With *C. porosus*, survey results allow changes in population density (abundance and biomass per km) and the population size structure, in different rivers, to be quantified over time (Fukuda *et al.* 2007, 2011). The results also provide insights into changes in the spatial distribution of both species over time. Such information from the analysis of the survey data is essential for the effective management of crocodile populations.

The original aim of surveying *C. porosus* populations was to quantify the status of the depleted wild populations in different rivers around the NT coastline; trying to discover where any larger populations may have been remaining. However, over time, the continued surveys focused on quantifying the rate of recovery over time and ensuring that the uses of crocodiles (ranching, problem crocodiles, wild harvest) were sustainable. To rationalize the costs of monitoring, the number of rivers surveyed regularly was reduced to 12, all with medium to high densities of Saltwater Crocodiles. Four of these rivers are within KNP and 8 are outside KNP [see Fukuda *et al.* (2011) for river specifications]. The frequency of surveys in these 12 rivers was annual for 5 rivers and biennial for 7 rivers. The results confirm the large and obvious recovery of *C. porosus* populations that has occurred in the NT (Webb *et al.* 1984, 2000; Fukuda *et al.* 2011). Abundance (number of non-hatchlings sighted per kilometre of river surveyed) and biomass (kilogram of non-hatchlings sighted per kilometre of river surveyed) have both increased (Fig. 1). It is expected that crocodile abundance will be saturated before the biomass density reaches the carrying capacity (Fukuda *et al.* 2011), because the mean size of animals continues to increase. The survey results provide unequivocal evidence that the harvest programs since 1979 have not been detrimental to the population.

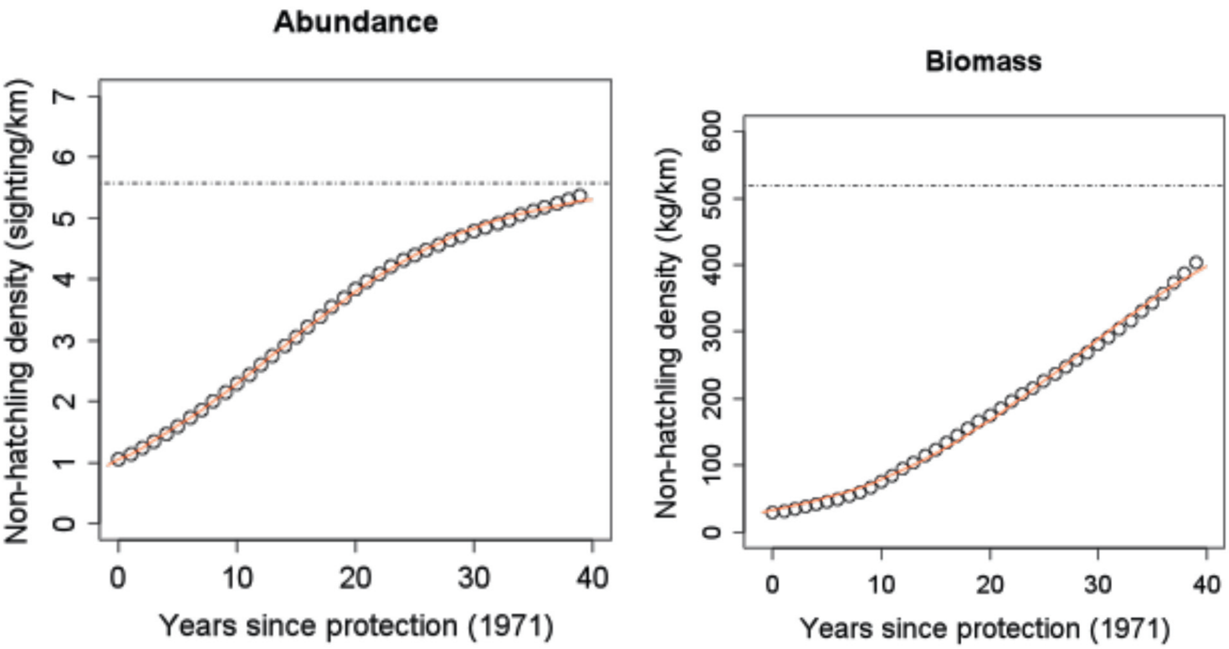

Figure 1. Abundance and biomass densities of non-hatchling (>0.6 m) *C. porosus* across all monitored sections of all monitored rivers (682 km) in the Northern Territory, Australia, predicted for 1971-2010 (derived from Fukuda *et al.* 2011).

For *C. johnstoni*, the Adelaide, Daly and Mary Rivers are surveyed for the population monitoring purpose under the current management program (Delaney *et al.* 2010). In the upstream tidal part of the Adelaide River, the numbers of Freshwater Crocodiles sighted are low by comparison to the increasing numbers and sizes of Saltwater Crocodiles (Fig. 2). Between 1977 and 2001 there was no significant relationship between density of *C. johnstoni* and time ($p = 0.44$; mean density= 0.20 ± 0.02), but between 2002 and 2011, density decreased by 67.3% (0.06 ± 0.01). Similarly, in the tidal parts of the Daly River, the populations of both *C. porosus* and *C. johnstoni* were increasing linearly up to 2001, when the Freshwater Crocodile population went into dramatic population decline (but not the Saltwater Crocodile population). In both cases these results are correlated with the arrival of invasive cane toads (*Rhinella marina*), which some evidence (Letnic and Ward 2005; Letnic *et al.* 2008) indicates are far more toxic to Freshwater Crocodiles than to Saltwater Crocodiles. Competitive exclusion of Freshwater Crocodiles by Saltwater Crocodiles has perhaps been ongoing in these areas of sympatry since the recovery of Saltwater Crocodiles started (1971) (Webb *et al.* 1983), but cannot explain the dramatic and sudden decrease in Freshwater Crocodile abundance.

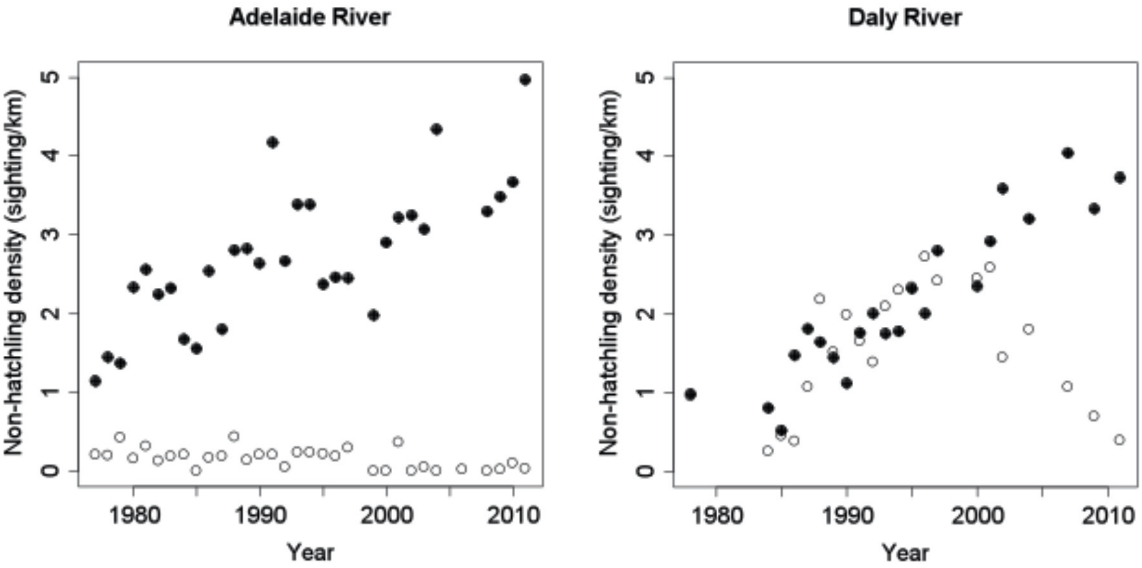

Figure 2. Abundance density of non-hatchling (>0.6 m) Saltwater Crocodiles (closed symbols) and Freshwater Crocodiles (open symbols) sighted during spotlight surveys.

These results of the monitoring programs detecting and quantifying the decline in Freshwater Crocodile populations confirm the ability of the monitoring programs sufficiently robust to detect any serious population decline resulting from unsustainable use or any other potential threat, and add weight to the case for standardized monitoring remaining an implicit part of all future management programs for crocodiles in the NT.

The long-term consequences of the decline in freshwater crocodile populations, due to cane toads, are unclear. In Queensland of Australia, cane toads occur in most areas where Freshwater Crocodiles occur, but there are no data indicating what happened to Freshwater Crocodile abundance when the cane toads first arrived (in the 1930s). Furthermore, the population processes may be further complicated by cane toads appearing to have an even greater impact on the monitor lizards, which are the major predator on freshwater crocodile eggs (discussed below in McKinlay River).

Sustainable Harvest

Prior to European settlement in the 19th century, Aboriginal people hunted crocodiles and harvested eggs for food and ceremonies for tens of thousands of years (Webb *et al*. 1984; Lanhupuy 1987). Their customary use is considered to have always been within sustainable levels (Webb *et al*. 1984; Leach *et al*. 2009).

Intense commercial hunting started in the 1940s and continued until Freshwater Crocodiles and Saltwater Crocodiles became protected in 1964 and 1971, respectively (Webb *et al*. 1984). The uncontrolled hunting resulted in a serious decrease in the number of crocodiles throughout northern Australia (Messel *et al*. 1981; Webb *et al*. 1984). As the populations recovered under protection, the experimental harvest of Saltwater Crocodile eggs started in the NT in 1983. Because the trial harvest of eggs in the first few years (1983-1985) showed no negative effect on the number of hatchlings in the harvested population (Webb *et al*. 1989), raised juveniles were not returned to the wild as compensation for the egg harvest. The egg collection program for commercial farming, without any compensation, has continued for almost 30 years (Leach *et al*. 2009). The annual quota of eggs has increased over time (Fig. 3) and is currently up to 60,000 live eggs per season (Leach *et al*. 2009). The extensive population monitoring has shown no detrimental impact of the harvest in any rivers (Fukuda *et al*. 2011). Direct harvest of crocodiles (hatchlings, juveniles and adults) from the wild also started in 1998. Currently, up to 500 hatchlings, 400 juveniles and 500 adults are allowed to be harvested annually under the management program (Leach *et al*. 2009). Safari hunting of up to 50 crocodiles (>3.5 m) per year as part of the annual quota for adults has been proposed by the NT Government, and the Australian Government is assessing the proposal for approval. Safari hunting will allow landowners to gain more income from the same crocodiles through charging higher fees for hunters to shoot a crocodile for a trophy under the supervision of licensed operators.

