

GIS Application on Data Base of Baba (*Caiman crocodilus*) Program in Venezuela

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ABSTRACT: GIS was applied to a database produced by the Program of Management of Baba (*Caiman crocodilus*) in Venezuela since 1991 to 2000. The database was built with harvests and population censuses recorded in geo-positioned farms located in seven ecological regions located in southwestern Venezuela. It includes number of harvested skins classified by industrial size classes, densities of animals estimated in surveys, type of farm accordingly to its land surface, and ecological characteristics of water bodies. The series of obtained thematic maps on harvests and densities, allows a historical spatial vision of the development of the Program results during its application. The areas with extraction of large skins for each ecological region showed a reduction since 1998 to 2000. The Ecological Regions Bajo Apure and Hoya de Arismendi presented the highest historical densities. Cumulative data since 1992 to 2000 allows establish general population trends in a spatial view.

RESUMEN: Se aplicó SIG a una base de datos producida por el Programa de Aprovechamiento de la Baba (*Caiman cocodrilus*) en Venezuela desde 1991 a 2000. La base de datos se construyó con las cosechas y censos poblacionales registrados en fincas geo-posicionadas, ubicadas en siete regiones ecológicas al suroeste de Venezuela. Incluye el número de pieles cosechadas clasificadas por clases de tamaño industriales, densidades de animales estimadas en censos, tipo de finca de acuerdo a su superficie de terreno, y características ecológicas de los cuerpos de agua. La serie de mapas temáticos obtenida con las cosechas y densidades, permite una visión histórica del desarrollo del Programa durante su aplicación. Las áreas con extracción de pieles grandes para cada región ecológica mostraron una reducción desde 1998 hasta 2000. Las regiones ecológicas Bajo Apure y Hoya de Arismendi presentaron los valores históricos más elevados de densidad. Los datos acumulados desde 1992 hasta 2000 permiten establecer tendencias poblacionales generales en una visión espacial.

INTRODUCTION

GIS relates geo-positioned locations on digital cartographic images with an associated database, allowing interactive achievement of a full description of the attributive database used to develop the system. Use of Geographical Information System (GIS) as a tool for spatial studies of crocodilians, including its biology, distribution, restoration, monitoring, modeling among other applications, have been recently transformed in one of the most efficient support for design and control of sustainable management programs (Miller et al. 1998, Campbell 1999). In this way, any population or descriptive information can be obtained directly from the thematic map. The present work describes the development of GIS application for the Program of Rational Use of the Baba Species (*Caiman crocodilus*) of the Ministry of Environment (MARN) in Venezuela.

METHODS

An attributive database containing information from all the farms involved in the Program since 1991 to 2000 was prepared, including land surface, cartographic position and location in the ecological regions defined by MARN: Aguas Claras, Alto Apure, Bajo Apure, Cajón of Arauca, Hoya of Arismendi, Llanos Boscosos and Guárico (Velasco & Ayarzagüena 1995).

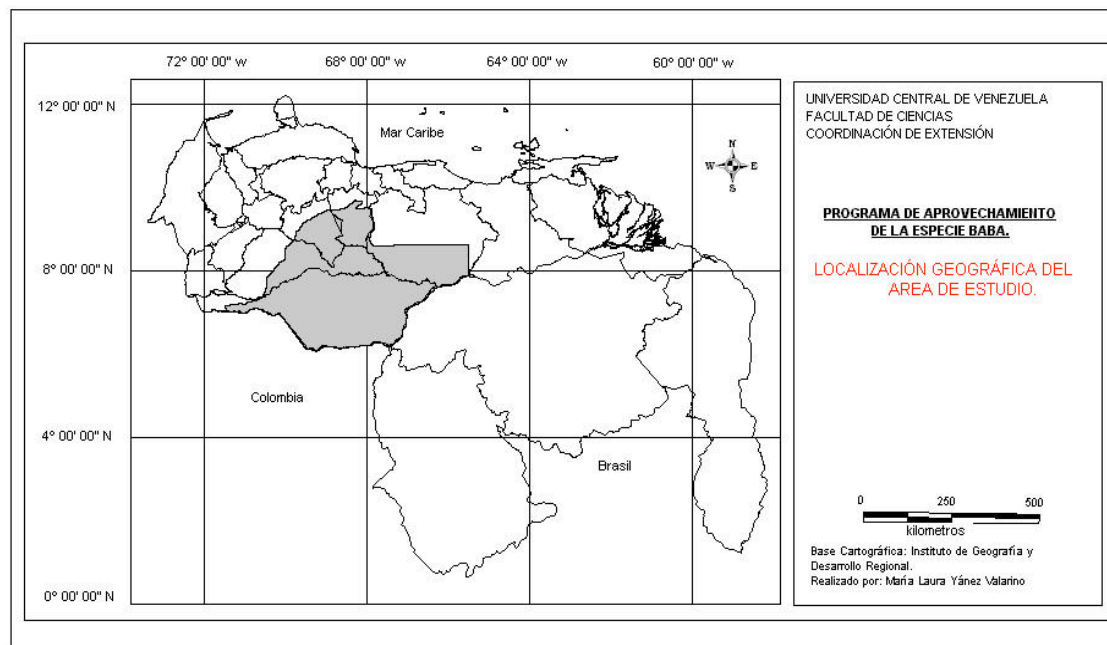
Ranches and farms participating in the Program were classified accordingly to their land surface. The number of harvested skins assigned for each ranch or farm is included, classified by industrial classes of size since 1981 to 2000 (Velasco & De Sola 1999); also, results of population censuses with estimations of density (number of counted babas / land surface in hectares), abundance and size structure in classes, type of water body, and environmental characteristics of habitat (border and aquatic vegetations) are included. Monitoring of population was performed during 1992, 1995, 1996, 1998, 1999, and 2000 to estimate wild population's densities and size classes. These results were grouped in three periods (1992, 1996 y 2000) in which all the ecological regions were surveyed (Colomine *et al.* 1996, Velasco *et al.* 1997 (1, 2), Colomine *et al.* 2000, Villarroel *et al.* 2000).

The database was applied to a Geographical Information System MAP-INFO to prepare thematic maps on farm location, harvests and estimated densities.

RESULTS AND DISCUSSION

NOTE: maps in text can be distorted.

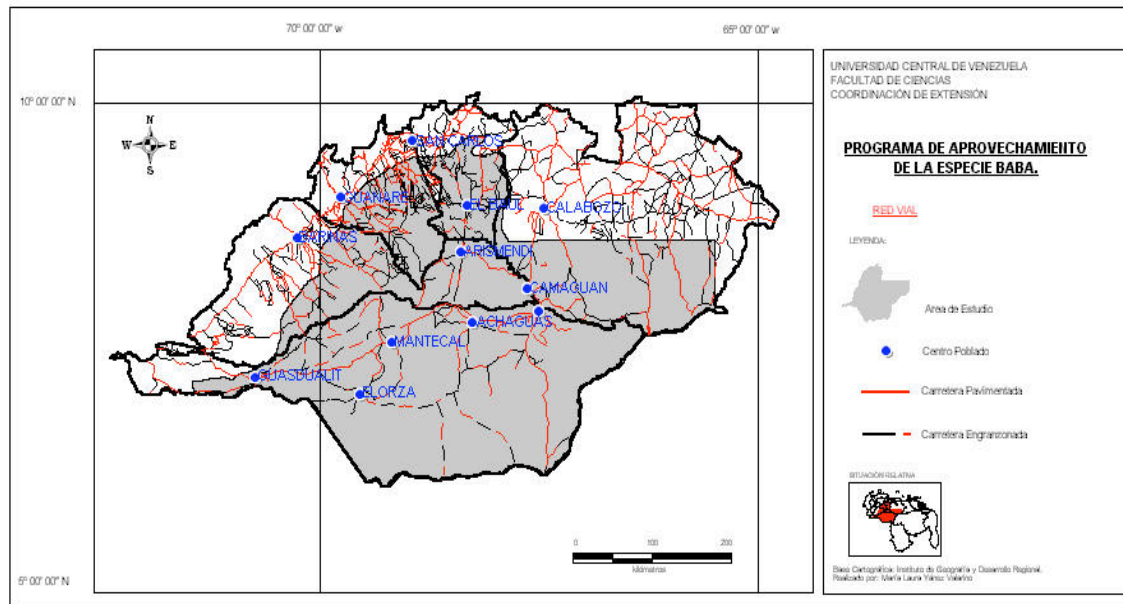
MAP 1: Study Area



The first GIS product is the location of the study area, on a cartographic base scaling 1:100.000. Map shows the limits of the ecological regions on the Western Llanos, grid in degrees, minutes and seconds.

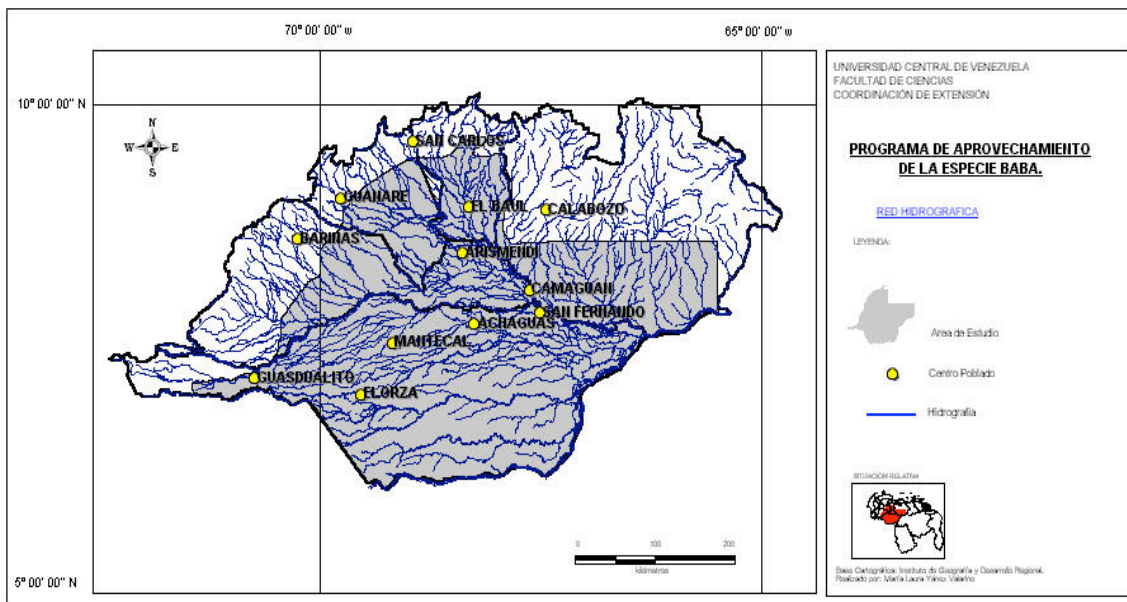
Map 2: Roads and main urban centers

On the map political limits of the States Apure, Barinas, Cojedes, Guárico and Portuguesa are included, marking the limit of ecological regions in which the Program is applied.



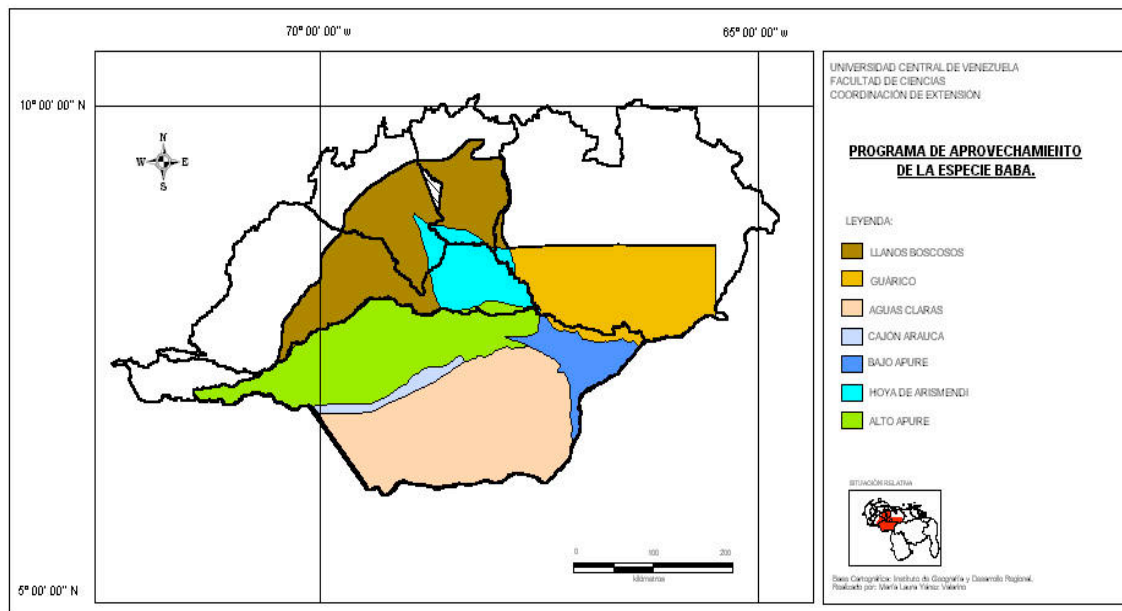
Map 3: Hydrographic system

Main rivers and natural drainages in the study area are presented .



