Status and Conservation of the American Crocodile in Florida: Recovering an Endangered Species While Restoring an Endangered Ecosystem

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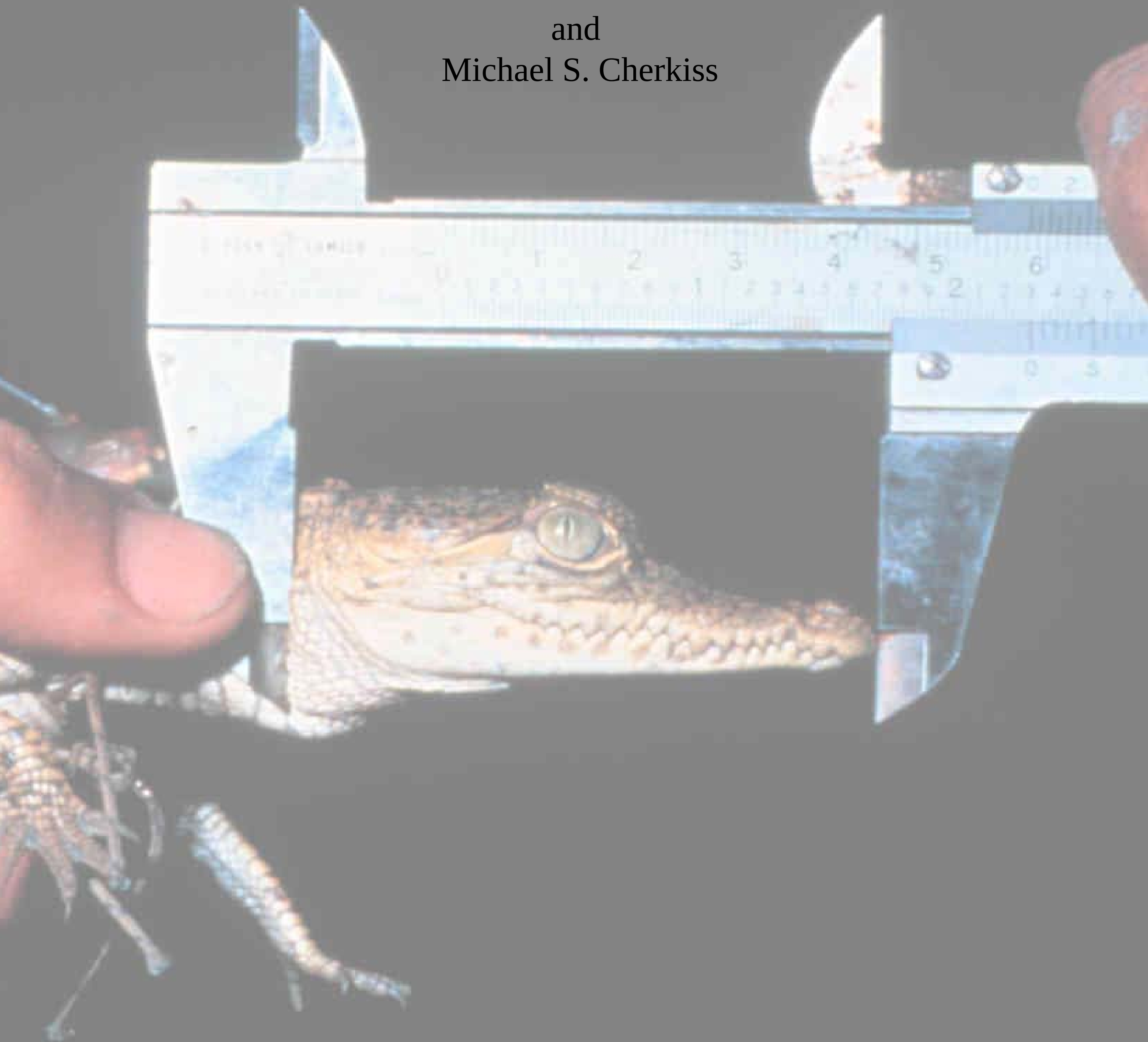

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Status and Conservation of the American Crocodile in Florida:
Recovering an Endangered Species While Restoring an Endangered Ecosystem

