

Status and conservation of the American crocodile, *Crocodylus acutus*, in Belize

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Abstract

The status of the American crocodile (*Crocodylus acutus*) in the coastal zone of Belize was investigated from July 1996 to October 1997. Two hundred and sixty-two crocodiles were observed during spotlight surveys of 952.2 km of the survey route (0.28 crocodiles/km). Encounter rates were highest in the Turneffe Atoll, and low to moderate elsewhere. Most nesting occurs on elevated beach ridges in the Turneffe Atoll. Freshwater and brackish lagoons adjacent to nesting sites provide essential nursery habitat. Despite legal protection, populations are threatened by opportunistic killing, accidental drowning in fishing nets, and habitat destruction, especially the development of critical nesting habitat. Protection of nesting and nursery habitat is of paramount importance for the continued survival of the American crocodile in Belize. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The American crocodile (*Crocodylus acutus*) occurs on the Atlantic and Pacific coasts of Mexico, Central America, and northern South America, as well as the Caribbean islands of Cuba, Jamaica, Hispaniola, and the southern tip of Florida, USA (Thorbjarnarson, 1989). American crocodile populations have declined throughout much of this range due to past over-exploitation, continued illegal hunting, and habitat destruction (Thorbjarnarson, 1989; Ross, 1998). *Crocodylus acutus* is currently considered vulnerable by the International Union for the Conservation of Nature and Natural Resources (IUCN), listed on Appendix I of the Convention on Trade in Endangered Species of Flora and Fauna (Ross, 1998), and considered threatened by the Belize Department of Fisheries (McField et al., 1996).

The American crocodile is one of two species of *Crocodylus* which occur in Belize (Groombridge, 1987). *Crocodylus acutus* is found in mainland coastal habitats and offshore islands, while Morelet's crocodile (*Crocodylus moreletii*) occurs in mainland coastal and inland habitats

(Platt, 1996). Over-harvesting by commercial skin hunters depleted crocodile populations in Belize, and by the late 1960s both *C. acutus* and *C. moreletii* were nearly extirpated (Charnock-Wilson, 1970). Legal protection was afforded both species under the Wildlife Protection Act of 1981 (Marin, 1981), and recent surveys suggest *C. moreletii* populations are recovering (Platt, 1996).

However, little is known concerning the abundance and distribution of *C. acutus* in Belize. Previous assessments of abundance are often conflicting and based largely on unspecified subjective criteria rather than quantitative survey data. Neill and Allen (1961) considered *C. acutus* extremely rare on the mainland. The Turneffe Atoll is the only Belizean locality given on the range map of Lee (1996). According to Ross (1997), few, if any *C. acutus* remained on offshore islands by the early 1970s. Powell (1971, 1973) concluded American crocodiles were present on some offshore islands, but extinct on the mainland, and King et al. (1982) noted some island populations had been extirpated. However, Perkins (1983) estimated a countrywide population as high as 10,000 to 20,000, but cautioned that these numbers are highly speculative and based solely on interviews with skin dealers.

These reports notwithstanding, the current status of the American crocodile in Belize remains poorly known,

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and comprehensive survey data are lacking. Such information is essential for the development of appropriate conservation strategies, and surveys of American crocodile populations in Belize have been accorded high priority by the IUCN/SSC Crocodile Specialist Group (Thorbjarnarson, 1992; Ross, 1998). The objectives of this study were to obtain baseline data and assess the status of American crocodile populations in the coastal zone of Belize, locate critical nesting habitat, and provide conservation recommendations based on these findings.

2. Study area

The coastal zone of Belize is defined as all wetlands, both freshwater and saline, within 10 km of the Caribbean Sea, and all offshore cays and atolls (McField et al., 1996). Extensive coastal wetlands occur on the mainland, particularly in northern Belize (McField et al., 1996). Water salinities range from 0 to 35 ppt depending on location, time of year, and amount of recent rainfall (Zisman, 1992). Mainland wetlands are dominated by mangroves (*Rhizophora mangle* and *Avicennia germinans*), with sawgrass (*Cladium jamaicense*) marsh in less saline habitats (Zisman, 1992; McField et al., 1996).