Map 4. Ecological Regions

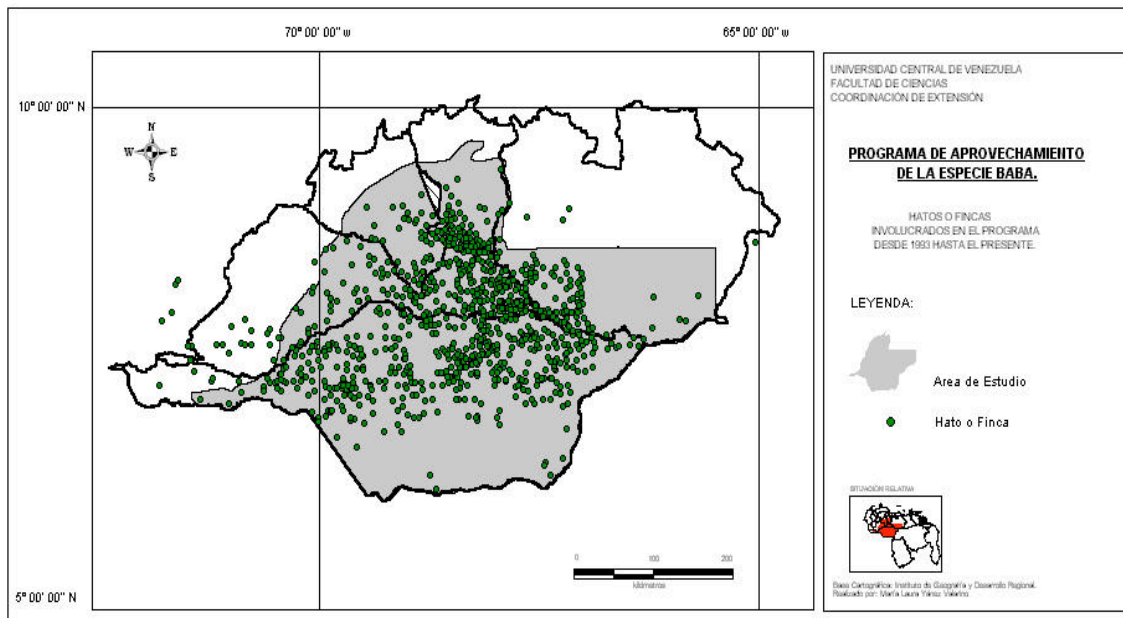
Limits of the ecological regions defined by MARN are presented.



THEMATIC MAPS ON BABA HARVESTS

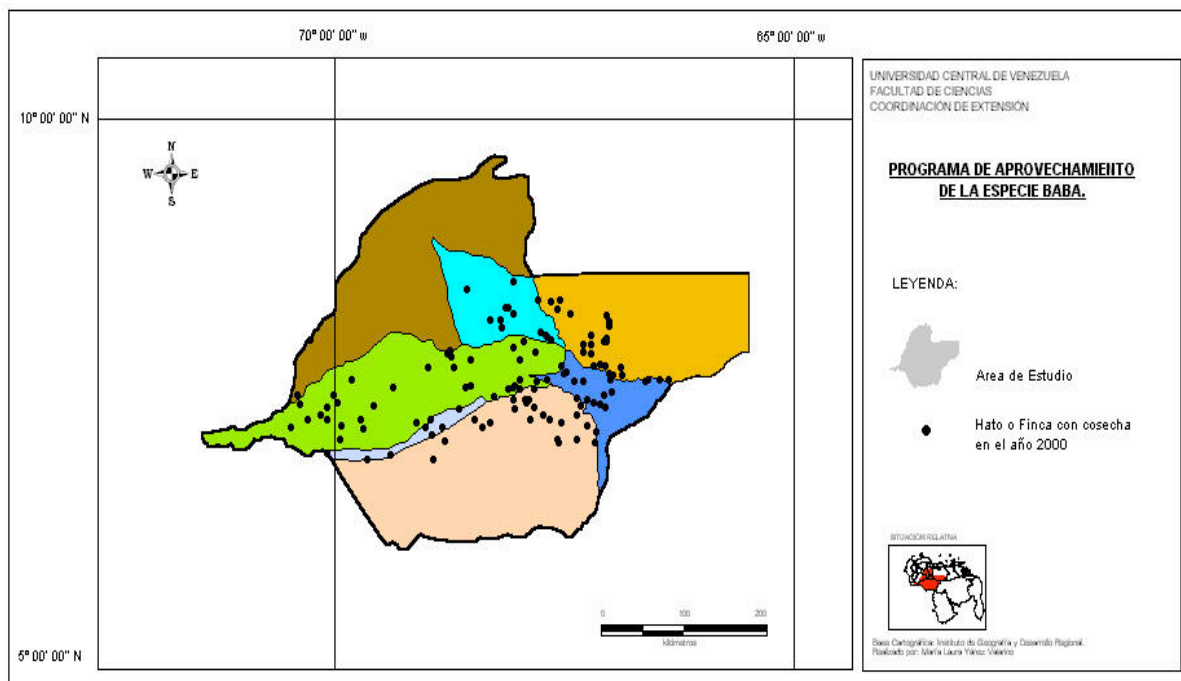
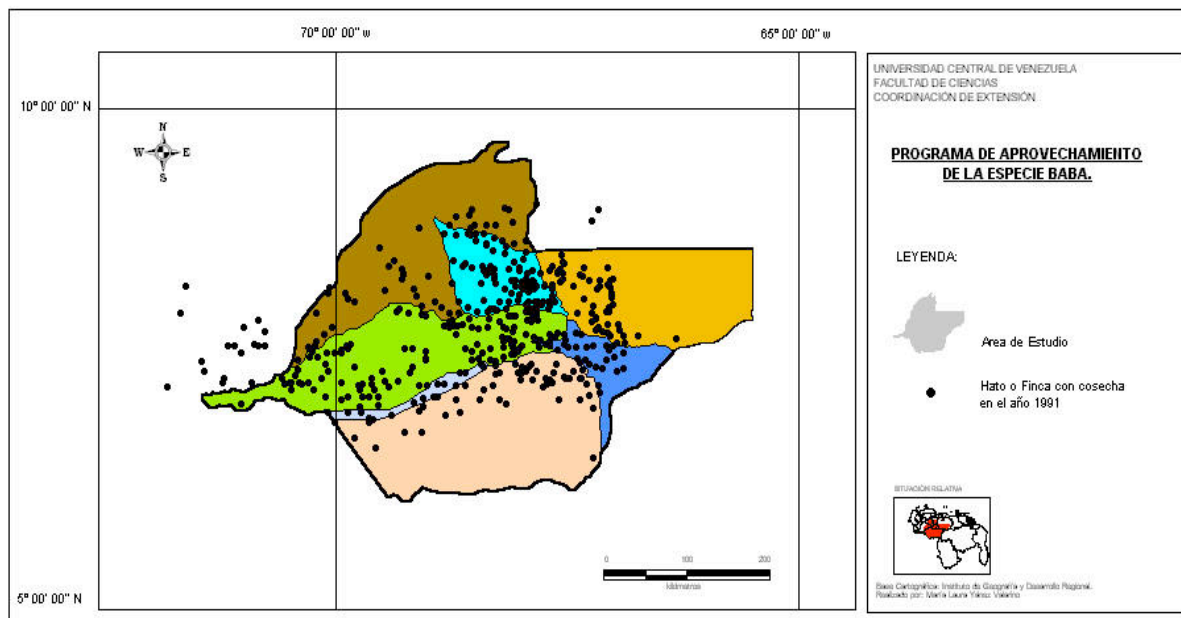
Map 5. Ranches and farms involved in the Program since 1990 to 2000.

This map contains all the geo-positioned points from the database. Points out of limits of the ecological regions are farms participating in the program before 1992, when ecological regions were defined. Each point is associated by GIS to its individual data in the database.



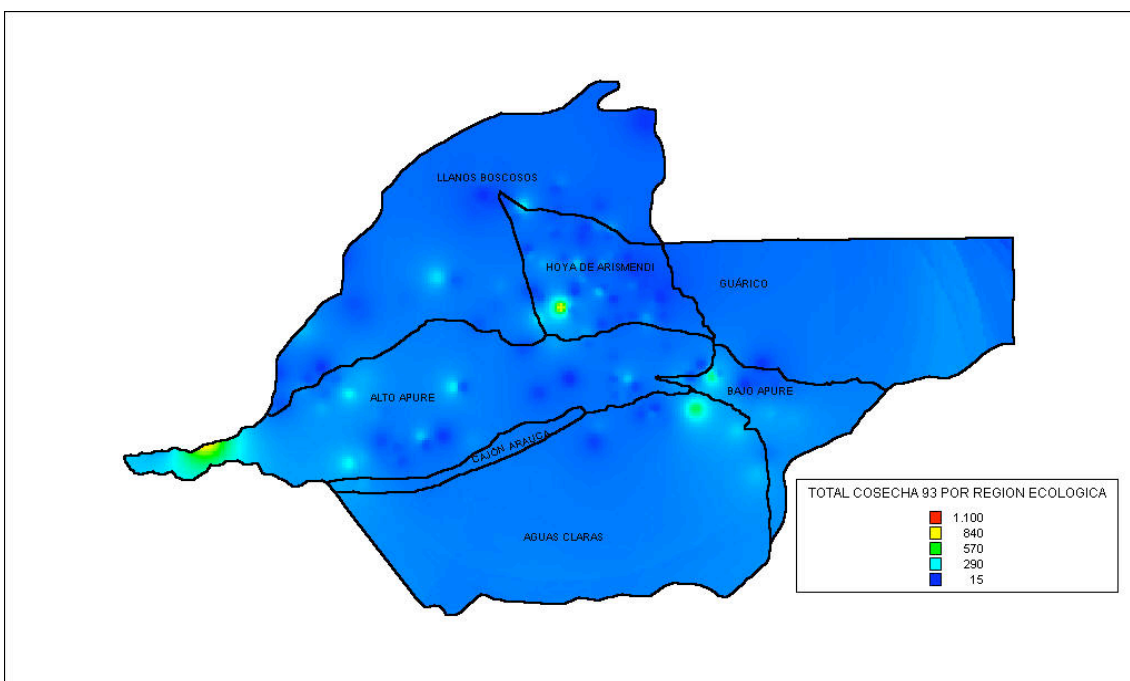
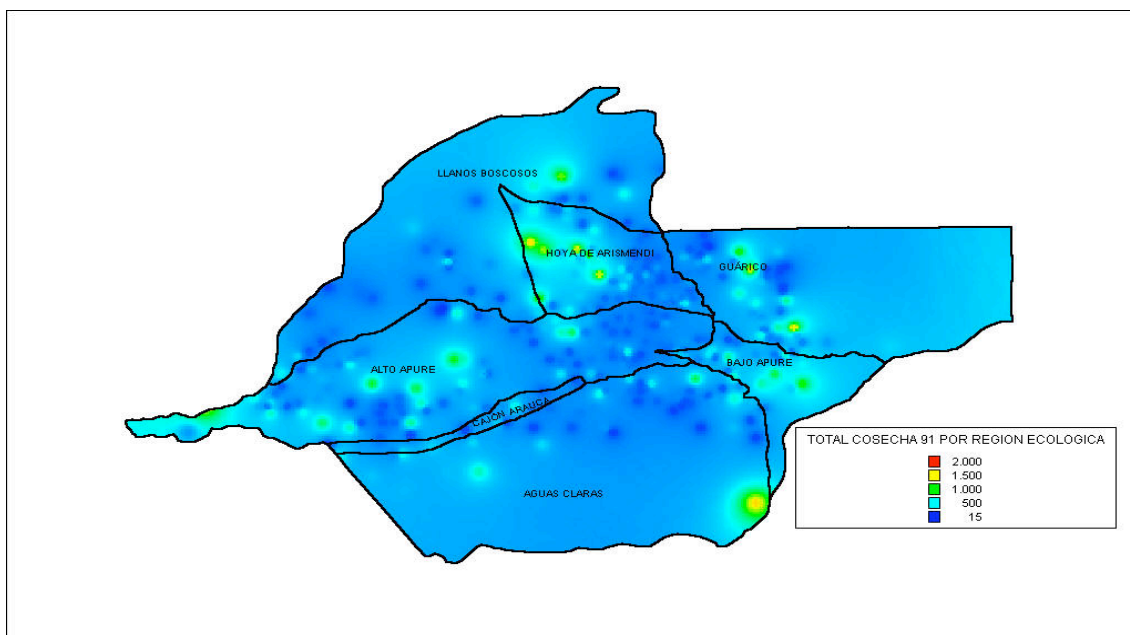
Maps 5.1 to 5.2. Ranches and Farms involved in the Program in 1991 and 2000

