American Crocodile (Crocodylus acutus) in Florida: Recommendations for Endangered Species Recovery and Ecosystem Restoration

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ABSTRACT.—When the American Crocodile (Crocodylus acutus) was declared endangered in 1975, scant data were available for making management decisions. Results of intensive studies conducted during the late 1970s and early 1980s by the National Park Service, Florida Game and Fresh Water Fish Commission, and Florida Power and Light Company resulted in an optimistic outlook for crocodiles. However, new issues face crocodiles today. Florida and Biscayne bays have undergone changes that have caused concern for the health of these ecosystems. The purpose of this paper is to review results of monitoring programs for C. acutus that have been used as a basis for consideration of reclassification of this endangered species and for restoration of its endangered ecosystem. More crocodiles and nests occur in more places today than in 1975. The maximum number of nesting females in Florida has increased from 20 in 1975 to 85 in 2004, and the number of concentrations of nesting effort from two to four. This evidence supports the proposed reclassification of the American Crocodile from endangered to threatened. However, crocodiles are still threatened by modification of habitat because of development adjacent to crocodile habitat and will benefit from restored freshwater flow into estuaries. As crocodiles continue to increase in number and expand into new areas, interactions with humans will occur more frequently. The challenge of integrating a recovering population of the American Crocodile with an ever-increasing use of coastal areas by humans will be the final challenge in successful recovery of this once critically endangered species.

The American Crocodile (Crocodylus acutus) is a primarily coastal crocodilian, which occurs in parts of Mexico, Central and South America, the Caribbean, and South Florida (Thorbjarnarson, 1989). Development supporting a rapidly growing human population in Florida along coastal areas of Palm Beach, Broward, Dade, and Monroe Counties has been the primary factor endangering the United States’ population (Mazzotti, 1983). This loss of habitat principally affected nesting range of crocodiles, restricting nesting to a small area of northeastern Florida Bay and northern Key Largo by the early 1970s (Ogden, 1978; Kushlan and Mazzotti, 1989a). At that time most remaining crocodiles (about 75% of known nests) were in Florida Bay in Everglades National Park (ENP) or on North Key Largo (25% of known nests), with few sightings in southwestern Florida (no nests).

When crocodiles were declared endangered in 1975 (Federal Register 40:44149), scant data were available for making management decisions. Field and laboratory data suggested that low nest success and high hatching mortality provided a dim prognosis for survival (Dunson, 1970; Evans and Ellis, 1977; Ogden, 1978). Results of intensive studies conducted during the late 1970s and early 1980s by the National Park Service, Florida Game and Fresh Water Fish Commission (now Florida Fish and Wildlife Conservation Commission), and Florida Power and Light Company resulted in a more optimistic outlook for crocodiles in Florida, as well as identification of a third crocodile nesting area at the Florida Power and Light Company, Turkey Point Power Plant (TP) site (Mazzotti, 1983; Gaby et al., 1985; Kushlan and Mazzotti, 1989b; Moler, 1992a, b).

To protect crocodiles, the National Park Service established a crocodile sanctuary in northeastern Florida Bay in 1980 (Federal Register 45:10350–10355), the U.S. Fish and Wildlife Service established Crocodile Lake National Wildlife Refuge (CLNWR), and Florida Power and Light Company developed a management plan for crocodiles. Monitoring programs were established for all three nesting locations. These monitoring programs focused on nesting ecology and growth and survival of crocodiles. Crocodiles have responded positive-
ly to these management efforts, and currently the Florida population of *C. acutus* is under review by the U.S. Fish and Wildlife Service for reclassification from endangered to threatened (Federal Register 70:15052–15062).

New issues face crocodiles in Florida today. Florida and Biscayne bays have undergone a number of changes that have caused a great deal of concern for the health of these ecosystems (McIvor et al., 1994; Wingard, 2004). Efforts are being made to improve Florida Bay and Biscayne Bay. Monitoring of crocodiles has continued, with dual purposes of assessing population status and evaluating ecosystem restoration efforts. As with other species of wildlife in southern Florida, survival of crocodiles and success of their nests have been linked to regional hydrographic conditions, especially rainfall, water level, and salinity (Dunson and Mazzotti, 1989; Mazzotti, 1989, 1999; Moler, 1992a). Alternatives for improving water delivery into South Florida estuaries may change salinities, water levels, and availability of nesting habitat in receiving bodies of water.

In South Florida, a unique opportunity exists to integrate endangered species recovery and conservation with ecosystem restoration and management. The purpose of this paper is to review results of research and monitoring programs for *C. acutus* that have been used as a basis for consideration of reclassification of this endangered species, and for setting performance measures for restoration of its endangered ecosystem (RECOVER, U.S. Army Corps of Engineers, Jacksonville, FL, 2004).