The Belize barrier reef extends 220 km along the coast, and is separated from the mainland by a narrow (19–30 km) stretch of water known as the inner channel (McField et al., 1996). Within this channel there are approximately 450 cays with a land area of 689 km² (Hartshorn et al., 1984). Most cays are less than 1.0 m above mean sea level and subject to periodic inundation (Hartshorn et al., 1984). Cays are dominated by mangrove vegetation, with littoral forest on elevated sites (McField et al., 1996).

Two coral atolls found outside of the Belize barrier reef were surveyed: Turneffe and Lighthouse Atolls. Turneffe Atoll has an estimated surface area of 533 km² (Perkins, 1983), and consists of a chain of islands partially enclosing three shallow lagoons. Lighthouse Atoll has an estimated surface area of 126 km², although most (>95%) of the atoll is underwater, and terrestrial habitat consists of four small cays (Hartshorn et al., 1984). Atoll vegetation is similar to other coastal habitats (McField et al., 1996).

3. Methods

Nocturnal spotlight surveys were used to census crocodile populations (Messel et al., 1981; Magnusson, 1982; Bayliss, 1987; O'Brien, 1990; King et al., 1994). Most surveys were conducted from a 7.5 m skiff equipped with two 60 hp outboard engines, although some were

conducted from an aluminium canoe when shallow water or navigational hazards precluded using the larger boat. Crocodiles were located with a 400,000 candle-power Q-beam spotlight and 12 V headlights. Only 12 V headlights were used during canoe surveys. Spotlight surveys began 15–30 min after sunset (Messel et al., 1981), and periods of inclement weather were avoided (Woodward and Marion, 1978).

The coordinates of the beginning and endpoint of each survey were determined with a handheld Global Positioning System (GPS). Distance travelled in each survey was determined from 1:50,000 topographical maps obtained from the Department of Lands and Surveys, Belmopan, Belize. Survey routes were calculated as shoreline distance along coastline and lagoons, or midstream length in linear habitats such as creeks and rivers (King et al., 1990). Encounter rates were calculated as the number of crocodiles observed per kilometre of survey route (Bayliss, 1987). The observed distribution of crocodiles in coastal mainland, cay, and atoll habitats was tested against a null model of random distribution using a chi-square goodness of fit test and a Z-test (Thorbjarnarson, 1988).

All crocodiles sighted were approached as closely as possible, identified to species, and total length (TL) estimated. On the coastal mainland where *C. acutus* and *C. moreletii* occur sympatrically, species identification was based on differences in head shape (Brazaitis, 1973), a characteristic readily apparent during spotlight surveys. American crocodiles were classified as hatchlings (TL < 30 cm), juveniles (TL = 30–90 cm), subadults (TL = 90–180 cm), or adults (TL > 180 cm). Crocodiles which submerged before TL could be determined were classified as “eyeshine only” (EO). Counts and size estimates were conducted by the same observer (SGP) on all surveys. A chi-square analysis was used to compare size-class distributions within each habitat against a null model of equal distribution.

Crocodiles were captured whenever possible to confirm size estimates, verify species identifications, and determine sex. With the exception of recent hatchlings, all captured crocodiles were sexed by cloacal examination (Brazaitis, 1968). Observed sex ratios were tested against a null hypothesis of a 1:1 sex ratio using chi-square analyses (Caughley, 1977).

Potential habitat was searched, often in conjunction with population surveys, to locate nesting areas. Females deposit eggs in hole nests, and return upon hatching to excavate nests and release neonates (Platt and Thorbjarnarson, in press). Nesting activity was verified by the presence of active and opened nests, eggshells, and eggshell membranes.

An estimate of the minimum number of crocodiles in the Turneffe Atoll was calculated by extrapolating our survey results to the entire atoll. The linear extent of shoreline in the atoll was measured from 1:50,000

topographical maps, and multiplied by encounter rates from spotlight surveys. One assumption of this method is that crocodile densities are relatively uniform throughout the atoll. As survey results did not include crocodiles that were concealed in mangroves or submerged, our calculations represent only a minimum number of crocodiles present.