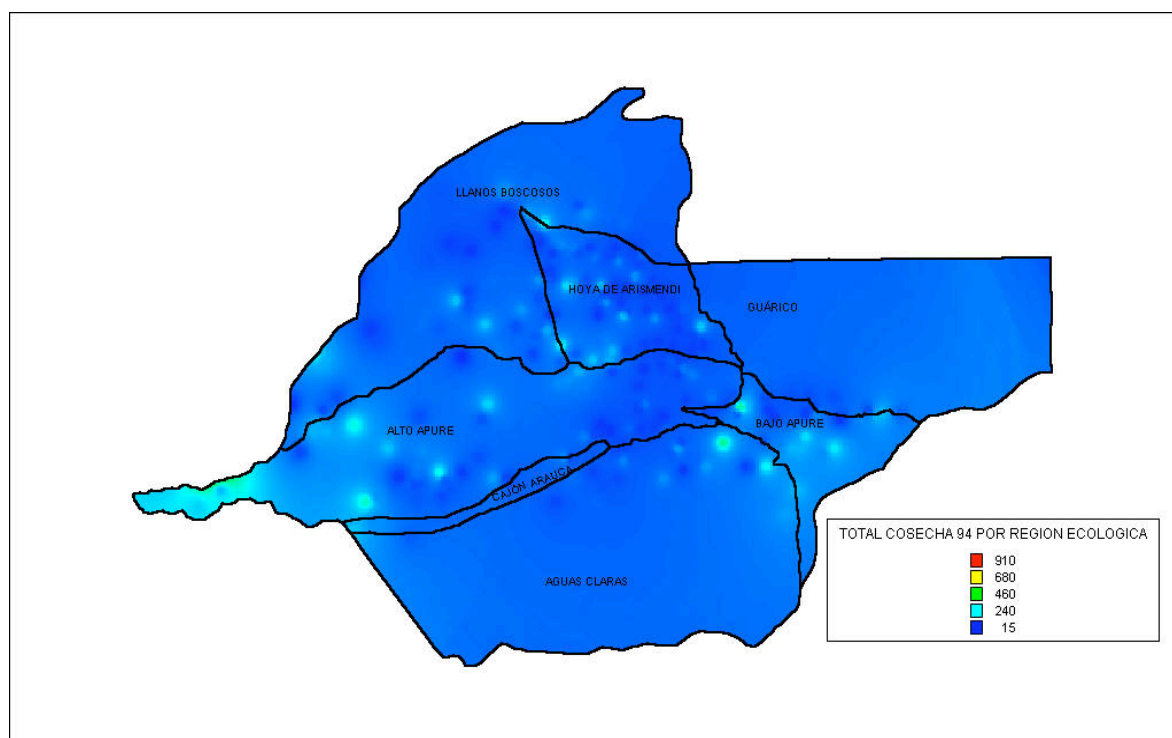
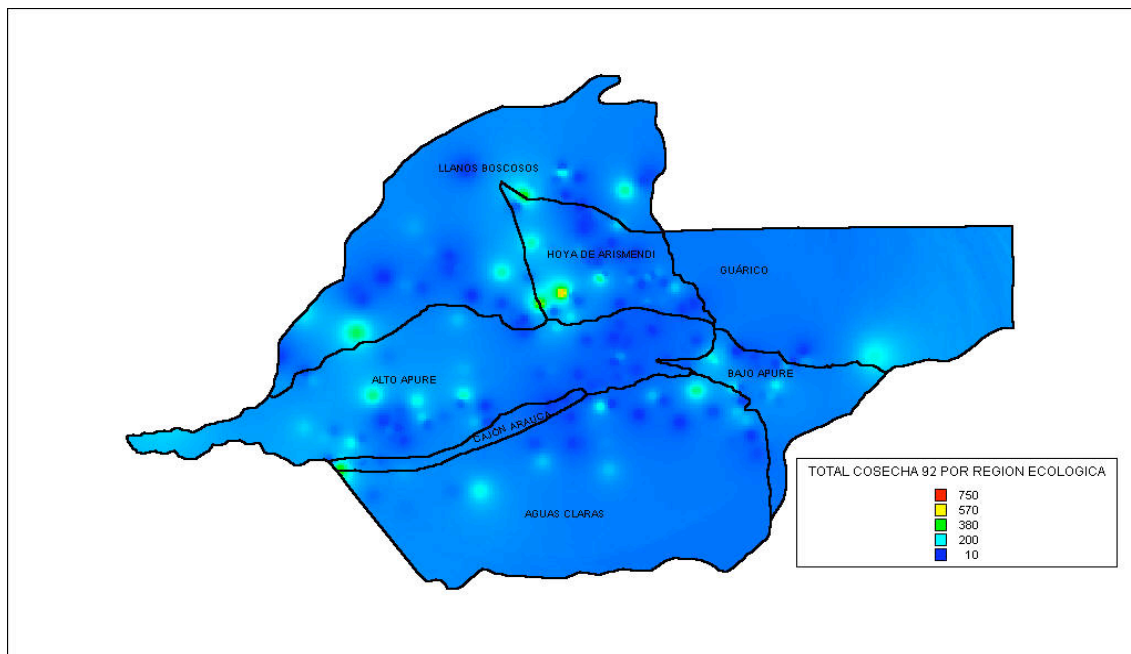
A strong reduction of the amount of ranches/farms participating in the program can be appreciated in 1991 and 2000.

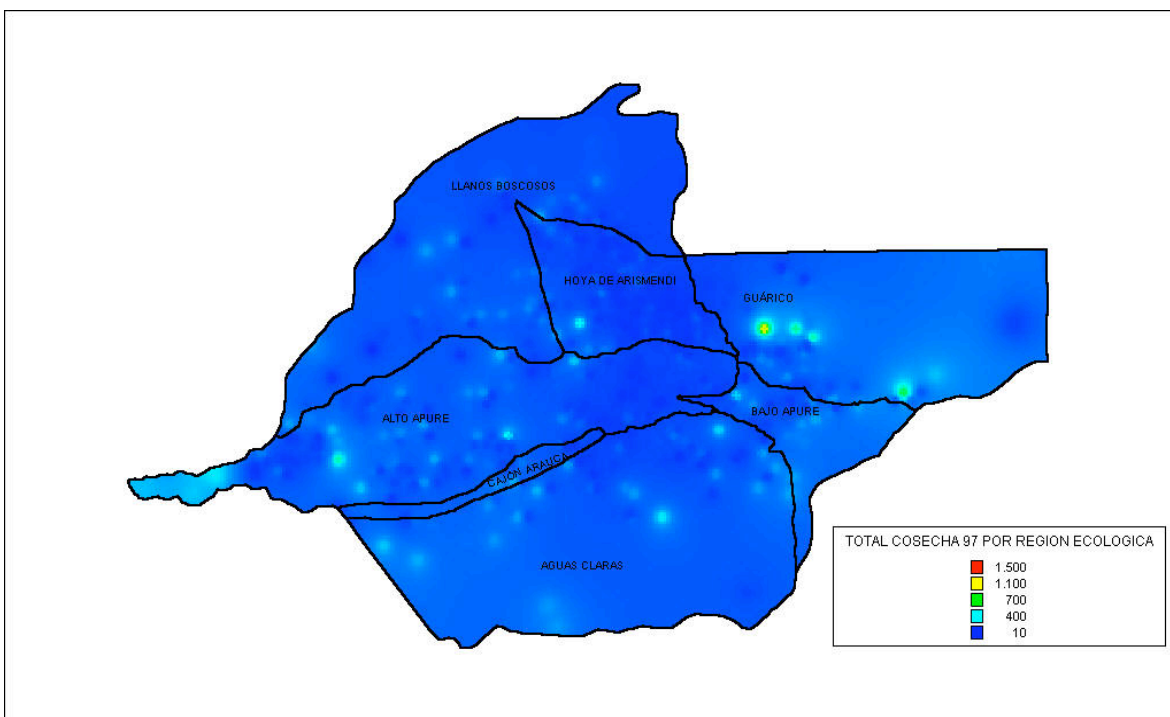
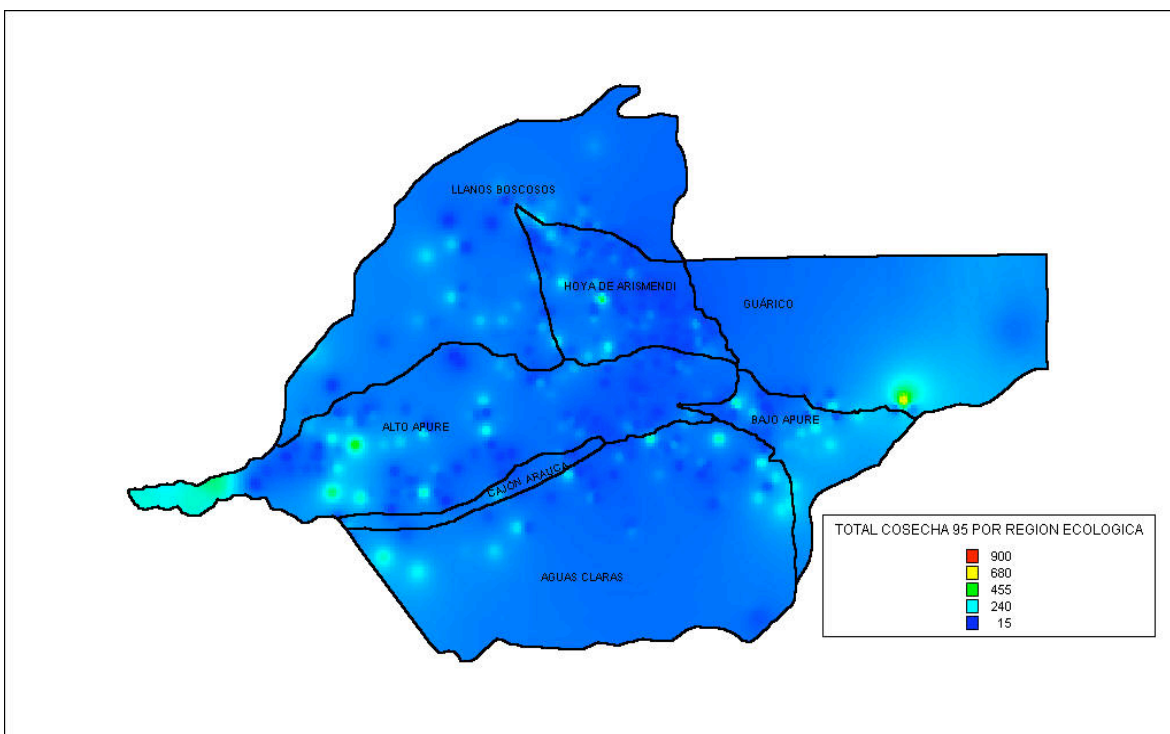