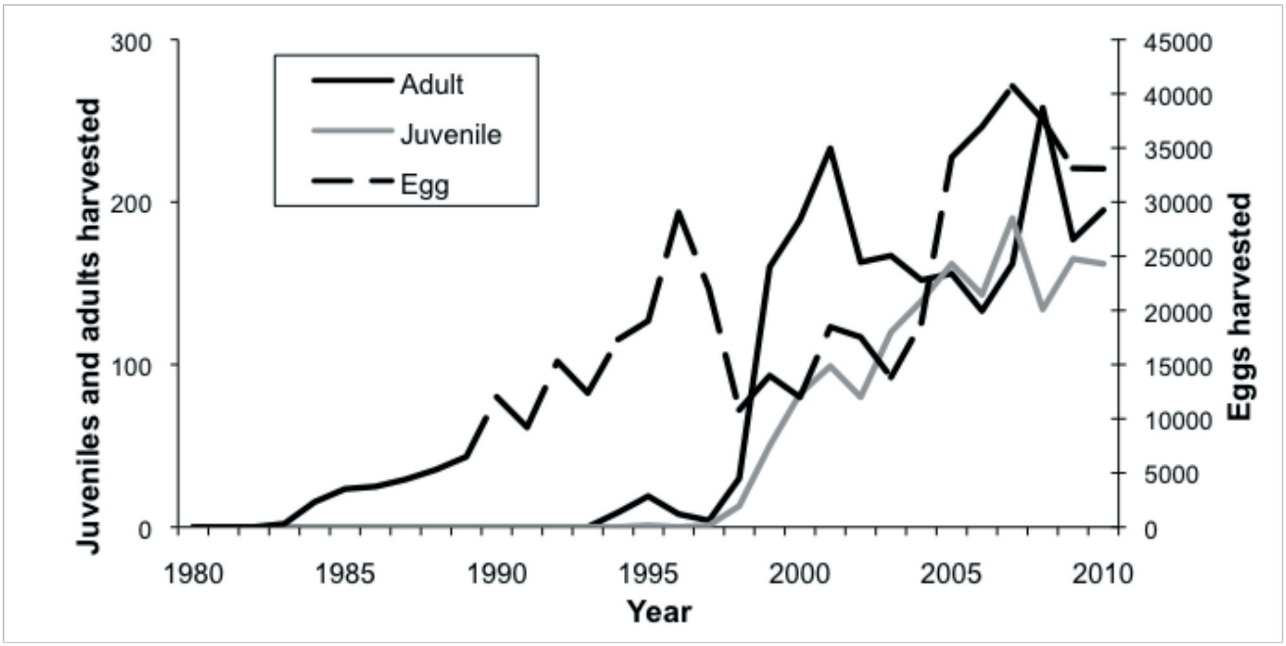

Figure 3. Historical harvest of eggs, juveniles and adults of Saltwater Crocodiles after protection (1971) in the Northern Territory.

Like Saltwater Crocodiles, the sustainable harvest of freshwater crocodiles has also been allowed under the management programs since 1983, mainly for eggs and hatchlings (Delaney *et al*. 2010). Because of the lower value of their skin due to larger osteoderms and scale pattern, the demands for leather from Freshwater Crocodiles, and thus pressure to harvest, havealways been small (Delaney *et al*. 2010). Neither eggs nor hatchlings of Freshwater Crocodiles are commercially harvested for farming although some are taken for the pet industry (Delaney *et al*. 2010).

All the harvest activities for both Freshwater and Saltwater Crocodiles are carried out under the Northern Territory permits (Leach *et al*. 2009; Delaney *et al*. 2010). The NT Government reports to the Australian Government to fulfill the requirements for the international trading of crocodile products under CITES. Harvesters are required as a permit condition to submit to the NT Government a return with harvest details (eg the number of eggs or animals harvested, GPS location, date, etc.).

Farming

Crocodiles and eggs harvested from the wild, and those produced through captive breeding, are reared and/or processed at licensed crocodile farms in the Northern Territory or interstate. There are currently 6 crocodile farms operating in the NT. For Saltwater Crocodiles, harvested eggs are transferred into an incubator immediately after collection and hatched crocodiles are reared in raising pens until they grow to a preferred size for production (approximately 1.8-2.1 m). Crocodiles are processed at an abattoir into skins, meat,backstraps, heads and other byproducts. Most skins are exported and most byproducts sold domestically. Crocodiles caught as problem crocodiles (see below) are also transferred tocontracted farms and they are either immediately processed for commercial production or kept as breeding stock.

The Management Programsfor both freshwater crocodiles and saltwater crocodiles approved by the Australian Government requires the NT Government to conduct annual audits of eggs and hatchlings to ensure that the harvest does not exceed the annual harvest ceiling (Leach *et al*. 2009). Should there be any permit compliance issue, such as a failure to submit the permit return or discrepancies between the number of animals reported and the number kept on farms, the case is further investigated by the responsible government agency (Leach *et al*. 2009). Animal welfare in capturing, keeping and processing crocodiles is also monitored by the NT Government. Harvesters and farmers are required to meet the animal welfare standards specified by the Australian Code of Practice and the *Animal Welfare Act*, as a condition of permits. All crocodile famers are visited regularly by the NT Government staff and welfare standards are monitored during these visits. The NT also issues a permit for exporting live crocodiles or their product to the other states and territories of Australia. Overseas export of live crocodiles and their products requires an additional CITES permit issued by the Australian Government.

Public Safety

Australian Freshwater Crocodiles are generally considered harmless to people unless provoked (Caldicott *et al*. 2005; Delaney *et al*. 2010), although some attacks occur and they can cause injuries (Hines and Skroblin 2010). In contrast, the frequency of human-crocodile conflict with Saltwater Crocodiles is increasingly becoming a major concern, particularly in urban and residential areas (Nichols and Letnic 2008; Leach *et al*. 2009). As the Saltwater Crocodile population recovered, crocodiles started appearing in areas where they had rarely been seen in the past (eg far upstream of freshwater rivers, recreational water areas for swimming and fishing), and where people had assumed swimming was "safe".

The NT Government runs a public safety management program which actively reduces crocodile numbers in populated areas(NRETAS 2012), and in other situations where they poseanundue risk to people or livestock. Such crocodiles are termed "problem crocodiles". The public safety program called "Be CROCWISE" is a strategy that combines a series of campaigns to increase the public awareness of the risk of crocodiles around NT waterways through public education, advertisement in the various forms of media and warning signs at sites. Problem crocodile management zones are defined around Darwin and Katherine as well as in various parks and reserves where recreational swimming is permitted (Leach *et al*. 2009). Problem crocodiles are removed from these management zones and are relocated to a crocodile farm by the crocodile management unit (Nichols and Letnic 2008; Leach *et al*. 2009; Letnic *et al*. 2011). Permits to remove problem crocodiles from private land such as pastoral and indigenous areas are also issued by request. With the increasing effort in catching problem crocodiles (eg increasing the number of traps and patrolling staff), the number of problem crocodiles caught by the NT Government has been consistently increasing (Fig. 4). As the population of both humans and crocodiles keeps expanding, the continuation of the crocodile management program is critical to reduce the conflict. Commercial harvest in its various forms (egg, hatchlings, juveniles and adults) under regulated quotas has not been considered an effective tool for controlling problem crocodile numbers in the NT as yet. Similarly, proposed safari hunting is primarily supported for commercial gain to the operators and landowners, and not as a strategy for improving public safety or reducing crocodile numbers.

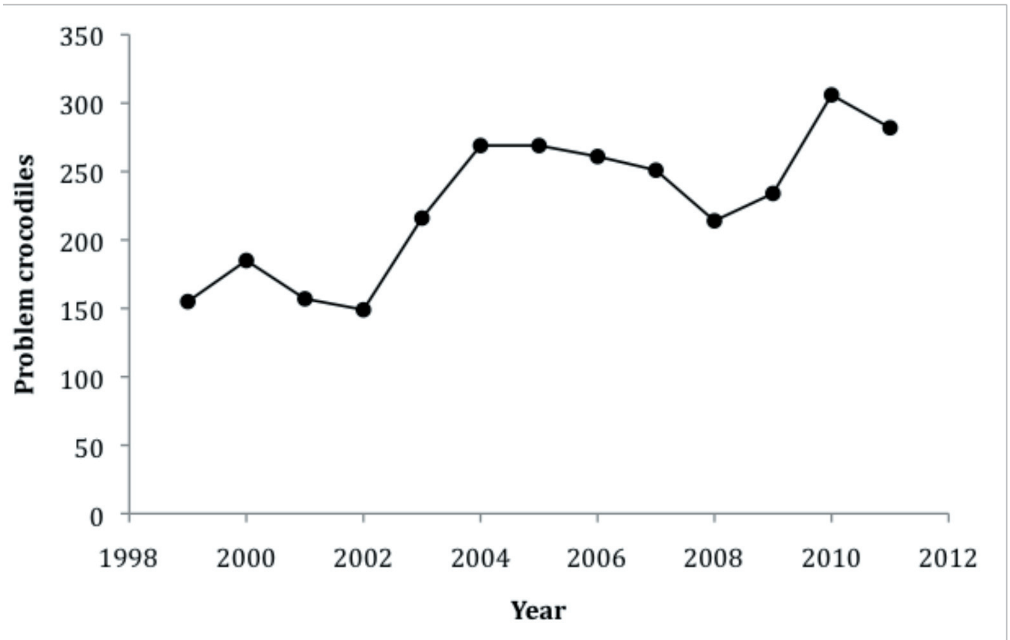

Figure 4. Numbers of Problem Saltwater Crocodiles captured in the Northern Territory, 1999-2011.