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Summary

The American crocodile (*Crocodylus acutus*) is primarily a coastal crocodilian that is at the northern end of its range in South Florida. In Florida, habitat loss due to expansion of a rapidly growing human population along coastal areas of Palm Beach, Broward, Dade, and Monroe counties has been the primary factor endangering the U.S. crocodile population. This loss of habitat principally affected the nesting range of crocodiles, restricting nesting to a small area of northeastern Florida Bay and northern Key Largo by the early 1970's. When crocodiles were listed as endangered in 1975, scant data were available for making informed management decisions. Field and laboratory data suggested that low nest success, combined with high hatchling mortality, provided a dim prognosis for survival. Results of monitoring programs conducted over the last 30 years by the National Park Service, U.S. Fish and Wildlife Service, Florida Game and Fresh Water Fish Commission (now Fish and Wildlife Conservation Commission), and Florida Power and Light Company focused on nesting ecology and growth and survival of crocodiles. These programs enabled managers to improve conservation efforts, to which crocodiles have responded positively resulting in a more optimistic outlook for crocodiles in South Florida. The purpose of this project was to collect and summarize data from those monitoring projects and to make comments on recovery, restoration and the future of crocodiles in Florida.

Data on captures, nests, and models relevant to the American crocodile in Florida were collected from individuals and agencies responsible for conducting research and monitoring on crocodiles since they were listed as endangered in 1975. Most of this work has centered on the main nesting colonies in Everglades National Park, Crocodile Lake National Wildlife Refuge, and Florida Power and Light Company's Turkey Point Power Plant site. Only recently have surveys systematically extended beyond these core areas. In addition, collection of data on crocodile mortalities, unusual locations, and relocations has been ongoing. The compilation of these data allows for comparisons between the three nesting colonies, affording us the opportunity to make determinations of long term trends in population parameters, such as nesting, and to monitor exchange and movements of individuals between and within study areas.

Crocodile models have been developed to assess effects of alternatives for delivery of freshwater to Florida Bay. Preliminary results support the importance of a more natural pattern of freshwater flow into the estuary for crocodiles. This underscores the flagship role that this endangered species has for protecting the integrity of estuarine ecosystems.

Crocodiles live in a variety of habitats in South Florida. These habitats range from physically undisturbed but hydrologically degraded in Everglades National Park to artificial and managed at the Turkey Point Power Plant site. All crocodile habitat can be characterized by low wind and wave action and a tendency towards lower salinities (< 50% seawater). Creation of nest sites incidental to dredge and fill activities has, to some extent, compensated for loss of nest sites to development elsewhere in Florida.

The maximum number of crocodiles known to nest in South Florida has more than doubled from an estimated 20 in 1975 to more than 50 today. Most of the increase in nesting can be accounted for by crocodiles nesting on artificial substrates. Nests at the Turkey Point Power Plant site are most successful, nests in Everglades National Park have intermediate success, and nests on Crocodile Lake National Wildlife Refuge are most likely to fail. Desiccation causes failure of nests at Crocodile Lake National Wildlife Refuge and desiccation, flooding and predation affects nests in Everglades National Park. Fire ants have caused nest failure at Turkey Point.

Absolute growth and minimum number known to survive were used to estimate growth and survival of crocodiles. Crocodiles grow slowest and survive least often in Everglades National Park. Hatchling crocodiles survive best in Crocodile Lake National Wildlife Refuge and grow fastest, with more variability, at the Turkey Point Power Plant site. Survival is inversely correlated with distance that hatchling crocodiles have to disperse to find nursery habitat. Lower growth rates have been spatially and temporally associated with patterns of higher salinity.

Minimum survival does not distinguish between death, dispersal, and wariness. Crocodiles have dispersed from all three natal sites to other sites. Although fewer hatchling crocodiles are marked at Crocodile Lake National Wildlife Refuge, most of the hatchlings that successfully dispersed from their natal area came from there. No hatchling crocodiles have dispersed from Everglades National Park since 1986.

There are more crocodiles in more places today than there were in 1975 when crocodiles were declared

endangered. Crocodiles now occur in most of the habitat that remains for them in southern Florida. Most of the remaining habitat is currently protected in public ownership or engaged in energy production. In these areas, destruction of habitat has not been an issue. However, questions of potential habitat modification through continued alteration of freshwater flow due to upstream development and potential curtailment of the range of crocodiles need to be addressed. Although the ecological condition of crocodiles in Florida has improved, existing regulatory mechanisms do not protect crocodiles from intolerance, relocation or adverse modifications to their habitats.