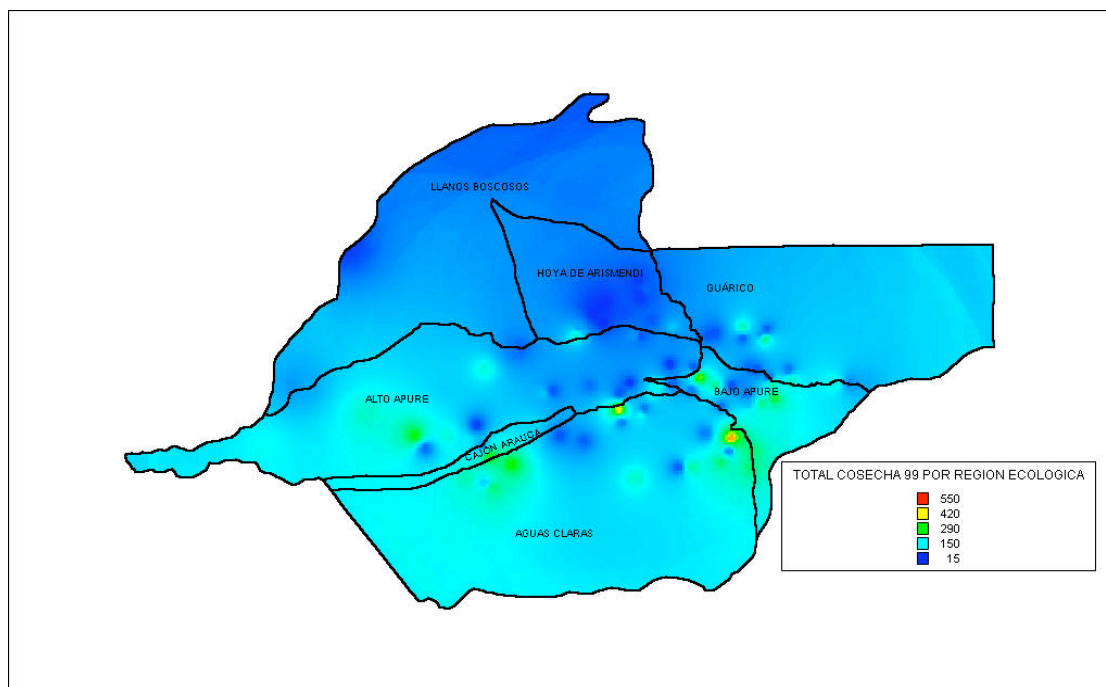
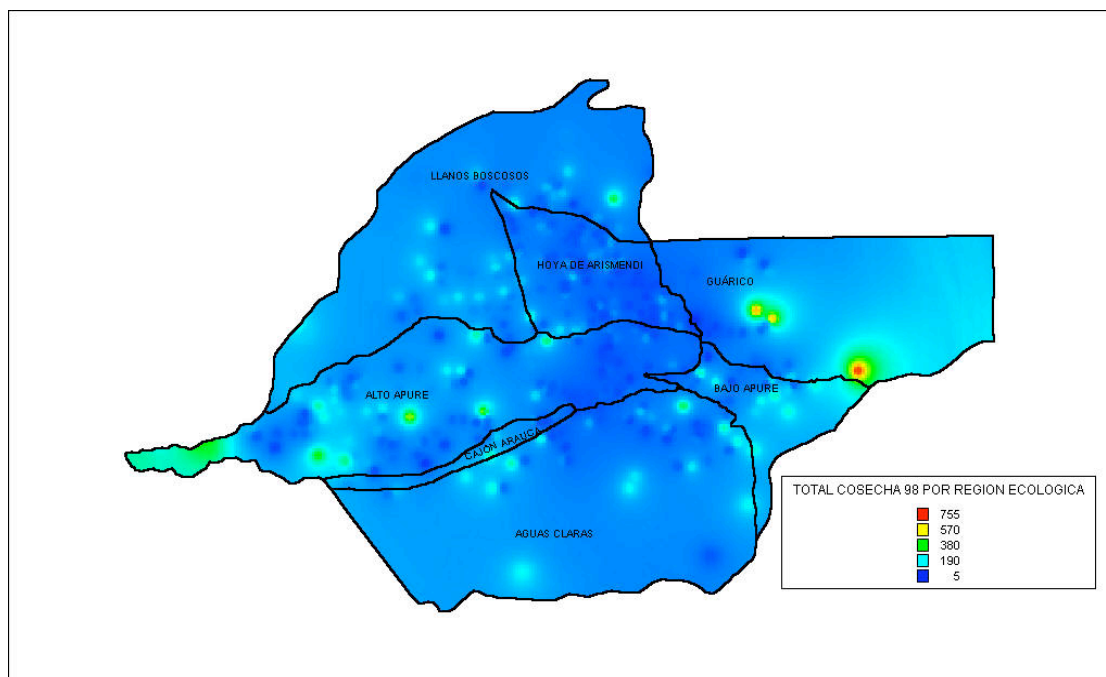
Maps 5.3 to 5.12. Thematic maps representing harvests of skins since 1991 to 2000 (except 1996 = Ecological Pause of MARN).

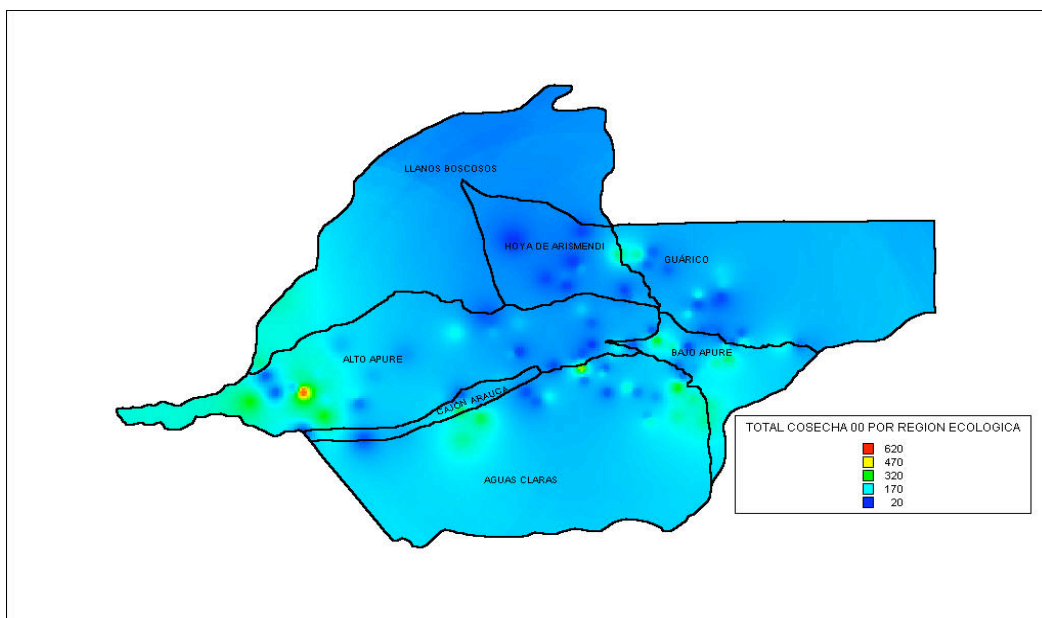
The amounts of skins were grouped into five intervals to show ranches/farms with these levels. The representation allows the location of areas from which these amounts of skins were harvested. Each map is linked to database with GIS.





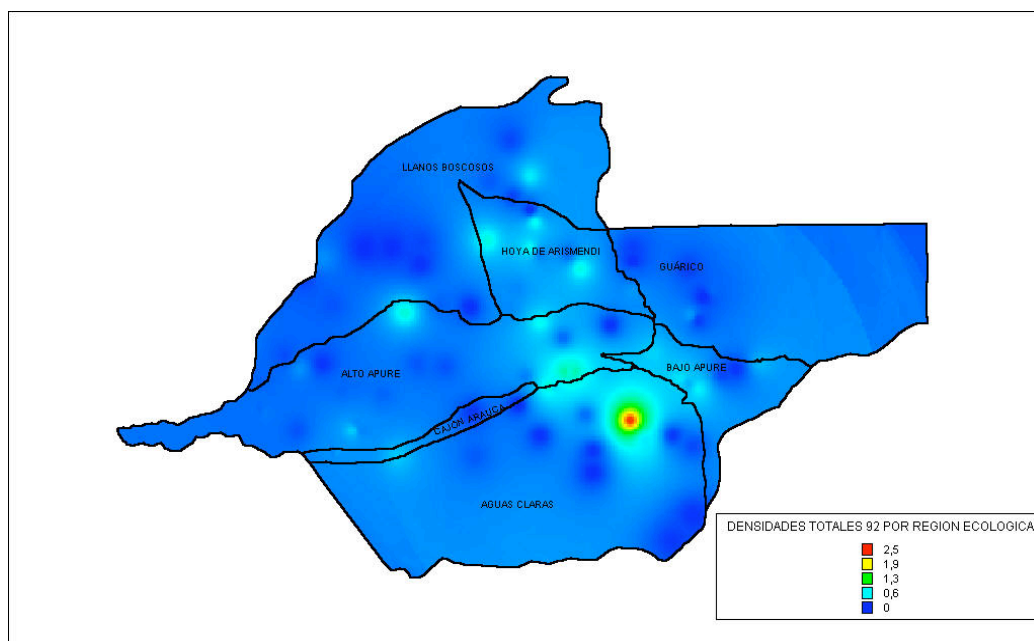


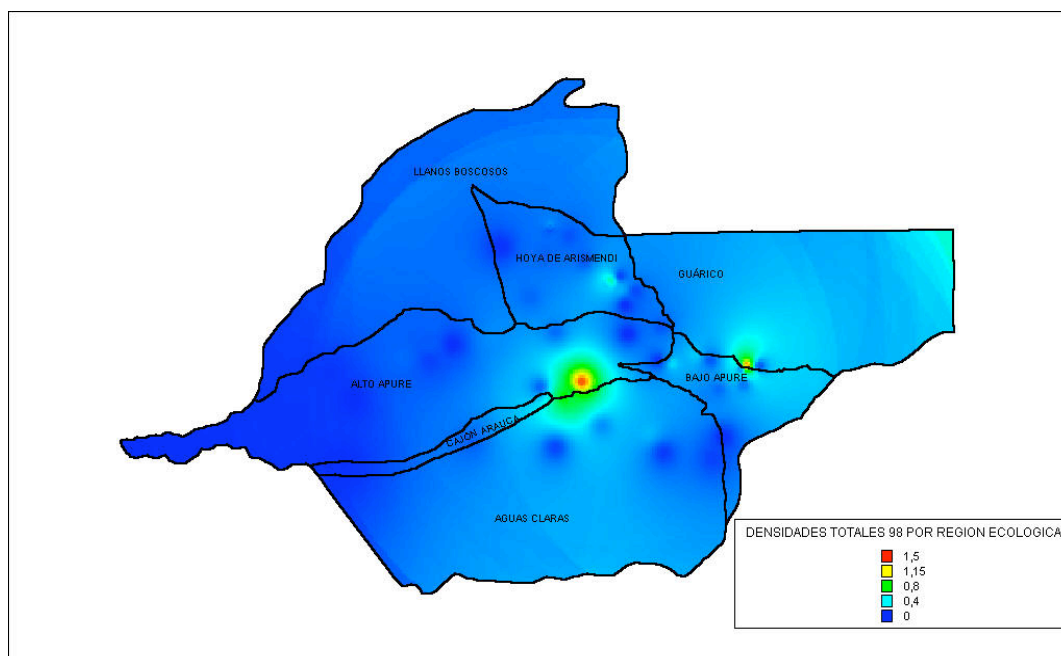
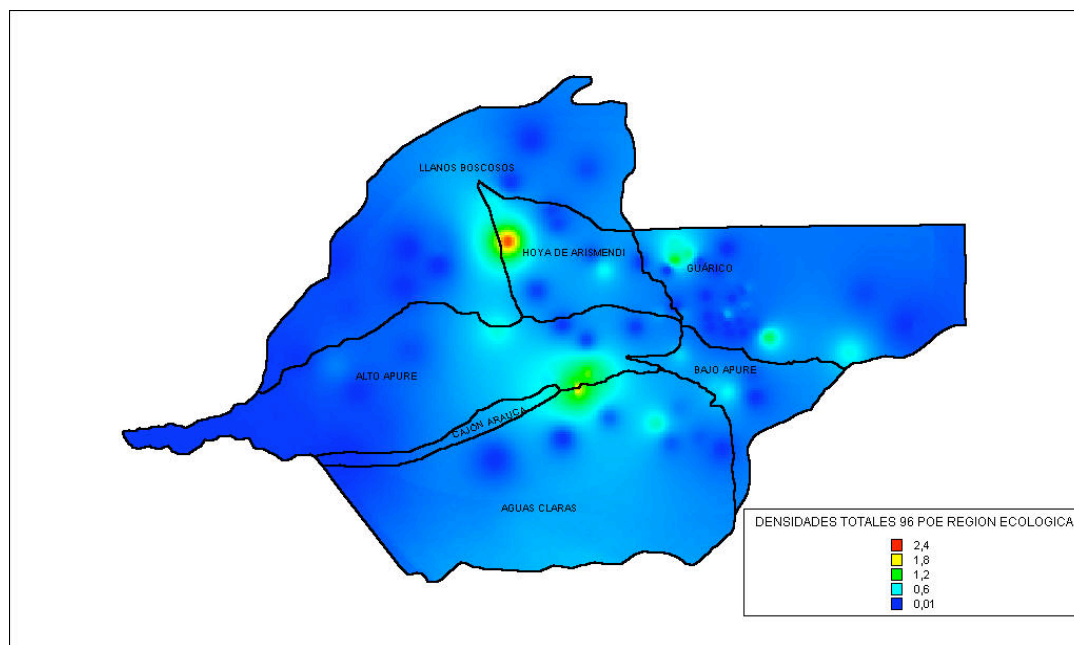




Map 6.1 to 6.3: Densities in 1992, 1996 and 1998-2000.