4. Results and discussion

4.1. Population surveys

Spotlight surveys were conducted from July 1996 to October 1997 throughout the coastal zone of Belize (Fig. 1). Beginning and endpoints, and a description of

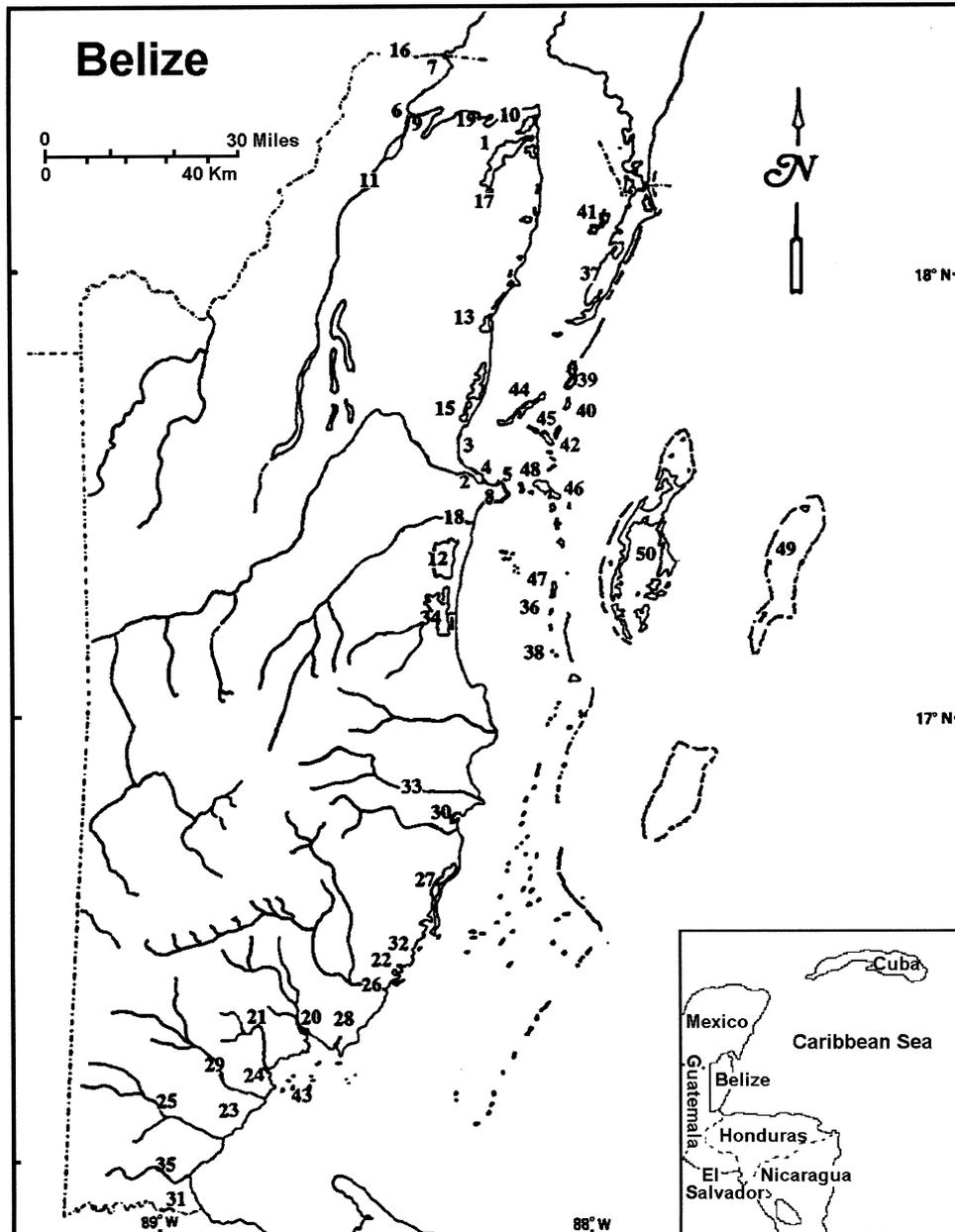


Fig. 1. Map of Belize showing approximate location of spotlight surveys conducted from July 1996 to October 1997. 1. Barracouta Pond; 2. Burdon Canal, Faber's Lagoon; 3. Coastline; 4. Ladyville; 5. Vista del Mar; 6. Four-mile (San Roque) Lagoon; 7. Four-mile Lagoon; 8. Haulover Creek; 9. Laguna Seca; 10. La Isle Cenote; 11. New River; 12. Northern Lagoon; 13. Northern River Lagoon; 14. Petrojam Lagoon; 15. Potts Creek Lagoon; 16. Rio Hondo; 17. Shipstern Lagoon; 18. Sibun River- Burdon Canal- Jones Lagoon; 19. Waree Bight Cenote; 20. Deep River; 21. Golden Stream; 22. Indian Hill Lagoon; 23. Joe Taylor Creek; 24. Middle River; 25. Moho River; 26. Monkey River; 27. Placencia Lagoon; 28. Punta Yacos Lagoon; 29. Rio Grande River; 30. Sapodilla Lagoon; 31. Sarstoon River; 32. Sennis River; 33. Sitee River; 34. Southern Lagoon; 35. Temash River; 36. Alligator Cay; 37. Ambergris Cay; 38. Bluefield Range; 39. Cay Caulker; 40. Cay Chapel; 41. Deer Cay; 42. Frenchman's Cay; 43. Gulf of Honduras; 44. Hicks Cay; 45. Long Cay; 46. Maps Cay; 47. Middle Long Cay; 48. Moho Cay; 49. Lighthouse Atoll; 50. Turneffe Atoll.

each survey route, is presented in Platt and Thorbjarnarson (1997), copies of which were deposited in the National Archives (Belmopan, Belize), Campbell Museum (Clemson University, South Carolina, USA), and Wildlife Conservation Society (Bronx, New York, USA). A total of 262 American crocodiles were observed along 952.2 km of the survey route (0.27/km). Considerable variation in encounter rates was noted between the Turneffe Atoll, coastal mainland, and cay habitats (Table 1). A chi-square goodness of fit test indicated crocodiles were not randomly distributed between habitats ($\chi^2 = 418.4$; $df = 2$; $P < 0.001$). *C. acutus* were significantly more abundant on cays and the Turneffe Atoll, and less abundant in mainland coastal habitats than would be expected in a null model of random distribution (Table 1).