Patterns of nesting, relative abundance and distribution, growth, and survival of crocodiles can provide insight into restoration of coastal ecosystems in Southeast Florida. For both Florida Bay and Biscayne Bay, restoring a more natural pattern of freshwater flow would provide the most benefit. Characteristics of flow patterns into Florida and Biscayne Bays that are beneficial for crocodiles include sheet flow through the fringing mangrove swamp that extends well into the dry season. Mid-to-late dry season discharges of freshwater that cause a reversal of water levels in the receiving body are hypothesized to cause a dispersal of prey items, making them less available to crocodiles and should be avoided. Shifting water delivery from Biscayne Bay to Florida Bay would degrade the quality of habitat in Biscayne Bay for crocodiles.

The American crocodile has been identified as having the potential to provide a quantifiable measure of restoration success. Determination of trends and year-to-year variations in population parameters are a critical part of an expanded monitoring program to support development of ecological indicators and success criteria for the restoration effort. The relevant biological factors of this endangered species are well understood and existing databases afford good records of past and present population parameters. This provides us the unique opportunity to integrate endangered species recovery and conservation with ecosystem restoration and management in South Florida.

Acknowledgements

The data compiled and summarized in this report is the result of more than 25 years of research and monitoring of the American crocodile in Florida sponsored by the U.S. Department of the Interior, U.S. Army Corps of Engineers, the Florida Fish and Wildlife Conservation Commission and Florida Power and Light Company. We are indebted to their cooperation in providing the results of those studies. We are especially grateful to Paul Moler and Joe Wasilewski. This project was funded by the U.S. Department of Interior’s Critical Ecosystem Studies Initiative in collaboration with the U.S. National Park Service. In particular, we thank Skip Snow and Sonny Bass for their long dedication to studying crocodiles. Geoff Cook assisted in compiling the databases. Jocie Graham and Alicia Weinstein provided editorial assistance.

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Introduction

The American crocodile (*Crocodylus acutus*) is a primarily coastal crocodilian that occurs in parts of Mexico, Central and South America, the Caribbean, and at the northern end of its range in South Florida. As with other species of crocodilians, hunting (for hides, meat, collections, and out of fear) and habitat loss (direct or due to degradation) have made the American crocodile endangered throughout its range. In Florida, habitat loss due to development required to support a rapidly growing human population along coastal areas of Palm Beach, Broward, Dade, and Monroe counties has been the primary factor endangering the United States population. This loss of habitat principally affected the nesting range of crocodiles, restricting nesting to a small area of northeastern Florida Bay and northern Key Largo by the early 1970's (Ogden 1978, Kushlan and Mazzotti 1989a). At this time most of the remaining crocodiles (about 75% of known nests) were in Florida Bay in Everglades National Park or on North Key Largo (25% of known nests), with a few sightings in Southwest Florida. When crocodiles were declared endangered in 1975 (Federal Register 40:44149), scant data were available for making informed management decisions. Field and laboratory data that were available suggested that low nest success, combined with high hatchling mortality, provided a dim prognosis for survival (Dunson 1970, Evans and Ellis 1977, Ogden 1978). Results of intensive studies conducted during the late 1970's and early 1980's by the National Park Service, Florida Game and Fresh Water Fish Commission (now Fish and Wildlife Conservation Commission), and Florida Power and Light Company resulted in a more optimistic outlook for crocodiles in South Florida, as well as the identification of a third nesting colony of crocodiles at the Florida Power and Light Company, Turkey Point Power Plant site (Mazzotti 1983; Gaby et al.1985; Kushlan and Mazzotti 1989b; Moler 1992a,b; Brandt et al. 1995). 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, and Florida Power and Light Company wrote a management plan for crocodiles in 1983 and revised it in 1991. 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 positively to these efforts.

Currently, new issues face crocodiles in Florida. Florida and Biscayne Bays have undergone a number of changes that have caused a great deal of concern for the health of these ecosystems. Efforts have been made, and continue to be made, to improve Florida Bay and Biscayne Bay. Monitoring and research studies have also continued on crocodiles with the dual purposes of assessing the status of the population and evaluating ecosystem restoration efforts. As with other species of wildlife in southern Florida, the survival of crocodiles has been linked to regional hydrological conditions, especially rainfall, water level, and salinity (Mazzotti 1983, 1999; Moler 1992a, b). Alternatives for improving water delivery into South Florida estuaries may change salinities, water levels, and availability of nesting habitat in the receiving bodies of water. Research and monitoring will be essential to ensure the continued survival of an endangered species in this changing environment.