The amounts of densities were grouped into five intervals to show ranches/farms with these levels. The representation allows the location of areas from which these densities were determined. Each map is linked to database with GIS.





CONCLUSIONS

The yearly series of thematic maps on harvests and densities, allows a spatial vision of the historical sequence of the Program during its application. The areas with extraction of large skins for each ecological region are presented. High densities were recorded in all the censuses for the Ecological Regions Bajo Apure and Hoya of Arismendi.

Cumulative data since 1992 to 2000 (new data from 2002 are not included) are used with GIS to establish general population tendencies in a spatial view. Analysis of numerical population variables (skin harvest, densities, abundance of individuals) are currently in development using factors as aquatic and terrestrial surface, habitat characteristics and variations in time. These analyses are facilitated by the use of GIS as a tool for supporting decision making by the Program Administration.

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Role of American Alligator (*Alligator mississippiensis*) in Measuring Restoration Success in the Florida Everglades

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ABSTRACT: The American alligator (*Alligator mississippiensis*) was abundant in the pre-drainage Everglades in Southern Florida, USA. The largest populations occurred in the broad marl prairies to the east and west of the southern ridge and slough and in the freshwater mangrove zone (Figure 1). Development and water management practices have reduced the spatial extent and changed the hydro patterns of these habitats. As a result of these activities, alligator populations have decreased. Currently, restoration of hydrologic pattern and ecological function is beginning in the Everglades. Due to the alligator's ecological importance and sensitivity to hydrology, salinity, habitat and system productivity, the species was chosen as an indicator of restoration success. A number of biological attributes (relative density, relative body condition, nesting effort, and nesting success) can be measured, standard methods for monitoring have been developed, and historical information exists for alligator populations in the Everglades. These attributes can be used as success criteria at different spatial and temporal scales and to construct ecological models used for predicting restoration effects. Here, we discuss Everglades alligator population status and its role in evaluating restoration success of the Southern Everglades.

The Effect of Imposing Hunting on an Unhunted Population of the American Alligator

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ABSTRACT: The American alligator (*Alligator mississippiensis*) was considered endangered, threatened, or threatened due to similarity of appearance once throughout much of its historic and present range. The American alligator was studied in Texas to determine the effect of hunting and the role of climatic conditions on size class structure, sex composition, population, and nesting effort. The study areas were the J. D. Murphree Wildlife Management Area (JDMWMA), Jefferson County, and Jefferson County in its entirety. Methods used to assess and interpret alligator populations were night-count lines, nesting surveys, harvest data, and weather conditions. Breeding populations of alligators were stable. Average size class had been reduced, but not enough to cause alarm from a management standpoint. Sex ratio of harvested alligators was not considered detrimental to the alligator population. Climatic influences played an insignificant role in night-counts and nesting surveys. Night-counts and nesting surveys were highly affected by minimum temperatures. Night-counts were moderately correlated with daily air temperature, average air temperature, and minimum air temperature on the JDMWMA. Precipitation was correlated to nesting in Jefferson County, but not on the JDMWMA.

Seasonal Thyroxine in the American Alligator (*A. mississippiensis*)

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ABSTRACT: Little information is available on the role of thyroid hormones in regulating reptilian metabolism. Wild alligators were captured throughout the year at the Rockefeller Wildlife Refuge in Grand Chenier, LA. Both males and females (N=1054) ranging from 58 cm to 361 cm in length were captured between 9 A.M. and midnight from May 2000 to April 2001. Animals were captured from a variety of habitats including marsh, open water, canals, and ponds. Thyroid hormones were measured by radioimmunoassay. Four criteria were used to evaluate changes in hormone levels: sex, total length, season, and time of day. Thyroxine (T_4) was found to be highly variable with levels ranging from 0.5 to 57 ng/mL. Triiodothyronine (T_3) levels were below the sensitivity of the assay (0.5ng/mL). No T_4 differences between the sexes were observed. A distinct seasonal peak in T_4 was observed between December and April, peaking in March with highest levels observed in the evening. No consistent relationship between hormone levels and length was observed. Alligators thus exhibit T_4 levels among the highest recorded for reptiles. The seasonal data suggest that behavioral or environmental conditions during early spring activate T_4 production in alligators.

Variation in Gonadotropin-Induced Testosterone Synthesis in Juvenile Alligators from Contaminated and Reference Lakes

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Keywords: endocrine disruption, xenoestrogens, American alligator, FSH, gonadotropin challenge, testosterone, embryogenesis

ABSTRACT: Previous research on alligators living in Florida's Lake Apopka (contaminated with organochlorines and other known endocrine disrupting chemicals) has shown that males have severely reduced plasma testosterone levels compared to males from Lake Woodruff National Wildlife Refuge (relatively uncontaminated). However, in vitro incubations of alligator testes from the two lakes resulted in similar testosterone production. Therefore, we hypothesized that the observed testosterone reduction is due to decreased testicular response to gonadotropin, resulting in low testosterone synthesis. Furthermore, we hypothesized that this is a persistent deficiency initiated during embryogenesis. Juvenile male alligators from Lake Apopka and Lake Woodruff were hatched and raised together in an enclosed outdoor pen in Gainesville, Florida. To test testicular response, each alligator was injected with a superphysiological dose of ovine FSH (150ng/mL plasma). Plasma testosterone was measured (by radioimmunoassay) in repeated blood samples taken at 0, 0.5, 1, 2, 3, 6, 12, 24, 48, and 72 (May and July only) hours after injection. To capture seasonal variation in response, we repeated the experiment three times during the normal breeding season (March, May, and July, 2000). All alligators responded to exogenous FSH by synthesizing increased levels of testosterone ($p < 0.0001$ for all months). However, alligators from Lake Apopka synthesized significantly less testosterone in July than those from Lake Woodruff ($p = 0.027$). In addition, alligators from Lake Woodruff exhibited strong seasonal variation in their response to gonadotropin, making more testosterone in July than in March or May ($p < 0.02$). No seasonal variation was observed in alligators from Lake Apopka ($p > 0.11$). We conclude that the reduction in plasma testosterone observed in wild alligators from Lake Apopka is due in part to decreased responsiveness to gonadotropin, and that this effect is initiated during embryogenesis.

Alligator Nest Attendance: Observations on Timing and Behavior

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ABSTRACT: The relationship between female alligators and their nests was investigated on Sabine National Wildlife Refuge, LA. During 1998 and 1999, 212 nests were monitored and 112 females captured and associated with specific nests. Data from 17 infrared activity monitors located at the base, and 16 at the top of randomly selected alligator nests provided activity information. Remote video verified that most records were alligators. Alligators spent less than 10% of time at nests and more time was spent at the base than the top of the nest. Visits to the top of nests were less frequent late in incubation and more time was spent at the base during daytime than nighttime. Visits did not differ between successful and unsuccessful nests or between nests with eggs and empty nests. Visits were less frequent at nests with fire ants. Alligators added material to nests early in incubation, but did not repair damage incurred later. Nests with structural manipulations (n=20) were not less successful than unmanipulated nests. Females located at nests rarely showed aggression. At #5 m of a nest all alligators located were female. Males were found near nests, but at distances >5 m.

Adult alligators (*Alligator mississippiensis*) in proximity to nests are presumed to be the attending maternal parent of the clutch within. Some researchers reserve this label for animals seen within 20 meters of a nest (Metzen, 1977; Hunt and Ogden, 1991). Others restrict the definition to include only animals found at the nest itself (Joanen, 1969; Deitz and Hines, 1980; Kushlan and Kushlan, 1980; Platt et al., 1995; Reagan et al., 2000). There has been little effort made to test the presumption of maternity for observed attending alligators. Hunt (1987) observed the same individuals, identified on the basis of distinctive morphological characteristics, attending nests throughout incubation, but did not confirm sex.

Functions of alligator nest attendance are described as nest maintenance and nest protection. Descriptions of nest maintenance have included repair of damaged nests (Deitz and Hines, 1980; Ruckel and Steele, 1984; Hunt and Ogden, 1991) and regulation of temperature and moisture (McIlhenny 1935). Lower rates of depredation have been found in conjunction with female activity at a site (Metzen, 1977; Deitz and Hines, 1980; Hunt and Ogden, 1991) and is considered evidence that females actively protect their nests. Aggression towards humans at nests is also considered an indication that protective behavior is directed towards smaller nest predators (Deitz and Hines, 1980; Hunt and Ogden, 1991).

Researchers report regular attendance (Deitz and Hines, 1980; Kushlan and Kushlan, 1980; Hunt and Ogden, 1991), maintenance (Ruckel and Steele, 1984; Hunt and Ogden, 1991), and protection (Joanen, 1969; Metzen, 1977; Deitz and Hines, 1980; Kushlan and Kushlan, 1980; Hunt and Ogden, 1991) of nests by adult alligators. The frequency of these behaviors, however, are not consistent within or across studies. Nest attendance ranges from only 14.9% (Deitz and Hines, 1980) to 66% (Hunt and Ogden, 1991). Nest maintenance is reported by several researchers (McIlhenny, 1935; Deitz and Hines, 1980; Ruckel and Steele, 1984; Hunt and Ogden, 1991), but is not noted in other nest ecology studies. Rates of female aggression towards humans at nests range from 0% (Goodwin and Marion, 1978; Platt et al., 1995) to 33% (Hunt and Ogden, 1991). Researchers have witnessed nest protection against simulated natural predators (Kushlan and Kushlan, 1980) and lower predation rates at attended nests (Metzen, 1977; Deitz and Hines, 1980; Hunt and Ogden, 1991). However, there are no observed occurrences of defense against natural predators reported, and Joanen (1969) saw predation of nests by racoon in the presence of attending adults.

Despite the purposes ascribed to attendance, constancy and aggressive defense do not fully characterize alligator nest attendance. Joanen (1969) recorded visitation to four nests and concluded that alligators pay little attention to their nests after egg deposition. Reagan et al. (2000) developed a model based on 137 nests that hatched indicating alligator nest attendance was influenced by fire ant presence, but attendance did not influence final nest success.

The goal of this study is to clarify the relationship between female alligators and their nests by describing nest attendance. Patterns of visitation at a random sample of nests are described, and individuals in proximity to nests are identified.

MATERIALS AND METHODS

The research was conducted on Sabine National Wildlife Refuge (Sabine NWR) in southwestern Louisiana. The coastal marsh study area included fresh (8 km²) and intermediate (21 km²) marsh impoundments (Chabreck and Linscombe, 1988). Bordering levees were dominated by Chinese tallow-tree (Sapium sebiferum) and interior areas by marshhay cordgrass (Spartina patens). The extensive areas of Spartina patens were broken by patches of roseau cane (Phragmites communis), cattail (Typha spp.), and by numerous small pools and shallow open water flats.

Nests were located during 1998 from an airboat and from an airboat and a helicopter during 1999. Nests were marked and monitored repeatedly throughout incubation. The areas around nests were searched for the presence of dens and submerged alligators by feeling the bottom of pools with a pole and investigating visual cues to alligator presence. When found, alligators were captured and marked with a tail-scute notch and a Passive Integrated Transponder (PIT) tag (American Veterinary Identification Devices [AVID], Norco, CA). Body measurements, sex, and general comments were recorded for each captured animal. The tail-scute notch served as a non-unique external visual mark. The PIT tag was a unique identifier and was used to re-identify individuals. Total length was used to assign adult animals to size classes; Small (<1.83 m), Medium (1.83 - 2.12 m), Large (2.13 - 2.42 m), and Very-Large (>2.42 m).

The association of captured alligators with nests was based on proximity, connecting trails, and the sex and size of the animal. Alligators were associated with nests if they were female, adult size (\$1.52 m total length), and in close proximity of a nest. Alligators within 5 m of a nest, or greater than 5 m and connected to the nest by a distinct trail, were considered to be in close proximity of the nest. An associated female alligator was assumed to be the maternal parent of the clutch in the respective nest. The behavior of associated female alligators was categorized on the basis of the attendance behaviors described by Kushlan and Kushlan (1980). Alligators that showed behaviors of 'Submerged' or 'Approach' were termed non-aggressive, while animals that used more aggressive behaviors were termed aggressive.

