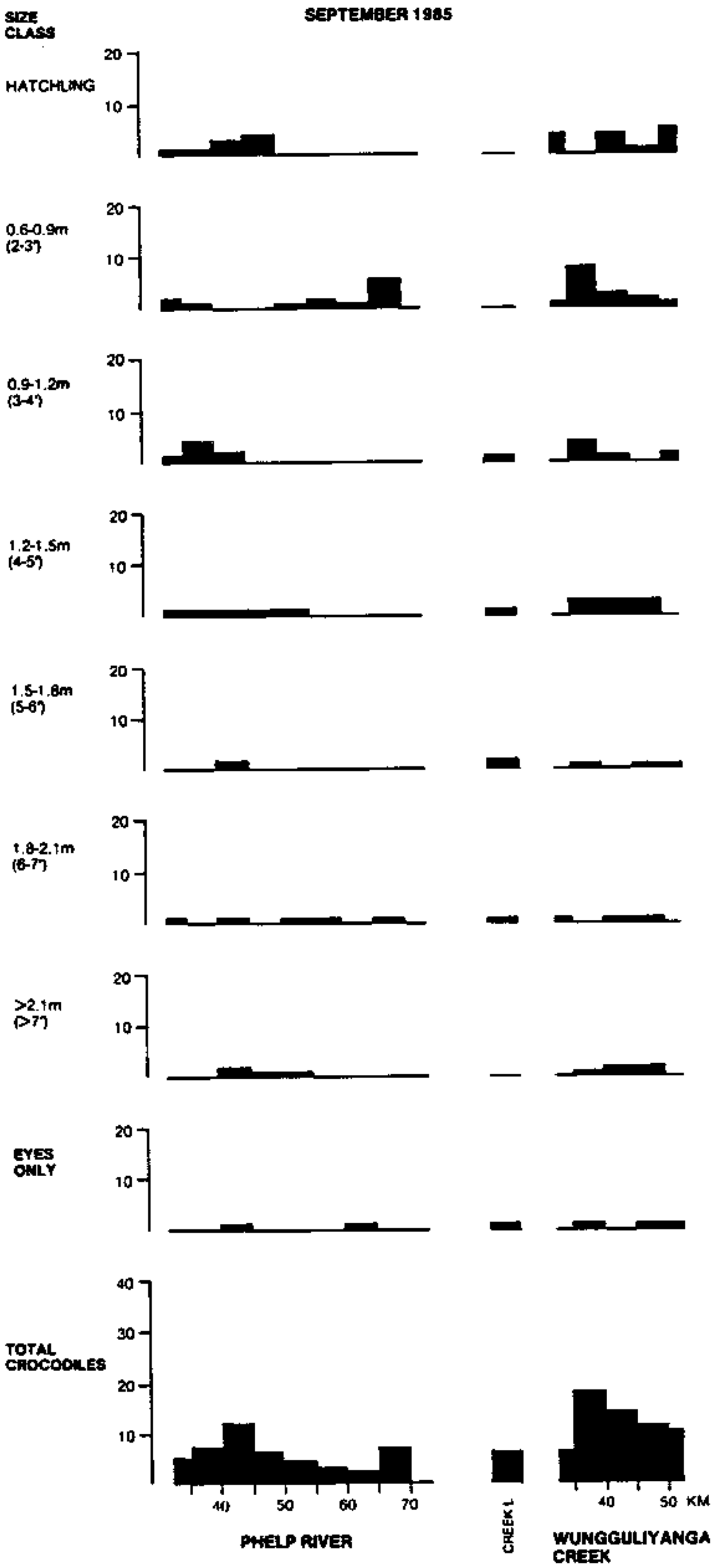

Figure 27. Distributional pattern of *Crocodylus porosus* on the Phelp River and Wungguliyanga Creek in September 1985 (from p. 118 Monograph 19).

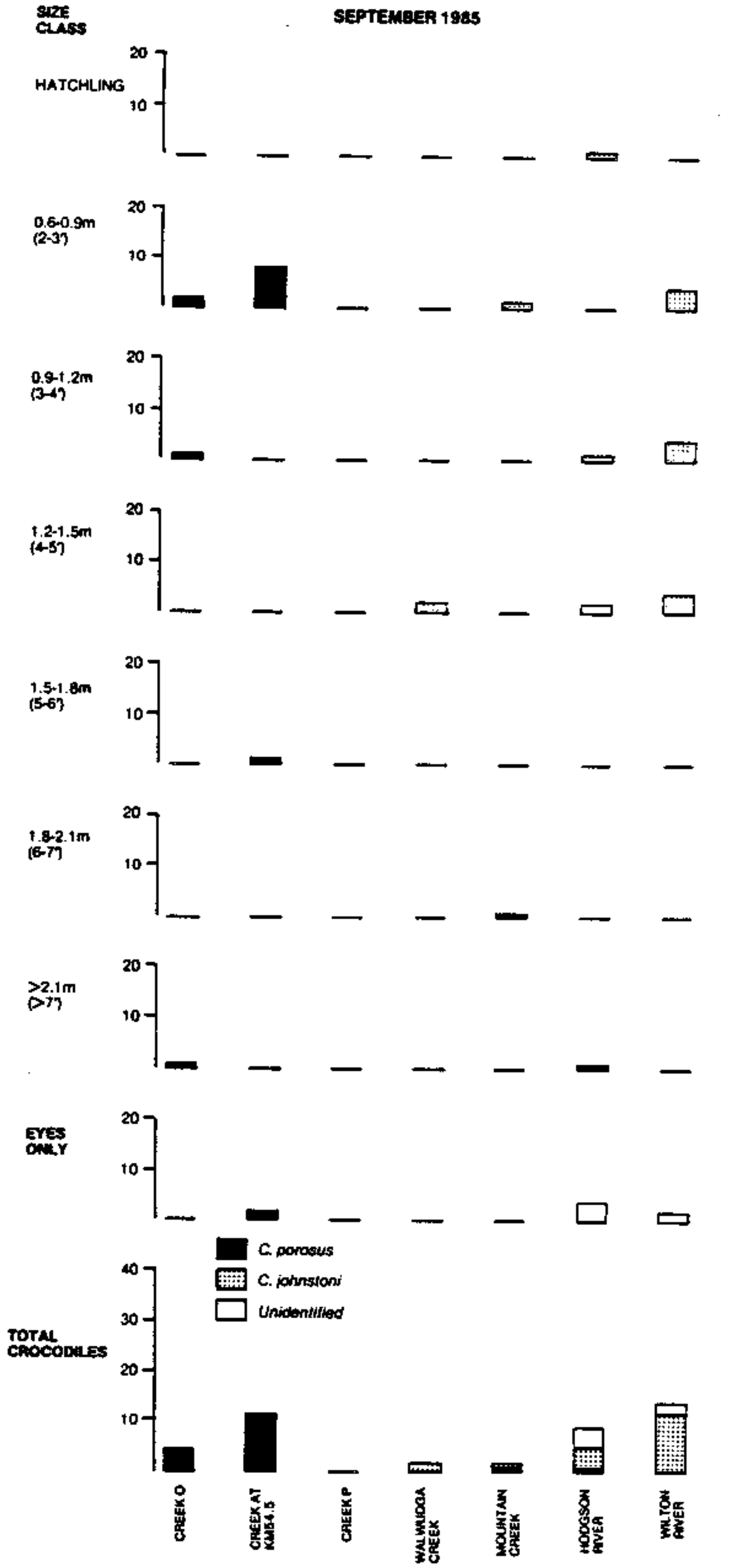

Figure 28. Distributional pattern of *Crocodylus porosus* and *C. johnstoni* on the Wilton and Hodgson Rivers and on the small creeks of the Roper River mainstream, upstream of km 25.0, in September 1985 (from p. 119 Monograph 19).

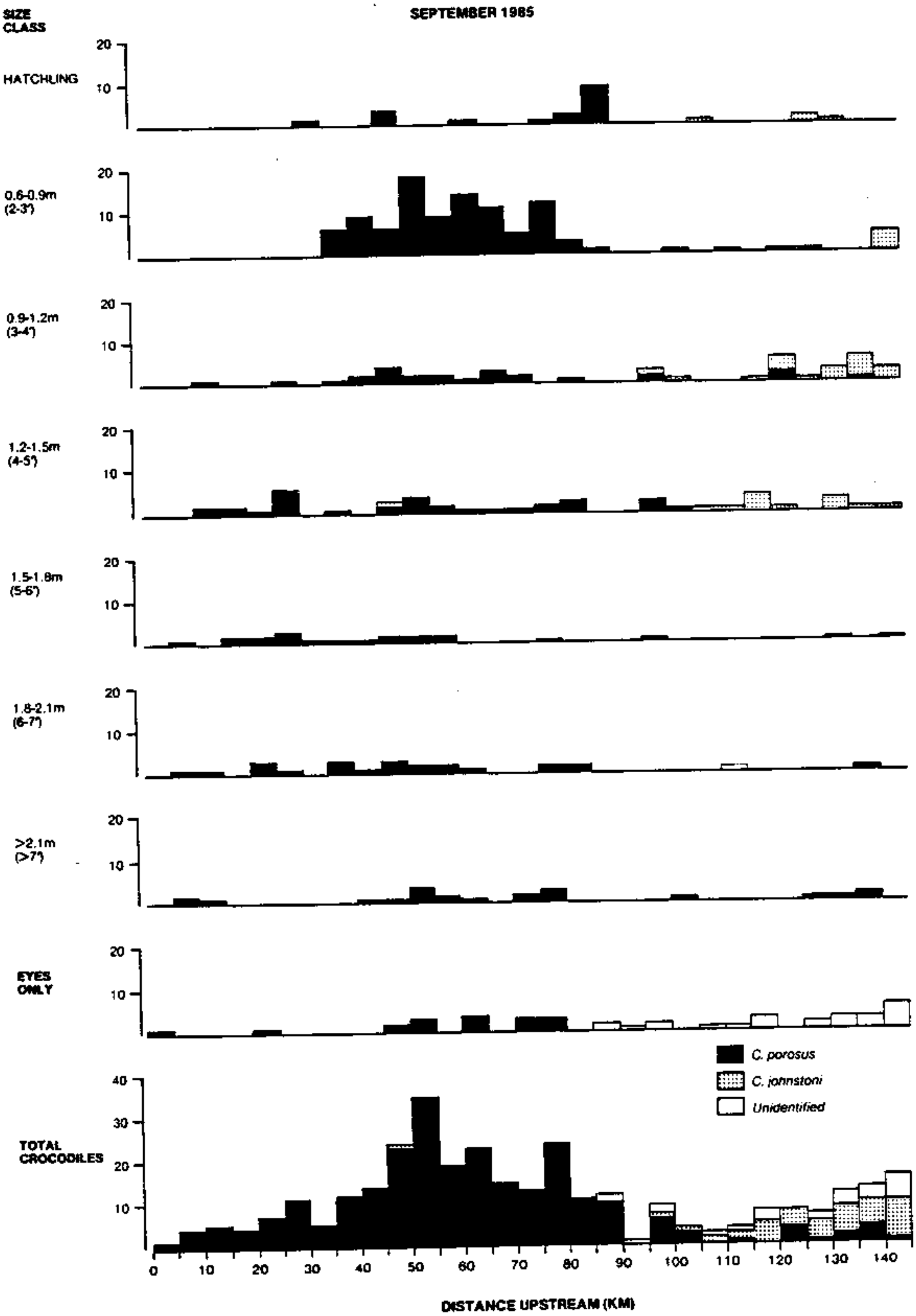

Figure 29. Distributional pattern of *Crocodylus porosus* and *C. johnstoni* on the Roper River mainstream in September 1985 (from p. 116 Monograph 19).