**MATERIALS AND METHODS**

Most research and monitoring of American Crocodiles in Florida since 1978 have focused on nesting, growth, and survival of crocodiles from nesting areas in Everglades National Park, Crocodile Lake National Wildlife Refuge, and Florida Power and Light Company’s Turkey Point Power Plant site (Fig. 1). Starting in 1995, surveys were extended beyond these core areas to cover potential habitat for crocodiles between Fort Lauderdale and Fort Myers, Florida.

Although all three nesting areas are in coastal areas of southeastern Florida, their extent of human alteration of habitat and access to researchers differ. The TP site has been altered by dredging, filling, and construction activities. Most crocodiles at TP occur in human-made canals and ponds, all of which are accessible by a combination of airboat, jon boat, and canoe. CLNWR is intermediate in disturbance, with human-made nesting and nursery habitat (berms and canals) surrounded by a natural mangrove matrix. Most human-made canals and ponds at CLNWR are accessible to researchers, and Crocodile Lake (for which the Refuge was named), an important location for crocodiles on northern Key Largo, is accessible by canoe. ENP provides the least disturbed habitat for crocodiles. Many ponds and creeks that provide habitat for crocodiles are accessible only by aerial surveys. The primary disturbance to northeastern Florida Bay has been diversion of freshwater flow to provide drainage and flood control for southern Miami-Dade County. Some human-made habitat suitable for crocodiles (canals and berms) occurs in the Flamingo/Cape Sable area of ENP. Detailed descriptions of physical features of crocodile nesting areas can be found in Mazzotti (1983, 1999), Gaby et al. (1985), Moler (1992a,b), and Brandt et al. (1995).

Surveys for nests were conducted by motorboat, airboat, jon boat, canoe, foot, and helicopter during June through August (hatching period), 1978–2004. Nests were located from evidence of crocodile activity (tail drags, digging, and scraping), and successful nests were determined by presence of hatchlings or hatched shells. Hatchlings were captured by hand or tongs and marked by removing tail scutes according to a prescribed sequence (Mazzotti, 1983). Growth and survival were determined by periodic efforts to recapture marked crocodiles. Nonhatching crocodiles were captured by hand, tongs, net, or by wire-noose as described by Mazzotti (1983). All crocodiles captured were weighed and measured. Total length (TL) and snout–vent length (SVL) were measured for all crocodiles, and head length, tail girth, hind foot length, mass, and other body measurements were recorded occasionally. Application of these methods varied among nesting sites and surrounding areas and has been described for each site.
Databases from all research and monitoring programs for crocodiles conducted in Florida between 1978 and 1998 were collected as part of the Critical Ecosystem Studies Initiative, funded by the U.S. Department of the Interior (Mazzotti and Cherkiss, 2003). These databases contained information on nests and captured crocodiles for all three main nesting areas. Additional data on crocodile captures, nests (to 2004), mortalities, and relocations (to 2005) were obtained from records of the Florida Fish and Wildlife Conservation Commission, the U.S. National Park Service, the U.S. Fish and Wildlife Service, and Florida Power and Light Company, Inc.

Differences in efforts to recapture crocodiles and in accessibility of crocodiles among study sites complicated analyses of growth and survival. To accommodate a management-driven time frame, we used measures of absolute growth and minimal survival as indices of relative growth and survival for purposes of comparing populations of crocodiles and for setting performance measures. For growth rate, we used changes in total length (TL) for crocodiles marked as hatchlings and recaptured as juveniles (less than 1.5 m TL), because those data were available for all three nesting areas and for other populations of *C. acutus*. Minimal survival was defined as proportion of hatchling crocodiles known to have survived for at least 12 months. Minimum survival does not differentiate between death, dispersal, and wariness. Dispersal was described as a direct enumeration of hatching crocodiles that survived and dispersed from a nesting area.

We estimated growth rates of 546 individual juvenile crocodiles using data from original and most recent captures. Mean and range of growth (change in TL) for crocodiles marked as hatchlings and recaptured as juveniles (less than 1.5 m TL), because those data were available. For each nesting area, and differences in growth were determined by ANOVA. Linear regression models were used for TP and CLNWR nest data for the period of 1978–2004. The Gauss-Newton non-linear regression model was employed for ENP for the same time period, since those data were nonlinear. Linear regression was used to determine trends in mortality and number of crocodiles relocated per year. A Chi-square test was used to test for difference in survival and dispersal among the three nesting areas.