American crocodiles were found at only five of 35 (14.2%) mainland sites we surveyed. However, failure to record *C. acutus* at particular sites should not be interpreted as a complete absence from an area. Instead, *C. acutus* may be present, but at such low densities that the probability of encountering one during a single survey is very small. A chi-square test indicated that encounter rates in coastal mainland regions of northern (0.01/km) and southern (0.02/km) Belize were not significantly different from a null model of random distribution ($\chi^2 = 0.90$; $df = 1$; $P > 0.05$). Most crocodiles found on

the mainland were subadults (see size class distribution), and may represent individuals dispersing from offshore islands, rather than members of an established population.

Encounter rates for *C. acutus* in other regions are not widely available (Thorbjarnarson, 1989), but tend to be highest in lacustrine and riverine habitats, and somewhat lower in coastal swamps (Table 2). Encounter rates in Belize are among the lowest reported, especially in mainland habitats, and may reflect a combination of past over-exploitation, habitat quality, and perhaps competition between *C. acutus* and *C. moreletii*.

4.2. Population size-class structure

A total of 289 American crocodiles were observed during daylight reconnaissance and spotlight surveys. Of these, 95 (32.8%) were classified as EO, and 194 (67.1%) were captured or approached closely enough to estimate size: 47 (24.2%) juveniles, 76 (39.1%) subadults, and 71 (36.5%) adults. Size-class distributions in cay habitats did not differ significantly from the null model, but significant differences were found in mainland habitats and the Turneffe Atoll (Table 3). Subadults were more abundant than expected in mainland habitats, and juveniles were less abundant than expected in the Turneffe Atoll. The high percentage of adults found in the Turneffe Atoll could be due in part to sampling bias; juveniles may remain concealed within mangrove vegetation and escape detection during spotlight surveys.