Activity monitors using active infrared light (TM-1500, Goodson and Associates, Lenexa, KS) were placed at nest sites to document visits by adult alligators throughout incubation. The activity monitors used infrared light pulses to establish an active line between two units, a flashing infrared light and recorder. Time and date were recorded with each interruption of the active line. A one-second interruption, the maximum possible, was specified to minimize records of non-target species. Active lines were placed at 20 - 26 cm above the ground surface or 10 - 16 cm above water.

During the nesting season of 1998, activity monitors were placed at the base of 19 randomly selected nests. They were placed tangential and within one foot of the nest base. The active line covered access to the most active aspect of the nest. Depending on the site specific habitat, the active line of the timer ran above mud, grass or water. During the nesting season of 1999, timers were placed with the active line crossing above the top center of 19 randomly selected nests. Vegetation was trimmed to maintain clear active lines.

The reliability of the activity monitors was tested using a linked 35 mm camera and video camera system (TM 35-1 Camera Kit, TM500 and TM Video Camera, Goodson and Associates, Lenexa, Kansas). The video system had a four second time delay following interruption of the active line.

Activity monitor reliability was also tested by placing monitors across 2 nests inside alligator enclosures.

Activity monitor data were expressed as the presence or absence of a visit during each 15-minute block of the monitored time. The data for each sampled nest were summarized using three measurements: the proportion of time that received visitation; the mean duration of visits; and the mean interval between visits. The proportion of time that nests received visitation was defined by the number of 15-minute blocks including visitation among those blocks monitored. The mean duration of visits at nests was defined by the number of consecutive 15-minute blocks including visitation. The mean interval between visits at nests was defined by the number of 15-minute blocks between successive visits. Nests monitored for less than 25% of the incubation season were excluded from analysis, two from 1998 and three from 1999. Nests without eggs (empty nests), three from 1998 and one from 1999, were excluded from all analyses excepting the comparison between empty nests and nests with eggs.

Patterns of visitation were assessed by comparing visitation during the following four incubation periods; early incubation (days 1-30 after deposition), temperature sensitive period (days 31-45 after deposition), late incubation (days 46-60 after deposition) and pre-release (>60 days after deposition). Single annual dates of deposition were defined for this purpose and correspond to dates of peak deposition in this study area. Daily patterns of visitation were assessed by comparing visitations during the following two daily periods: daytime (06:00 - 19:59 hours), and nighttime (20:00 - 05:59 hours). Visitation patterns were also compared based on nest success and physical characteristics of nests and associated females. Visitation at successful nests was compared to visitation at failed nests. Visitation was compared between nests with adjacent water and those nests without adjacent water. Visitation at nests with fire ant colonies was compared to nests without colonies, and visitation at empty nests was compared to visitation at nests with eggs. Visitation at nests with associated females was compared between nests with females of different size classes.

All comparisons were made using Analysis of Variance with an alpha level of 0.05 and nests as the experimental unit. Comparisons were made between the activity monitor location (base of nest, top of nest), the group (incubation periods, daily periods, or physical characteristics), and interactions of the location and group. The sample year (1998, 1999) and location were confounded in these analyses.

Modifications to the structure of 20 randomly selected nests were made during days 30 or 31 of incubation in 1999. Nest material was removed and left at the base of 10 nests; removal halved the depth to the top of the clutch. At the remaining 10 modified nests, nesting material was gathered on site and added to nests; additions doubled the depth to the top of the clutch. Strings were placed across the top of modified nests to assist in recognition of alligator nest repairs by researchers during successive visits. Two-tailed Fisher's Exact tests were used to compare the observed and expected counts for success of nests modified by addition and removal of material, and 38 randomly selected and unmanipulated control nests.

RESULTS

During the 1998 and 1999 nesting seasons 117 adult alligators were captured in close proximity to alligator nests. The proportion of captured adult alligators in proximity to nests that were female decreased with increasing distance from the nest (Table 1). Within five meters of nests all 81 adult alligators found were female. At distances greater than five meters, not all adult alligators found in proximity of nests were female. Five adult male alligators were found in proximity to nests, but were excluded from association due to their sex. All associated females were located within 30 m of the nests, except one female at 100 m. This animal was linked to the nest by a single, clear trail across drying mud flats between the nest and the den. The alligator at a nest was identified more than once during incubation at five nests. At two nests the associated female was identified within 20 m of the nest twice and at one nest, a third time as well. At one nest the same large male was identified within 20 m of the nest two times, and at the final nest a large male replaced the female identified earlier during incubation. No female was located in proximity of the nests at the same time these males were present.

Table 1. Adult alligators found in proximity to alligator nests, Sabine NWR, 1998-99

Distance from a nest	No. of animals captured	Proportion female
≤ 5 meters	81	1.00
6 - 10 meters	13	0.92
11 - 15 meters	12	0.83
>15 meters	11	0.82

A total of 212 nests with eggs were monitored throughout this study. Female alligators were associated with 52.8% of these nests. The majority (99/112) of all associated females identified were submerged in a den during researcher visits to the nest. Alligators displayed aggression towards humans at only five (2.4%) of all monitored nests. In all cases, these individuals were adult females within 5 m of a nest. In two of these cases, the females were captured on land and did not have water available at the site.

Nests were visited by researchers an average of 6.6 times during each nesting season. Associated females were found during only 8% of all visits at nests. Nest material was added by alligators after egg deposition to 21 nests during 1998 and 15 nests during 1999. In 1998, 90% of new material applications were made before day 30 of incubation. During 1999, 93% of new material applications were also made before day 30 of incubation. The latest addition of material by alligators was by day 34. None of the 20 nests with applied structural modifications were repaired by alligators. The success of nests with researcher additions of material was not different than those treated with removals of material (Fischer's exact test: $P=1.00$). When these treatment nests were pooled and compared to control nests, there was no evidence that nest success differed (Fischer's exact test: $P=0.731$).

A total of 126,649 15-minute blocks were monitored for visitation during 1998 and 1999. Activity data indicated visitation to nests occurred at relatively low levels throughout incubation, regardless of location of the monitors (Table 2). At the base of the nest the proportion of time spent visiting was greater ($F_{1,27}=53.83$, $P<0.01$), the duration of visits was longer ($F_{1,27}=70.74$, $P<0.01$), and the interval between visits was shorter ($F_{1,27}=7.80$, $df=1$, $P<0.01$) than at the top of the nest (Table 3).

Table 2. The amount of visitation at alligator nests, Sabine NWR, 1998-99.

Incubation Period	Mean Proportion of Time Spent (SE)	
	Base of nest	Top of nest
Early Incubation	0.104 (0.018)	0.014 (0.018)
Temperature-Sensitive Period	0.060 (0.018)	0.009 (0.017)
Late Incubation	0.048 (0.018)	0.003 (0.017)
Pre-Release	0.142 (0.030)	0.004 (0.017)

Table 3. The overall amount of visitation at alligator nests, Sabine NWR, 1998-99.

Visitation Measurement	Base of nest			Top of nest		
	Mean	Among nest SE (df)	Within nest SE (df)	Mean	Among nest SE (df)	Within nest SE (df)
Proportion of time visiting	0.071	0.008 (13)		0.007	0.006 (14)	
Duration of visits, in hours	0.735	0.175 (13)	0.034 (1019)	0.313	0.066 (14)	0.011 (358)
Interval between visits, in hours	14.023	7.443 (13)	0.361 (1898)	86.257	93.097 (14)	4.374 (339)

Comparisons among the base of nest measurements indicated significant differences occurred between the proportion of time spent during daily periods ($F_{1,54}=6.14$, $P<0.02$) and the proportion of time spent ($F_{2,9}=9.59$, $P<0.01$) and duration of visits ($F_{2,9}=5.44$, $P<0.03$) between size classes of females. Visits included a greater proportion of daytime (0.086, $SE=0.0068$) than nighttime (0.049, $SE=0.0068$) hours. Very-Large females ($n=5$) spent a greater proportion of time visiting (0.104, $SE=0.0063$) and had longer visits (0.859 hours, $SE=0.0507$) than females in smaller size classes. Large females ($n=4$) also spent a greater proportion of time visiting (0.061, $SE=0.0071$) and had longer visit duration (0.686 hours, $SE=0.0567$) than Medium females ($n=1$)(0.009, $SE=0.0141$)(0.318 hours, $SE=0.1133$).

Differences occurred among top of nest measurements for the interval between visits for incubation periods ($F_{3,84}=3.20$, $P<0.03$)(Table 4) and nests with and without fire ant colonies ($F_{1,25}=5.21$, $P<0.03$). The pre-release period had longer intervals between visits than any earlier period, and late incubation had longer intervals than early incubation. The interval between visits was much longer for nests with ants (182.45 hours, $SE=35.79$) than nests without ants (62.21 hours, $SE=17.9$). Visitation measurements were not statistically different between successful and unsuccessful nests, nests with eggs and empty nests, or nests with water on site and those without ($P>0.10$).

The video camera confirmed that at least 61% of records were caused by adult alligators. An additional 16% were explained by purple gallinule (*Porphyryla martinica*), common moorhen (*Gallinula chloropus*), and boat-tailed grackle (*Quiscalus major*). The remaining 23% were unexplained because the source of the record could not be seen. Activity monitors within alligator exclosures recorded nine erroneous visits, which represent 0.07% of the 12,719 15-minute blocks monitored.

Table 4. Intervals (hours) between visits at alligator nests, Sabine NWR, 1998-99.

Comparisons not significantly different at the 0.05 level are indicated by same letter groupings.

Incubation Period	Mean Interval Between Visits at the Top of Nest, in hours (SE)		
Early Incubation	20.617 (32.057)	a	
Temperature-Sensitive Period	74.080 (28.416)	a	b
Late Incubation	133.365 (33.622)		b
Pre-Release	236.996 (30.692)		c

DISCUSSION

Alligators spent less than 10% of the time during incubation at the randomly selected and monitored nests. Alligators spent a greater proportion of time at the base of the nest than at the top. The difficulty of locating and associating females with nests corroborates these low visitation rates. Despite repeated visits and thorough searches at each nest site during both years, adult females were located during only 8% of all visits and at only roughly half of all nests. Overall, alligators visited the base of nests on average every 14 hours and stayed for three-quarters of an hour. On average, visits to the top of nests occurred every 86 hours, and lasted one-third of an hour. Female alligators do maintain a loose association with their nests throughout incubation, however they do not spend much of their time at the nest itself. The high variability in visitation measurements among nests suggests that unexplained variability among females is substantial. This substantial variation also impacts our ability to detect differences in means between groups.

Although alligators spent little overall time at nests and variation between nests was high, some patterns of visitation across nests were identified. Similarly to the findings of Joanen (1969), nest top visits did not show the frequency or patterns of visitation expected of alligators performing regular nest maintenance. The differences in visitation across incubation periods may indicate that nest top visits are influenced by time; visitation to nests decreased as incubation progressed. Additions of nesting material were documented during early incubation (days 1-30), but nest repair could not be

stimulated with human-caused damage after day-30 of incubation. Deitz and Hines (1980) also saw additions of nest material during the first four weeks of incubation, and Hunt and Ogden (1991) observed repairs made to damaged nests prior to July 10, but not later. Alligators appear to have a long period of nest construction, but after this period interest in the nest structure wanes. Unrepaired modifications to nest structure after day 30 of incubation did not affect nest success. Repair by females was apparently not necessary for successful incubation and the structural modifications did not inhibit subsequent release of hatchlings. Nest maintenance seems to be an early incubation behavior and may be better described as a continuation of nest construction behavior than as on-going maintenance of nest structure.

This study suggests that fire ants in alligator nests affect alligator nest visitation, but that visitation does not affect nest success. These observations of nest visitation support the model developed by Reagan et al. (2000) predicting these same relationships. The interval between alligator visits to the top of nests with fire ants was roughly three times longer (7.6 days / 2.6 days) than that at nests without ants. Apparently site conditions, such as aggressively stinging ants in the nest, can be associated with modified attendance behavior of females, in this case decreased frequency of visits. These data also indicate success of nests is not associated with the level of visitation to a nest. Studies that have shown relationships between nest attendance and nest success (Metzen, 1977; Deitz and Hines, 1980; Hunt and Ogden, 1991) have focused on broadly categorized levels of attendance and failure due strictly to mammalian predation.