**RESULTS AND DISCUSSION**

Nesting—Mazzotti (1989) defined optimal nesting habitat for American Crocodiles as presence of elevated, well-drained, nesting substrate adjacent to relatively deep (>1 m), low to intermediate salinity (<20 ppt) water, protected from effects of wind and wave action, and free from human disturbance. Human-made nesting areas along canal banks (berms) at CLNWR, East Cape Canal in ENP, and the cooling canal system at TP provide nearly ideal nesting conditions. The exception is the relatively high salinity in the cooling canals proper, although this has been ameliorated by creation of oligohaline ponds in the interior of berms. In contrast, in northeastern Florida Bay, the most successful natural nesting areas (sandy beaches) are often kilometers away from good nursery habitat. Creek nest sites in ENP are within good nursery habitat but are at low elevation, making them susceptible to flooding (Mazzotti, 1989, 1999). Nests on artificial substrates in the Flamingo/Cape Sable area of ENP are also in nursery habitat (Mazzotti, 1999). Unwitting creation of human-made nest sites has provided good conditions for nesting and, to some extent, has compensated for loss of nesting areas elsewhere in South Florida. As exemplified in South Florida, one of the most striking aspects of nesting habits of the American Crocodile is a crocodile’s ability to find and use artificial substrates for nesting.

The number of crocodile nests increased at the TP site, where two nests were discovered in 1978 and 19 were observed in 2004 (Fig. 2), all on artificial substrates. The number of nests at CLNWR fluctuated between four and 10 (Fig. 2). The number of nests also increased in ENP, from 11 in 1978 to 55 in 2004 (Fig. 2). Most of the increase in nesting in ENP occurred on Cape Sable. Much of the increased nesting in South Florida since 1975 was caused by nesting on artificial substrates at ENP, CLNWR, and TP. Nests were found outside of the three primary nesting areas in or near two Miami-Dade County Parks (seven nests, five successful, 1997–2004), a private residence on Lower Matecumbe Key (three nests, two successful, 2002–2004), and a private resort on northern Key Largo (one successful in 2004). In 1975 when *C. acutus* was declared endangered, the maximum annual number of nests in Florida was 20 (Ogden, 1978). In 2004, the maximum number of nests was estimated at 85. Sixty nesting females in Florida was the target of the 1979 recovery plan for the American Crocodile in Florida (U.S. Fish and Wildlife Service, 1984).

The rapid increase of crocodiles nesting in Everglades National Park is accounted for by an increase in nesting in the Cape Sable area, especially East Cape Canal. Nesting began at East Cape Canal after the canal was plugged by the National Park Service in 1986 (and again in 1990). The purpose of this plug was to retain fresh water in interior marshes and prevent...
saltwater intrusion. We hypothesize that the canal plug worked as intended, lowering salinities interior to the plug, making the habitat more suitable for nesting by the few crocodiles that were known to be in the area (Mazzotti, 1983). We further hypothesize that the lowered interior salinities adjacent to nest sites increased both growth and survival of hatchling crocodiles (see discussion below). The rapid increase in nesting that occurred in 2000–2001 is coincident with when these first hatchlings would have been expected to reach sexual maturity and enter the breeding population.

Eight hundred thirty-six crocodile nests were located between 1978 and 2004. Five hundred eighty-nine (71%) were successful. TP had the highest rate of nest success (proportion of all nests laid that produce at least one hatchling) between 1978 and 1999 at 99% (N = 232) and the lowest annual range (91–100%) in success. In ENP 65% of all nests (N = 439) were successful (annual success ranged 36–100%), and at CLNWR 46% of nests (N = 165) were successful (0–100%). Predation, flooding, and desiccation caused nest failure in ENP (Mazzotti, 1989, 1999), with nests on artificial substrates being prone to predation, sand nests susceptible to desiccation and predation, and nests along creek banks prone to flooding (Mazzotti, 1989, 1999). Desiccation is rare in ENP and occurs only in years of very low rainfall (Mazzotti et al., 1988). In contrast desiccation is hypothesized to be the main cause of nest failure at CLNWR (Moler, 1992b). Fire ants depredated all three nests lost at TP.

Nesting success of *C. acutus* in Florida is on the high end of that reported for *C. acutus* in other parts of its range (14–75%; Thorbjarnarson, 1989; Arteaga and Gomez, 2000; Schubert, 2002) and for other species of crocodiles (Metzen, 1978; Webb et al., 1983; Hall and Johnson, 1987; Allsteadt, 1994). Mean clutch size (39) and proportion of fertile eggs (82%) reported for *C. acutus* in Florida (Mazzotti, 1983, 1989) is also on the high end of the range reported for *C. acutus* elsewhere (mean clutch size 17–33, proportion fertile 33–74%; Abadia, 1996; Arteaga and Gomez, 2000; Platt and Thorbjarnarson, 2000b; Venagas de Anaya, 2000). Hence, we conclude that success of nests and production of hatchlings has not limited *C. acutus* in Florida.