Only 17 (8.7%) crocodiles for which size could be determined in this study had an estimated total length greater than 240 cm. The largest was a 3.2 m individual encountered in the Turneffe Atoll. *C. acutus* is known to attain maximum total lengths of 6.25–7.0 m, although today individuals over 4.0 m are rare (Thorbjarnarson, 1989). Our observations indicate *C. acutus* in Belize may attain a smaller body size than reported for other populations. It is unknown whether this is due to genetic and environmental factors, or past over-exploitation which removed most large adults.

Table 1
Comparison of encounter rates of American crocodiles in coastal habitats of Belize

Habitat	Number of crocodiles	Kilometres surveyed	Encounter rate (crocodiles/km)	Z-score
Mainland	14	575.6	0.02	-18.10 ^b
Cays	96	219.8	0.43	5.68 ^a
Turneffe Atoll	152	156.8	0.96	17.90 ^b

^a $P < 0.05$.

^b $P < 0.001$.

Table 2
Encounter rates reported for spotlight surveys of the American crocodile

Location	Encounter rate (crocodiles/km)	Habitat	Source
Belize	0.02	Mainland	This study
Belize	0.43	Cays	This study
Belize	0.94	Atolls	This study
Costa Rica	2.9–4.5	River	Sanchez et al. (1997)
Haiti	6.3	Lake	Thorbjarnarson (1988)
Honduras	0.51	River	Thorbjarnarson (1989)
Honduras	0.34	Coastal/River	King et al. (1990)
Mexico (Chiapas)	0.6–2.1	Coastal	Martinez-Ibarra et al. (1997)
Mexico (Sinaloa)	6.94	Coastal	Ojeda et al. (1997)
Venezuela	2.52–7.13	River	Arteaga and Sanchez (1996)

4.3. Sex ratio

Sex was determined for 83 *C. acutus* captured during our study (Table 4). The resulting overall sex ratio, and the sex ratio for mainland habitats and the Turneffe Atoll was not significantly different from parity. The sex ratio for the cays was significantly different from 1:1 and was male biased. Mainland populations may also be different from 1:1, but the small sample size lacked sufficient statistical power to detect differences. Although male biased populations have been reported (Thorbjarnarson, 1988, 1989), the sex ratio of most *C. acutus* populations is not significantly different from 1:1 (Gaby et al., 1985; Kushlan and Mazzotti, 1989; Moler, 1991; Brandt et al., 1995).

4.4. Nesting habitat

Fifty-seven nests at 12 sites were located from 1994 to 1997. Eight nesting sites (66.7%) were found on beach ridges, three (25.0%) on spoilbanks, and one (8.3%) on a low-relief beach. Colonial nesting (more than one nest at a site) occurred at five (41.6%) nesting sites, and accounted for 41 (72.0%) nests. Nesting activity was concentrated in the Turneffe Atoll, where 41 nests were found and up to 15 clutches were deposited annually. Nesting sites are reused annually, and nesting occurred in multiple years at ten of 11 (91.0%) sites for which more than one year of data is available. Colonial nesting and nest site reuse among *C. acutus* is common,

especially where suitable nesting habitat is scarce (Thorbjarnarson, 1989).

Most nests were found on elevated beach ridges composed of coarse sand. These beaches are often associated with shallow lagoons, which serve as critical nursery habitat for hatchling crocodiles. These lagoons are rich in prey, offer abundant cover, shelter from wave action, and most importantly, provide a source of fresh or brackish water. Water salinity in these lagoons is seasonally variable and strongly influenced by rainfall events. Salinity is lowest following heavy rains, which occur during late June and July (Hartshorn et al., 1984), a period coinciding with hatchling emergence (Platt and Thorbjarnarson, 2000). Hatchlings cannot maintain body mass in seawater (36 ppt; Dunson, 1982), and access to fresh or brackish water (≤ 10 ppt) is necessary for osmoregulation (Mazzotti et al., 1986). Hatchling survival is typically high where nursery habitat is available (Kushlan and Mazzotti, 1989). At other sites in Belize lacking suitable nursery habitat, hatchlings may be subject to prolonged periods of osmotic stress, resulting in decreased growth and survival.