In 1993, the Federal Government initiated the South Florida Ecosystem Restoration Initiative (SFERI). The purpose of this Initiative is to protect and preserve South Florida's natural environment, enhance water supplies, and maintain flood protection. The Comprehensive Everglades Restoration Plan (CERP) provides the basis for the SFERI and is part of a larger effort to provide for a sustainable South Florida. In conjunction with the SFERI, the U.S. Fish and Wildlife Service has completed the Multi-Species Recovery Plan (MSRP), which identifies the recovery and restoration needs of listed species in the South Florida Ecosystem.

In South Florida, there is a unique opportunity to integrate endangered species recovery and conservation with ecosystem restoration and management. Determination of long-term trends and year-to-year variations in population parameters of selected species are an important part of an expanded monitoring program to support the development of ecological indicators and success criteria for the restoration effort. American crocodiles thrive in healthy estuarine environments and are particularly dependent on natural freshwater deliveries (Dunson and Mazzotti 1989, Mazzotti 1999). The American crocodile has been identified in the South Florida Water Management District (SFWMD) Conceptual Model process (Ogden and Davis 1999) as having the potential to provide a quantifiable measure of restoration success. The relevant biological factors of this endangered species are relatively well understood and existing databases afford good records of past and present population parameters.

The objectives of this project were to:

1. Compile and provide databases on captures and nests of the American crocodile in Florida in a format compatible with National Park Service standards.
2. Identify and describe access to relevant regional environmental databases (e.g. rainfall, water levels, and salinities).
3. Identify and describe population and habitat models for American crocodiles in Florida.
4. Evaluate databases for long-term trends and between site comparisons.
5. Make recommendations for restoration success criteria and endangered species recovery.
6. Recommend standardized protocols for research and monitoring.

Databases

Data on captures and nests of the American crocodile in Florida were obtained from the individuals and agencies responsible for conducting research and monitoring on crocodiles since they were declared endangered in 1975. Most of this work has centered on the main nesting colonies in Everglades National Park, Crocodile Lake National Wildlife Refuge, and Florida Power and Light Company's Turkey Point Power Plant site (Figure 1). Only recently have surveys systematically extended beyond these core areas. Table 1 summarizes the crocodile databases obtained for this project. The data are in Volume 2.

These databases were examined and then a common format was established using Microsoft Excel for data on captures, nests, surveys, and eggs. Three separate databases were designed to accommodate all of the information collected by different investigators.

We also collected data on crocodile mortalities, unusual locations, and relocations from the Florida Fish and Wildlife Conservation Commission and the U.S. Fish and Wildlife Service.

Environmental data (hydrological and meteorological) are collected by a number of agencies at various locations in South Florida. These include the Water Quality Monitoring Network, which is made up of the SFWMD, Environmental Protection Agency, National Oceanic and Atmospheric Administration, and the Southeast Environmental Research Center (SERC) at Florida International University. Other agencies responsible for collecting environmental data include the U.S. Geological Survey and U.S. National Park Service.

Table 2 summarizes the source and availability of hydrological and meteorological databases for locations in crocodile habitat in South Florida. Figure 2 shows the locations of marine and hydrological stations in Everglades National Park. Multi-agency hydrological data for South Florida can be obtained from the SFWMD database (DBHYDRO) and from SERC. Maps showing the locations of hydrological stations managed by SERC and SFWMD, along with forms requesting access to the data can be located at their respective websites (Table 2).

Models

Crocodile models have been developed as part of a C-111 Basin assessment sponsored by the U.S. National Park Service (Mazzotti and Brandt 1995) and the Across Trophic Level System Simulation by the U.S. Geological Survey (Richards and DeAngelis 2000). Descriptions and results of the models were obtained from reports and directly from the investigators.

The Mazzotti and Brandt (1995) model is a salinity based habitat suitability model. It was developed to evaluate the impacts of water delivery alternatives to the Taylor Slough/C-111 Basin. In this model, habitat was defined as red mangrove lined ponds, creeks, coves, and bays in the headwaters area of Florida Bay (Mazzotti 1983). Suitability of habitat was based on salinity levels, with the most suitable habitat being 0-20 ppt, intermediate suitability as 20-40 ppt, and the least suitable areas over 40 ppt. Water salinity was estimated from seasonal isohalines obtained from monthly summaries of water quality data provided by the SFWMD. Results of sample runs are shown in Figure 3. The following interpretations can be made from the salinity based habitat model:

1. More fresh water (lower salinity) in northeastern Florida Bay increases the amount and suitability of crocodile habitat.
2. Flow through Taylor Slough (rather than C-111) would provide more and better crocodile habitat.
3. Under current conditions the most suitable crocodile habitat occurs closer to the C-111 drainage area than to Taylor Slough.