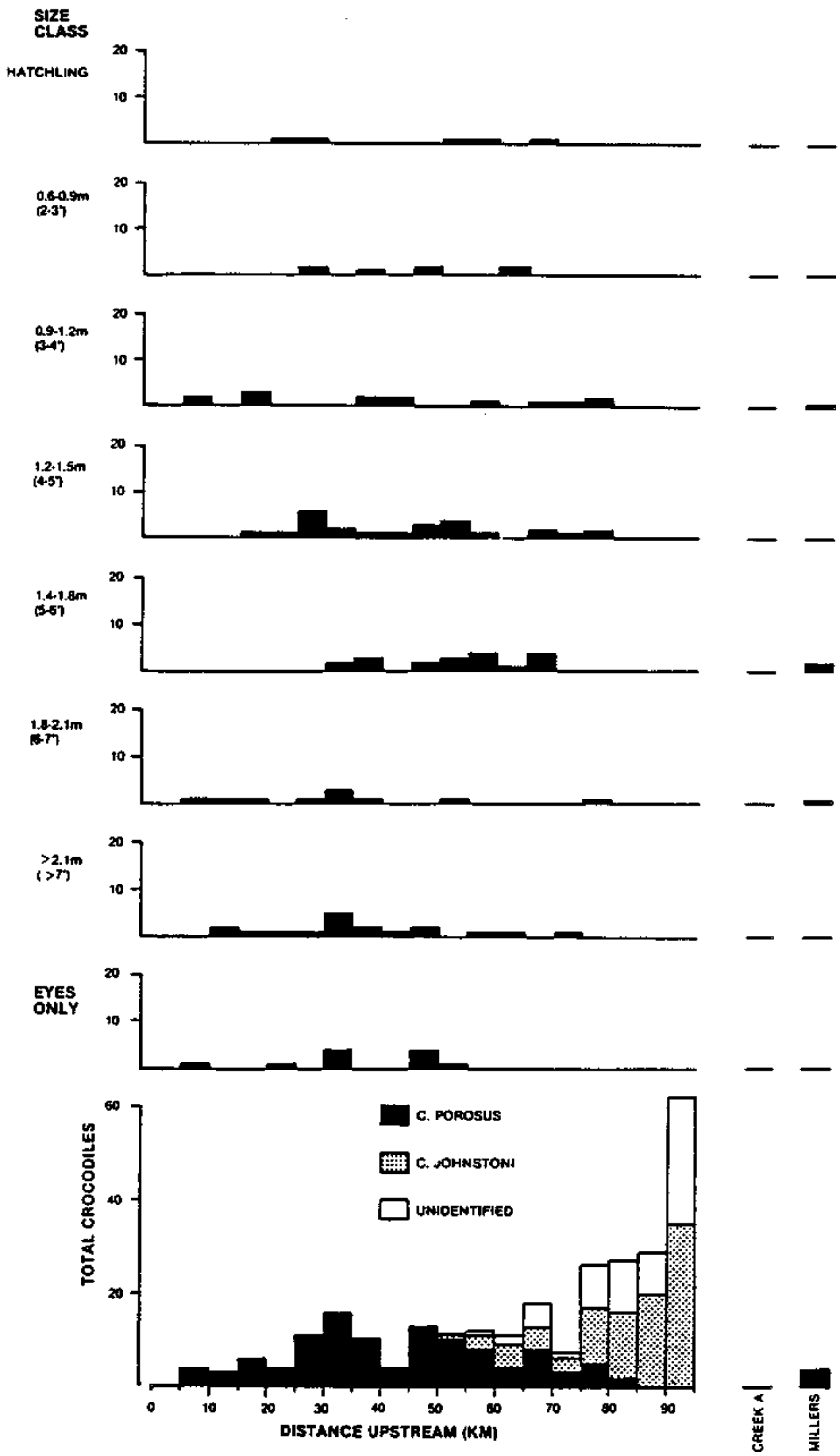

Figure 30. Distributional pattern of crocodiles on the Daly River System in August 1978 (from p. 51 Monograph 3).

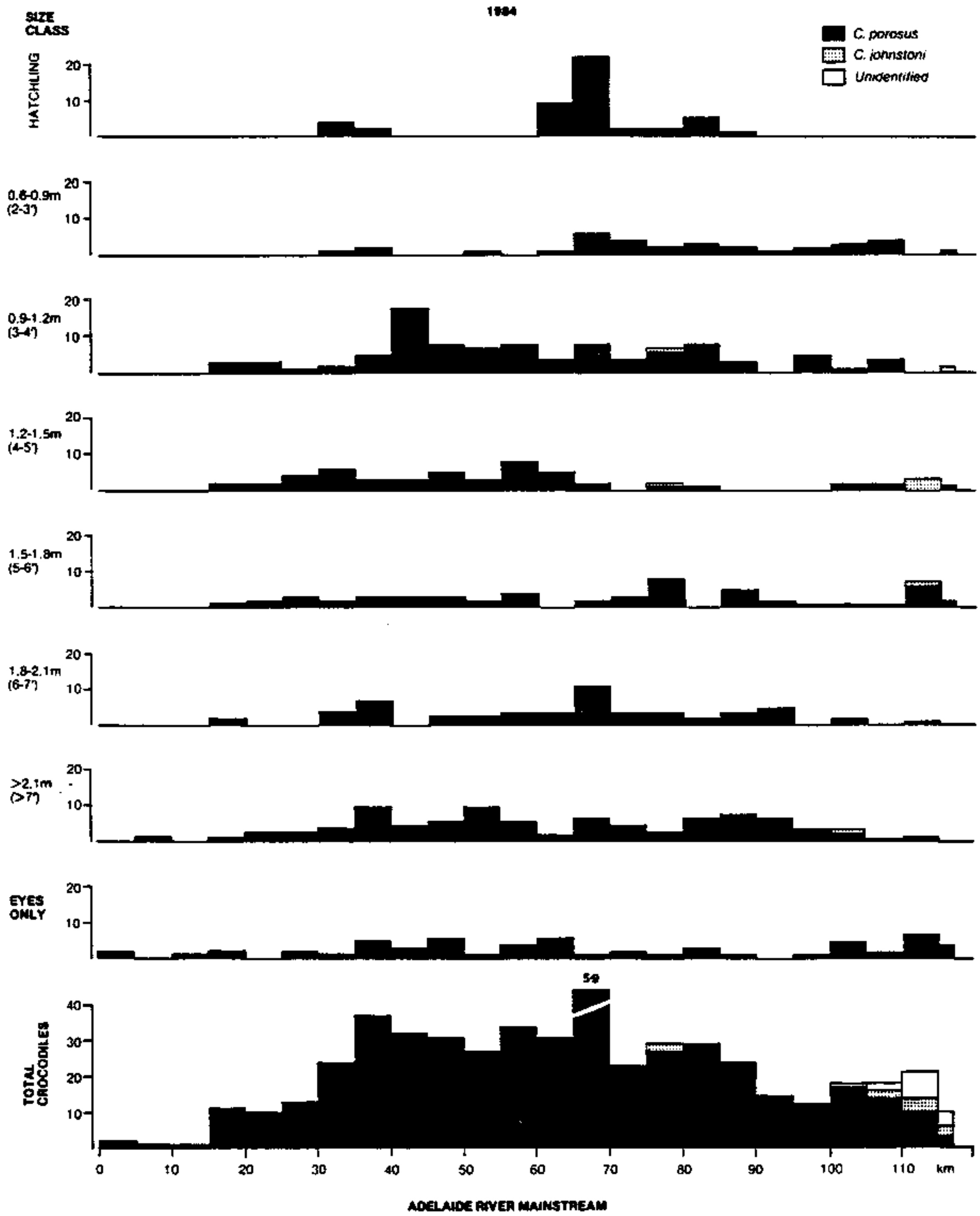

Figure 31. Distributional pattern of crocodiles on the mainstream of the Adelaide River in July 1984 (from p. 98 Monograph 19).

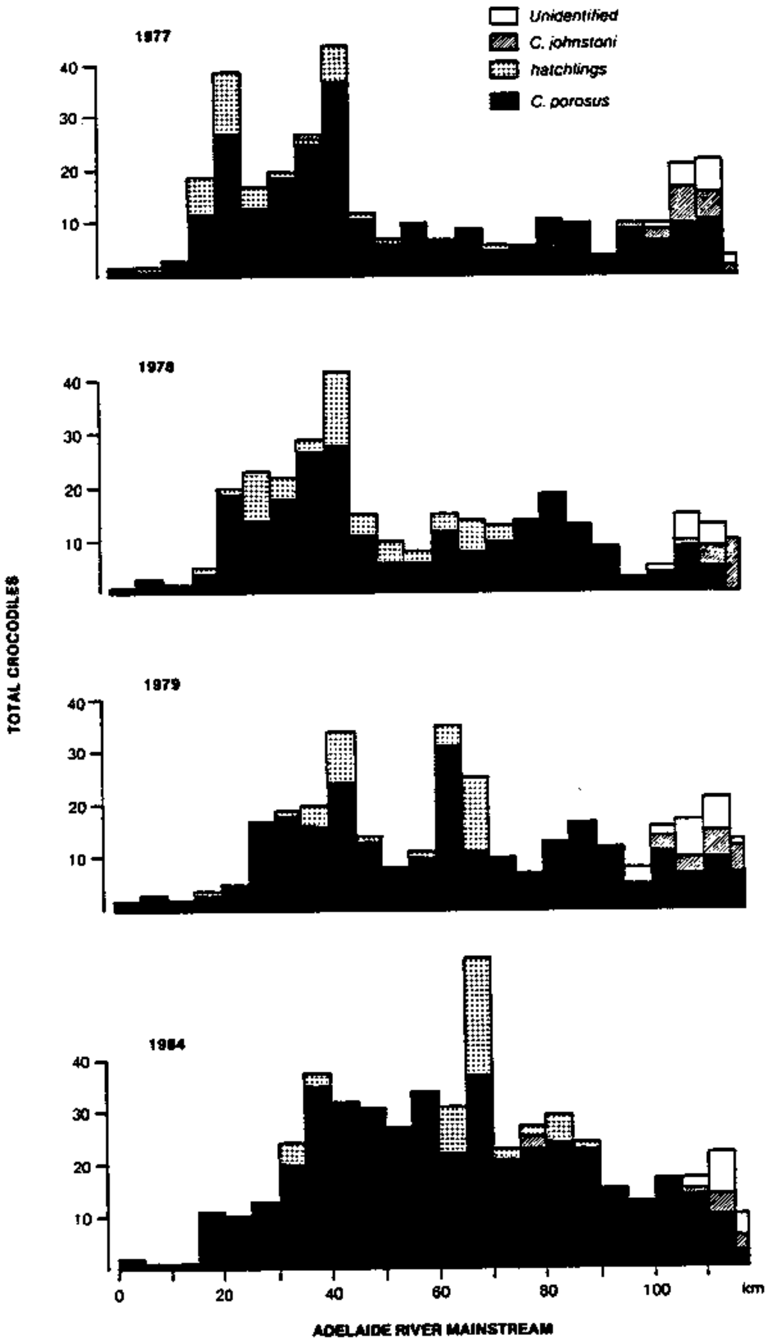

Figure 32. Distributional pattern of *Crocodylus porosus* on the Adelaide in July 1977, September 1978, September 1979, and July 1984 (from p. 100 Monograph 19).