**Growth, Survival, and Dispersal.**—Between 1998 and 2004, 6596 crocodiles were captured in Florida (Fig. 3). Ninety percent (5925) were captured as hatchlings. Most (54%) crocodiles were captured at the TP site and fewest (11%) were captured at CLNWR (Fig. 3). Crocodiles were captured from Biscayne Bay, Miami-Dade County, to Rookery Bay, Collier County. Patterns of capture effort and ease of capture of crocodiles explain much of the above difference. For example, more hatchlings per nest may be captured at TP because nests are accessible in a confined area, there has been a consistent annual effort at catching hatchlings, and hatchlings do not immediately leave the nest site. However fewer adults were captured at TP.
Table 1. Growth, survival (proportion of hatchling crocodiles that survived for at least 12 months), and dispersal (proportion of hatchling crocodiles that survived and dispersed out of their natal area) of American Crocodiles in Florida. Growth was different among the three nesting areas (ANOVA, $F_{2,541} = 3.91; P = 0.02$; LSD T-test, $\alpha = 0.05$). More hatchlings survived than expected by chance at CLNWR ($\chi^2 = 423.9; P \leq 0.001$), whereas more hatchlings dispersed from the TP site ($\chi^2 = 7.4; P \leq 0.025$). Different superscripts indicate significant differences among growth rates.

<table>
<thead>
<tr>
<th>Location</th>
<th>Juvenile Growth cm/day Mean (Range)</th>
<th># (%) Survived for &gt; 12 months</th>
<th># (%) Dispersed from natal area</th>
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<tbody>
<tr>
<td>TP</td>
<td>0.11 ($-0.8$ to $1.30^a$) ($N = 205$)</td>
<td>59 (1.71%) ($N_1 = 3452$)</td>
<td>17 (29.0%) ($N_2 = 59$)</td>
</tr>
<tr>
<td>CLNWR</td>
<td>0.10 (0.000 to $0.42^a$) ($N = 246$)</td>
<td>94 (17.97%) ($N_1 = 523$)</td>
<td>14 (15.0%) ($N_2 = 94$)</td>
</tr>
<tr>
<td>ENP</td>
<td>0.07 (~$-0.057$ to $0.16^b$) ($N = 93$)</td>
<td>28 (1.50%) ($N_1 = 1871$)</td>
<td>2 (7.0%) ($N_2 = 28$)</td>
</tr>
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Because there has been a prohibition on catching adults since 1996. In contrast, fewer hatchlings per nest were caught in ENP because nests were less accessible and occurred over a much larger area, annual effort to capture hatchling crocodiles was inconsistent, and hatchling crocodiles immediately dispersed from the nest in northeastern Florida Bay. More adults have been captured in ENP because annual effort to capture adults has been more consistent there.

Hatchling crocodiles in Florida Bay, ENP have the lowest survival and growth rates (Table 1). Hatchling crocodiles had the highest survival rate on North Key Largo but grew a little faster (with more variability) at the TP site (Table 1). The relatively high survival of hatchlings, combined with more consistent growth rates in the higher end of the range reported for American Crocodiles in Florida, make CLNWR on North Key Largo a critical location for hatchling crocodiles in Florida. Overall, growth rates for crocodiles in Florida compare favorably with growth rates reported for \textit{C. acutus} elsewhere (Thorbjarnarson, 1989; Platt and Thorbjarnarson, 1996; Schubert et al., 1996).

Because of their small size, hatchling crocodiles are vulnerable to biotic and abiotic stressors. To grow and survive, hatchling crocodiles need to find food and benign environmental conditions (or at least avoid harsh conditions) and avoid predators. Diminished growth rates and higher mortality have been associated with areas that pose a greater risk to hatchling crocodiles (Mazzotti, 1999). Apparent survival of hatchling crocodiles decreased with increasing distance that hatchlings had to travel to nursery habitat with suitable salinities (Moler, 1992a; Mazzotti, 1999). Nursery habitat can be defined as areas that are protected from wind and wave action and have access to low to moderate salinity (0–20 ppt) water, abundant food, and places to hide from predators. In Florida, estuarine creeks, coves, ponds (natural and human-made), and canals meet these habitat requirements. At CLNWR, nests are adjacent to nursery habitat. At TP, the distance from nest to nursery can range from meters to hundreds of meters. Until recently, most hatchlings in ENP were produced from shoreline nests, which can be kilometers from nursery habitat. We assume that greater dispersal distance primarily increases risk to predation; however, it may also expose a hatchling crocodile to harsher environmental conditions during transit. Historical flow patterns into Florida Bay probably pushed lower salinity water farther out into the bay, reducing the distance hatchlings would have to disperse to find suitable nursery habitat. Less fresh water in Florida Bay means that crocodiles would and do grow slower and have to disperse farther. Both factors negatively impact survival. Our hypothesis is that in northeastern Florida Bay, the combination of saline water and long distance dispersal limits hatchling growth and survival. However, low apparent survival of crocodiles in ENP may be a result of greater proportion of inaccessible habitat decreasing probability of recapture.