The Richards and DeAngelis (2000) model is a work in progress. The purpose of this individual-based American crocodile model is to predict how the American crocodile population will respond to alterations of freshwater flow into estuarine habitat. In the current working version of the model, individuals grow, interact, breed, and suffer mortality depending on

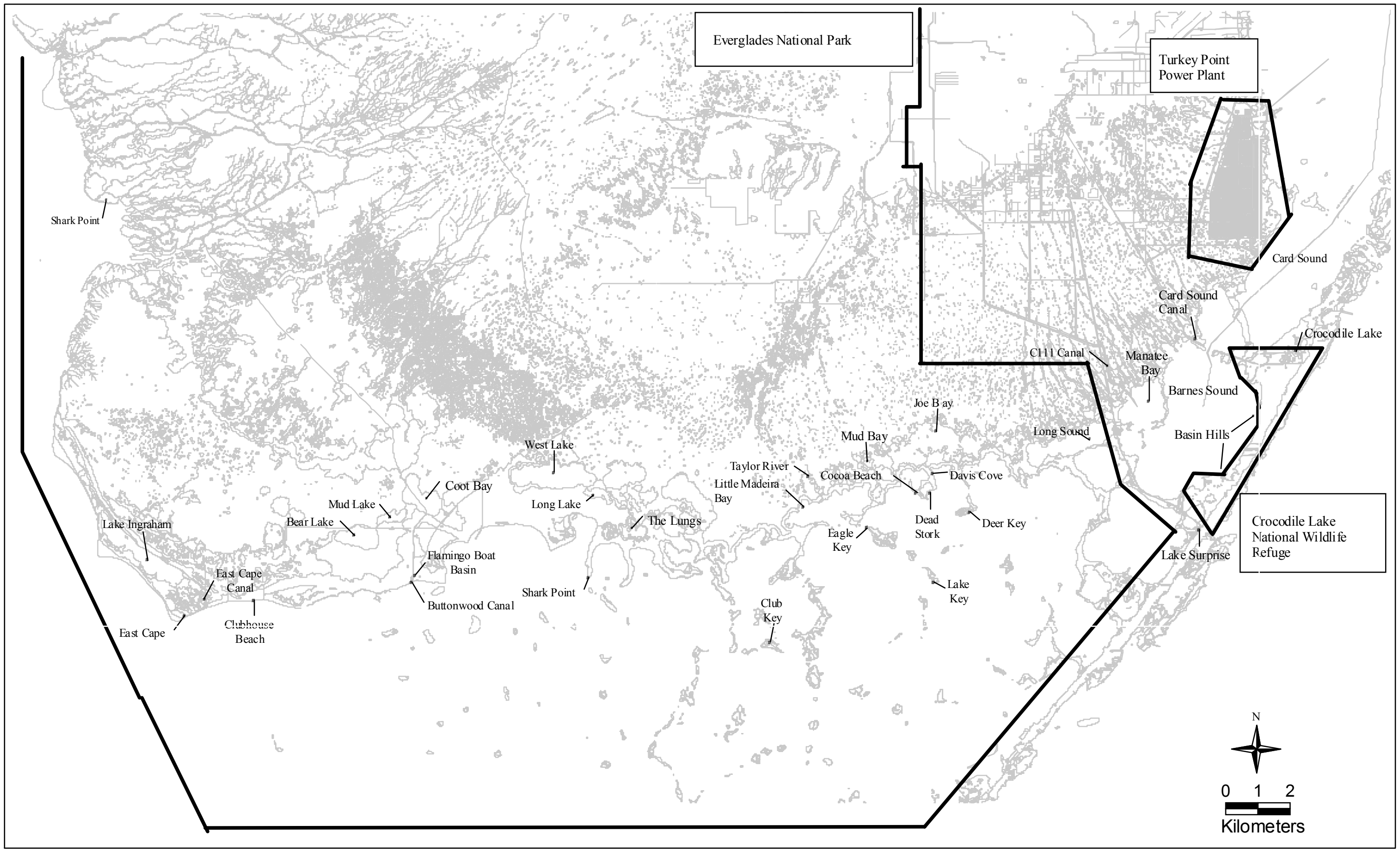


Figure 1. Locations of the three crocodile nesting colonies in South Florida.