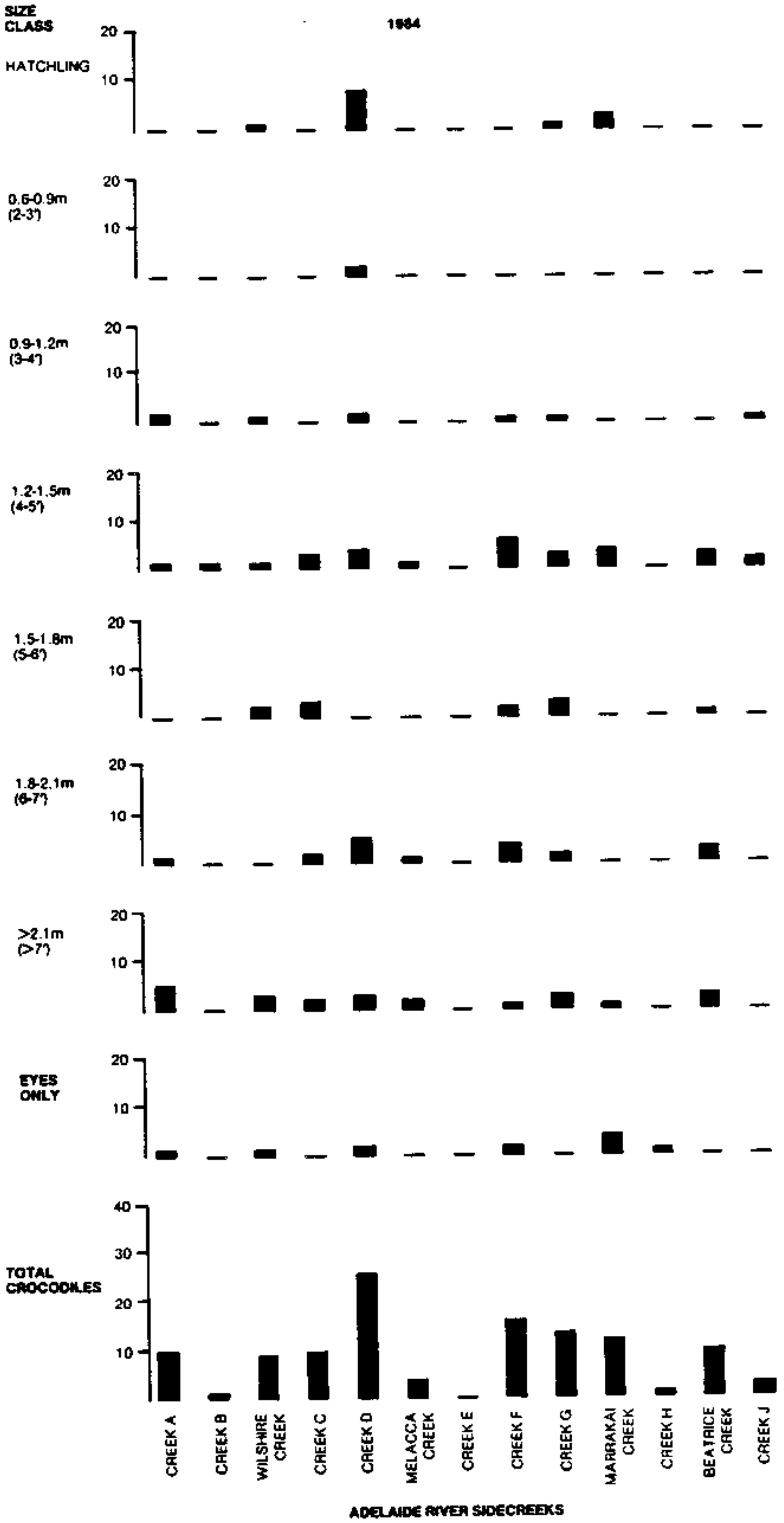

Figure 33. Distributional pattern of *Crocodylus porosus* on the sidecreeks of the Adelaide River in July 1984 (from p. 99 Monograph 19).

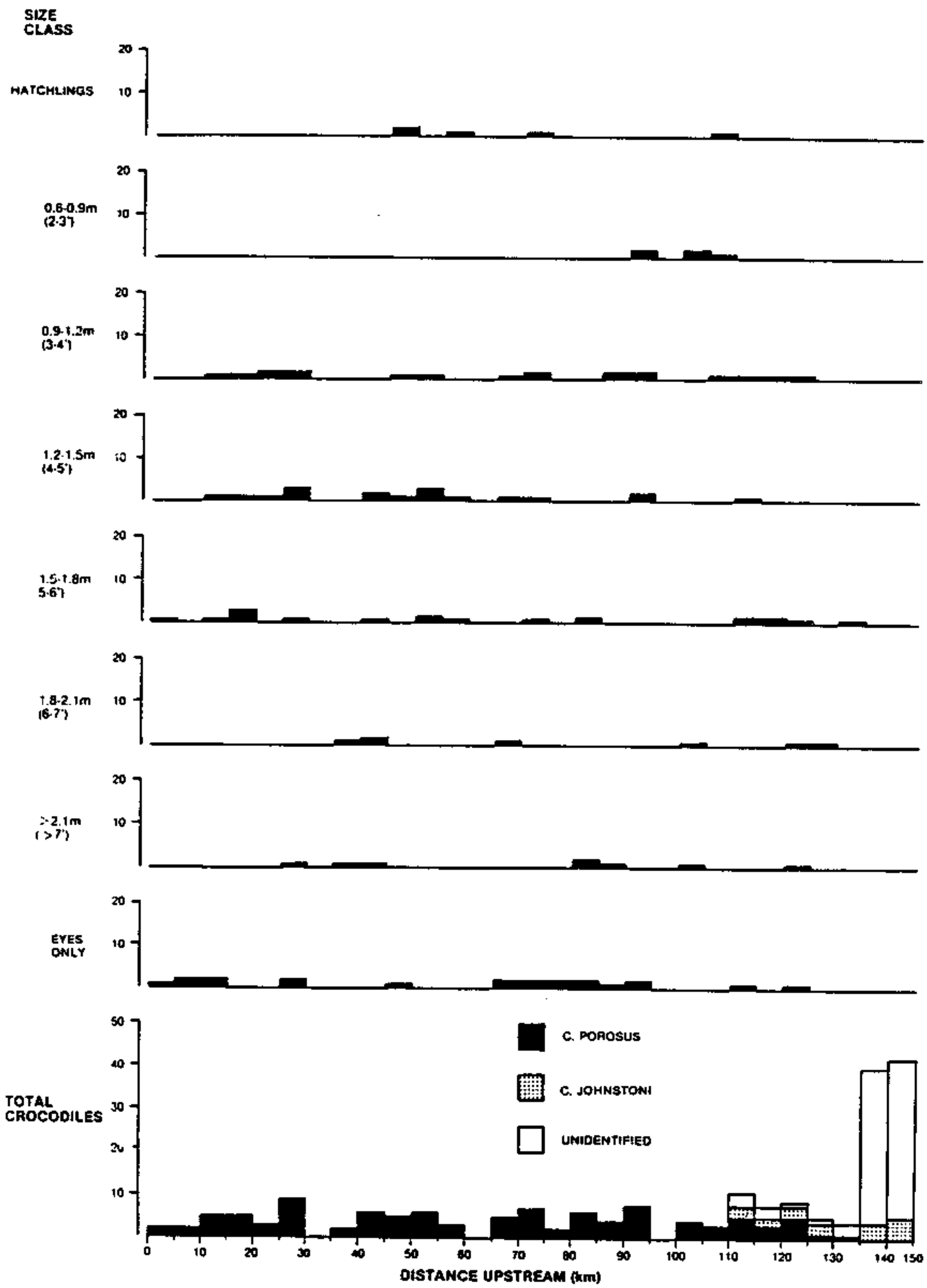

Figure 34. Distributional pattern of crocodiles on the mainstream of the Victoria River System in August 1978 (from p. 34 Monograph 2).

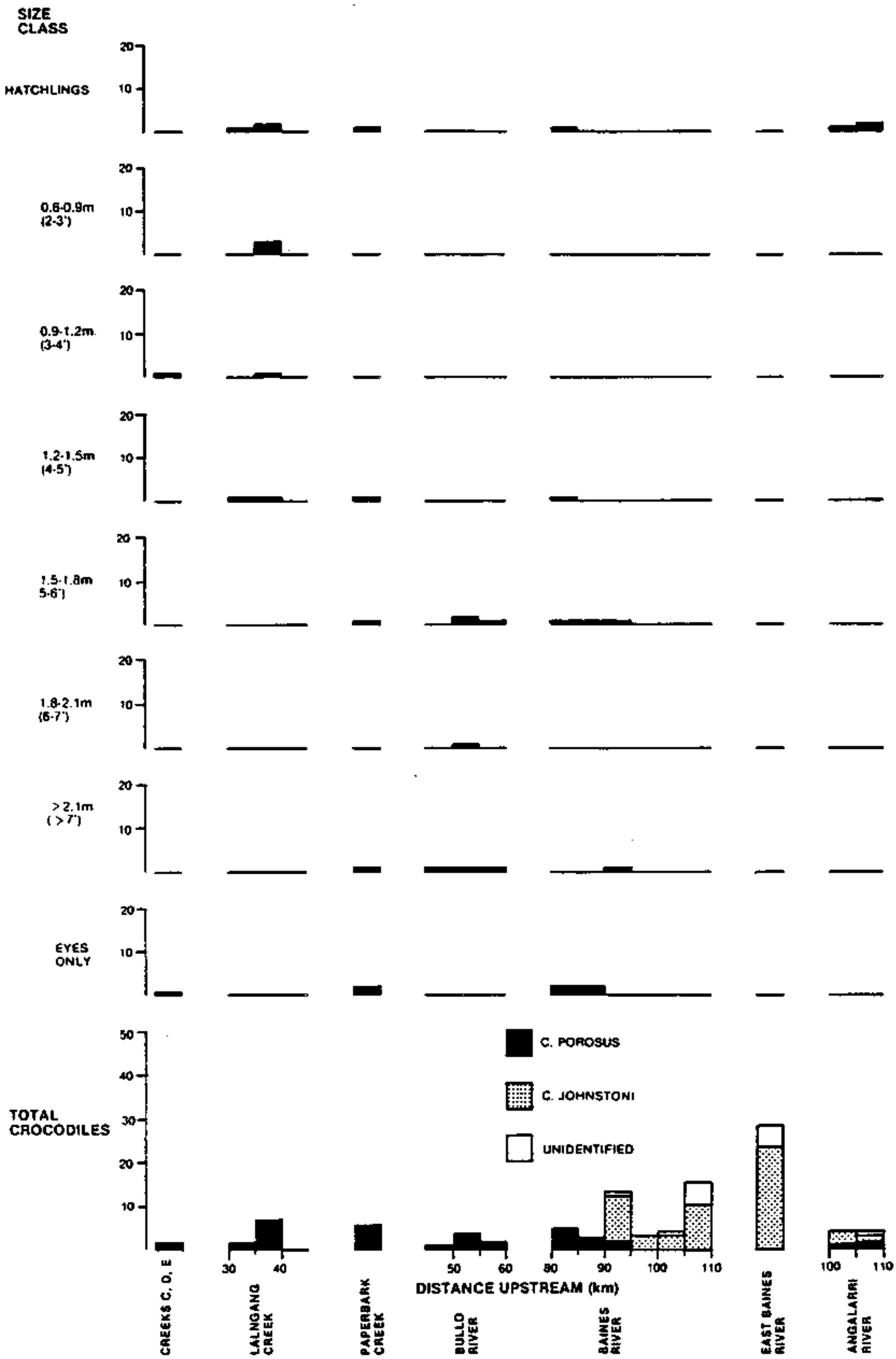

Figure 35. Distributional pattern of crocodiles on the sidecreeks and/or rivers of the Victoria River System in August 1978 (from p. 33 Monograph 2).

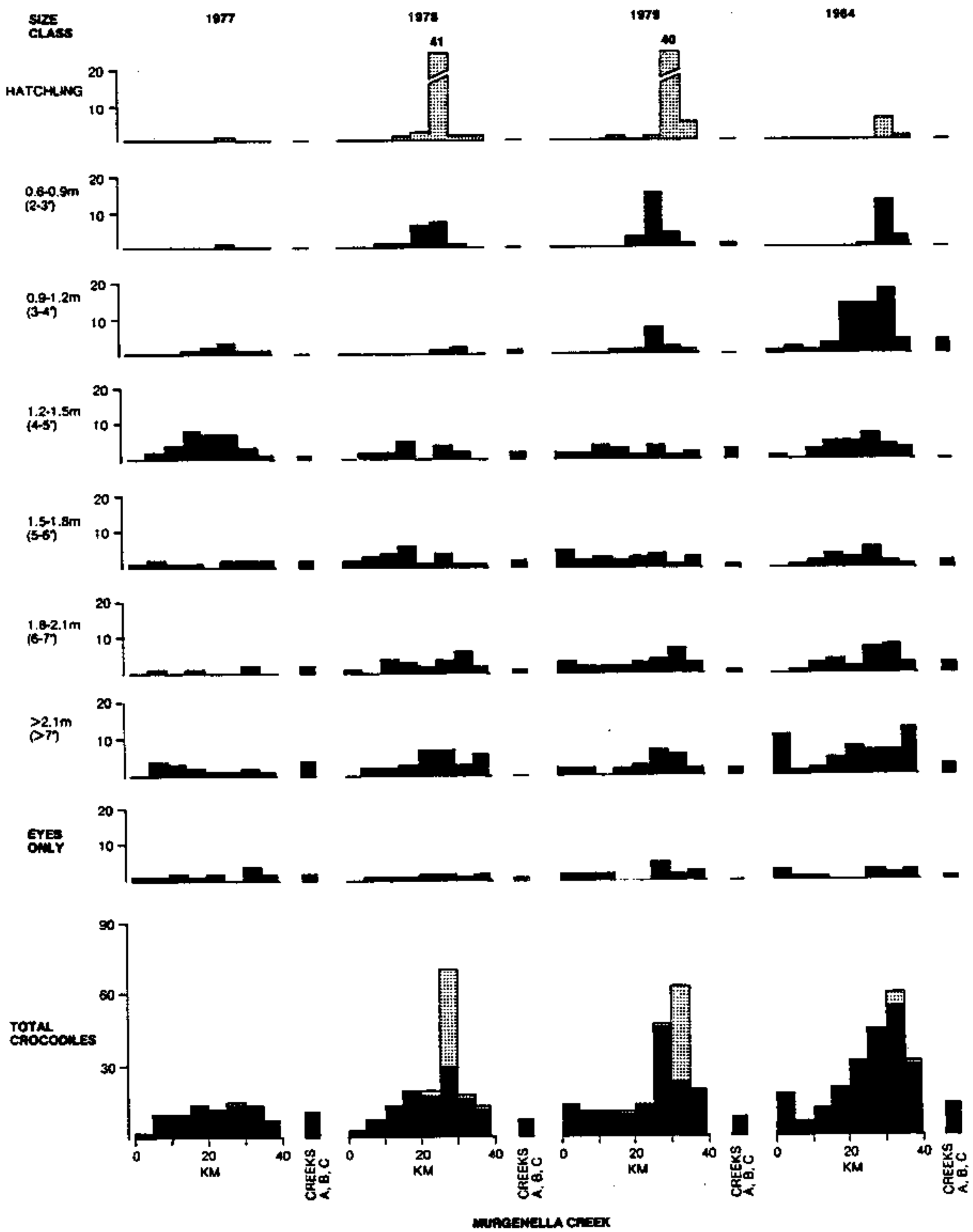

Figure 36. Distributional pattern of *Crocodylus porosus* on Murgenella Creek in October 1977, June 1978, August 1979, and July 1984 (from p. 177 Monograph 19).