Use of the nest base was relatively constant regardless of the stage of incubation. There was also no difference in visitation detected between nests with eggs and those without; both types of nest sites received similar levels of visits. These observations suggest that alligators visit nest bases because of site preference rather than in response to the status of the clutch. Rootes and Chabreck (1993) hypothesize that behavior interpreted as nest attendance actually represents a tendency for females to localize near dens during summer. More time was spent at the base of nests during the daytime, which suggests use of nest sites for basking or resting as suggested by LeBuff (1957). Larger animals spent more time at nest sites than smaller animals, which may reflect affects of female experience, social patterns among females, or habitat quality. If larger females nest in better quality habitat then their summer core use areas may be smaller and, therefore, used more intensely than those of smaller females.

Few incidences of aggression by nesting female alligators were seen. Two of the five aggressive animals had no den or water available as escape cover. These cases of aggressive behavior could be considered self-defense. The majority of alligators at nests were retiring, and such alligators were often found within 1 m of the nest and submerged, but had not indicated their presence in any way. Deitz and Hines (1980) suggest that approach of nests by airboat may decrease visual estimates of attendance and defense. Most nest visits during this study were made by airboat, but retiring behavior by females also occurred when nest sites were approached by foot. All animals that showed aggression were at nests approached by boat. Researchers describing alligator attendance behavior (McIlhenny, 1935; Kushlan, 1973; Kushlan and Kushlan, 1980; Hunt, 1987; Hunt and Ogden, 1991) have focused their observations only on alligators that display strong protective behavior, and sample sizes have been low. These reports over-emphasize aggressive behavior, which was seen at only 2.4% of nests at Sabine NWR and at a reported maximum of 33% (Hunt and Ogden, 1991) of nests in other areas.

Identification of animals in proximity of nests showed that the assumption that an adult near the nest is the maternal parent is not always reasonable. Within 5 meters of nest sites all adult animals found were females, but at distances greater than 5 meters adult males were also found in proximity to nests. Also, at some nests with adults identified more than once, they were not found to be the same individual or sex. However, at nests with repeated identifications involving only females, it was the same individual female near the nest repeatedly. This study did not demonstrate that females found at nests were the maternal parents of the respective clutches. However, given that exclusively females were found within 5 m of nests while both sexes were found at greater distances, and in the absence of genetic evidence, it seems a reasonable working assumption that animals seen at distances within 5 m

of a nest are the maternal parent, but not those seen at greater distances.

This study suggests that alligators spend a small proportion of time during incubation at nests, alligator presence at nest sites indicates use of preferred habitat rather than strictly nest attendance, alligator contact with the nest may not affect nest success, and alligators near nests are not necessarily the maternal parent. It is, therefore, more representative to discuss females as being 'in association' with nests, rather than 'in attendance'. These conclusions are in conflict with some earlier published works on nesting ecology (McIlhenny, 1935; Metzen, 1977; Deitz and Hines, 1980; Kushlan and Kushlan, 1980; Hunt and Ogden, 1991) but are consistent with suggestions made in other works (LeBuff, 1957; Joanen, 1969; Rootes and Chabreck, 1993; Reagan et al., 2000). Alligator activity at nests and its affect on nest success needs to be further tested.

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Heart Rate Reflexes and Hysteresis during Thermoregulation in the Estuarine Crocodile, *Crocodylus porosus*

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The effect of heating and cooling on heart rate in the estuarine crocodile, *Crocodylus porosus* was studied in response to different heat transfer mechanisms and heat loads. Three heating treatments were investigated. *C. porosus* were:

1. exposed to a radiant heat source (infrared lamp) under dry conditions;
2. heated via radiant energy while half submerged in flowing water at 23°C; and
3. heated via convective transfer by increasing water temperature from 23 to 35°C.

Cooling was achieved in all treatments by removing the heat source and with *C. porosus* half submerged in flowing water at 23°C. In all treatments, the heart rate of *C. porosus* increased markedly in response to heating and decreased with the removal of the heat source. Heart rate during heating was significantly faster than during cooling at any given body temperature, i.e. there was a significant heart rate hysteresis. There were two identifiable responses to heating and cooling. During the initial stages of applying and removing the heat source, there was a dramatic increase and decrease in heart rate, respectively, indicating a possible cardiac reflex. This rapid change in heart rate with only a small change or no change in body temperature ($< 0.5^{\circ}\text{C}$) resulted in Q_{10} values greater than 4000, calling into question the usefulness of this measure on heart rate during the initial stages of heating and cooling. In the later phases of heating and cooling, heart rate changed with body temperature with Q_{10} 's = 2-3. The magnitude of the heart rate response (reflex and hysteresis) differed between treatments, with radiant heating during submergence eliciting the smallest response. The heart rate of *C. porosus*, outside of the reflex periods, was found to be a function of the heat load experienced at the animal surface. Heart rate increased or decreased rapidly when *C. porosus* experienced large positive ($> 25 \text{ W}$) or negative ($< -15 \text{ W}$) heat loads, respectively.

Our data indicate that changes in heart rate constitute a thermoregulatory mechanism that is modulated in response to behavioural posture, but that heart rate during heating and cooling is, in part, controlled independently from body temperature.

Orinoco Crocodile (*C. intermedius*) Breeding in two Venezuelan ranches for Re-introduction Purposes

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ABSTRACT: Since February 2001, FUDECI has been in charged of the Orinoco Crocodile breeding operations at Agropecuaria Puerto Miranda (APM) and collaborated with Hato Masaguaral (HM) in order to increase growth rates through applied research. Refuges assays were conducted at APM producing higher growth rates with larger refuges within the pens. Fixed-density assays showed that 1.25 ind/pen was the optimal, being recommended to reduce it as time goes by. At HM, a faster growth rate was recorded with a shallow level of water. In June 2001, 318 15-months-old juveniles were released at the Caño Guaritico Wildlife Refuge, the Aguaro-Guariquito National Park, and for

the first time at the Cinaruco river, located in the Cinaruco-Capanaparo National Park. From the total, 202 corresponded to APM with an average TL: 808.09 mm and W: 1,839.38 g; and 116 from HM with TL: 726.64 and W: 1,576 g. In July 2002, 294 16-months-old individuals were also released in almost the same locations: 188 from APM (LT: 891.72 mm, W: 2,635.75 g), and 106 from HM (LT: 838.16 mm, W: 2,136.79 g). This research is being funded by the National Office on Biological Diversity – Ministry of Environment and Natural Resources.

Effects of Egg Shell Marking on the Viability of American Alligator Eggs

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ABSTRACT: Crocodile research and management programs routinely mark alligator eggs with waterproof pens or pencil to maintain their orientation. The possible toxicity of these marking pens has been a concern. In order to test the effect of various marking methods on alligator egg hatchability and hatchling survival, alligator eggs were marked with one of five methods and a sample of eggs were not marked. Study eggs were collected from various wetlands and placed in an incubator. The hatch rate and hatchling survival of the marking methods were compared with unmarked eggs. There was not a significant difference in hatchability or survival between the marking methods. However, unmarked eggs had a significantly lower hatch rate than marked eggs.

Using the Market to Create Incentives for the Conservation of Crocodilians: A Review

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on behalf of the IUCN/SSC Crocodile Specialist Group

EXECUTIVE SUMMARY

In many countries, programmes for the conservation of crocodiles, alligators and caimans - collectively known as crocodilians – have been designed around the marketing of products from the consumptive use of wild animals. Some of these schemes have been in operation for over 25 years, and in general they have delivered tangible conservation benefits. However, there have also been difficulties and failures, which are more rarely documented. In reviewing the relationship between markets and conservation here, we have not dwelt on the successes, which are reasonably well known. Rather we have sought to document many of the problems experienced, in the hope that the inherent lessons will be useful to policy-makers, regulatory agencies, academics and practitioners of market-driven conservation.

The general findings are:

1. Markets have created economic incentives for crocodilian conservation in a diverse range of circumstances and contexts. Sustainable use has been achieved many times and some of the most commercially valuable species are widespread and abundant, rather than being threatened with extinction. There is no doubt that the economic importance of crocodilians has often led directly to stronger institutional arrangements for their conservation and ongoing management.
2. The most successful crocodilian programmes are those that: encouraged a broad range of inputs during their preparation and implementation; were flexible enough to adapt to changing circumstances; accounted for the socio-economic environment in which the programme was expected to work; and, ensured that institutions of regulation could operate in an environment as free of perverse incentives as possible.
3. The six most endangered crocodilians in the world today include both commercially valuable and valueless species. In almost every instance, a strong case can be made that the factor most influencing survival is the status of their habitat – not the level of exploitation. With some species there may be little or no scope for conservation strategies based on the marketing of biodiversity products. Other approaches will be required, despite resources being typically limited for such approaches. Unfortunately, one perverse effect of the market is that it has resulted in new and additional resources being found for the most economically important species, while the most critically endangered species have tended to remain neglected.
4. As a generalisation (to which there are some notable exceptions), it has proved more difficult than anticipated to design and implement market-driven schemes which result in crocodilians becoming a significant economic asset to the private or community landholders who live with them, and on whose goodwill their survival will ultimately depend. Government agencies, crocodilian producers (farmers, ranchers) or traders have been the most obvious beneficiaries of market-driven conservation programmes. They have received the conservation incentives and have typically been most active in ensuring that resources for crocodilian conservation keep flowing.

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5. Crocodilian resources exist mainly in less-developed countries, yet finished products are sold mostly in the more affluent industrialised nations. International trade is fundamental to programmes based on the exploitation of crocodilians, and thus CITES, the convention that controls international trade in wild species, has had an enormous impact on all operations. In the case of crocodilians, CITES has encouraged sustainable commercial use and has devised highly sophisticated mechanisms for the regulation and control of trade. Despite many historical predictions to the contrary, one outstanding result of the market-driven conservation of crocodilians is that illegal trade has all but been eradicated in the face of well-regulated legal trade. Governments and business interests have worked against illegal trade which might compromise their investment in conservation, management and production.
6. Although most crocodilian production programmes started with strong conservation objectives, it has often been difficult to adhere to these over the long term. In this respect, one important lesson from crocodilians is that success hinges on the relationship between government regulators and business interests, from the planning stages forward.
7. The private sector may not understand the conservation focus of crocodilian management programmes as much as governments, but tends to tolerate expenditure during start-up phases even if it considers it cosmetic or unnecessary. However, investment has proved to be a powerful political tool and once programmes are established, economic interests have often conflicted with, and sometimes prevailed over, conservation interests. The financial stress of falling markets in the early 1990s provides an extreme example. In many countries it has resulted in pressures to reduce the costs associated with resource monitoring and other regulation and in some cases there is reason to believe that resources were harvested illegally to bypass regulatory costs. On the other hand, government regulators often have little understanding of, or sympathy for, the needs and realities of sustaining a business. Conservation objectives have sometimes been compromised by governments, notably when they expose business to insecurity with respect to long-term access to wild resources.
8. Even where programmes have been well planned, and income from high-value wild crocodilian resources is generated, reinvestment in the resource has not always followed. Government agencies have sometimes preferred to use revenues for other priorities. Fiscal priorities of governments change regularly, at all levels of administration, and even where the wildlife authority rather than central government receives the funds, other issues can take priority over crocodilians. In some countries, other perverse outcomes have absorbed funds from crocodilian programmes.
9. A central lesson from experiences with crocodilians is that flexibility and a willingness to change is essential to success. It is not simply a matter of implementing a rigid programme and letting it operate indefinitely without change. This is an area where CITES has created problems. Despite its overall positive role in the creation of successful market-led conservation, CITES has been relatively slow to respond to changing circumstances. As a consequence, management has often been restricted to a narrow range of fixed options, such as ranching and captive breeding, regardless of whether these are the best options for conservation or business.
10. A perceived shortcoming of CITES is that it emphasises the biological determinants of sustainability, while the success or failure of most conservation programmes is ultimately determined by economic and social factors. Even at the national level, the biological elements of market-driven conservation programmes tend to be subjected to close scrutiny, while only scant attention is paid to the social, cultural and economic elements. This is perhaps a legacy of wildlife management decisions having been taken largely by biologists who often seem to assume that the marketing of products – a key element of success – has no relevance to conservation.