Table 1. Summary of tables in Volume 2 containing data relevant to the American crocodile.

Table # (Vol. 2)	Source	Data Type	Location of Data Collection
Table 1	FWC[1],UF[2],TP[3]	Abbreviations	South Florida
Table 2	FWC	Capture	CLNWR[4]/ South Florida (Fig.1)
Table 3	FWC	Nest	CLNWR/ South Florida (Fig.1)
Table 4	TP	Capture	Turkey Point Power Plant (Fig. 2)
Table 5	TP	Nest	Turkey Point Power Plant (Fig. 2)
Table 6	UF	Capture	ENP[5]/South Florida (Fig. 1)
Table 7	UF	Nest	ENP/South Florida (Fig. 1)
Table 8	UF	Helicopter	ENP/South Florida (Fig. 1)
Table 9	UF	Egg	ENP/South Florida (Fig. 1)

[1]FWC - Florida Fish and Wildlife Conservation Commission
[2]UF - University of Florida
[3]TP - Florida Power and Light, Turkey Point Power Plant
[4]CLNWR - Crocodile Lake National Wildlife Refuge
[5]ENP - Everglades National Park

Table 2. Source and availability of hydrological station data within American crocodile habitat for South Florida.

Source of Data	Station Locations	Availability of Data	Contact Information
ENP[1]	ENP	Available upon request	Hydrological Station Manager (305) 242-7800
SERC[2]	ENP & South FL	Available online	http://serc.fiu.edu/wqmnetwork/
SFWMD[3]	ENP & South FL	Available upon request or by remote access	http://www.sfwmd.gov/curre/requests/requests.htm

[1]ENP - Everglades National Park
[2]SERC - Southeastern Research Center
[3]SFWMD - South Florida Water Management District

a static portion of the South Florida landscape, salinity level, and interactions with other crocodiles. The American crocodile individual-based model has been developed within the OSIRIS framework (Mooij et. al. 1996). The model runs at a 1-day time-step at a 30m-resolution and a scale of approximately 65,000 cells. The landscape is comprised of 3 GIS raster layers: vegetation, salinity level, and water depth. The vegetation layer is derived from the 30m-resolution Florida Gap Project vegetation map. The salinity and water depth layers are coded for the presence or absence of low salinity (10%) seawater. Application of the model is dependent upon development of a dynamic model of the South Florida estuaries and bays and completion of parameterization of the crocodile model.

Ecology of Crocodiles in Florida

Although capture and nest data were obtained from all of the investigators working on crocodiles in South Florida, permission to summarize and analyze unpublished data was not transferred with the data sets, and databases cannot be used without the permission of the investigator. However, extensive portions of the databases have been published (or are in preparation to be published) in journal publications, project reports, and theses. These published sources of data were used to evaluate spatial and temporal patterns of crocodiles in South Florida.