Nesting habitat in Belize is limited due to a combination of natural and anthropogenic factors. Elevated beaches generally occur only on the eastern shores of cays, and are absent on many, especially those inside the barrier reef. Additionally, beaches are highly sought as sites for fishing camps and tourist resorts, further reducing available nesting habitat.

4.5. A population model for the American crocodile in Belize

From topographic maps we measured 229 km of shoreline habitat in the Turneffe Atoll. Multiplying this value by the observed encounter rate (0.96/km) yields an estimate of 220 non-hatchling crocodiles. This should be considered a minimum estimate as not all crocodiles are sighted during spotlight surveys, and the actual population is undoubtedly larger.

Using this estimate for the Turneffe Atoll and the area of mangrove habitat in the coastal zone, it is possible to obtain a crude approximation of the country-wide population of *C. acutus* (Table 5). There are 8771 ha of mangrove habitat in the Turneffe Atoll (McField et al., 1996), and assuming a population of 200–300 non-hatchling crocodiles, a low and high density of 0.023 to 0.034 crocodiles/ha is calculated. The ratio between the encounter rate in the Turneffe Atoll (0.96/km), and encounter rates in the cays (0.43/km) and mainland (0.02/km) is 0.448 and 0.0208, respectively. Crocodile densities for cay and mainland habitats can thus be calculated by multiplying the estimated density in the Turneffe Atoll by these ratios. Multiplying these densities by the area of available habitat then yields population estimates for cay and mainland habitats. Summing the

Table 3
American crocodile size classes compared by habitat^a

Habitat	Juveniles	Subadults	Adults	χ^2
Mainland	2 (13.3) ^a	11 (73.3)	2 (13.3)	10.8 ^b
Cays	21 (35.0)	20 (33.3)	19 (31.6)	0.10 NS ^c
Turneffe Atoll	24 (20.1)	45 (37.8)	50 (42.0)	9.6 ^b

^a Total number of crocodiles followed by frequency (%) within each habitat in parentheses.

^b $P < 0.05$.

^c NS Not significant.

Table 4
Comparison of the sex ratio of American crocodiles captured in coastal habitats of Belize (1996–1997)^{a,d}

Habitat	Females	Males	Sex ratio	χ^2
Mainland	1	5	1:5	2.6 NS ^b
Cays	3	19	1:6.3	12.1 ^c
Turneffe Atoll	32	23	1:0.7	0.92 NS
Total	36	47	1:1.3	2.09 NS

^a Sex ratio presented as female:male.

^b NS, Not significant.

^c $P < 0.01$.

^d $P < 0.001$.

Table 5
Population estimates of *C. acutus* in the coastal zone of Belize

Habitat	Density (crocodiles/ha)		Mangrove habitat (ha) ^a	Estimated population
	Low	High		
Turneffe Atoll	0.023	0.034	8771	200–300
Cays	0.010	0.015	12 913	132–198
Mainland	0.0004	0.0007	54 255	26–39

^a Data from McField et al. (1996).

resulting values gives a country-wide population of only 358–537 crocodiles. We are aware of the uncertainty and potential sources of error inherent in our attempts to estimate the population of *C. acutus* in Belize. However, even if our upper estimate is doubled, there are still less than 1100 non-hatchling American crocodiles in Belize, considerably less than the estimate of 10,000–20,000 proposed by Perkins (1983).

The crocodiles in the Turneffe Atoll may function as a regionally important source population. Large juvenile and subadult *C. acutus* enter a dispersal phase as they mature and begin to come into territorial conflict with adults (Thorbjarnarson, 1989). Crocodiles often move long distances during this phase, and tagged juveniles have been recovered up to 112 km from their initial point of capture (Moler, 1991). The Turneffe Atoll is only 15–20 km from the chain of offshore cays inside the barrier reef; well within the dispersal capabilities of emigrating crocodiles. Given the relatively large number of adults and the highest concentration of nesting activity in the coastal zone, it is probable that the Turneffe Atoll population is extremely important in regional metapopulation dynamics.