Research

The effective management of wild and captive crocodiles relies on evidence-based decisions, ideally derived from scientific research. The NT has a long history of pursuing crocodile research, and there remain many different people and organisations involved in general research involving crocodiles. Some of the research programs currently being undertaken in the NT are summarised below.

Satellite Tracking (G. Webb, C. Manolis, G. Lindner and M. Brien)

The upstream movement of large Saltwater Crocodiles into freshwater areas used for recreational activities by people (Letnic and Connors 2006) poses a particularly challenging management problem, yet our knowledge base on the movement of large saltwater crocodiles remains remarkably limited. Under the direction of Wildlife Management International (WMI), a consortium of interested stakeholders [Parks Australia North (PAN), WMI, Parks and Wildlife Service of the Northern Territory (PWSNT), Charles Darwin University (CDU); NT Tourist Commission] initiated a satellite racking study, mainly of large Saltwater Crocodiles. A novel method for attaching the transmitters was developed (Brien *et al*. 2010), and tracking devices were deployed on 22 mainly adult males, 4 of which were relocated 350 km from their site of capture. The relocated individuals were highly mobile after release (relative to those released at their capture site), but did not return to their capture site. The results are still in the process of being analysed.

Mckinlay River (G. Webb, C. Manolis)

The Australian Freshwater Crocodile population in the McKinlay River was the main population at which basic research on the ecology and population dynamics of this species was conducted. Part of that study was a large mark-recapture study, initiated in 1978, which led to one of the first descriptions of the age-structure of a crocodile population, which in turn allowed calculation of age-specific mortality rates (Smith and Webb 1986; Webb *et al*. 1983). During the 1980s and 1990s various additional studies resulted in a high proportion of the crocodiles in the river system being marked, with a known history. Prior to the arrival of cane toads, a major recapture effort (with more marking) was conducted so that survival rates could be quantified before the cane toads arrived (2004-05) and resources permitting a further capture effort will be made in 2013, to quantify survival rates since the toads arrived. It has already been established that cane toads are particularly toxic to the varanid lizards that are the main predator on crocodile eggs, and that hatchling recruitment increased by 600% after the toads arrived (even if less nests are made).

Hatchling *C. porosus* growth and survival (M. Brien, G. Webb)

Survival rates of hatchling *C. porosus* to one-year-of-age are a fundamental population dynamic contributing to the health and ongoing survival of the wild population (Webb and Smith 1987), but also to the captive or farmed population which ultimately generates the economic incentives needed for the public to tolerate large, wild populations of a serious predator within the NT (Webb *et al*. 2000).

Survival of hatchling *C. porosus* to one-year-of-age in captivity (85-90%) is high compared to in the wild (20-60%) in northern Australia. However, not when compared with survival rates (95-99%) of farmed American Alligators (*Alligator mississippiensis*) (Joanen and McNease 1976). Mortality of hatchling *C. porosus* is ultimately due to a 'failure to thrive syndrome' (FTT) in which growth is compromised for unknown reasons in a segment of the population ultimately leading to increased mortality.

The main focus of this study is to examine poorly understood aspects of thermal and social behaviour of hatchling *C. porosus* both in the wild and in captivity. The results of this research will improve our understanding of the requirements of hatchling *C. porosus*, and will provide valuable information to help achieve conservation, management and industry goals for this species.

Harvest simulation Models (Y. Fukuda)

To understand better the impacts of the harvest and removal of problem crocodiles on the population size and structure, stage-based matrix models were developed for the density-dependent Saltwater Crocodiles (*C. porosus*) population in the NT, incorporating environmental stochasticity and harvest at historical (1983-2010) and projected (2011-2030) levels.

The models simulate the population growth based on vital rates, some of which are density dependent, derived from the literature and survey data. It provides the estimates of the population size and structure at any year in 1971-2030, as well as the different influences of each life stage (egg, hatchling, juvenile and adult) on the viability of the whole population. By running the models with harvest intensities at different levels for each of the life stages, it can also simulate the likely impact of the harvest under different scenarios.

This will be used as a tool for assessing the sustainability of the future harvest quota and the effectiveness of the strategic removal of problem crocodiles. The scale of this study is the Northern Territory (one large population for the whole Northern Territory) but the models are expected to be divided into regions or catchments, especially where intensive harvest consistently occurs, as more localised, deficient data become available in the future. The project is conducted as a part of the crocodile population monitoring program by the NT Government (Leach *et al*. 2009).

Acknowledgements

The Department of Natural Resources, Environment, the Arts and Sport of the Northern Territory, and Wildlife Management International, provided resources needed for preparing this paper. We thank to all involved in the management and research of crocodiles in the Northern Territory of Australia. Without the commitment of hundreds of people over many years, we surely would not have been this far today with the conservation of crocodiles.

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Assessing Crocodile Conservation Potential in Non-Protected, Rural South Africa

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Abstract

Following the die-off in 2008 of several hundred Nile Crocodiles within a protected area of the Olifants River, crocodiles were moved to the forefront of conservation attention in South Africa. One major concern that arose from this event was the need to reassess the balance between conservation in non-protected versus protected areas. Smaller populations of crocodiles that reside outside the borders of protected areas may offer a valuable buffer to the metapopulation of the species. However, crocodiles living in unprotected habitat are often overlooked by conservation measures. Under this premise, a small population of Nile Crocodiles outside of the Kruger National Park, South Africa, was chosen as a focal sample for a pilot study to assess the likelihood of a successful conservation program in the area. A rapid habitat assessment, in conjunction with an assessment of resource availability, was performed to determine suitability for further population expansion.

Introduction

In a country where developing and developed overlap so assiduously, the Nile Crocodile (*Crocodylus niloticus*), an iconic species of the African continent, is becoming lost in the South African mix. As rivers turn from main resources of human survival to recreational areas, crocodile habitat, while it should be experiencing benefits from reduced human conflict, is being contaminated by signs of development. Of other concern, the IUCN ranks *C. niloticus* as "of least concern" throughout its range. Outside of South Africa, these areas have high human-crocodile conflict, no fenced protected areas, and little to no enforced policies to protect either crocodiles or the habitats in which they abide. South Africa boasts reduced conflict due to development and the ability to move away from dependence on rivers, fenced protected areas such as Kruger National Park, a reptile protection legislation instated for over 40 years (Ashton 2010), and a forward thinking water policy (*The National Water Act of 1998*). However, the crocodile in this country is considered vulnerable. Current estimates suggest that only 12,000 Nile Crocodiles remain in the wild throughout southern Africa and populations are on the decline in much of their home range (Alexander and Marais 2007). In South Africa, the current range is restricted to the eastern and northern areas of the country between the Limpopo and Tugela Rivers and is largely limited to protected areas like nature and game reserves (Calverley 2010; Alexander and Marais 2007). Crocodile numbers are declining in both protected and non-protected areas due to threat by direct and indirect human influence (Combrink 2011; Fergusson 2010). In South Africa, the main threats to crocodile populations are habitat loss due to water extraction by humans and water pollution (Alexander and Marais 2007).

The restriction to protected areas suggests that success of Nile Crocodiles in South Africa will be highly dependent on the size and scale of these reserves (Calverley 2010). However, river systems are difficult to conserve and 82% of rivers in South Africa are threatened, with 44% of those being critically endangered (Driver *et al*. 2004). The 2008 die-off in the Olifants River Gorge highlights the vulnerability of these freshwater systems (Ashton 2010; Ferreira and Pienaar 2011). While many actions are in place to alleviate the pressures on these systems, the dependence on protected areas for assurance of healthy freshwater systems must be supplemented with successes in non-protected areas.

In the remote hills of Venda country near the Zimbabwe border, a small, remnant population of crocodiles exist in the Mutale River. The dynamic of the river, and in turn, the crocodile population, was immensely altered by the floods of 2000, creating a shallow, narrow river with very few tributaries having enough water to sustain individual crocodiles. This habitat is limited in its capacity to carry crocodiles as the breeding habitats are minimal. However, despite this, nests have been located and the population has been sustained, in small numbers.

The interest in the area is in several arenas (1) the comparison between protected areas and non-protected areas with concern to river health and crocodile conservation, (2) the basic ecology of a population limited to a linear system and the distribution along that system with regard to age and size class, (3) and the effects of a coal mine on the health of the river prior to entering a reserve and the greater complex of the park systems, (4) which also includes the comparison between the Olifants River Gorge due to the possibility of acid mine drainage in the system and similarities in landscape.

A short-study was conducted to determine the plausibility of conducting research on the crocodiles upstream (of the coal mine) and the likely success of a conservation program. Pre-emptive action often reduces misallocation of time and funds. The information gathered in this study will be repeated both at the mine and further downstream as the study progresses.

Methods

Study Site

The Mutale River flows through the north of South Africa in the Limpopo Province. Its source is Lake Fundudzi, a sacred site to the Venda culture. The lake itself is believed to have numerous crocodiles, but can only be accessed with special permission. The river then flows through villages and agricultural fields through a gorge. Further downstream, Tshikondeni Coal Mine uses tributaries of the river in the mining process. Finally, the Mutale enters the Makuya Reserve, where it joins the Luvuvhu River to flow into Kruger National Park.

The study site was located in HaMakuya, a collection of 19 villages in the rural Mutale Municipality of the Vhembe district in Limpopo Province. The Mutale Local Municipality consists of 58 villages, contains approximately 100,000 inhabitants, and is one of the poorest districts in South Africa (Rietveld *et al*. 2008; Vhembe district stats overview 2011).