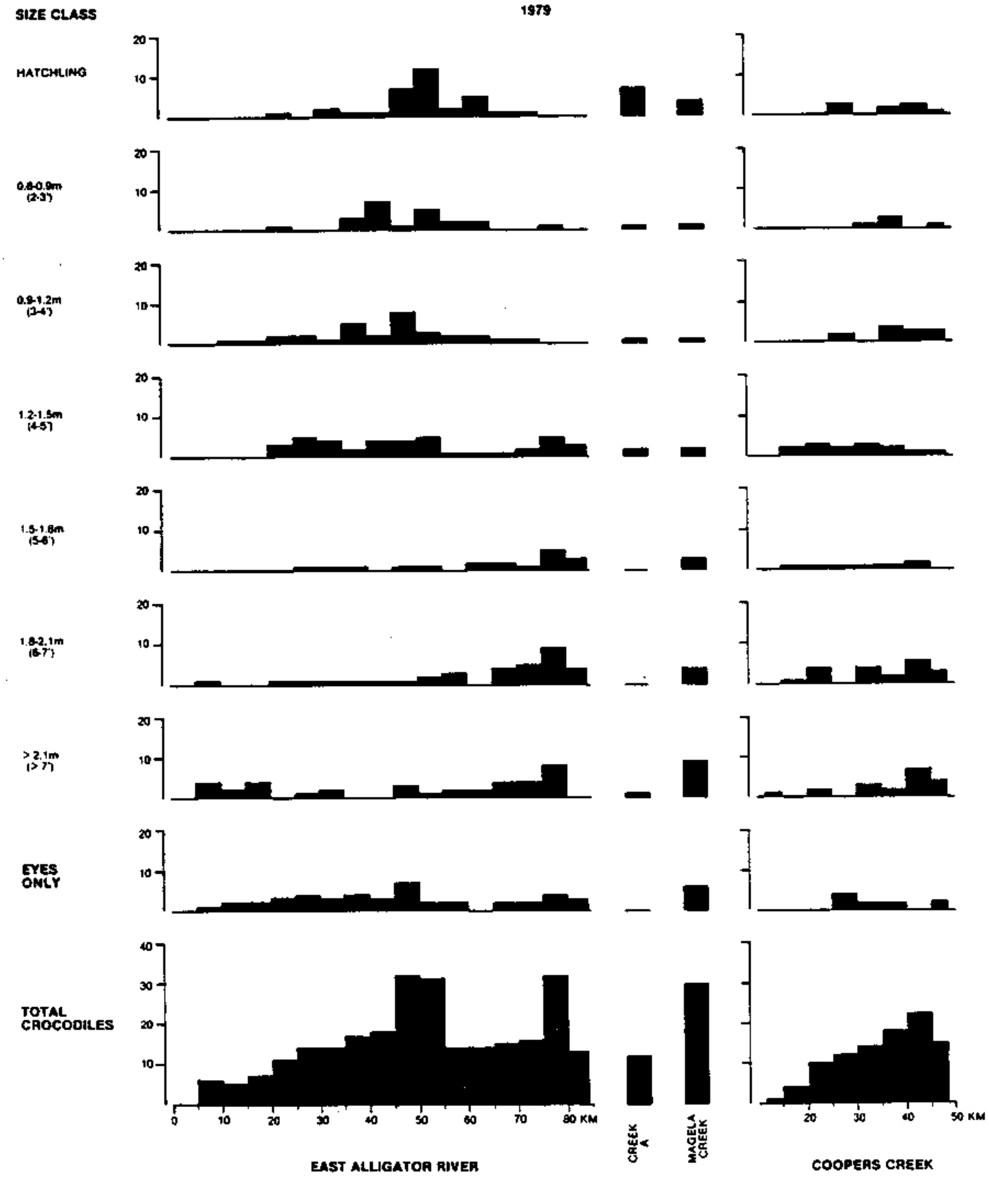

Figure 37. Distributional pattern of *Crocodylus porosus* on the East Alligator River System in August 1979 (from p. 87 Monograph 14).

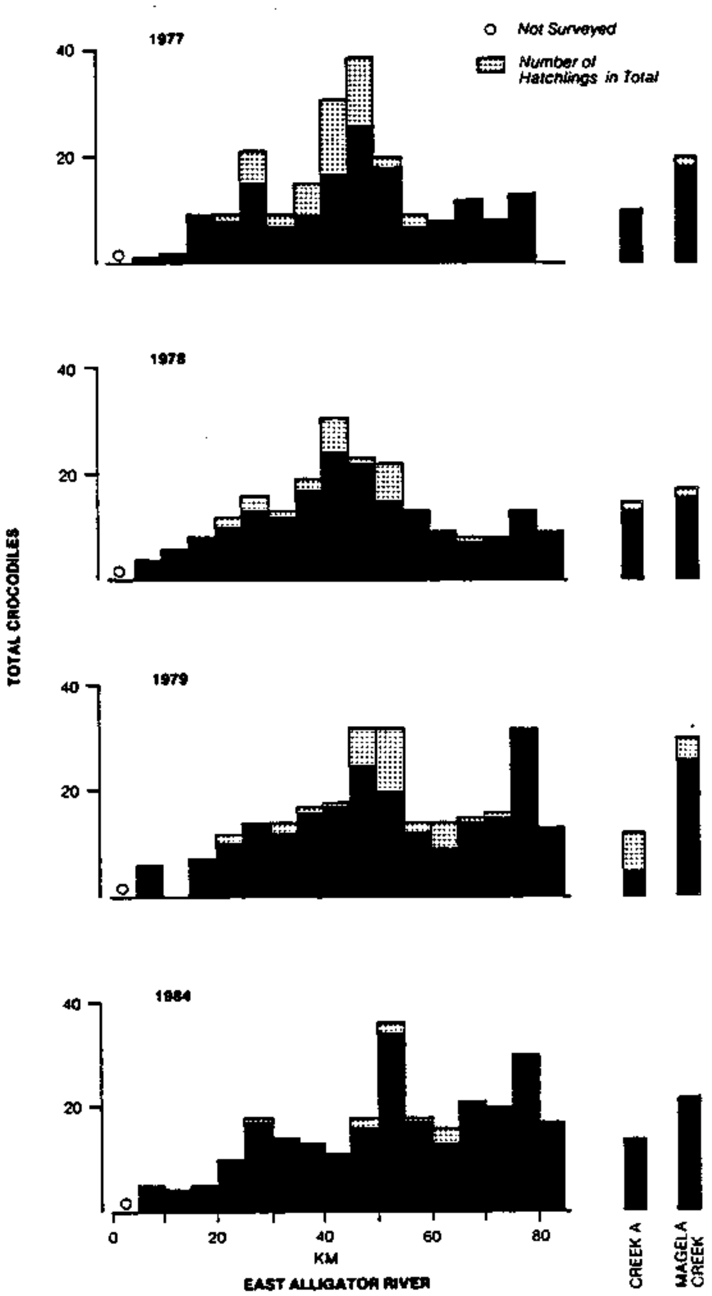

Figure 38. Distributional pattern of *Crocodylus porosus* on the East Alligator River in October 1977, June 1978, August 1979, and July 1984 (from p. 179 Monograph 19).

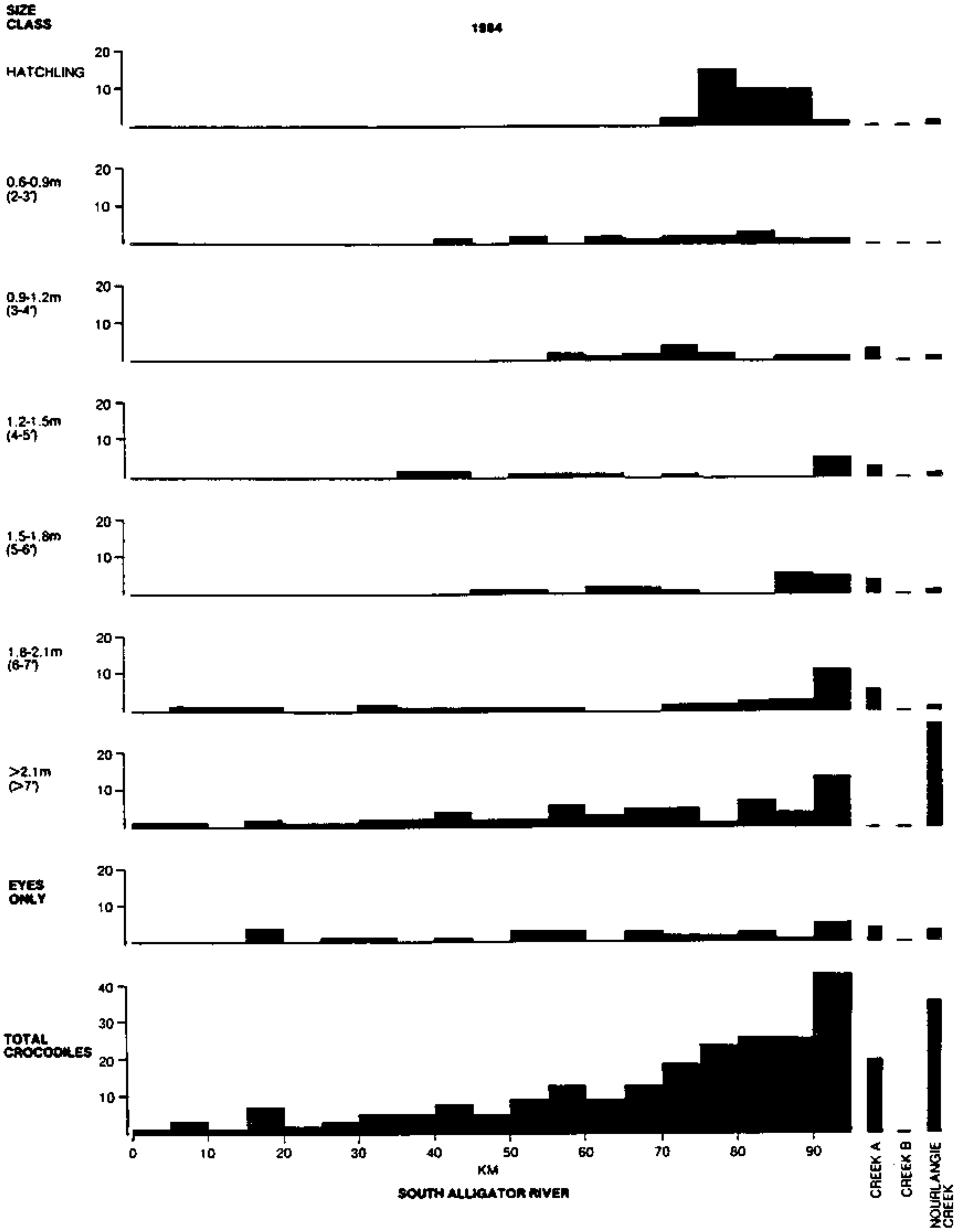

Figure 39. Distributional pattern of *Crocodylus porosus* on the South Alligator River in July 1984 (from p. 180 Monograph 19).