5. Conclusions and conservation recommendations

Most crocodile populations are resilient to over-exploitation and respond well to protection (Bayliss, 1987). Elsewhere, rapid recovery of American crocodile populations has occurred following the cessation of commercial hunting (Ross, 1998). However, there is little evidence to suggest that recovery of *C. acutus* populations has occurred in Belize. Our surveys indicate populations remain low on most offshore cays and atolls, and *C. acutus* is extremely rare on the mainland. Encounter rates are among the lowest reported anywhere and the rarity of juveniles is strongly suggestive of diminished recruitment.

The largest *C. acutus* population and most nesting activity occurs in the Turneffe Atoll. Additionally, this population appears to play a vital role in regional metapopulation dynamics. The status of this population remains tenuous, however, as the atoll is inhabited by only 200–300 non-hatchling crocodiles, and based on

the number of nests, perhaps 15–25 breeding females. Reproduction is dependent on beaches, which remain unprotected and vulnerable to development. Extrapolations, based on density estimates from the atoll, suggest a country-wide population of fewer than 1000 individuals. Furthermore, because crocodiles in marine habitats tend to disperse widely (Moler, 1991), many occurrences outside the Turneffe Atoll may represent transient individuals rather than members of an established population.

Despite legal protection, several threats remain to the continued survival of *C. acutus* in Belize. Although we found no evidence of commercial poaching, opportunistic killing of crocodiles is commonplace. Most are shot near fishing camps, a problem exacerbated by careless waste disposal practices, which tend to attract crocodiles. However, the greatest source of mortality appears to be the incidental drowning of crocodiles in monofilament fishing nets. While it is impossible to quantify mortality from these sources, the loss of even a few crocodiles from small populations, especially adult females can have a significant negative impact.

The destruction of nesting beaches and associated nursery habitat is the greatest threat to continued viability of *C. acutus* populations in Belize. Beach ridges, where most nesting occurs, are extremely limited and under increasing pressure for development. Consequently, these ridges and associated plant communities are considered the most endangered habitat in the coastal zone (McField et al., 1996). Furthermore, lagoons and freshwater pools adjacent to beach ridges are critical for the survival of hatchling and juvenile crocodiles. Without suitable nursery habitat neonates may experience severe osmotic stress and a corresponding reduction in survival.

The low population densities found in the coastal zone, coupled with the loss of nesting and nursery habitat warrant the continued protection and classification of *C. acutus* as a critically threatened species in Belize. Population recovery is dependent upon the implementation of appropriate conservation strategies. The preservation of nesting and nursery habitat is crucial for long-term population viability, and the most important element of any conservation plan. It is imperative to protect known nesting sites through zoning or incorporation into existing protected areas. Also, proposed developments must be evaluated with regards to potential nesting habitat before building permits are issued. We recommend incorporating Turneffe Atoll into the national protected areas system, and affording maximum protection to crocodile nesting areas. Banning the use of monofilament fishing nets in all protected areas of the coastal zone will reduce the accidental drowning of crocodiles. Crocodiles could also be promoted as an ecotourism attraction. Small-scale ecotourism is a preferred option in recent development plans (McField et al., 1996), and coastal residents (e.g.

tour operators and guides) whose livelihood depends on the continued survival of American crocodiles can be expected to support future conservation efforts.

Furthermore, population recovery may benefit from a head-starting program, a management strategy in which wild caught hatchlings are reared in captivity until attaining a body size less vulnerable to predators, and then released into suitable habitat. This technique has been used successfully to enhance recovery of other endangered crocodilians (Thorbjarnarson, 1992). Finally, a long-term (10+ years) population monitoring program, based on nest counts and spotlight surveys is needed to determine population trends and evaluate the success of conservation strategies.

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