Study Design

A rapid habitat assessment was conducted in October and December of 2011 and March 2012 on a 10-km stretch of the Mutale River between the Tshikondeni Mine and Lake Funduduzi at the Thusulu Trust Research Camp (S22 34.779' E30 48.518'). The river was described, including a 7 m buffer zone from the edge of the water, to identify tributaries, ponds, rapids, pools, and sand banks, in order to asses usable, suitable habitat need for basic ecological needs of crocodiles. In both October and December, invertebrates were sampled for indication of diversity and water health under the SASS5 guidelines (Chutter 1994). In December, the fish populations were surveyed over three days to identify potential prey items.

Night surveys were conducted over three 6-day periods in October, December and March to assess the current population in the 10-km stretch.

Five fishermen were interviewed in March 2012 to better understand the human perspective on the conflicts with and fear of crocodiles and the current attempts to alleviate those conflicts and fears.

Results

The rapid habitat assessment gave a general overview of the suitability of the river for crocodile presence and population expansion and of the health of the river. The invertebrate studies, fish count, and habitat description defined the resource availability while the surveys gave some insight to the carrying capacity of the area. Finally, the interviews gave some context to the interest in and vulnerability to of the villagers of HaMakuya to local crocodile populations. When combining these above factors, the success of the area as a conservation area could be assessed.

Habitat Description

Within the description of habitat, 61% of the river described consisted of pools and runs. The presence of rapids will limit the movement of crocodiles until a certain size is reached, therefore altering distribution by age and size class. Habitat studies found the presence of suitable nesting grounds, defined as sandy banks, in ≈19% of the river (of 10-km stretch studied). Only one nest was found during the study periods, suggesting space for other breeding females.

Resource Availability and Quality

Invertebrates collected represented 11 different families, of which three have extremely high water quality requirements (Table 1). The invertebrates also offer plentiful prey for fish, the main diet of crocodiles in the river.

Nine different species of fish were trapped and identified (*Barbus annectens*. *Marcusenius macrolepidotus, Labeo cylindricus, Petrocephalus wesselsi, Schilbe intermedius, Tilapia sparrmanii, Mesobola brevianalis* and *Clarias gariepinus*). Of these six species (*B. annectens, M. macrolenidotus, L. cylindricus, P. wesselsi* and *S intermedius*) are known to occur in shoals (Skelton 2001), suggesting ample food supply. Bottom-feeders such as catfish (*C. gariepinus*), a link in the bioaccumulation and die-offs of crocodiles in the Olifants, are the main fish present in the area. These are the dominant prey item for Nile Crocodiles (Alexander and Marais 2007).

Table 1. Invertebrates captured in a 10-km stretch of the Mutale River near Tshulu Camp, HaMakuya in March 2012. Sensitivity scales were derived from pollutant tolerance levels as used in the SASS-5 scoring system. 1-5 Highly tolerant to pollution; 6-10 Moderately tolerant to pollution; 11-15 Very low tolerance to pollution (Gerber and Gabriel 2002).

Invertebrate	Category	Number	Sensitivity
Batidae	Mayfly larvae	3	4
Dytischidae	Beetles	3	5
Ecnomidae	Caddisfly larvae	4	8
Hydraenidae	Beetles	1	8
Leptophlebiidae	Mayfly larvae	2	9
Libellulidae	Dragonfly larvae	18	5
Notonectidae	Brushlegged mayfly	35	15
Notonemouridae	Stonefly larvae	4	14
Oligochaetae	Aquatic earthworm	5	1
Oligoneuridae	Mayfly larvae	1	15
Perlidae	Stonefly larvae	4	12

Population Surveys

Crocodile presence was confirmed (N= 23), with larger crocodiles (>2.5 m) preferring the gorge area, which offers deeper pools, often with larger fish. Larger crocodiles are also found downstream in areas where livestock graze close to the river. Smaller crocodiles form more communal groups or as individuals are found in shallow waters, not conducive to larger crocodiles. Crèches seem to be in these shallow waters or in short runs between rapids. Hatchlings (N= 18) were found in December and by March, 12 of those were sighted again despite the flood in January.

Human Influence

Human-crocodile conflict is passive, taking shape in the consumption of livestock by large crocodiles. For the most part, people avoid crocodiles through acknowledged methods- setting up fishing locations away from bank, no fishing at night, avoidance in general of crocodiles, and telling newcomers where to fish to avoid crocodile territories. In the past, there are stories of people being attacked, but it is assumed that two factors influenced this: (1) more crocodiles were in the area given the deeper waters prior to the 2000 floods and (2) people relied more heavily on the river before the placement of bore holes in the villages. Currently, there are initiatives in place for incurring consequences for killing a crocodile by the municipal government. Local people may contact the municipality or the local Makuya Reserve for the removal of problem crocodiles. Recently, two crocodiles moved into a dam, primarily used for watering livestock. The crocodiles took several cattle. The nature reserve rangers shot one of these; the other was relocated to the reserve.

Discussion

With the increase in development outside of reserves in South Africa, potential threats to the health of freshwater systems increases and the efficacy of protected areas with regard to river systems reduces. The rapid habitat assessment along with information gleaned from the local peoples highlights the potential success of this non-protected area as a conservation site for dilapidated crocodile populations in the north of South Africa.

We expect a larger population to be currently in the area then what was assessed given the difficulty of surveying large sections of the river. Given the availability of suitable habitat within the 10-km stretch, the river is capable of maintaining a higher load of crocodiles than is currently present. Some sections of the river are not ideal for stagnant populations as they have shallow waters, but could cater to younger crocodiles before they are physically too large for the depth of the water column.

The local peoples of HaMakuya do not use the river as means of a main economic resource and therefore would not be at odds with a full conservation program within the area. With the installment of water taps in the villages, the dependence on the river has itself been reduced. Even the chief of Tshikundamalema across the Mutale River from HaMakuya has expressed interest in crocodile conservation, suggesting that there is local support for a future conservation program.

From these assessments, we have concluded that a conservation movement would in fact be successful, to further stabilize the population in the upper reaches of the Mutale River. The limitations exist in suitable habitat to maintain nesting locations. With further studies, researching the effects of the mine downstream (around 12 km from the current site), we will be able to identify further needs of the Mutale River population based on present pollutants and the health of the river as it enters Makuya Reserve to join the Luvuvhu. We will also be able to identify any threats to the river as it flows into Kruger National Park, thereby reducing the chance of another incidence like in the Olifants River gorge and perhaps lending further insights into the reasons behind the die-offs.

While the preliminary study is informative, the overlap between ecology of this population of crocodiles and the habitat available needs to be more closely analysed. The full range of river used by these individuals needs to be monitored and more areas along the river need to be surveyed to assess the current population. These small populations become valuable as larger populations in protected areas are threatened by side-effects of development, such as habitat encroachment and water pollution. Rivers are one of the most difficult natural resources to protect as between the source and the delta the river may flow through multiple countries, landscapes and protected and non-protected areas alike. The knowledge gained in the exploration of this site will be helpful in other locations of Africa and other progressing countries to identify a balance between development and conservation and the value of non-protected areas in buffering metapopulations.

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Extinction of the Orinoco Crocodile, *Crocodylus intermedius,* in the Guárico River, Venezuela

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Abstract

The Orinoco Crocodile (*Crocodylus intermedius*) historically inhabited all the Orinoco River basin of Venezuela and Colombia. As a result of indiscriminate commercial hunting in the first half of the 20th Century the species was greatly depleted and in danger of extinction. Over the last 60 years, the Guárico River, previously one of the most important rivers in the central Venezuelan Llanos for crocodiles, has lost its entire *C. intermedius* population. With the development of the Camatagua and Guárico Reservoirs about 50 years ago, most of the Guárico River has been reduced to a polluted trickling watercourse, severely limiting possibilities for recovery programs for the species.

Introduction

Commercial hunting of the Orinoco Crocodile begun in the Venezuelan and Colombian Llanos at the end of 1920, with a peak in the mid-1930s (Godshalk 1982; Thorbjarnarson and Hernández 1992; Seijas 2007). Around 900,000 hides were exported from Venezuela to Europe between 1933 and 1935. At that time 3000 to 4000 hides where sold daily. Although trade persisted until the end of 1960, in most Venezuelan and Colombian rivers commercial hunting had finished by the end of 1940 and the beginning of 1950 (Fig. 1).

Figure 1. Commercial hunting of *C. intermedius* lasted some 40 years, until the species in the Llanos was almost extinct. Photograph: Faoro (Photograph Archive of Ernesto O. Boede).

On his journey in 1800, Alexander von Humboldt wrote that there were so many crocodiles and he could see up to 10 animals sunbathing on the river banks of each meander of the Apure River (Humboldt 1959; Seijas 2001; Boede 2009). Even Calzadilla Valdez (1988), in his reports from 1932, wrote that these crocodilians in the dry season swarmed in the marshy lagoons of the almost dry rivers.

It is thought that there were more than three million *C. intermedius* in the Llanos at the beginning of the 20th Century (Antelo Alberts 2008). The total population in Venezuela is now around 1500 individuals, with even less in Colombia (Seijas and Chávez 2000; Llobet and Seijas 2003; Rodriguez and Rojas-Suárez 2008). There are few reports of *C. intermedius* in the Guárico River, which begins at the northern Venezuelan State of Carabobo near the village of Belén, and flows 580 km from north to southeast through the Llanos of Aragua and Guárico States, and into the Orinoco River, near the village of Cabruta.

The Chilean priest José Cortés de Madariaga, sailing in 1811 from the Orinoco River into the Guárico River to the villages of Guayabal and Calabozo, wrote that it was a wide river, navigable, with much current, and many "caimanes" or Orinoco Crocodiles (Portal Oficial. Guárico 2011). Also, Humboldt, travelling from Calabozo to San Fernando de Apure, crossed the Orituco River, which is a tributary of the Guárico River, and described the danger of the crocodiles there, which could be very aggressive for his companion dogs, where they could be predated even on land by these huge reptiles (Humboldt 1959; Seijas 2001).

In 1932 the author's father, Ernesto G.A. Boede travelled by boat south on the Guárico River, from the nearby village of Calabozo to Guayabal (Fig. 2). He observed and photographed the huge Guárico River before two dams were built upstream, and also photographed some of the last Orinoco Crocodiles in this river (see Figs. 3-7).