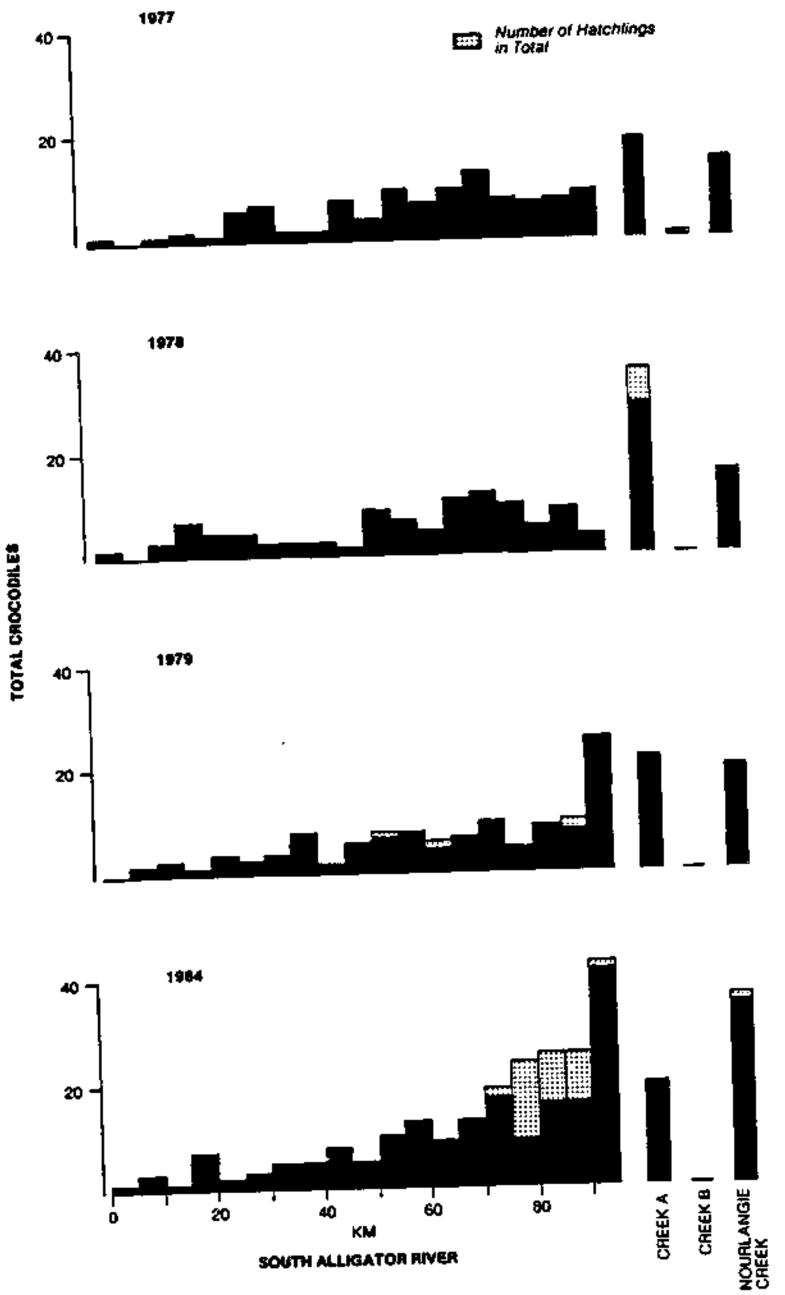

Figure 40. Distributional pattern of *Crocodylus porosus* on the South Alligator River in October 1977, July 1978, August 1979, and July 1984 (from p. 181 Monograph 19).

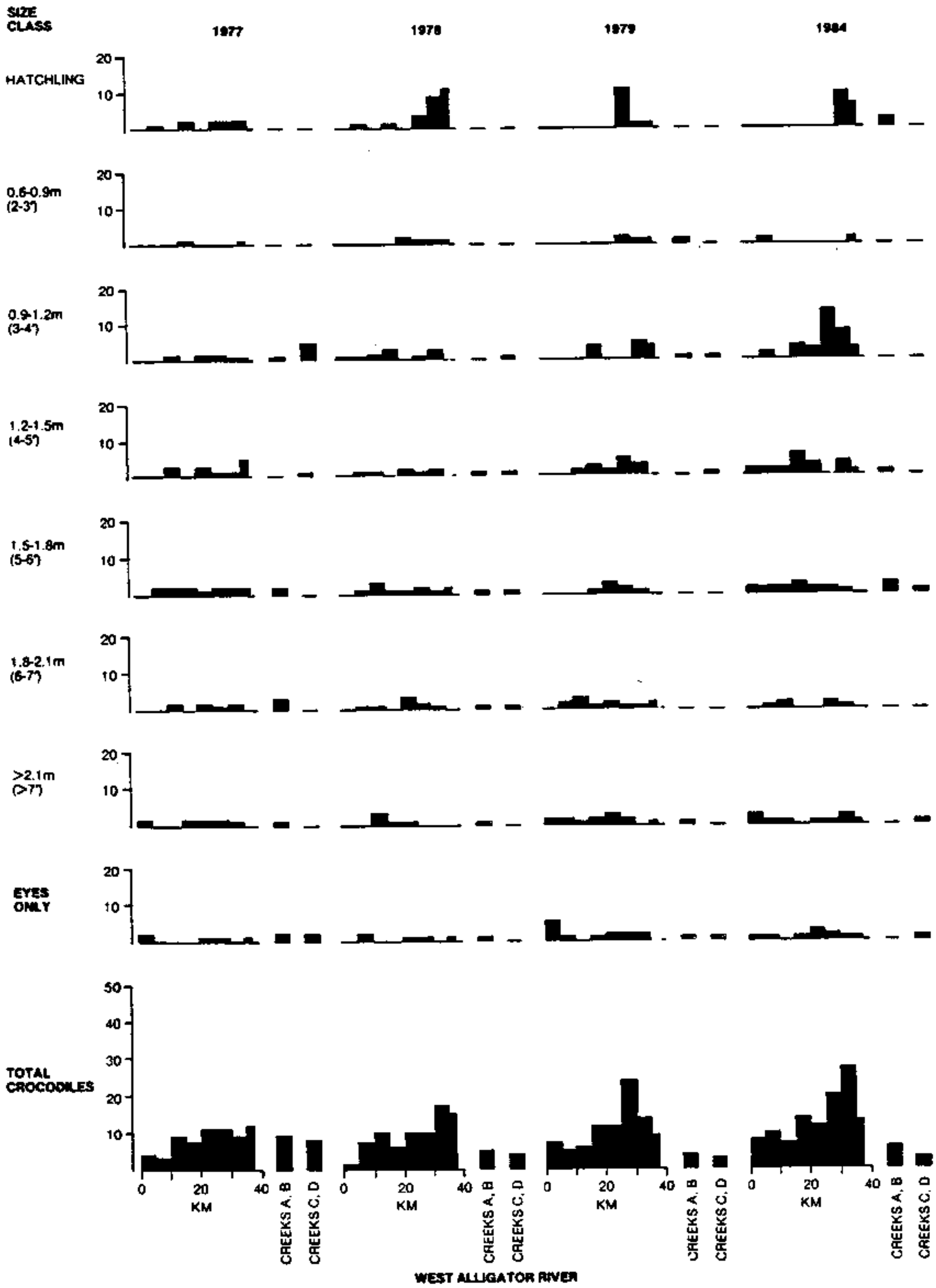

Figure 41. Distributional pattern of *Crocodylus porosus* on the West Alligator River in October 1977, July 1978, August 1979, and June 1984 (from p. 182 Monograph 19).

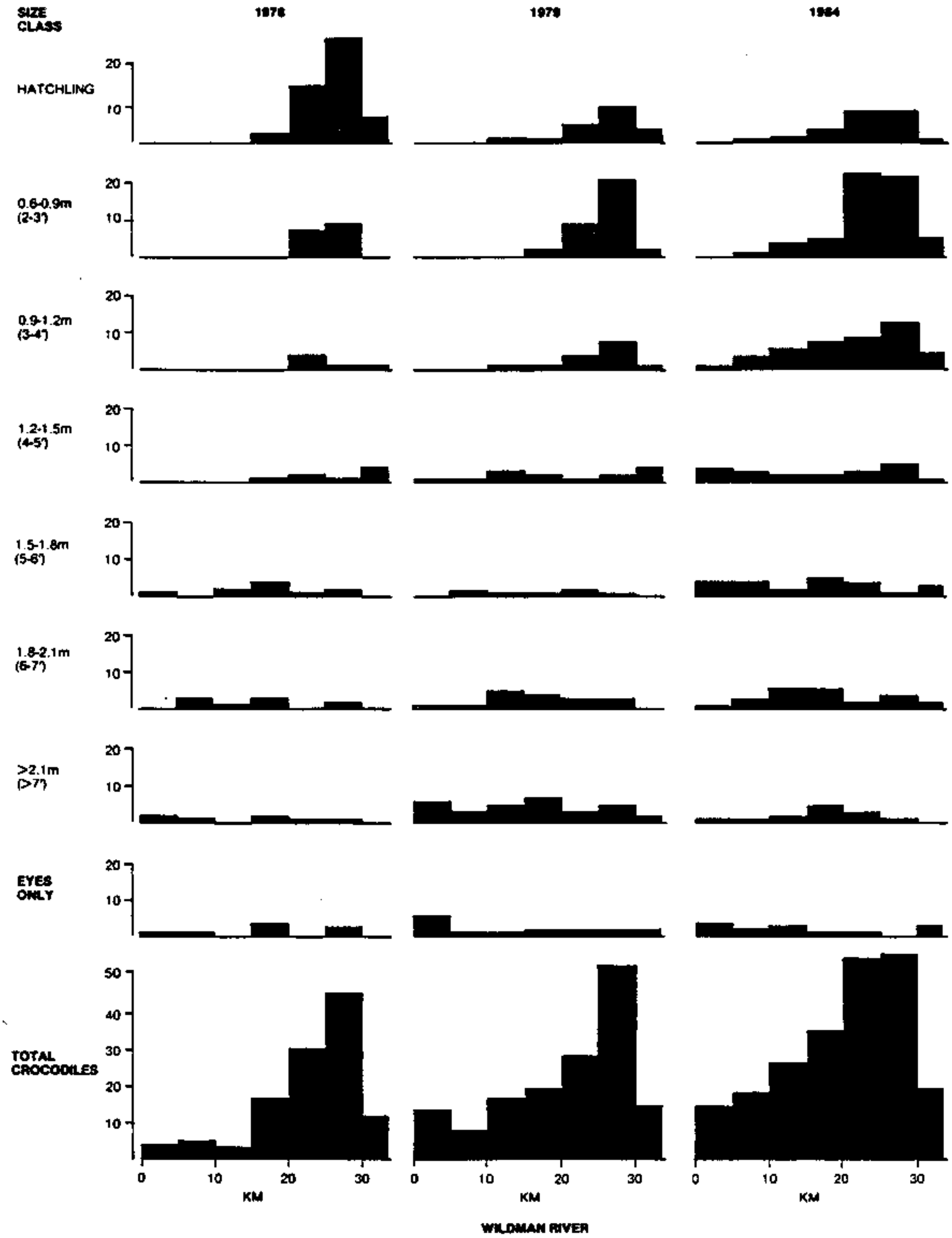

Figure 42. Distributional pattern of *Crocodylus porosus* on the Wildman River in September 1978, August 1979, and June 1984 (from p. 183 Monograph 19).