11. The market for crocodilian raw materials is determined largely by the economic status of consuming nations and superimposed on this are the unpredictable vagaries of the fashion industry. Demand tends to be elastic while supply is relatively inelastic. As a result the market is characterised by marked price fluctuations with at least two severe crashes in the last 30 years. Although overall production has continued to increase, this is the result of a drive for increased efficiency rather than new investment. Indeed, a number of individual producers have gone out of business during the difficult periods and several national programmes have become uneconomic to operate, which in turn has removed the incentives for conservation.
12. Where the impact of market-related problems on conservation has been recognised, some producers and regulators have been able to work together to reduce costs and increase demand. However, conflicts have arisen between transparency and the protection of intellectual property rights, particularly as new technologies and marketing strategies have been developed.
13. When initiating market-driven conservation programmes for crocodilians, advice has often been sought from experts. There are clear cases where poor information has resulted in unrealistic expectations, poor investment strategies and badly designed programmes, generating neither conservation nor economic benefits.
14. In some circumstances, the drive to reduce costs through increased efficiency has had conservation benefits (more production can be achieved for the same level of harvest from the wild). However, problems with access to the wild resource have tended to encourage captive breeding, perhaps the first step towards domestication. Captive breeding may be a valuable strategy to boost production, or reduce dependence on an unpredictable wild resource (or regulator), but it breaks the link between the market and the wild population, removing incentives for conservation.
15. There have been no real global efforts to regulate supply or demand. On the supply side, there is no international producers' cartel, nor have the costs and benefits of such an approach been evaluated. Producers often seem to react to falling prices and overproduction by increasing production in an effort to maintain profitability. It is also common, particularly in developing countries, for the supply of raw crocodilian materials to continue below financially viable levels due to the attraction of foreign exchange earnings, either to the producer or to the government which then may respond with subsidies. On at least one occasion, producers have been provided with subsidies due to the conservation value of production.
16. A common response to weak markets has been: value-added production, the diversification of products and the creation of new markets. On the whole, outcomes have tended to be positive, but it has not proved easy to add value to the raw product in producer countries due to vested interests. In addition, the technology is expensive and expertise is not freely available. It has proved difficult for many developing countries to produce the high quality required by a market specialising in luxury items. Most success has come, not from the penetration of the luxury market, but rather from the creating of new markets, often of a domestic nature, providing goods of lesser distinction to ordinary consumers.
17. The dynamics of demand for luxury leather products is complex and poorly understood by most producers. While the post-CITES trade has seen a reduction in the number of the intermediaries between producer and consumer, vertical integration has consolidated the critical role of tanneries. They act as the principal buyers and wholesalers. The number of tanneries has declined, partly due to environmental regulation, and while there is not yet a monopoly, the few tanneries that remain are probably in a position to exert the largest single influence on the market.
18. A significant obstacle to the market-led conservation of crocodilians is the widely held opinion that the economically-driven consumptive use of wildlife is incompatible with conservation. This lingers on, despite dramatic changes in our understanding of the reasons why difficulties

occurred so commonly in the past. Wildlife trade is, in some cultures at least, now considered undesirable and even immoral.

19. In order to strengthen markets, producers, traders and some conservationists have called for the endorsement of market-driven conservation programmes by international conservation agencies and have suggested the introduction of a certification or eco-labelling schemes. These possibilities merit detailed investigation, though it is far from clear where the lead will come from and who will benefit most.
20. As far as the market is concerned, the burden of regulation that has been imposed over recent years, often with the best of intentions, has been a major disincentive for business to invest in conservation. Eco-labelling may help, but restrictions on the movement of personal possessions made of crocodilian leather, combined with information discouraging consumers from buying wildlife products (even if these are directly linked to improved conservation) are obvious disincentives to investment. The practice of adopting domestic control and regulation measures that are more restrictive than CITES, which is common in OECD countries, adds a further tier of complexity. If we want to encourage business investment in conservation, these issues must be addressed as a matter of urgency. It is not clear whether this might be best pursued on a generic basis or with respect to crocodilians alone.

INTRODUCTION

The natural “ecosystems” and “biodiversity” of resource-rich tropical countries are said to be important and highly valued public goods. Accordingly there is considerable alarm at their current rate of erosion. Part of the concern stems from an appreciation that in many developing countries the use of wild species is essential to human livelihoods and even survival. In addition it is often argued that biodiversity is important for maintaining long-term agricultural output and for producing new generations of medicines. There are also fears that the depletion of natural ecosystems may threaten human well-being more generally: for example, through the destabilisation of local water cycles or even the global climate. Finally, there appears to be a growing acceptance, particularly within economically-powerful industrialised countries, that the natural world should be preserved for its intrinsic values.

Over the last century, our attempts to maintain natural ecosystems and biodiversity have tended to revolve around the regulated protection of land or species against damaging human influences, notably agriculture and harvesting. This reflects the fact that two of the greatest threats to biodiversity are land clearance for farming and the direct exploitation of species, whether for subsistence or commercial purposes. Unfortunately, even where protected areas have been effective, their relatively small size, coupled with human population pressures and the competitive advantage of farming over livelihoods based on the harvesting of wild resources, has resulted in a landscape dominated by agriculture. This is a landscape that is always biodiversity-unfriendly to some degree and which, where agriculture is at its most industrial, specifically excludes most wild species – irrespective of whether or not direct exploitation is prohibited. The conventional response to this situation, as exemplified by the US Endangered Species Act, is to extend regulation still further to include the prohibition of any act that harms a species of particular interest – including the conversion of its habitat for agriculture (Littell, 1995).

In recent years, there has been growing recognition that it is beyond the law enforcement capacity of most governments to implement restrictive regulations, and that for many it is worth more than their political survival to try to do so. As a consequence, wild species continue to disappear despite efforts to save them. As an alternative, two general mechanisms have evolved. In the first, society is asked to pay the true cost of the public goods, usually through direct subsidies to the landholder. However, transfers of this sort are notoriously difficult, especially between developed and less-developed countries. In the absence of workable mechanisms for internalising the cost of public goods, there have been attempts in many parts of the world to overcome macro-economic market failures by reversing the dominant paradigm in which exploitation is outlawed in an attempt to reduce economic rent. Instead, models have emerged in which rents from wild ecosystems are encouraged through

markets and enough rent captured by the landholder⁴ to provide an incentive for conservation of the “resource”. This new paradigm is often called “sustainable use”, but we prefer the more accurate term “market-driven conservation”. Market-driven conservation is often controversial and not even its most enthusiastic proponents are suggesting that it is a universal panacea against biodiversity loss. However, there are now many programmes in which markets for biodiversity products and services have successfully been harnessed to generate conservation incentives. At the same time, others have failed conspicuously to do so. We argue here that it is essential for resource managers to review and draw lessons from operating programmes so that we can better understand the factors that contribute to success – and those that lead to failure.

Crocodiles, alligators and caimans (collectively known as “crocodilians”) are found in 90 or more countries around the world. They have been exploited for generations, usually but not exclusively for their hides, used to make fashionable leather items. Over the last 20-30 years there has been a dramatic shift in the relationship between conservation, exploitation and trade. Initially seen as a conservation problem, trade has increasingly been co-opted as a conservation solution. The IUCN/SSC Crocodile Specialist Group (CSG) has responded positively as both a facilitator and arbiter in this process, working with elements of business to promote the sustainable use and legal trade of many crocodilian species all over the world. Management programmes allowing for the consumptive use of crocodilians now operate in some 30 different nations (Table 1). Each programme has its strengths and weaknesses. Over time, the dependence or near dependence of many crocodilian conservation programmes on international markets has highlighted issues which we believe have relevance to other markets for biodiversity products and services. There are many examples where conservation and economic benefits have been achieved simultaneously with crocodilians and we remain confident that:

1. Conservation incentives can and have been generated by markets.
2. The economic importance of the resource has led directly to stronger institutional arrangements specifically for conservation and sustainable management.
3. Illegal international trade, which flourished before CITES encouraged legal trade, has been all but eradicated.

On the other hand, there have been failures. There are dangers in assuming that all conservation programmes involving markets will be successful.

Here we review the many practical lessons learned from the market-driven conservation of crocodilians, in the hope that the insights gained will be of broader value to policy-makers, regulatory agencies, academics and practitioners. That we tend to concentrate on the problems and difficulties rather than the successes, should not be misinterpreted. Successes tend to be much better known than failures, but there are important lessons in both.

FROM CALAMITY TO CONSERVATION

Of the 23 crocodilian species generally recognised, 15 or more have commercially valuable hides. They have experienced remarkably similar histories of utilisation, conservation and management, regardless of the countries in which they occur (Ross, 1989). In historical times, most crocodilian species were regarded as pests. Control measures resulted in local declines and, in some areas, eradication. From the 1800s onward, crocodilian skins were also used commercially in some countries. In the USA, for example, trading firms in New York were handling up to 60,000 American alligator *Alligator mississippiensis* skins a year in the late 19th Century (Fuchs *et al.*, 1989). Demand appears to have increased exponentially after World War II. In the late 1940s it is reported that 120,000 Nile crocodile skins were being exported annually from Madagascar alone to tanneries in France (Games, Ramandimbison and Lippai, 1997) and in the mid-1950s, nearly 60,000 Nile crocodile skins were exported from East Africa every year (Fuchs *et al.*, *op cit*). By the 1960s almost all wild populations of commercially important species were being exploited for trade to some degree, and in many if not most cases, wild crocodilian densities fell dramatically, sometimes to levels where the populations

⁴ The individual or group that has defined, exclusive and enforced property rights over the resource.

were in danger of becoming extinct (e.g. Cott, 1961: p215). At that time, few people were concerned about crocodiles and those who were, tended to advocate conservation responses prohibiting use. Research into the biology and population dynamics of crocodilians was in its infancy and the concept of managed harvests that would maximise the long-term benefits derived from the commercial use of crocodilians, had not yet evolved.

The development of programmes through which wild populations of crocodilians were harvested on a sustainable basis in order to generate ongoing economic and conservation benefits, gathered momentum in the 1970s and 1980s. It started in several countries with diverse economic, social and cultural settings, notably Australia, the USA, Papua New Guinea, Venezuela and Zimbabwe, and the impetus for market-driven conservation often came from quite different directions (Webb, Manolis and Whitehead, 1987). Some harvested species had recovered from historical declines and were becoming common in the wild. Others were still classified as “endangered” when the programmes were initiated⁵. In Zimbabwe, for example, Nile crocodile populations were recovering after protection and it was recognised that, as dangerous predators of people and their livestock, crocodiles would soon find themselves in conflict with legitimate human interests. Thus using the market to drive conservation was a pragmatic and contrived response to the need to find alternative long-term conservation strategies (Child, 1987). In contrast, the harvesting of wild crocodiles in Papua New Guinea was a well-established livelihood strategy for rural people and even though wild populations may have been reduced relative to historical times, there was never any serious suggestion that the outlawing of use could be a viable response to the conservation dilemma. The challenge facing wildlife managers in Papua New Guinea was to change existing patterns of exploitation so that use would once again be at sustainable levels (e.g. Genoloangi and Wilmot, 1990).

Those designing market-driven conservation programmes for crocodilians tended to start their work from one of two directions. The first approach was characterised by the gathering of copious biological data on the species and its population ecology⁶, so that harvesting models could be constructed and tested with a view to the establishment of commercial programmes in which the regulator could have a high degree of confidence from day one (e.g. Joanen *et al.*, 1997; Webb, Whitehead and Manolis, 1987). Indeed, there was strong public expectation that this would be the case in some countries. The second approach has been described as ‘adaptive-management’. Baseline indices of abundance were established for the target crocodilian population, commercial harvesting introduced and the effects monitored in order that harvesting levels might be adjusted if the population entered a period of decline beyond expected levels (e.g. Fernandez and Luxmoore, 1996). In reality, these distinctions were blurred and despite a commitment to biological research, a great deal of trial and error was involved in all programmes, while biological research was introduced into many adaptive-management schemes (e.g. Loveridge, 1996).

Today, crocodilians are subject to biologically sustainable harvests linked to markets in a diverse range of circumstances and contexts (Fernandez and Luxmoore, 1996; Joanen *et al.*, 1997; Loveridge, 1996; Thorbjarnarson and Velasco, 1998; Webb, Whitehead and Manolis, 1987). As a result, eleven of the most commercially valuable species are now the species *least* threatened with extinction (Ross, 1998). The six most endangered crocodilians include some species that have commercial valuable and others that have never been traded. The main process threatening their survival in each case is the status of their habitat (Ross, *op cit.*). In these worst cases, there may be little or no scope for conservation strategies based on the marketing of biodiversity products, because: there is insufficient wild habitat; national conservation policy precludes such approaches (e.g. Hutton 1993); or the species is not attractive in the market. The conservation challenge in these cases is considerable, because funding tends to be available for economically important species rather than critically endangered ones (Ross 1997; Thorbjarnarson, 1999).

⁵ Because the exploitation of endangered species has been allowed in order to generate tangible incentives for conservation, crocodilians are widely regarded as pioneer species for the concept of market-driven conservation.

⁶ An expensive and time-consuming approach.