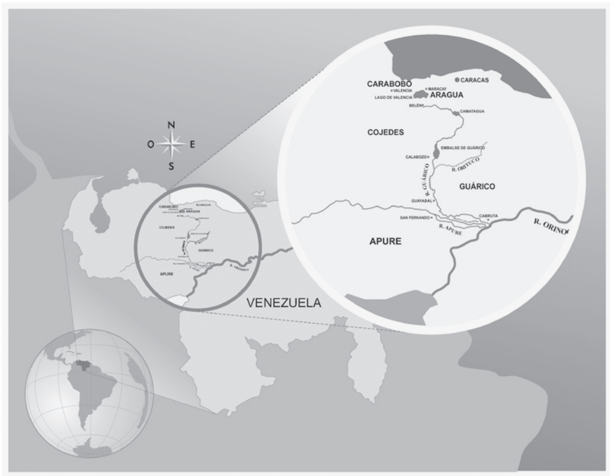

Figure 2. Map showing Guarico and Apure Rivers.

Figure 3. Crocodiles hunted in the Guárico River in 1932, ready to be skinned and the hide sold. Photograph: Ernesto G.A. Boede (Photograph Archive of Ernesto O. Boede).

Figures 4 and 5. The skins of Orinoco Crocodiles slaughtered in the Guárico River were commercially exported. In the era of the commercial hunting in 1932, there were still challenging and intimidating crocodiles to be found in the Guárico River. Later on, the few survivors left in some rivers in the country were wary, and learned to elude and avoid humans to survive (Godshalk 1978). Photograph: Ernesto G.A. Boede.


Figures 6 and 7. Large Orinoco Crocodiles on the banks of the Guárico River in 1932. Photographs: Ernesto G.A. Boede.

Methods

Twenty-five (25) photographs, taken in the 1930s, of the Guárico River and its Orinoco Crocodiles were collected and analyzed. Recent photographs were taken in the Guárico Reservoir and the downstream river channel. For the literature review, data were collected from scientific papers and from unpublished data of the Venezuelan Crocodile Specialist Group (GECV).

Results and Discussion

The Guárico River was an important navigable river until the beginning of the 20th Century (Fig. 8; Portal Oficial. Guárico 2011). Big bongos and houseboats came along the river in the rainy season from the villages of San Fernando de Apure and Guayabal to Calabozo for commercial trade. They transported back to San Fernando de Apure, with the main storage facilities, the Orinoco Crocodile hides that were taken along the Guárico River (Figs. 1, 3-5; Boede, pers. comm.; Godshalk 1978; Calzadilla Valdez 1988; Boede 2009). As in the rest of the country, in the Guárico River the Orinoco Crocodiles were overhunted and driven to local extinction between 1920 and 1960 (Godshalk 1978, 1982; Thorbjarnarson and Hernández 1992; Seijas 2007).

Before the Camatagua and the Guárico Dams and Reservoirs where built, in the dry season the Guárico River had many sandy riverbanks, and in the rainy season it was very wide and flooded the nearby savannas and its gallery forests - suitable habitats for crocodiles (Figs. 4-7). Over the last 40 years the river downstream of the Calabozo Dam has been transformed into a polluted narrow waterway (Fig. 8; Portal Oficial. Guárico 2011).

Figure 8. (Left) Until the beginning of the 20th Century, the Guárico River was an important waterway for trade and crocodile habitat. (Photograph: Ernesto G.A. Boede). (Right) Today, most of the Guárico River is a trickling watercourse, probably without any Orinoco Crocodiles left. Photograph: Ernesto G.A. Boede.

Godshalk (1978) wrote that a lot of crocodile hides were harvested from the Guárico River some years before his visit. Confidential sources told him that some crocodiles were still seen in the artificial Guárico River reservoir, built in 1957, upstream of its dam near the village of Calabozo. Due to intense agriculture near the village, the presence of crocodiles in that part of the river was very doubtful. But downstream the river has many meanders and there could be some Orinoco Crocodiles left, according to his informants. Between 1987 and 1988 Thorbjarnarson and Hernández (1992) were informed that downstream in "Caño el Caballo", a river arm of the Guárico, some crocodiles had been seen. These authors commented that a few adult crocodiles also lived more upstream to the north, in the Camatagua Reservoir. These crocodiles were derived from resident animals from the Guárico River, before the construction of the Camatagua Dam in 1969. Few crocodiles survived in the Camatagua Reservoir, and Blohm (1982) wrote that in July 1980 3 nests were recorded on an island in the artificial lake of the reservoir. One month earlier (June 1980) 6 hatchlings were observed 3 km south of the nest site. In 1971 Blohm (1982) reported seeing 3 crocodiles 16 km to the east, and in 1972 a poacher killed one about 9 km eastwards.

In 1985, 5 hatchlings collected in Camatagua Reservoir, were brought to the El Pinar Zoo in Caracas. Around the beginning of 1990 an adult Orinoco Crocodile was killed in "Caño Rabanal", which is also a southern river arm of the Guárico River (A. Seijas, pers. comm.). In October 2006, 152 one-year-old *C. intermedius* from the Venezuelan Captive Breeding Program were released in the Orituco River, 9 km upstream from its mouth into the Guárico River (Venezuelan Crocodile Specialist Group, unpublished data).

Conclusions

Now, at the beginning of the 21st Century, about 50 years since the construction of two important dams and reservoirs on the Guárico River, it is now a bad-smelling trickling watercourse, polluted from Calabozo village and surrounding agricultural plantations. Its main channel and river banks are now dense bushes and forests, which is not a suitable habitat for Orinoco Crocodiles (Fig. 8). But downstream to the south the Guárico River receives some fresh water from its tributaries, the Orituco River and the Apurito River arm, where perhaps some Orinoco Crocodiles could exist. Upstream to the north, in the Guárico and Camatagua Reservoirs, *C. intermedius* is probably extinct.

Since mid-1990, no data have been collected nor any census undertaken, but there have been no reported sightings or any *C. intermedius* being hunted in the Guárico River. Intensive hunting between 1920 and 1960 is considered the main factor contributing to the probable extinction of *C. intermedius* in the Guárico River, with recovery constrained by alteration of the river through the construction of dams.

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Population Status of the American Crocodile (*Crocodylus acutus*) in the Tempisque Great Wetland, Guanacaste, Costa Rica, 2009-2010

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Abstract

To determine the status of the crocodile (*C. acutus*) population in the Tempisque River, Guanacaste, Costa Rica, I studied the whole influence area of the river, rather than just its navigable segment. Every contributor river, small lagoon and related wetland were taken into account, in what I named here as the Tempisque Great Wetland (TGW). I partially examined the effect of some climatic factors, as well as the historical use of land. I estimated the population size as 2315 individuals, and a total of 1951±25.26 (84.3%) non-hatchling crocodiles; split in 292 (15.0%) in the Upper Basin, 1262 (64.7%) for the Lower Basin, and 397 (20.4%) for the Marshes Area. Relative density is 4.56, 8.79 and 23.08 ind/km respectively. Estimated general relative abundance was 8.68 ind/km. General size structure estimated was 386 (16.7%) recruits, 454 (19.6%) juveniles, 648 (28.0%) sub-adults, and 463 (20.0%) adults. Sex ratio was 3.3:1 (male:female).

Introduction

Studies about the state of the populations of crocodiles (*Crocodylus acutus* Cuvier 1807) are nowadays more frequent in Costa Rica, with pronounced interest in the populations of the Pacific coast (Sasa and Chaves 1992; Bolaños *et al*. 1997; Piedra 2000; Porras-M 2004); as much as to determine the population of the Tempisque River as the most important among all others in the country. Information exists regarding the size and sex distribution of this population (Bolaños *et al*. 1997; Sánchez 1992, 2001). Nevertheless, these studies have been carried out only in the navigable river channel, with an approximate total length of 50 km from its mouth in the Gulf of Nicoya, to the place known as La Cutacha, upstream at a height of the Hacienda El Viejo.

During the last 15 years, repeated accident occurrence with crocodiles, reports of crocodiles in places where they had not been sighted before, as well as reports of high numbers of individuals in several Tempisque's contributors, like the Bebedero, Charco and Cañas Rivers; besides the worrying crocodile visit in aquaculture ponds in the counties of Cañas and Bagaces (Bolaños, in prep.), have attracted attention towards the possibility that the actual evaluations of the population of crocodiles in the Tempisque river have been showing underestimated results, if considered that the studied population was always the same relatively small fraction of the real population of crocodiles of what I call here as the Tempisque Great Wetland (TGW), from the High Basin of the river in the birth of the Tempisquito River, down to the Gulf of Nicoya in the Toro Island; including its most important contributors and adjacent wetlands along its trip towards the sea.

The present study establishes an integral conception of the habitat of the crocodile in the Tempisque River, as well as an improved conceptualization and better estimation of the status of its crocodile population.

Materials and Methods

Study Area

It is possible to split the TGW into Upper Basin, Lower Basin and Area of Marshes, since each of them is clearly differentiated by conditions of soil genesis, geomorphologic gradient, water regime and green coverage.

The Upper Basin is characterized by soils of volcanic origin (Cabrera 2007) where the clear water runs on a stone bed where the river has washed cannons of up to 6 m deep in the stone, with a range in altitude from up to 90 m asl at the bridge of the Inter-American Highway on the Tempisquito River, down to 30 m asl along the community of Guardia (Cabrera 2007). This condition determines the existence of a system of gradients, by means of which the connection is established between long ponds of up to 600 m long and with a 30 m average width. There exists an average threshold of 30 m of area of damping forest coverage in both margins of the watercourses, with secondary forest mostly, with a canopy of approximately 10 m high in species as espavel (*Anacardium excelsum*), jobo (*Spondias mombin*), gallinazo (*Schizolobium paraibum*), ceibo (*Ceiba pentandra*), tempisque (*Sideroxylon capiri*) among others. During the achievement of the study, I observed local proper fauna, like coyote (*Canis latrans*), nutria (*Lutra longicaudis*), iguana (*Iguana iguana*), garrobo (*Ctenosaura similis*), guatuza (*Dasyprocta punctata*), pizote (*Nasua narica*), mapache (*Procyon lotor*), urraca (*Calocitta formosa*), martín peña (*Tigrisoma mexicanus*), garza real (*Ardea alba*), tamandúa (*Tamandua tetradactyla*), mono congo (*Alouata paliata*), mono cariblanco (*Cebus capuchinus*), boa (*Boa constrictor*) among others. There is an extensive use of land to raise cattle for meat, with wide extensions of area covered by pastures (Peters 2001). The urban pressure on the water river beds is here of low impact, with the unique reference to the small town of Irigaray.