At CLNWR and TP, creation of canals not only unwittingly created nesting habitat but also resulted in a productive aquatic environment as evidenced by growth rates of crocodiles and abundant prey items at the two locations. Even so, lower growth rates at CLNWR have been associated with temporal patterns of higher salinity (Moler, 1992a). Richards (2003) found that \textit{C. acutus} feeding in high salinity water at night and retreating to low salinity ponds during the day grew quite rapidly at the TP site. Platt and Thorbjarnarson (2000a,b) found on atolls off the coast of Belize that fresh and brackish water lagoons adjacent to nest
sites provided essential nursery habitat, and Schubert et al. (1996) found use of and dispersal to freshwater habitat was crucial for survival of hatchlings. In addition to direct effects of salinity on growth of hatchling crocodiles, in northeastern Florida Bay, ENP, lower aquatic productivity has been associated with elevated salinities caused by diversion of fresh water for drainage and flood control (Lorenz, 1999). Although faster growth decreases exposure to threats of predation by noncrocodilian predators, it also shortens the time it takes to become a subadult crocodile and, hence, susceptible to aggression from adult crocodiles. When a population of crocodiles has good nest success and adequate hatchling survival, mortality and dispersal of older juveniles and subadults become the most likely factors to limit population numbers (Magnusson, 1986; Abercrombie, 1989).

Minimum survival was a direct enumeration of crocodiles known to have survived for at least 12 months. Missing crocodiles could have died, dispersed, been inaccessible to surveys, or simply been too wary to be observed. Table 1 shows the minimum number of crocodiles that have dispersed from one nesting area to another. Crocodiles have dispersed from all three natal sites to other sites. Fifty-eight percent of all hatchling crocodiles marked (N = 5925) have come from TP, whereas 52% of recaptured dispersing crocodiles (N = 17) have come from there. Likewise, 32% of hatching crocodiles came from ENP but only 6% of recaptured dispersing crocodiles came from there. In contrast, only 9% of hatching crocodiles have originated from CLNWR, but this location accounts for 42% of dispersing crocodiles. Only one crocodile is known to have dispersed from ENP since 1986, and no crocodiles are known to have dispersed from northeastern Florida Bay to the Flamingo/Cape Sable area (or vice versa). This is in spite of increased efforts at capturing crocodiles during the 1990s in Biscayne Bay and Card Sound and in the Flamingo and Cape Sable areas (Cherkiss, 1999; Mazzotti, 1999; Mazzotti and Cherkiss, 2003).

Effectiveness of using absolute growth and minimum survival as indices of relative growth and survival is unknown but is being tested. However, they did allow for comparison among nesting areas and with other populations of American Crocodiles, and they did meet the purposes of providing information for recategorization of American Crocodiles in Florida and setting performance measures (RECOVER, 2004). However, these indices could be confounded by a number of factors, including differences in efforts in catching crocodiles, accessibility of crocodile habitat, and ages of crocodiles recaptured. Additional analyses of data for growth and survival are underway to evaluate results reported in this paper.

Mortalities and Relocations.—Seventy-eight crocodiles were found dead between 1971 and September 2005. Cause of death was determined for 55 crocodiles. Automobiles killed 52, two were killed with malice, and one was killed by another crocodilian. Five were found dead after hard freezes, but no cause of death was determined. Thirty-nine crocodiles were relocated between 1991 and September 2005. Both mortalities and relocations have increased over time (Fig. 4). Mortalities caused by collisions with automobiles could be decreased by locating underpasses with drift-fencing at areas where crocodiles are known to cross roads, are frequently killed, or both.

Recovery of the American Crocodile in Florida.—When crocodiles were declared an endangered species by the U.S. Fish and Wildlife Service, the following were cited as the five primary factors that prompted listing (Federal Register 40:44140). Progress toward addressing these factors can be assessed with information presented in this paper and other studies.

Overuse for Commercial, Sporting, Scientific, or Educational Purposes.—Crocodiles were killed or injured accidentally or maliciously between 1978 and 2004, but none were killed for sport or commercial purposes. Crocodiles in northeastern Florida Bay/North Key Largo were exploited as an ecotourism attraction by at least one organized tour operation. The location and frequency of tours is unknown, and impacts from this operation are unknown. Crocodiles required for scientific or educational purposes can be obtained legally from captive-breeding operations.