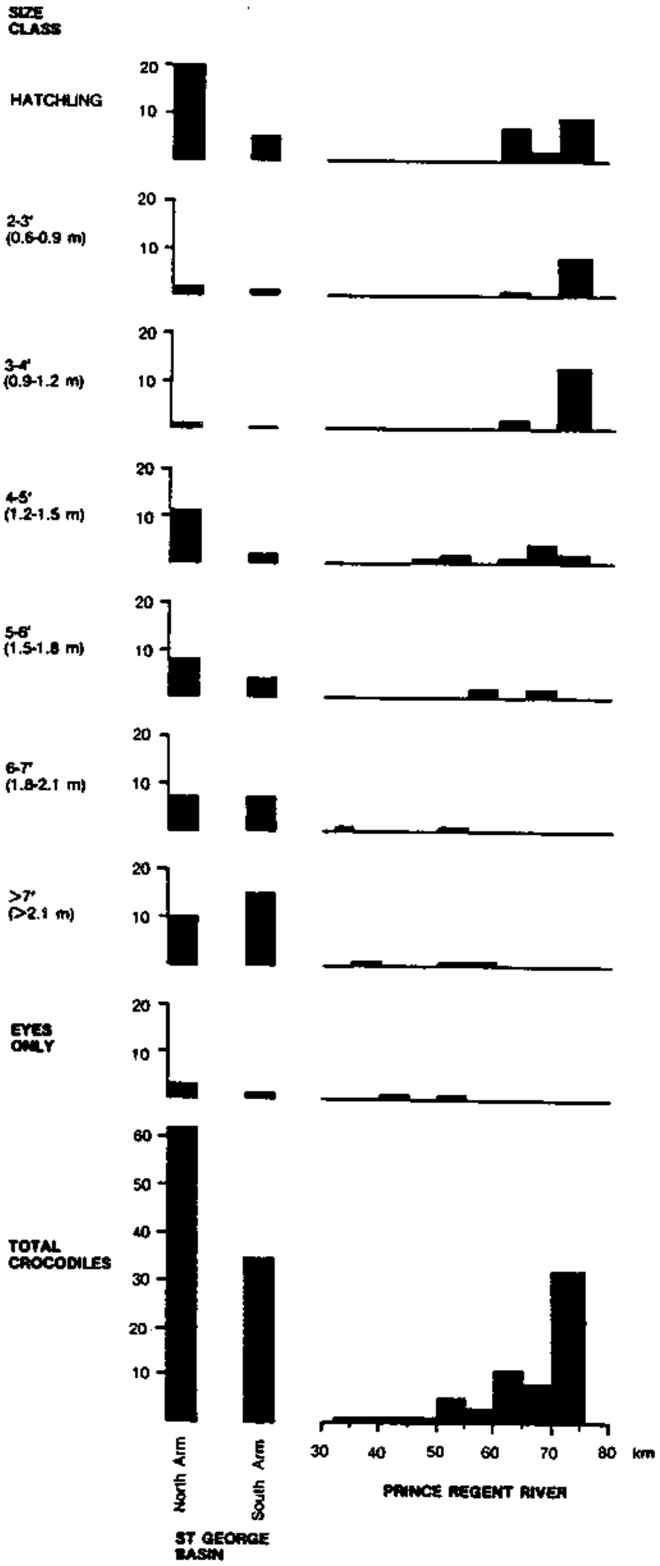

Figure 43. Crocodile distribution on the Prince Regent River and the St. George Basin in July 1978 (from p. 24, W.A. Report No. 34).

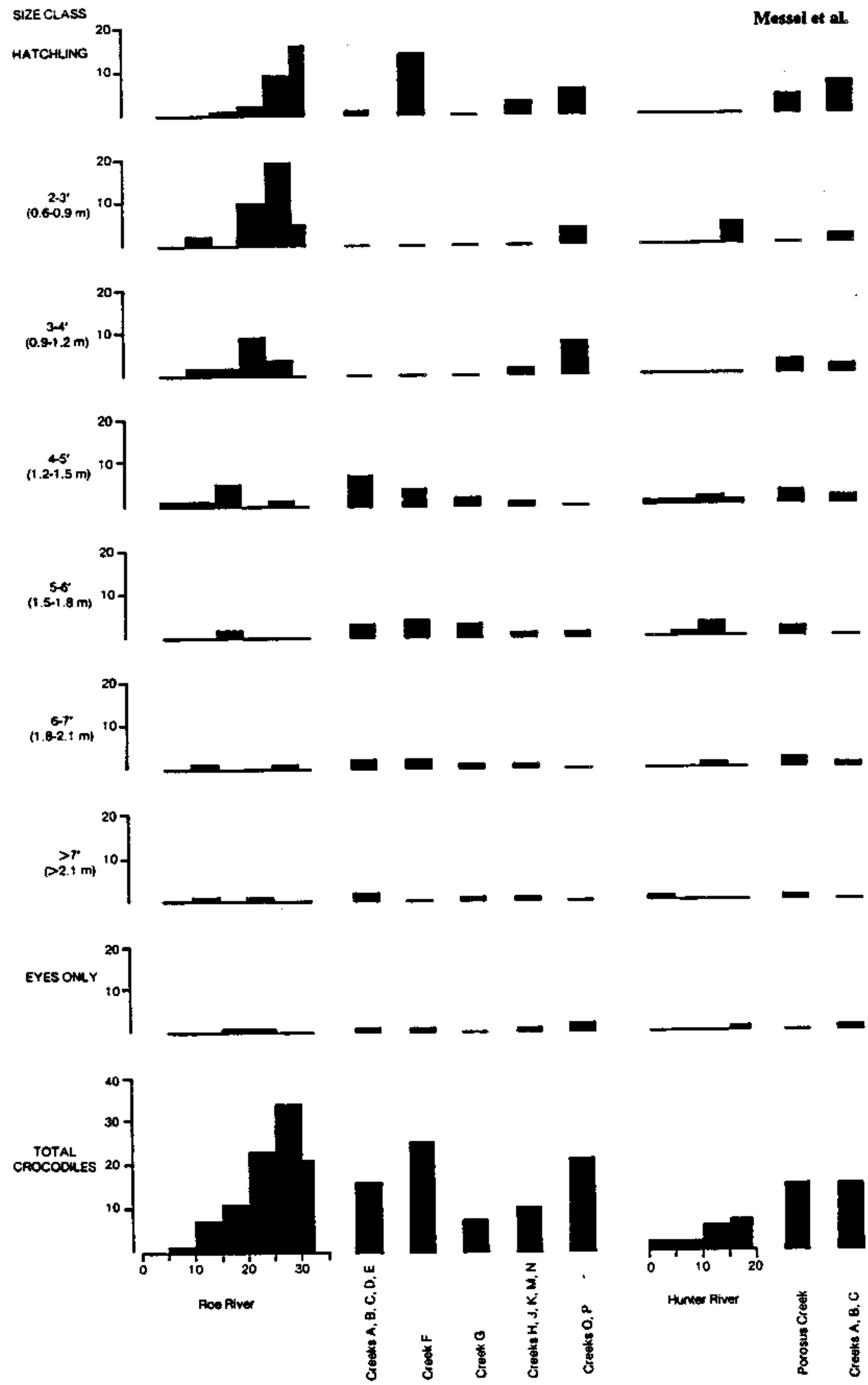

Figure 44. Crocodile distribution on the Roe River System in July 1977 (from p. 33 W.A. Report No. 24).

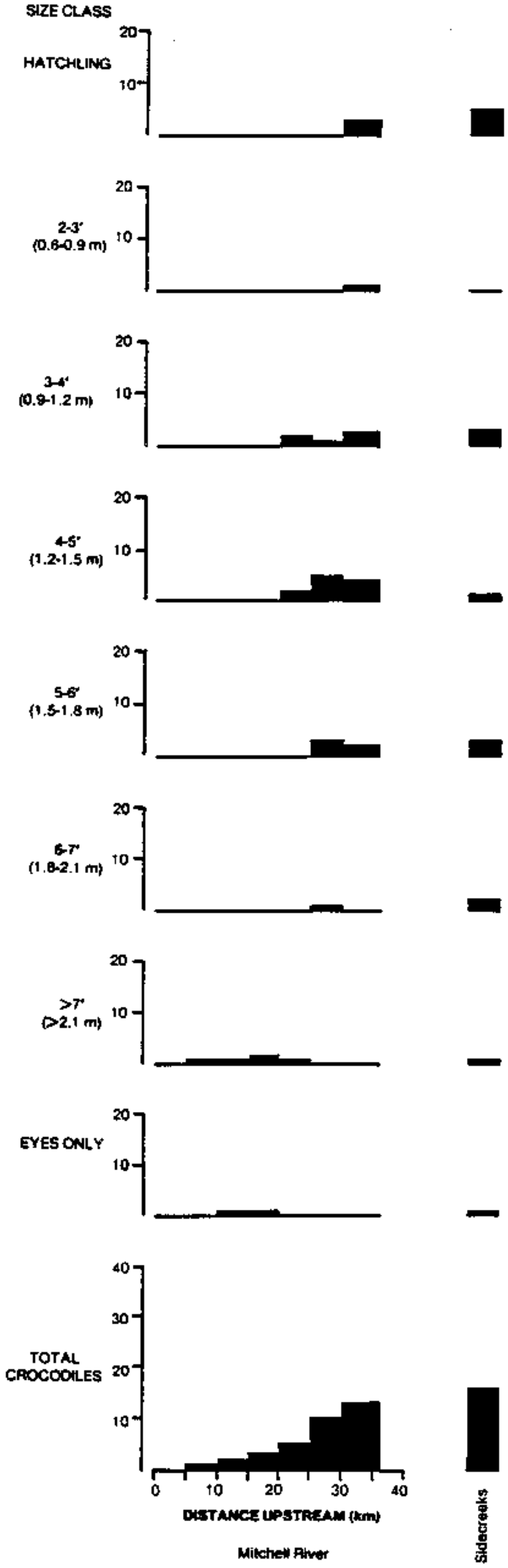

Figure 45. Crocodile distribution on the Mitchell River in July 1977 (from p. 28 W.A. Report No. 24).

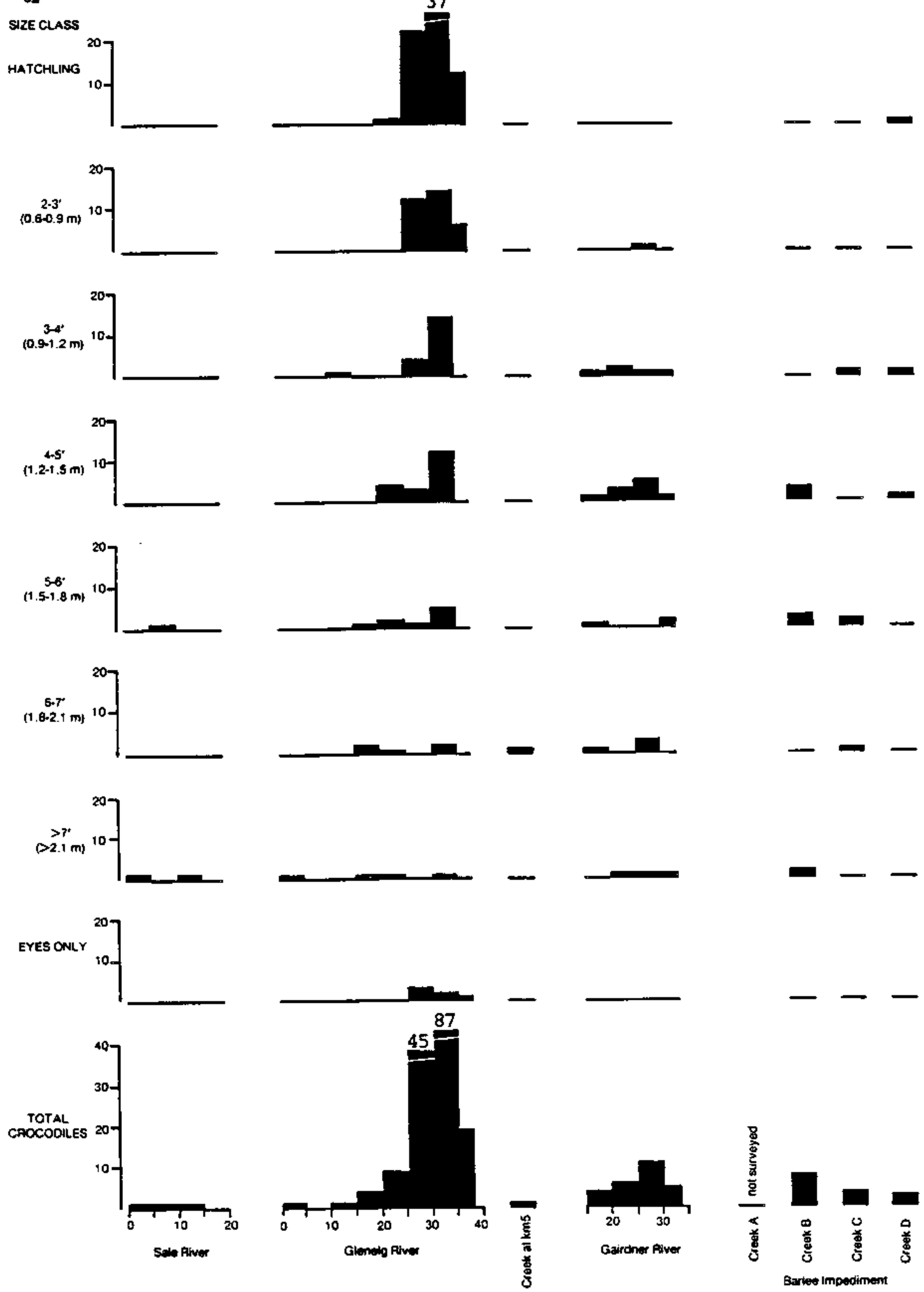

Figure 46. Crocodile distribution on the Glenelg and Gairdner Rivers in July 1978 (from p. 14 W.A. Report No. 34).