The Lower Basin is considered from the community of Guardia, 30 m asl down to 0 m asl, at the mouth of the river in the sea. The river's water runs here in a sedimentation substratum of alluvial origin, which goes by a lot slower than it uses to go in the High Basin, without the presence of rapids along the river bed. The waters here are cloudy, as a result of the sedimentary effect of waters running on soil. The river has here a 50 m average width and the average depth is of between 6 and 8 m during the rainy season. Meanwhile, during the dry season, the width of the river and its average depth is 20 m and from 2 to 4 m respectively, with the frequent existence of deep large ponds. From La Cutacha to its end in the sea, the river reduces the speed of its current, acquires more width and depth and allows, thanks to the fact that the tides affect up to this sector, the navigation by crafts of low openwork like boats and tourist longboats. In this area the shores of the river are of light slopes, with green coverage basically of bushes, except in the area protected by the Palo Verde National Park, where the forest coverage is from primary and secondary forest composed by proper forest species of the area (Sánchez, 2001) and from swamp and mangrove forest. The agricultural activities as the raising of rice, sugar cane and watermelon or cantaloupes are taken up to the very margin of the river, without respect of the damping area required by Law 276 for protection of the watercourses. Along the river, every year the companies dedicated to the production of these goods accustom to "clean" the shore of the river with heavy machinery up to a 50 m margin from shore, they keep and maintain the dike that must protect them from the winter floods, jeopardizing the crocodile nesting banks already established. There also exist water authorizations granted by Servicio Nacional de Aguas Subterráneas, Riego y Avenamiento (SENARA) for the irrigation of cultures in the Low Basin of the Tempisque. During the dry season (ENE-ABR) this water extraction goes as far as to reduce the water volume in a very significant way (Alvarado *et al*. 2008), to the point in which the inhabiting fauna migrates in search of water and life in the internal area of the territory, in the areas of cultivation. The Low Basin of the Tempisque presents a strong impact for urban pressure, owed to the growth of cities like Guardia, Liberia, Filadelfia, Santa Cruz, Bagaces, Cañas, Bebedero, Comunidad, Belén, Bajo Tempisque. Some of the faunistic species sighted during the achievement of the work were raccoons (*P. lotor*), pizotes (*N. narica*), coyote (*C. latrans*), garza real (*A. alba*), martin peña (*T. mexicanum*), iguana (*I. iguana*), garrobo (*C. similis*), mono cariblanco (*C. capuchinus*), mono congo (*A. paliata*), chocuaco (*Cochlearius cochlearius*), garza azul (*Egretta caerulea*), cigüeñón (*Mycteria americana*), garza bueyera (*Bubulcus ibis*).

As Area of Marshes I classified to what would represent a species of attached wetland inside the TGW adjacent to the Tempisque river in the field of its Lower Basin and in the side of the Peninsula de Nicoya. This area gets completely connected every year with the main river bed of the Tempisque during the rainy season, product of the floods; but it remains in a relative separation during the months of the dry season, only connected across minimal courses of water of the El Charco and Bolsón Rivers, as well as other small meanders that drain the area, thus connecting the lagoons Mata Redonda, Corral de Piedra and Sonzapote with the rest of the marsh and with the main river channel.

Since the beginning of the colonization of the Guanacaste Province in 1821, it has been experienced a sensitive decrease of the green coverage, and a large area has been transferred from wilderness to the development of pastures for cattle raising, both in the Upper Basin and in the Lower Basin (Peters 2001). Further on, the advent of the mechanization in the cultivation, supported by the creation of the Irrigation District of Moracia, made possible the incorporation of more grounds of the Lower Basin plains, as well as the replacement of some areas of extensive cattle for cultivation like rice, sugarcane, sorghum, cotton and corn (Peters 2001). At present the basic cultivation is rice and sugarcane, watermelon and cantaloupe, which occupy large extensions of land, up to the very margin of the water courses, and which minimize the water volume of the Tempisque River, determining that with a normal environmental water volume, only 31% of the whole of profiles of depth fulfill with the requests of *C. acutus* (Alvarado *et al*. 2008).

The development of the livestock business, and then the expansion of the agricultural border, promoted in the area the improvement of the road network and general routes of communication, to ease the supply of inputs and products extraction to the available markets (Peters 2001); as a result, the additional labor force brought with it a strong urban development, which expanded the limits of the existing establishments and propitiated the establishment of more urban centers for the development of the area. Under these circumstances, the habitat provided by the rivers, estuaries, swamps and attached wetlands, turned out to be submitted to the joint effect of these factors, and led to a reduction of the space available for the species that inhabit this habitat, to the overcrowding of their populations, and to an inconspicuous condition of life, in which there was more and more frequent and normal to meet a crocodile, and crocodiles were pressed to be mobilized up to places that earlier they had not dared to visit, in search for water and their natural preys.

During the 1990s it initiated the development of aquaculture in the area, with the consolidation of companies favored by the Irrigation District of Moracia, dedicated to the production of tilapia in the counties of Cañas and Bagaces, which establishments induced positively the food offer for the native fauna and relieved the scarcity that should have happened as a result of the negative effects aimed in the previous paragraph.

Table 1. Sampling segments in the area within the established cartographic land marks.

Segment	Location	m asl
Upper Basin		
Corobicí River	10° 27' 11.1" N 85° 07' 44,6" W	29
Interamericana - Tenorio	10° 26' 00.2" N 85° 09' 24.2" W	21
Tempisquito River		
Interamericana - Ahogados	10° 48' 56.1" N 85° 32' 37.3" W	90
	10° 44' 00.5" N 85° 31' 32.9" W	75
Los Ahogados River	10° 48' 10.0" N 85° 30' 02.1" W	66
Ahogados - Tempisquito	10° 44' 00.5" N 85° 31' 32.9" W	75
Colorado River	10° 39' 43.3" N 85° 31' 37.2" W	60
Colorado - Tempisque	10° 38' 08.5" N 85° 33' 46.8" W	42
Tempisque River		
Irigaray - Guardia	10° 43' 14.6" N 85° 31' 09,8" W	66
	10° 34' 13.6" N 85° 35' 20.8" W	39
Lower Basin		
Tempisque River		
Segment A	10° 12' 44.6" N 85° 14' 05.0" W	0
Níspero - Puerto Humo	10° 18' 59.2" N 85° 21' 09.7" W	0
Segment B	10° 18' 59.2" N 85° 21' 09.7" W	0
Pto. Humo - Pto. Chamorro	10° 20' 31.1" N 85° 21' 59.3" W	8
Segment C	10° 20' 31.1" N 85° 21' 59.3" W	8
Pto. Chamorro - Bolsón	10° 21' 53.8" N 85° 24' 36.6" W	7
Segment D	10° 21' 53.8" N 85° 24' 36.6" W	7
Bolsón - Puente Pelón	10° 25' 20.1" N 85° 24' 08.0" W	9
Bebedero River	10° 22' 11.4" N 85° 11' 50.9" W	11
Bebedero - Tempisque	10° 15' 08.4" N 85° 14' 20.6" W	1
Tenorio River	10° 22' 11.4" N 85° 11' 50.9" W	11
Bebedero - Interamericana	10° 27' 59.6" N 85° 09' 44.1" W	34
Blanco River	10° 22' 11.4" N 85° 11' 50.9" W	11
Bebedero - Puente bajo	10° 23' 24.4" N 85° 12' 38.1" W	12
Cañas River	10° 21' 11.3" N 85° 08' 05.0" W	17
Hotel - Bebedero	10° 20' 04.7" N 85° 12' 04.4" W	
Tempisque River		
Palmira - Filadelfia	10° 30' 47.8" N 85° 34' 08.8" W	21
	10° 25' 19.5" N 85° 31' 42.7" O	17
Tempisque River		
Las Bombas - El Pelón	10° 26' 37.2" N 85° 26' 14.9" W	17
	10° 25' 48.1" N 85° 24' 37.1" O	9
Marshes Area		
Mata Redonda Lagoon	10° 19' 58.7" N 85° 24' 50.3" W	4
	10° 18' 47.8" N 85° 24' 42.5" O	3
El Charco River	10° 20' 26.7" N 85° 25' 29.2" W	9
	10° 20' 48.2" N 85° 24' 29.8" O	7
Bolsón River	10° 22' 08.2" N 85° 25' 41.3" W	8
	10° 21' 53.7" N 85° 24' 37.8" W	7

The Working Segments

I determined the study area based in available information in the cartographic sheets 1:50000 of the National Geographical Institute; numbers 003 Murciélago, 004 Ahogados, 006 Carrillo Norte, 065 Belen, 066 Tempisque, 067 Cañas, 021 Talolinga, and 022 Abangares; with support in reviews realized in Google Earth. I proceeded to evaluate thru actual surveys in the field, the best possibilities of both day and night action, as well as the importance and relevancy of inclusion of the segments; according to the knowledge acquired thru years of work in the rivers and marshes of the studied area, and of the dynamics of the populations of crocodiles in every place. This way, according to my best criterion, I chose to make direct observations in the following study segments.

Related to climate, the National Meteorological Institute (2010) has two small meteorological stations in the study area, Llano Grande in Liberia and Taboga in Cañas. According to information gotten from this source in series of time of 20 years between 1989 and 2008, Table 2 delivers information about the behavior of some climatic factors at both stations.

Table 2. Average daily climatic parameters (standard deviation in brackets) by meteorological station and season, for 2008.