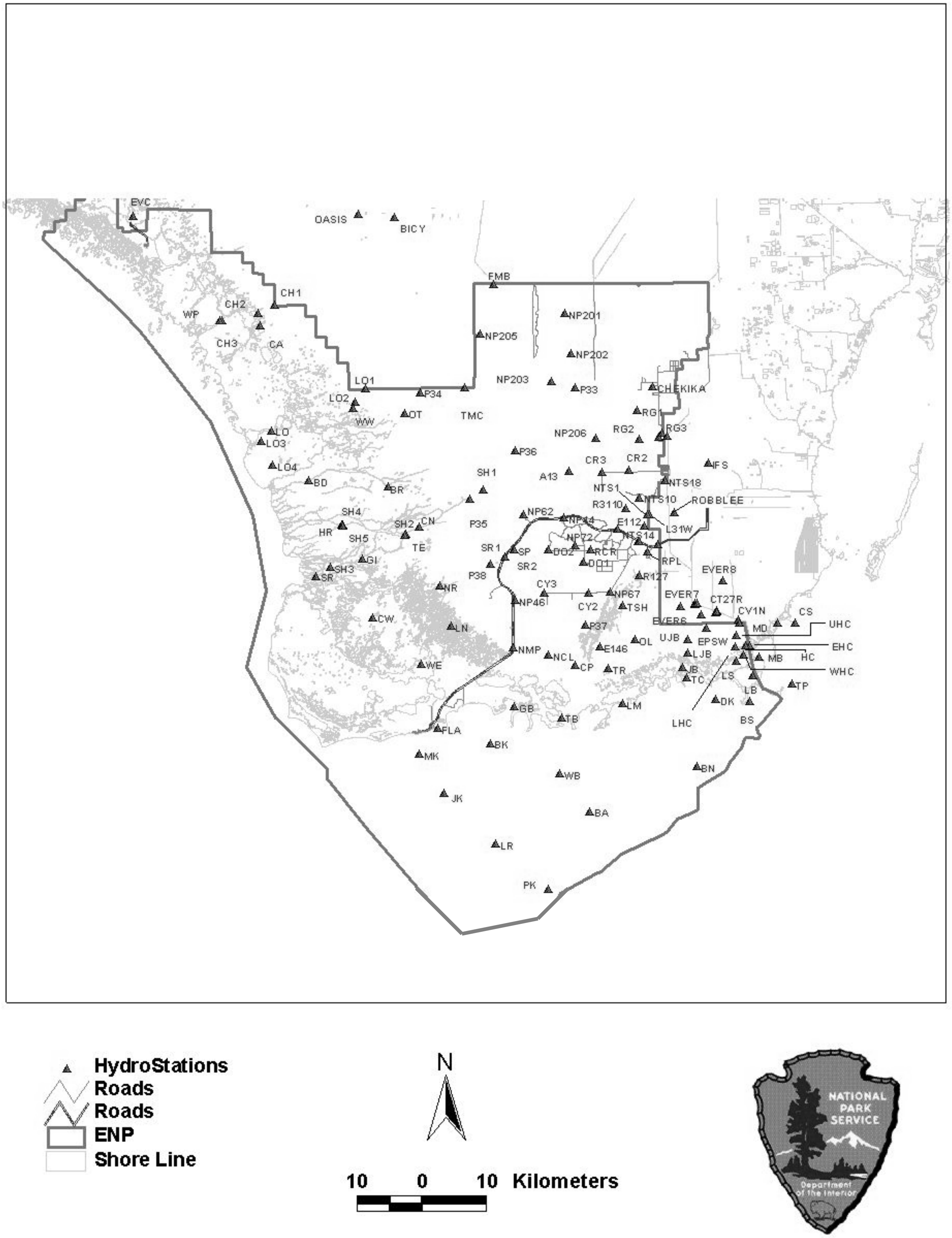


Figure 2. Locations of hydrological stations in Everglades National Park.