Disease and Predation.—There is no evidence that disease has ever been a problem for crocodiles in Florida. Tracks of raccoons and
large wading birds have been regularly interspersed among locations of hatchling crocodiles, and one instance of a raccoon (Procyon lotor) eating a carcass of a hatchling was observed. On another occasion, a blue crab (Callinectes sapidus) was caught in the act of drowning a hatchling crocodile (Mazzotti, 1983). Richards and Wasilewski (2003) found microchips that had been implanted in small crocodiles at the Turkey Point site in stomachs of larger crocodiles at the same location.

Nesting success of American Crocodiles is relatively high compared to that of other species of crocodylians. Fire ants have depredated crocodile nests at TP and consumed a partial clutch in ENP. Predation on nests by raccoons has been documented in ENP but not at CLNWR or TP. The rate of predation on nests in ENP has been variable since the early 1970s (Mazzotti and Cherkiss, 2003). When nests on artificial substrates were first discovered, they seemed susceptible to predation (Mazzotti, 1999). Predation there now appears to be similar to that on natural nests. Since 1998, beach nest sites have been especially vulnerable to raccoon predation (Mazzotti and Cherkiss, 2003).

Environmental contamination was not considered a listing factor for crocodiles in 1975. Contaminants were evaluated from eggs in ENP during early and late 1970s and early 1980s and from the TP site in the early 1980s (Hall et al., 1979; Stoneburner and Kushlan, 1984; Environmental Science and Engineering, Gainesville, FL, 2000). Eggs were tested for both organochlorine and heavy metals. In no case were exceptional levels reported.

Destruction, Modification, or Curtailment of Habitat or Range.—Greater numbers of crocodiles cover a larger range today than in 1975 when crocodiles were declared endangered. Crocodiles now occur in most of the habitat that remains for them in southern Florida. Most remaining habitat is currently protected in public ownership or engaged in support of energy production. In these areas, further destruction of habitat has not been an issue. However, questions of potential modification of habitat through continued alteration of freshwater flow caused by upstream development, and potential curtailment of range resulting from relocation of crocodiles, need to be addressed. When possible, freshwater flows should be directed through the fringing mangrove swamps rather than discharged through canals. Adequacy of regulatory mechanisms to protect or to help restore the hydrological integrity of crocodile habitat is discussed below.

The increase in crocodile numbers and locations has resulted in an increase in interactions between crocodiles and humans. Presence of crocodiles in Florida tends to surprise people. In no instance has aggressive behavior by crocodiles towards humans been observed. However, there has been a consistent lack of tolerance expressed by a few individuals. This intolerance has contributed to relocation of at least 20 crocodiles. Ecological impacts of relocation are unknown. No education program exists to prepare residents and tourists who encounter crocodiles. A proactive policy for dealing with problem crocodiles that relies on public education and reducing risks to crocodiles and humans is needed.

Inadequacy of Existing Regulatory Mechanisms.—Because malicious attacks on crocodiles or nests have been rare, ability to enforce State and Federal policy protecting individual crocodiles from harm has not been an issue, but policies concerning relocation of crocodiles have been of concern because relocated crocodiles often return. Effectiveness of regulatory mechanisms intended to protect crocodile habitat from modification is dubious.

Because most available habitat for crocodiles is under public ownership, adequacy of regulatory mechanisms to protect crocodile habitat from direct loss is not a concern. However, development of areas adjacent to, or in proximity to, crocodile habitat creates two problems that are challenging regulatory agencies. First, ability of regulatory mechanisms to protect integrity of freshwater flows to mangrove estuaries making up crocodile habitat is questionable at best. For example, regulatory decisions regarding the Urban Development Boundary in Miami-Dade County have compromised the ability of Everglades restoration plans to restore freshwater flows to Northeast Shark Slough and the headwaters of Taylor Slough, and hence to Florida Bay. New plans for development outside of the Urban Development Boundary threaten restoration of flows to Biscayne Bay (Torres, 2005).

Second, the manner of development (creation of canals and ponds for drainage, storm water management, and fill and creation of elevated, well-drained spoil areas) taking place adjacent to, or in proximity to, coastal estuaries can enhance habitat conditions for crocodiles. Creation of nesting areas on artificial substrates has already been discussed. So far, with the exception of ENP, new sites have been created in areas remote from human activity. The same is not true of human-made ponds and canals, which in many cases have been created in areas of human activity, such as residential and business properties, golf courses, and marinas (Cherkiss, 1999; Mazzotti and Cherkiss, 2003). This promotes interactions between humans and crocodiles. Crocodiles regularly show up...
in areas where residents are not knowledgeable of the nonaggressive nature and endangered status of this species. Although responses of humans to the presence of crocodiles have varied, there has been a consistent lack of tolerance for crocodiles expressed by some individuals, especially as shown in the media. The crocodiles have been relocated more in response to intolerance than to legitimate threats to human safety; however, at least three adult crocodiles were injured or killed when they were not relocated. Increased interaction between the American Crocodile and humans in South Florida is becoming a major conservation issue for this endangered species, and regulatory approval of projects that will have the unintended consequence of enhancing habitat conditions for crocodiles in areas of human activity will exacerbate this growing problem.