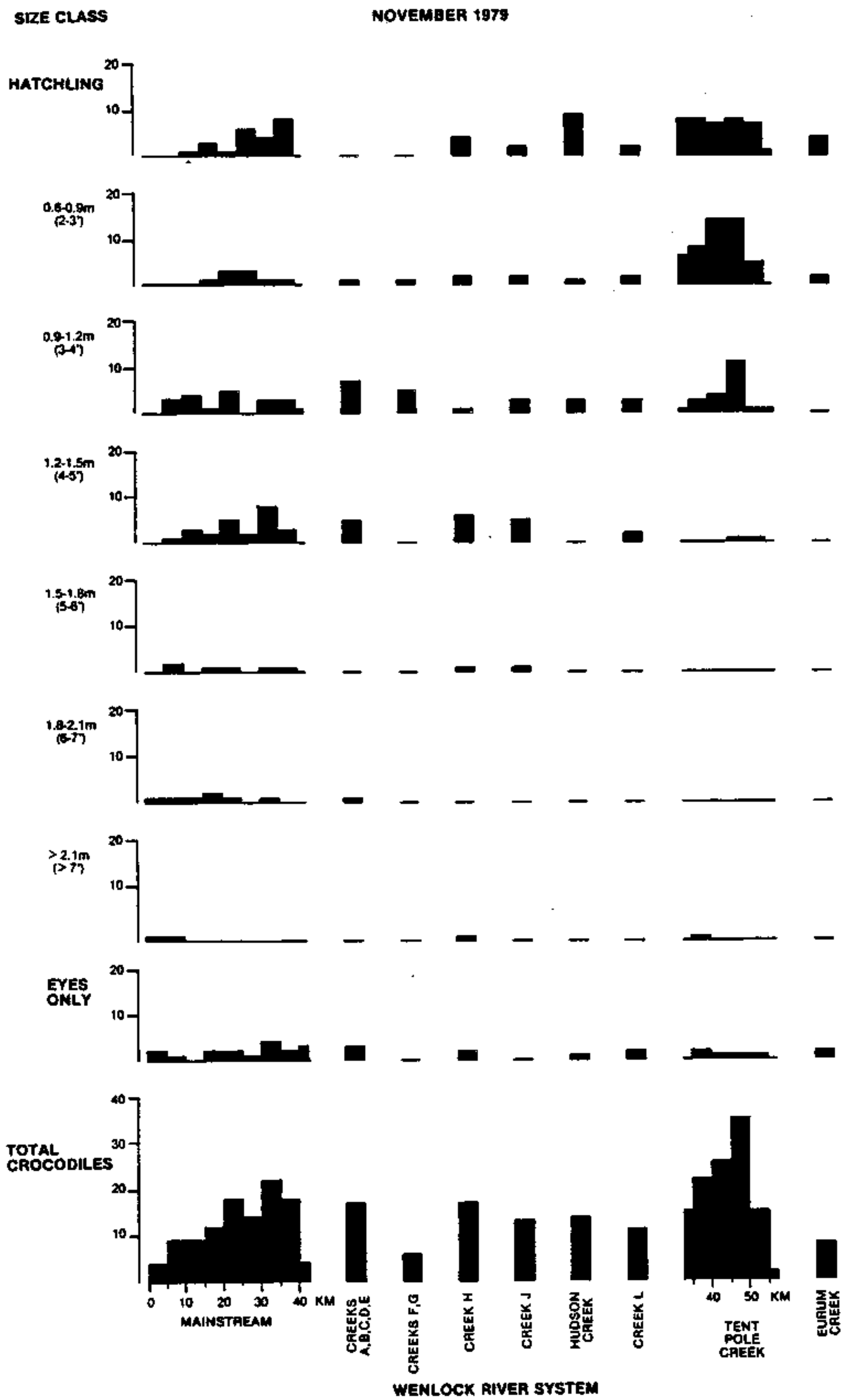

Figure 47. Distributional pattern of *Crocodylus porosus* on the Wenlock River System in November 1979 (from p. 89 Monograph 16).

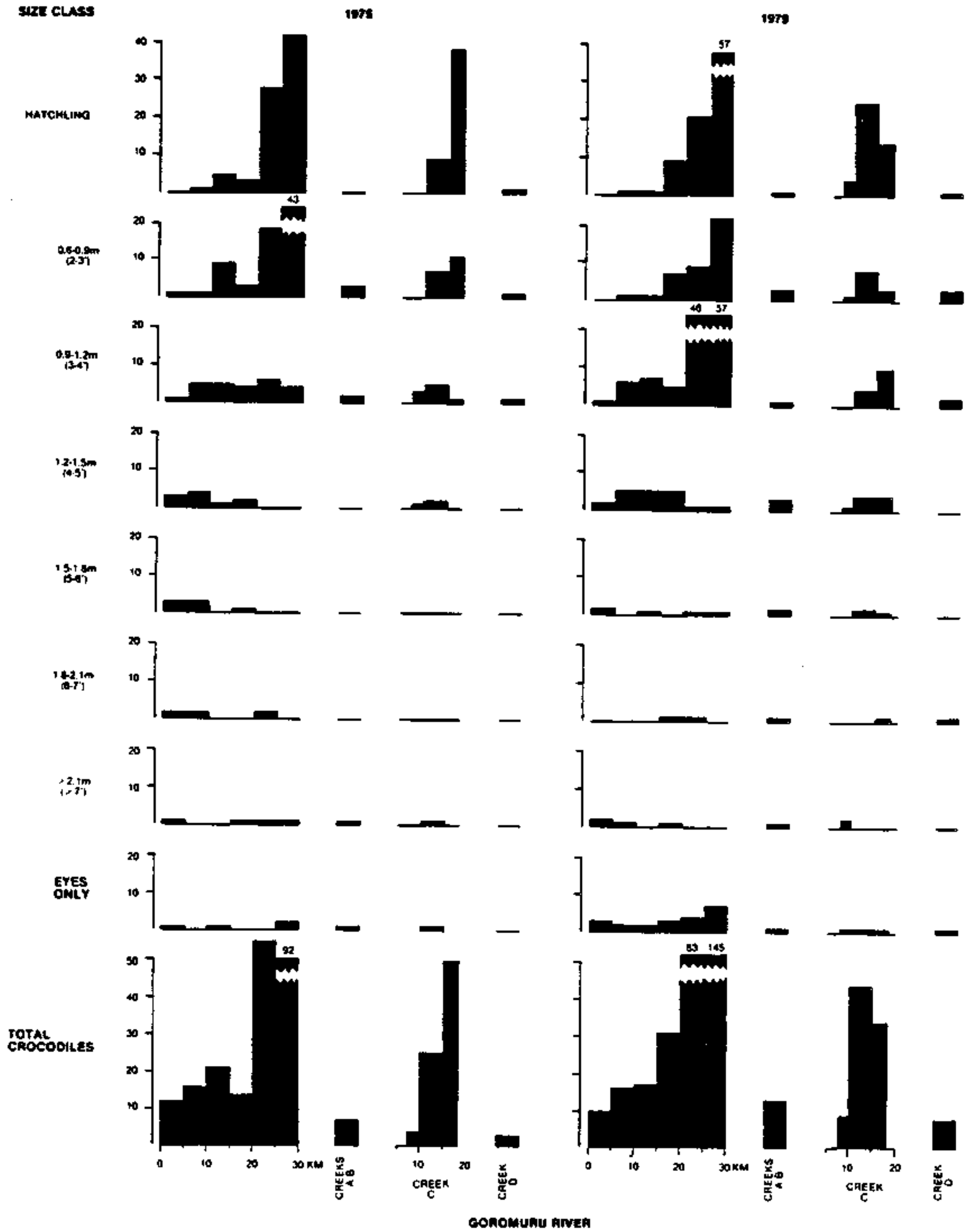

Figure 48. Distributional pattern of *Crocodylus porosus* on the Goromuru River in October 1975 and June 1979 (from p. 118 Monograph 11).

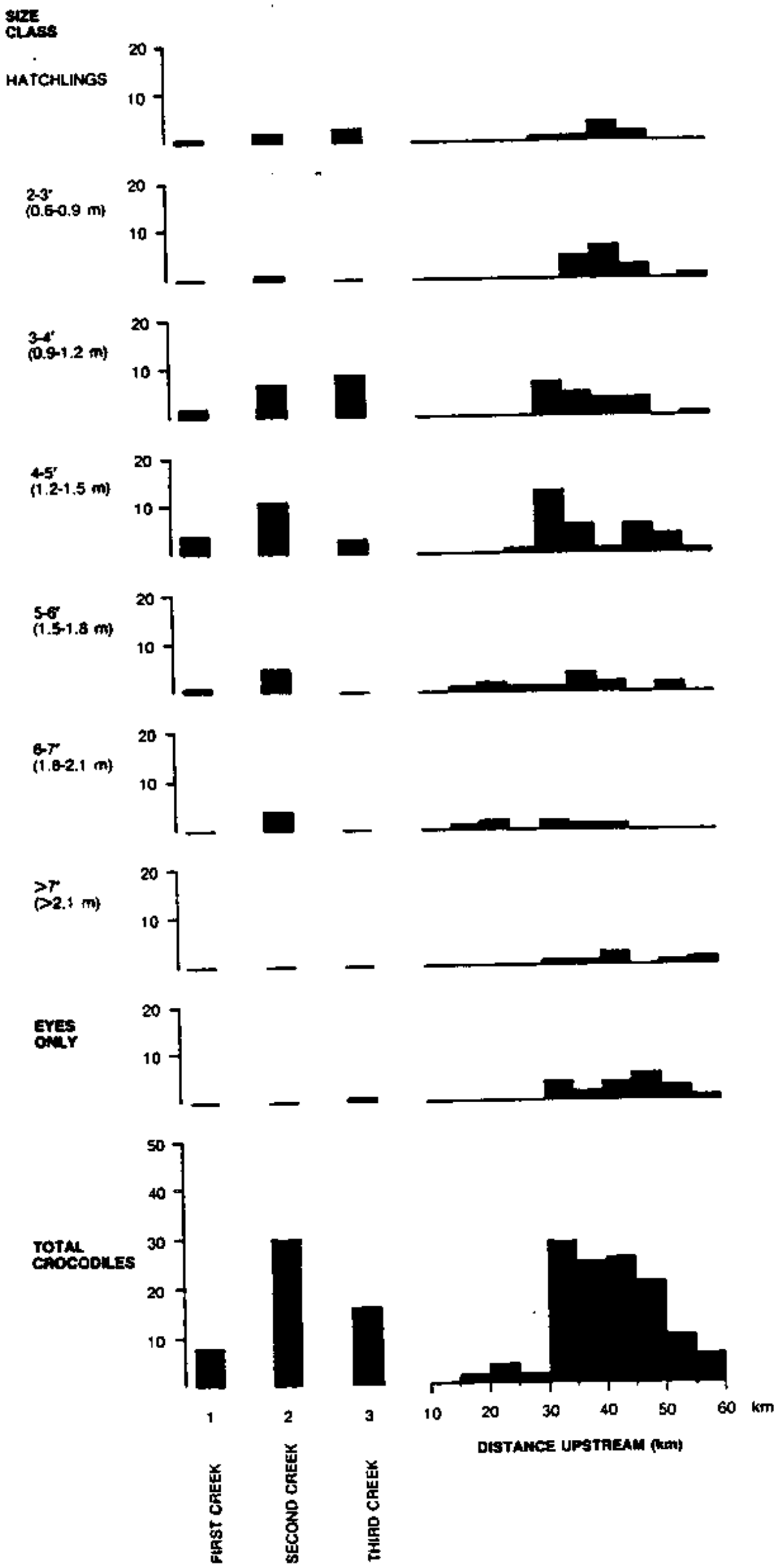

Figure 49. Crocodile distribution on the Ord River System in July 1978 (from p. 32 W.A. Report No. 34).