Parameter	Season	Llano Grande	Taboga
Humidity (%)	Dry	62.39 (4.37)	65.21 (5.34)
	Rainy	83.27 (4.94)	82.72 (5.34)
Rainfall (mm)	Dry	7.5 (17.86)	17 (34.01)
	Rainy	283.3 (212.52)	253.97 (159.81)
Maximum Temperature (ºC)	Dry	34.65 (1.16)	33.18 (1.25)
	Rainy	31.43 (0.97)	31.76 (0.79)
Minimum Temperature (ºC)	Dry	21.5 (1.11)	23.31 (1.43)
	Rainy	22.21 (0.65)	22.64 (0.93)

Data Collection

I made as much as 22 field trips of an average of 3 nights each, between December 2008 and October 2010. Sometimes I could make observations both day and night. In every case, I did the field work during nights with no moon light, in order to prevent from affecting crocodile sighting in the river. I used a 3.5 m inflatable boat AVON and a 15HP Yamaha engine, in the usually navigable rivers like Tempisque from the ocean to the Bridge at Hacienda El Viejo, and the Bebedero River, from its confluence with the Tempisque River, up to the town of the same name. I worked the Blanco River using the same boat, but with a 2.5 HP motor in the first section from Bebedero, and continued then by rowing when it was necessary to remove the engine in order to go on. In the rest of segments of the Upper Basin, where there are frequent rapids and areas of very low depth and cobbled floor, I required to use a 3.2 m inflatable boat AIR brand, and worked sliding stream down, rowing from the beginning point. This was also the way I did the Cañas River and the Lagoon of Mata Redonda. Every time it was needed, I walked at the water body to come closer the animal and to observe it straight or to capture it, so that the depth was not a factor preventing me from doing an observation or capture. Five of the field trips were dedicated exclusively to the apprehension of the crocodiles that would provide with information about the sex rate in the TGW. I used a 6V and 10A RAYOVAC head lamp, as well as a Garmin ETREX GPS to trace the routes and monitoring of the trips.

Size structure was done by means of visual estimation, whenever it was possible to observe the complete animal, or for extrapolation when I could only observe its head on the surface of the water, according to which the length of the head fits 6.6 times in the entire size of the crocodile, in accordance with performed measurements I made in up to 275 crocodiles of all the different sizes. According to this, individuals were placed in a size classification every 0.5 m between SIZE I and SIZE IX, this is, from "X≤ 0.5 m" to "4≤X≤ 4.5 m". Whenever it was not possible to determine any measurement of the animal, and as it gets used in this type of studies, I checked the observation as "eyes only" (King *et al.* 1990). Then these classes were added up into groups representing actual stages in the natural growing up of the crocodile, as hatchlings, recruits, juvenile, sub-adult and adult. The class "hatchling" (≤0.5 m) appears in the remarks table because it exists as such, and its report turns out to be important to demonstrate a working and dynamic population, nevertheless, its number will not be considered for further analysis in this study, since the survivorship percentage in this class is about 5%, and its incorporation to the active population is as improbable as that.

Trying to maintain parallelism with earlier studies performed in the main river bed of the Tempisque during the past 19 years, I kept the division of the observations in four segments, in order to be able to make segment counts when the climate conditions demand so. Statistical tests were done using SPSS, version 15 for Windows.

Results

I designed this work to estimate the real size of the population of the TGW, determining the structure of its population for sizes and for sex. I established for the first time the distribution of the crocodiles along the diverse water courses, and made an estimation of the relative abundance of crocodiles in the whole wetland. In the hope to construct a sufficient factual foundation to sustain some management lines to wisely handling the actual problem being faced by civil population and environmental authorities related to crocodiles in the TGW, in such a way that they allow to preserve this crocodiles population, at the same time relieve the pressure that they allege to suffer. I analyzed my field observations considering historical information of meteorological nature, as well as information relative to the green coverage of the area of study, the agricultural and cattle practices in the place, and the town-planning pressure in the area.

Thinking that the work segments are a representative partial vision of the existing reality in the whole study area, I estimated the whole population using sampled values gathered, with the information obtained in every class of habitat as it is the case.

Table 3. Crocodile counts in the Tempisque Great Wetlands by area and segment. Counts were corrected for area not surveyed (Correc. km), and then for visibility bias (Correc. visib.). H= hatchlings, R= recruits, J= juveniles, SA= sub-adults, A= adults, EO= eyes only.

Area/Segment Size category (m)	H <0.5	R 0.5- 1.0	J 1.0- 1.5	SA 1.5- 2.0	SA 2.0- 2.5	A 2.5- 3.0	A 3.0- 3.5	A 3.5- 4.0	A 4.0- 4.5	Eyes Only	Counts	Correc. km	Correc. visib.
Upper Basin													
Corobicí R.			4	3			4			2	13	13	14
Tempisquito R.		5	6	3	5	8	1			1	29	52	56
Los Ahogados R.	10	6	2	6	7	1					32	56	60
Colorado R.	4	4	5	2	4	3	1				23	23	25
Irigaray - Guardia	65	31	27	15	5	5				13	161	178	192
Sub-Total	**79**	**46**	**44**	**29**	**21**	**17**	**6**	**0**	**0**	**16**	**258**	**323**	**347**
Lower Basin													
Tempisque - main channel													
Níspero - Humo	15	33	8	8	18	10	18	2	2	9	123	123	140
Humo - Chamorro	6	21	8	10	5	1	11	1		2	65	65	74
Chamorro - Bolsón	22	18	14	16	38	24	33	4	4	5	178	178	202
Bolsón - Puente Pelón	25	13	3	3	12	13	18	8	3	11	109	109	124
Bebedero R.	4	27	26	16	11	6	3		1	5	99	99	113
Tenorio R.	5	6	7	6	4	5	10			4	47	47	53
Blanco R.		8			2	1	1			2	14	30	34
Cañas R. - Cañas	11	2	5	1	2	9	3	1		4	38	67	76
Palmira - Filadelfia		3	26	3	10	5	1			4	52	62	70
Las Bombas - Pelón		16	68	47	44	3	4			8	190	538	612
Sub-total	**88**	**147**	**165**	**110**	**146**	**77**	**102**	**16**	**10**	**54**	**915**	**1317**	**1497**
Marshes Zone													
Mata Redonda Lagoon	20	6	24	3	25	6	4			25	113	283	314
Charco R.	3	3	4	2	3	2	2	0	0	2	21	21	23
Bolsón R.	7	7	9	5	7	4	4	1	0	4	48	120	133
Sub-Total	**30**	**16**	**37**	**10**	**35**	**12**	**10**	**1**	**0**	**31**	**182**	**424**	**471**
Totals	**197**	**209**	**246**	**149**	**202**	**106**	**118**	**17**	**10**	**101**	**1355**	**2064**	**2315**
Totals (size categories)	**197**	**209**	**246**	**351**			**---------------- 251 ----------------**			**101**			

These observations were done along the different segments of work, the length of those segments is presented in Table 4.

Table 4. Total river distances and survey lengths.

Area/Segment	Surveyed (km)	Total (km)	Area/Segment	Surveyed (km)	Total (km)
Upper Basin					
1. Corobicí River	6	6	10. Bebedero River	20.5	20.5
2. Tempisquito River	9	16.22	11. Tenorio River	18.2	18.2
3. Los Ahogados River	6	10.5	12. Blanco River	3.3	7
4. Colorado River	7	7	13. Cañas River	10	17.5
5. Tempisque River Irigaray - Guardia	22	24.37	14. Tempisque River Palmira - Filadelfia	14.5	17.27
Sub-total	**50**	**64.09**	15. Tempisque River Las Bombas - El Pelón	6	17
Lower Basin			**Sub-total**	**118.6**	**143.57**
6. SEGMENT A - Tempisque Níspero - Puerto Humo	22	22	**Marshes Zone**		
7. SEGMENT B - Tempisque Pto. Humo - Pto. Chamorro	7.7	7.7	16. Mata Redonda	4	10
			17. Charco River	2.2	2.2
8. SEGMENT C - Tempisque Pto. Chamorro - Bolsón	7.7	7.7	18. Bolsón River	2	5
			Sub-total	**6**	**17.2**
9. SEGMENT D - Tempisque Bolsón - El Pelón	8.7	8.7	**Total**	**174.6**	**224.86**

The field work considered a fraction of 78% of the whole potentially workable kilometres. Segments from 1-5 (Upper Basin) represent 29% of the surveyed area with visibility of 93%; segments 6-15 (Lower Basin) represent 68% of the surveyed area with visibility of 88%, and segments 16-18 (Marsh Zone) represent 3% of the surveyed area with visibility of 90%.

I could only work 35% of the available Marshes Zone habitat, due to the difficulties imposed by the environment to actually make effective observations, with too many vegetation in the edge of the water, and a profuse aquatic flora or tifa (*Typha domingensis*), lotus (*Nymphaea* sp)., choreja (*Eichhornia crassipes*), elodea (*Elodea canadensis*) and gamalote (*Paspalum fasciculatum*), which seriously difficult the transit of any type of craft, and even the researcher himself whenever I decided to get to the water trying to improve my possibilities. On the other hand I covered more than 75% of the sampleable potential habitat of the Upper Basin and Lower Basin, and in general more than 75% of the available habitat in the TGW.

A proportional distribution of the "eyes only" among the size classes results in a distribution of: hatchlings 364 (15.7%), recruits 386 (16.7%), juveniles 454 (19.6%), sub-adults 648 (28.0%) and adults 463 (20.0%).

Given that hatchlings are not considered to be a part of an effective and stable population, then substrating them from the gotten numbers, the entire number of crocodiles estimated in the TGW added up to n = 1951 crocodiles, ± s=25.96.

Distributed by area with 292 (15.0%), 1262 (64.7%), and 397 (20.4%) individuals, according to Upper Basin, Lower Basin and Area of Marshes respectively; for a general relative abundance of 8.68 ind/km; and partial for area of 4.56 in the Upper Basin, 8.79 in the Lower Basin and 23.08 in the Area of Marshes.