Hence, we conclude that existing regulatory mechanisms do not protect crocodiles from intolerance, relocation, and continued modification of their habitat. Examples of effective regulatory mechanisms, including the Endangered Species Act, to protect habitat for endangered species are rare. For example, existing laws have failed to protect panthers from loss of habitat resulting from conversion to more intensive land uses (Kautz et al., 2006).

Other Natural or Human-Made Factors.—Collisions with automobiles continue to be the greatest documented cause of mortality of crocodiles in Florida (Mazzotti and Cherkiss, 2003). Most of these collisions have occurred on US 1 or SR 905 (Card Sound Road) in southernmost Miami-Dade and eastern Monroe County. Despite these mortalities, nesting effort on North Key Largo has remained constant (Fig. 2).

Restriction of freshwater flow into fringing mangrove swamps and associated estuaries by human development has been discussed above. In addition to our hypothesis that reduced freshwater flow into Everglades estuaries can limit growth, survival, and abundance of crocodiles, we further hypothesize that these factors, in combination with increased predation on beach nest sites, may reduce the value of northeastern Florida Bay as a source nesting area for crocodiles in Florida.

Twelve hurricanes or tropical storms have passed through crocodile habitat since crocodiles were declared endangered in 1975 (Mazzotti and Cherkiss, 2003; National Hurricane Center: http://www.nhc.noaa.gov/pastall.shtml). These hurricanes and tropical storms have not had a catastrophic effect on crocodiles. The best evidence for this is that Hurricane Andrew made a direct hit on the TP site on 24 August 1992 with no immediate or lasting impact. However, past hard freezes have been reported to cause mortality of crocodiles (Mazzotti, 1983, 1999). Four crocodiles were found dead after the Christmas freeze of 1989 (Moler, 1992a; Mazzotti and Cherkiss, 2003). Based on lack of a detectable effect on numbers of nesting crocodiles (Fig. 2), we hypothesize that freezing temperatures may limit the range of crocodiles in Florida but not abundance of crocodiles within the range.

Potential effects of sea-level rise on crocodiles have not been evaluated. This should be of concern because of vulnerability of natural nest sites to increases in water levels (Mazzotti, 1999). A long-time “Glades” explorer, Glenn Simmons, has observed that creek nest sites have already been adversely affected by sea-level rise (Simmons and Ogden, 1998). All potential crocodile-nesting habitat should be identified and mapped. A forecasting model should be developed to evaluate spatial and temporal patterns of nesting habitat loss in response to sea-level rise.

A more immediate threat to nesting sites comes from the high proportion of unnatural sites. Natural forces maintain natural sites, whereas unnatural sites are not naturally regenerated. Most unnatural sites are made of organic soils and dredge materials. Once exposed to air, soils are steadily lost to oxidation, wind erosion, and storm overwash. Creation of these sites may have been unwitting, but they will need to be actively regenerated if they are to be of long-term importance.

Ecosystem Restoration.—Do historic and current patterns of nesting, relative distribution and abundance, growth, and survival of crocodiles provide any clues for restoration of Florida and Biscayne bays? Water management practices have changed natural patterns of freshwater inflow to both bays (Smith et al., 1989; McIvor et al., 1994; Wingard, 2004). For example, Taylor Slough was once a major source of fresh water for central and northeastern Florida Bay. During the wet season, fresh water would pool behind a series of marl and sand berms along the north shore of Florida Bay. Restricted by berms, fresh water would flow into northeastern Florida Bay through Taylor Slough and into central Florida Bay primarily through McCormick Creek. Potentially large amounts of water would continue to flow into Florida Bay during the dry season. This historical, early to mid dry season flow from Taylor Slough, coupled with rainfall, could have provided saline conditions suitable for hatching crocodiles closer to shoreline nests and longer into the dry season. This would have reduced dispersal distance, stimulated food production, and enhanced growth and survival.

Relative distribution and abundance of crocodiles also reflect these salinity patterns.
Within an area, most crocodiles occur at the lower end of the available salinity gradient (Mazzotti, 1983, 1999; Brandt et al., 1995; Cherkiss, 1999). Most crocodile sightings are in water of less than 20 ppt. A majority of crocodile sightings in more saline water are females attending nest sites, hatchlings at nest sites, or juveniles presumably avoiding adults. We hypothesize that restriction of freshwater flow into an estuary would decrease relative density of crocodiles and that restoring or enhancing freshwater flow would increase relative density. The increase in crocodiles and crocodile nests on the estuarine sides of Buttonwood and East Cape canals after they were plugged provides support for this hypothesis.