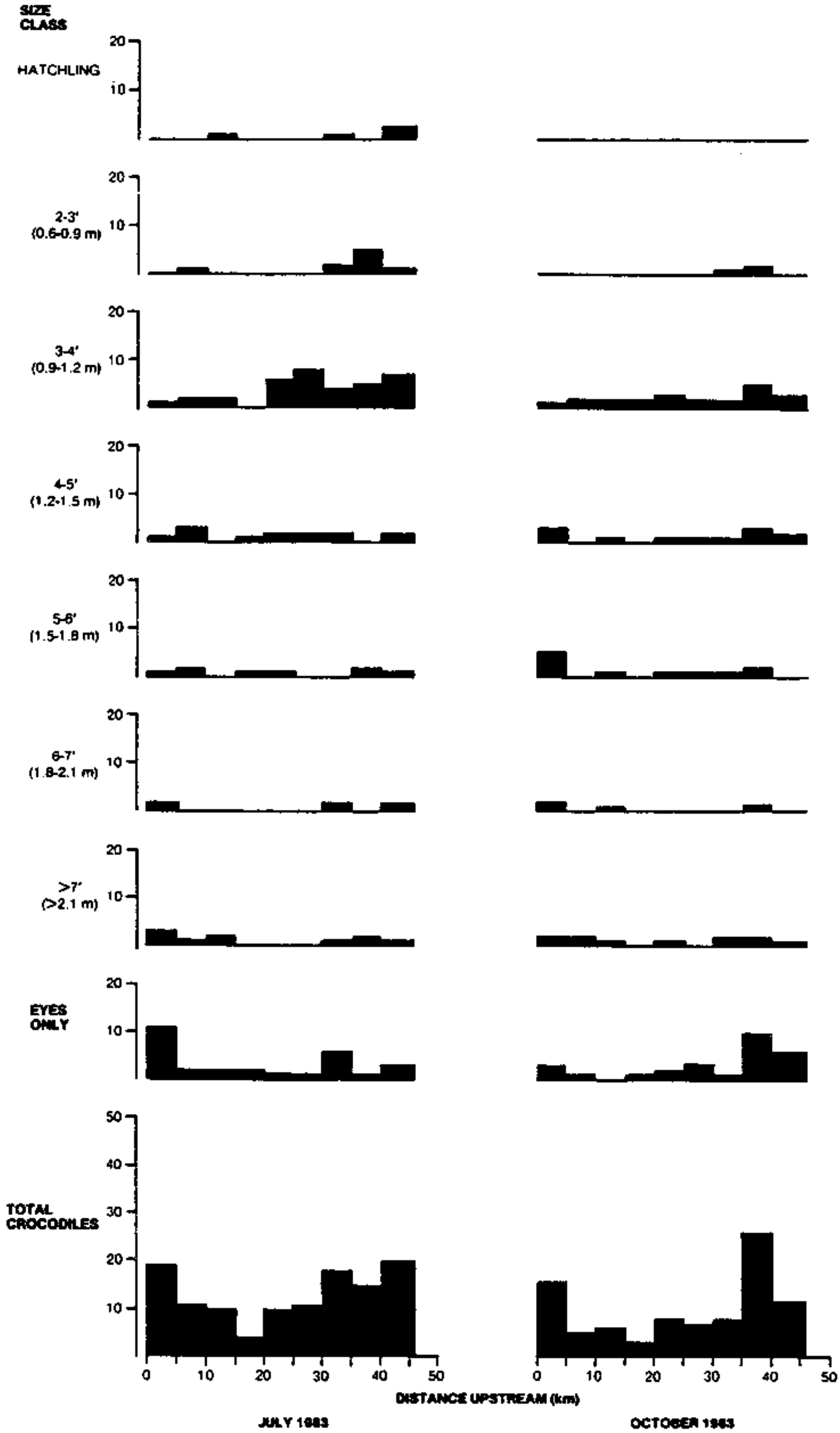

Figure 50. Distributional pattern of *Crocodylus porosus* on the Glyde River in July and October 1983 (from p. 307 Monograph 18).

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°18S	128°04'E
Canal Creek at km 16.0	15°18S	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.

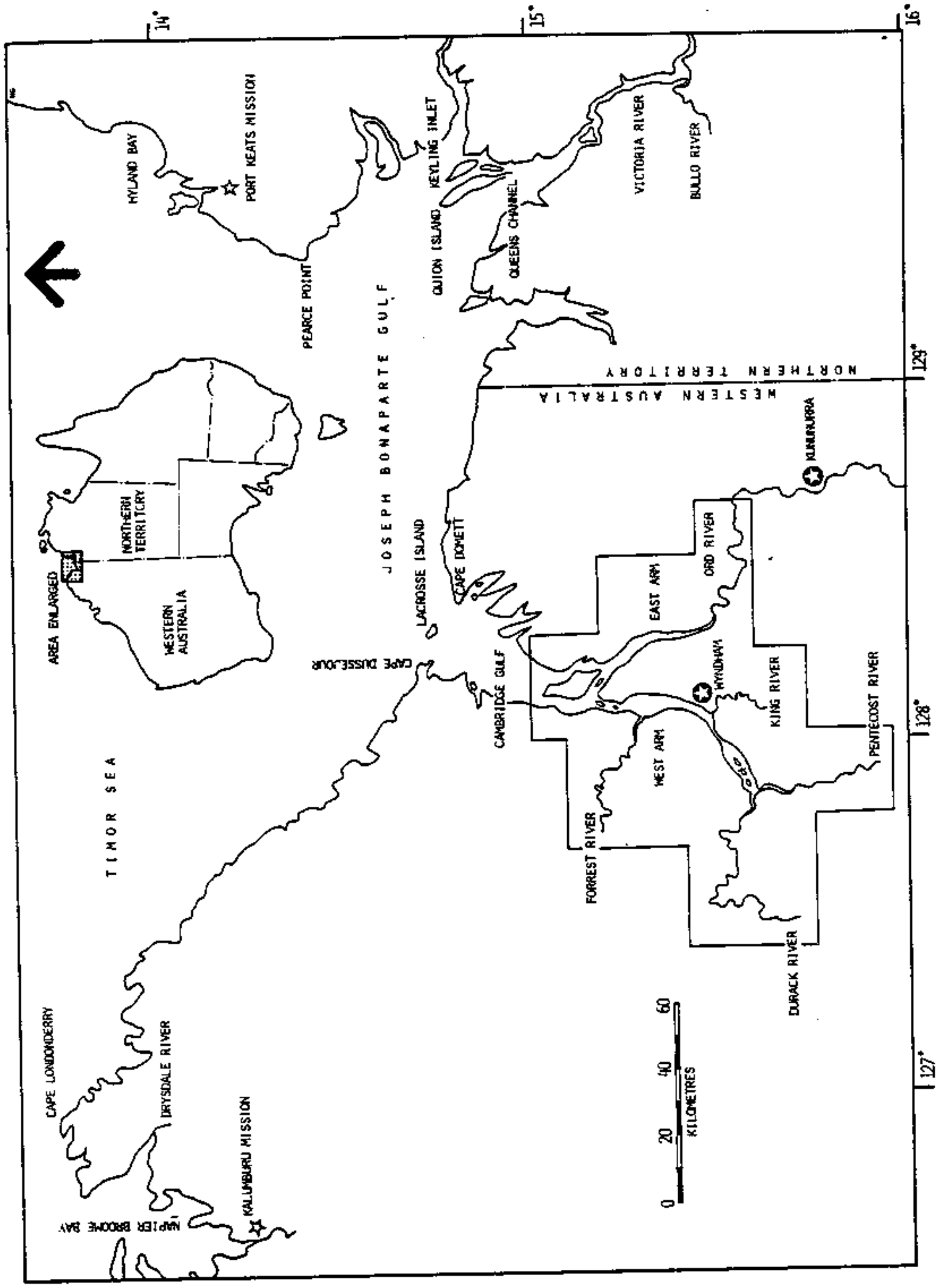

Figure 1. General area map 1: East Kimberley, Western Australia.

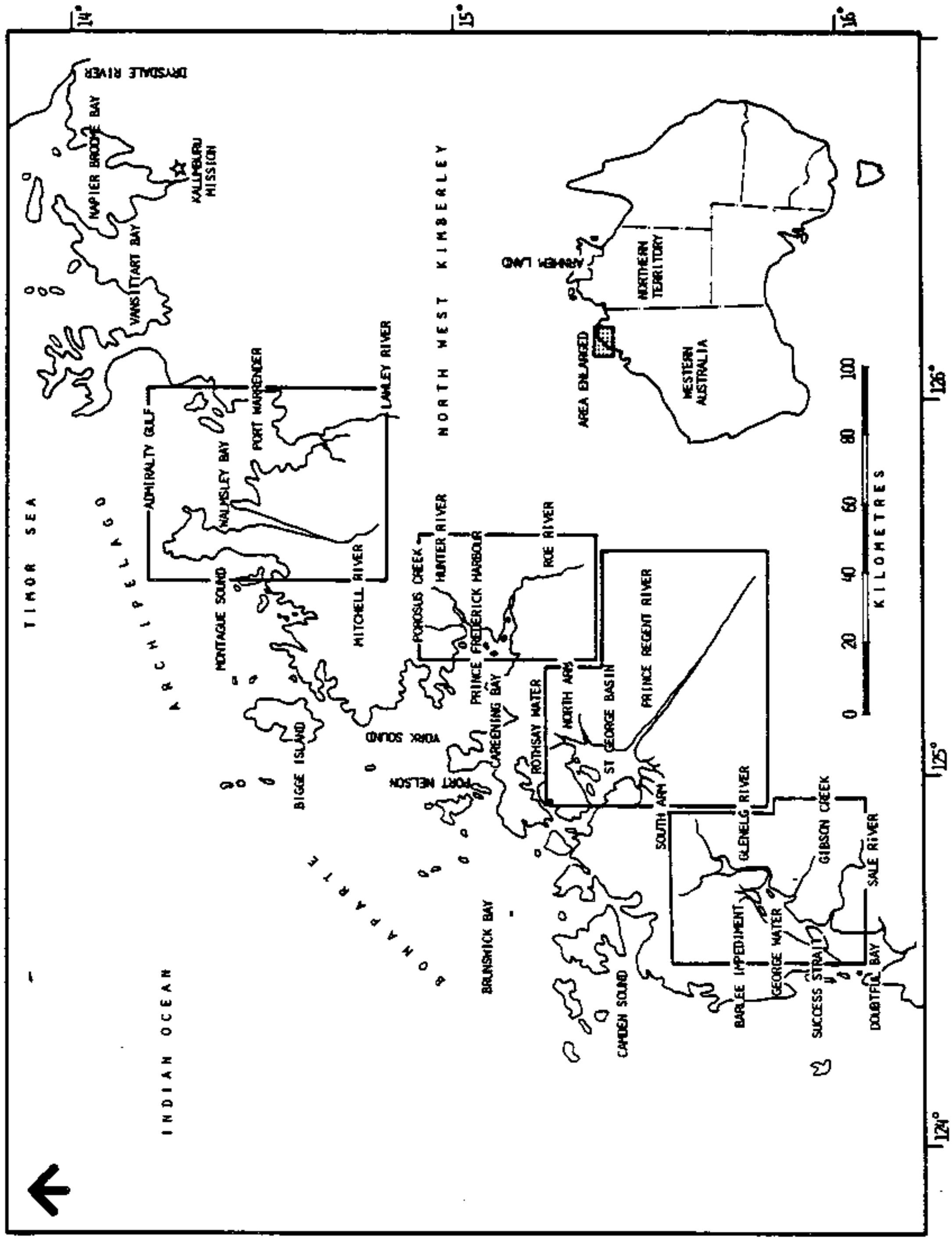

Figure 2. General area map 2: North West Kimberley, Western Australia.

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 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 as 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^2 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 (≥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, Finniss, 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 (≥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 ≈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, as 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 Adeliade 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 norther 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 2.5km 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 our 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 analyses 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 fo 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

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.

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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.

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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. Wlldl., 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 Austalia, 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.

		Numbers in size class								km		95%	
System	Totals	H	2-3	3-4	4-5	5-6	6-7	>7	EO	Surveyed	Density	Levels	TYPE
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 H	2-3	3-4	4-5	5-6	6-7	>7	EO	km Surveyed	Density	95% Levels	TYPE
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 H	2-3	3-4	4-5	5-6	6-7	>7	EO	km Surveyed	Density	95% Levels	TYPE
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: H	2-3	3-4	4-5	5-6	6-7	>7	EO	km Surveyed	Density	95% Levels	TYPE
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 ≥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 (≥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