I captured 25 small crocodiles during the general observation field trips, every time it meant no extra difficulties to grab and manipulate them while accomplishing the general objectives of the survey. Furthermore, I carried out five field trips with the only aim of capturing as many crocodiles as possible in every one of the three environments studied. Among some other complementary targets, the purpose of these captures was to get information to estimate the population sex rate. I captured a total of 72 crocodiles, 55 males and 17 females, for a general sex rate of 3.3:1 male:female. In the High Basin I captured 12 crocodiles, 3 females, for a sex rate of 3:1 male:female. In the Low Basin I captured 52 crocodiles, 12 turned out to be females, for a sex rate of 3.33:1 male:female. I captured 8 crocodiles in the Area of Marshes, 2 of which were females, for a sex rate of 3:1 male:female. The size of capture was between 75 and 352 cm. I avoided sexing individuals of a smaller size due to the difficulties in determining sex in hatchlings and small recruits, as well as the risk injury they would run trying to sex them (Allsteadt and Lang 1995).

Table 5. Comparison of 1989-1994 (early) and 2003-2008 (late) periods with respect to meteorological station. Values are Student-t and probability. Mean (and estimated deviation) values are also provided for rainfall and minimum temperature.

	Years	Llano Grande	Taboga
Humidity		t= 0.005	t= -1,635
		p= 0.996	p= 0.105
Rainfall	1989-94	110.14 (125.47)	113.07 (106.33)
	2003-08	160.25 (181.92)	160.82 (171.98)
		t= -1,924	t= -2
		p= 0,057	p= 0.048
Max. Temp.		t= 1.015	t= 0.439
		p= 0.312	p= 0.662

On a 20-year time series between 1989 and 2008, for the climatic factors precipitation, temperature and moisture, I run a statistical analysis to contrast between the first six and last six years of the series, considering only 4 summer months in each of two existing meteorological stations in the studied area. I did this, trying to determine the effect of the climate on the skewed sex rates in the TGW, and the chosen months are these in what eggs incubate. I found significant values just for precipitation at both meteorological stations; and for the minimal values of temperature at the Taboga station, in Cañas (Table 5).

It can be seen that there has been a significant increase of up to 50.11 mm in the precipitation levels between the first and last years of the series; nevertheless, although it is true that the increase in the precipitation favors the general conditions of the crocodile's habitat, it is not proven that precipitation influences somehow the sex definition during the incubation time.

On the other hand, a highly significant change has been acquainted, of 0.66°C during this 20 years time span in the minimum temperature, in the Taboga meteorological station. In spite of this, the compared averages as can be seen in Table 6, do not even reach 24°C, therefore they do not qualify as temperatures to incubate crocodile eggs, and could not be associated this variable to the sex rate encountered.

Discussion

The crocodile population along the navigable main river channel, represents 23% of the whole estimated population for the Tempisque Great Wetlands; I verified that in effect, the real size of the local population of crocodiles has been underestimated, as a product of a limited conception of what should be the objective habitat.

The Area of Marshes constitutes a nursery for the individuals of lesser sizes, and a refuge area for crocodiles of medium total length (Sánchez 2001). Some adult crocodiles rejected from the main river channel during the season of courtship and mating, use to visit this place, and sometimes they remain there indefinitely. Lara (1990) reports as better relative abundance 5.9 ind/km for the marsh crocodile (*C. moreletii*) in a marsh segment in secondary forest, in the Petén area, Guatemala, and he argues reasons similar to those of Sánchez (2001). Casas-A and Méndez-DC (1992) report 12.3 ind/km, for a study on *C. acutus* done in 1989, in the Cuitzmala River, Jalisco, Mexico. Barahona-B and Bonilla-C (1999) report 2.16 ind/km for Orinoco Crocodile (*C. intermedius*) in the Arauca area in Colombia. Sánchez (2001) accounts for a relative abundance of 18.3 ind/km in the Tempisque river, on the navigable main river bed; right after his Sánchez *et al.* (1993) report of a relative abundance of 2.3 ind/km , scarcely in an 8 years time span. This present study, of a more integral character from the spatial point of view, seems to agree more with the last observation of Sánchez, if it is considered that there have been visited areas of diverse environmental characteristics, and the hatchlings have been excluded definitely from the analysis. It might be speculated that important events have happened during this time, to justify, along with normal changes that usually happen in any natural environment, for a jump of up to almost four times in the growth of this population, unwillingly of what it would be expectable given the loss of habitat due to the advance of the agricultural border and of the urban pressure. Porras-M (2004) reports 5.58 ind/km of *C. acutus* in the Tusubres River, in the Central Pacific coast of Costa Rica, in the area of coverage of the Playa Hermosa Wildlife Refuge, with important agricultural activity in the area, and the constant alertness of the wildlife rangers; without mentioning that according to personal information under analysis, apparently the most pristine and rainy areas affect negatively the relative abundance of *C. acutus*. As a corollary, given the existence of a report of a relative abundance of 2.28 for the Sierpe and Térraba Rivers (Bolaños *et al.* 1997), and under this former assumption, this datum is not a good reference to compare for the occasion, since the environmental conditions in the South Pacific coast of the country (Very Humid Tropical Forest) are a lot different from those found in the North Pacific coast (Tropical Dry Forest); and the impact of man is also different in both regions. Cedeño *et al.* (2006) report relative abundances from 0.13 to 2.69 ind/km for C. acutus; and of between 0.87 and 7.57 ind/km for C. moreletii, in the state of Quintana Roo, Mexico. Rainwater and Platt (2009) report 0.49 ind/km for *C. acutus* in the keys of Blackbird and Calabash, in Turneffe Atoll, in Belize. Sasa and Chaves (1992) and Piedra (2000) found in the Tárcoles River, in the Central Pacific Ocean, relative abundances of 19.2 and 32.02 respectively; comparison that must be carefully done, considering that the Tárcoles River in the segment where these studies were done, passes by the edge of the Carara National Park and also considered the Guacalillo protected mangrove. Besides, and this is more important, the tourist activity with crocodiles was born and it has developed in this place, and the tourist guides provide the animal of a special protection and feeding; without mentioning that the hatchlings class was part in these studies, and depending on the season, a large number of eyes can be seen in the river during the nights when the bloom has just taken place.

The size structure presents a peak in the class of sub-adults with 28%, and then fall down up to 20% in the adults class. The classes of lesser size, although with a high absolute frequency, are relatively speaking, of low profile, since the samplings were done almost always during the second semester of the years of field observation, and present hatchlings show a very low survivorship during the first two months of age. As for the recruits (17%) and juvenile (20%), although they were also observed in fair amount, it turns out to be very probable that they prefer to inhabit the small adjacent wetlands to the river, areas of cultivation and proper and abundant channels of irrigation in the TGW, to avoid the contact with their major size congeners and to hide better than their natural predators, until the time of having a more competitive size to introduce themselves openly before their community.

On having compared the results obtained in previous studies with the present one, it turns out to be clear that the percentage contribution of "recruits" to the population grew scarcely moderately in 6%, followed by an average growth of 8% "juvenile" in the class. In both cases the increase happened during the first 8 years of the interval, and stayed approximately stable during the space of 7 remaining years up to the present study. This might be reflecting that the nests quantity in the field increased the same way as the reproductive females stock increased in the wild during the first period. Apparently this condition remained constant during the second period.

Table 6. Comparative distribution (%) by size according of the TGW crocodile population in different years. * Sánchez *et al*. (1996); ** Sánchez (2001).

Class	1993*	2001**	2008
Recruits	12	18	18
Juveniles	14	24	7
Sub-adults	5	8	23
Adults	7	17	32

Of the same way, the quantity of "sub-adults" increased lightly from 5% to 8% during the first lapse, to advance in a change of 20% for the second period, in which the surviving recruits of the first period reached sizes of up to 2.5 and 3 m. The same relation is observable in the class of "adults", which reached an increase of 10% in the first period, and 3 more points during the second, consistent with the fact that during this stage of its lives, the crocodiles approach more its asymptotic size, and its yearly growth is perceptibly slower than the one shown by individuals of lesser sizes.

In general, the evidence points towards a population in plain growth, as demonstrated by the absolute numbers, and although it should not have been an object of this study, it would be necessary to expect that the dispersion of this population should happen of a homogeneous form in the whole area of the TGW, and according to the proper characteristics of different habitat recounted, with a better expectation in the Lower Basin of the river, because of the aquaculture companies cited.

Cedeño *et al*. (2006) reported percentages of 6.25, 34.3 and 53.1 for juvenile, sub-adult and adult respectively in the *C. acutus* population in Quintana Roo in Mexico, which demonstrates an increasing tendency towards the individuals of larger sizes, which joined to the low relative abundance might indicate a population being harvested in its individuals of lesser sizes, what marks the disappearance of these classes of size.

The fragmentation of the habitat product of the economic activities, along with the human increase in the river as a product of the boom of the tourist activities, and of the fact that human settlements seek always to be established next to the water courses; the loss or migration of the considered species "natural preys" for the crocodile, and the disappearance of some of the species that normally would prey on crocodiles during their first weeks, like coyote (*C. latrans*), puma (*Panthera concolor*), garrobo (*C. similis*), pizote (*N. narica*), martín peña (*T. mexicanus*) and real heron (*A.alba*) among others, have brought as a result that the loss of nests and of hatchlings owed to natural depredation has diminished, and that for his part, due to its proximity with man, crocodiles have changed their everyday menu towards other species that previously were not occupying its interest, like dogs, ducks, pigs, calves, and even humans when the occasion has allowed it. Additional to this, the successful establishment of the aquaculture industry has meant a constant food provision in the form of tilapia (*O. niloticus*) in all the watercourses in the area; and with this, it is reasonable to hope that the implicit reduction in the competition for food, have brought a consistent increase in the numbers of the populations of the species that feed on this fish, crocodiles one of them.

Although places exist with similar relative abundance inside the limits of our borders, and although the existing habitat presents conditions the same way adapted for the development of a numerous population of crocodiles, according to the stereotype of which places more retired and less invaded by the man present better characteristics for the development of a better population of crocodiles, nevertheless, they do not exhibit higher values and do not even be equal to what I found.