Based on this, ecosystem restoration goals for crocodiles in Florida Bay would be to restore Taylor Slough as a main source of freshwater for the eastern and central Bay areas and, specifically, to restore early dry season flow (October to January) from Taylor Slough to Florida Bay. Measurable objectives of success would be as follows: a fluctuating mangrove back-country salinity that rarely exceeds 20 ppt in northeastern Florida Bay; an increase in relative density of crocodiles in areas of restored freshwater flow; increased growth and survival of hatching crocodiles to levels observed in other nesting areas in Florida; and continued increase in nesting.

In terms of crocodiles, restoration would be considered a success when freshwater flows to estuaries are restored to a more natural pattern, enhancing habitat conditions, and prey production and availability for crocodiles. It is important to emphasize that lowering salinities should not be used as a justification for late dry season releases of water into northeastern Florida Bay. Late season reversals in water level are not the natural pattern, and we hypothesize they would have a negative effect on crocodiles by dispersing prey and reducing their availability to crocodiles. Improving conditions in Florida Bay should not be used as an excuse to degrade or diminish the flow of freshwater to Biscayne Bay.

Greater numbers of crocodiles and nests cover a larger range currently than in 1975, when the American Crocodile was declared an endangered species. The maximum number of nesting females in Florida has increased from 20 in 1975 to 85 in 2004, exceeding the target of 60 females in the 1979 Recovery Plan. Two new nesting areas have been discovered at Turkey Point and the Cape Sable area of ENP. Nests have been found at four additional locations. This evidence of progress toward recovery of the American Crocodile population in South Florida can be attributed to a matrix of natural and human-made habitats that together meet all the life stage requirements necessary for this species (Mazzotti, 1999; Mazzotti and Cherkiss, 2003) and supports the proposed reclassification of the American Crocodile from endangered to threatened.

However, crocodiles are still threatened in Florida by modification of habitat caused by development adjacent to crocodile habitat and by intolerance by humans. Management of the American Crocodile in South Florida provides an opportunity to integrate habitat enhancement for an endangered species with environmental education. Crocodiles will benefit from restored freshwater flow into estuaries. This includes redirecting flows through mangrove swamps instead of canals when possible, and removing impediments to freshwater flow. In particular, water should not be taken from Biscayne Bay to solve problems in Florida Bay. Regulatory and planning mechanisms should be used more effectively to ensure that all coastal projects, either for development or restoration purposes, provide a net enhancement of patterns of freshwater flow to adjacent estuaries.

Recommendations by the Science Subgroup of the South Florida Ecosystem Task Force (Science Subgroup, Working Group of the South Florida Restoration Task Force Report, 1996) that land and water use planning and regulation complement or at least not hinder ecosystem restoration have not been implemented but need to be. Land and water use changes currently being planned and permitted are threatening natural systems and endangered species to the point of potentially compromising ecosystem restoration (Grunwald, 2006). Integrating regulatory processes with ecosystem restoration is also important in preventing endangered species recovery from compromising ecosystem restoration.

The U.S. Fish and Wildlife Service has increasingly relied on multispecies recovery plans to avoid problems of competition between recovery actions for different endangered species or between endangered species and ecosystem management (Clark and Harvey 2002). The South Florida Multi-Species Recovery Plan (U.S. Fish and Wildlife Service, 1999) was designed to employ an ecosystem approach to endangered species recovery. However, multispecies recovery plans have not been as successful as hoped (Clark and Harvey, 2002). The main reason for failure of multispecies recovery plans has been lack of implementation (Lundquist et al., 2002). Such is the case for the South Florida Multi-Species Recovery Plan. Signed by Secretary of Interior Bruce Babbitt in 1999, the South Florida Multi-Species Recovery Plan has
never been implemented, leaving endangered species recovery to occur on a species by species basis in South Florida. A survey of land use regulators and planners in South Florida revealed that most had never heard of the South Florida Multi-Species Recovery Plan (Sinclair et al., 2005).

Reoccurrence of crocodiles in areas of Biscayne Bay and Key Largo, where they had been absent for over 20 yr, is good news, but it does present challenges for land and water managers. As crocodiles continue to increase in number and expand into new areas, interactions with humans will occur more frequently. An increase in presence of crocodiles will exacerbate the growing problem of interactions between humans and crocodiles. The challenge of integrating a recovering population of the American alligator with an everincreasing use of coastal areas by humans will be the final challenge in the successful recovery of this once critically endangered species.

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