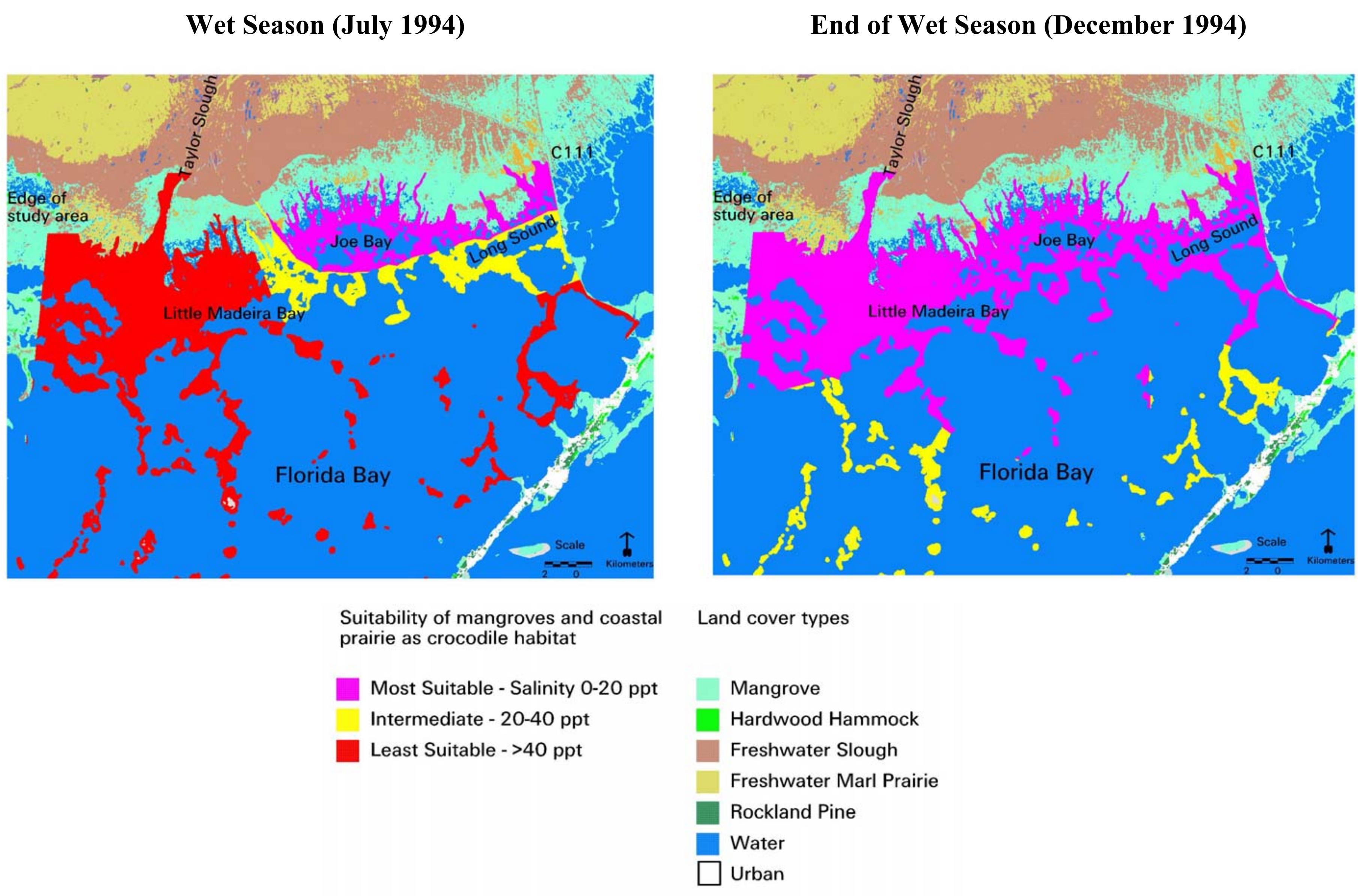


Figure 3. Graphical display of sample C-111 Basin Assessment Model runs for Northeastern Florida Bay. Isohalines were redrawn by hand from the South Florida Water Management District *Month in Review: Water Quality Conditions.* End of wet season 1994 (December) was during an El Niño event and demonstrates the positive effect of freshwater on crocodile habitat.

Habitats

Although all three nesting colonies are in coastal areas of southeastern Florida, they are remarkably different in their intensity of human alteration. The Turkey Point Power Plant site (Figure 4) has been greatly changed by dredging, filling, and construction activities. North Key Largo is intermediate in disturbance, with man-made nesting and nursery habitat (canals) surrounded by a natural mangrove matrix (Figure 1). Everglades National Park provides the most natural habitat for crocodiles. The primary disturbance to northeastern Florida Bay has been the diversion of freshwater flow to provide drainage and flood control for southern Miami-Dade County. Some man-made habitat suitable for crocodiles (canals and berms) occurs in the Flamingo/Cape Sable area of Everglades National Park (Figure 1).

Turkey Point Power Plant Site

The Turkey Point Power Plant Site is located in southeastern coastal Miami-Dade County, Florida, on property owned by Florida Power and Light Company (Figure 4). The property comprises approximately 2830 hectares (h) and contains a closed loop cooling canal system that serves two nuclear and two fossil fuel generation units, and a number of adjacent canals and roads. Biscayne Bay borders the site on the northeast and Card Sound borders it on the southeast.

Most of the power plant site was altered by excavation and filling. This was, in part, for construction of the power plant site canal system. The cooling canal system and the adjacent canals (the Interceptor Ditch, C-107, the Sea Dade Canal, Model Land Canals North, South, and East, the moat and L-31E) are defined as crocodile habitat and are described below (Gaby et al. 1985).

<u>Cooling Canal System</u>: The cooling canal system was completed in 1974; it is 8.2 km long, 4.2 km wide, and consists of 32 discharge and 6 return canals totaling 270 km in length. Each of the cooling canals is 60 m wide and shallow (0.5 m to 2 m deep). Within the cooling canals the water temperature ranges from 14 to 42 ^{o}C, with a mean of 30.4 ^{o}C. Salinity within these canals ranges from 0 to 46 ppt with a mean of 36.2 ppt. Of the 2430 h contained within the cooling canal system, 64% is water and 36% is spoil berm. The berms that separate the canals were created from dredge material obtained during canal construction. Berms range from 1 to 5 m in height and average 27 m in width. Berms support a variety of vegetation, ranging from barren areas to areas interspersed with salt tolerant species (e.g. *Salicornia spp., Sesuvium sp., Batis sp)* to forested areas. Forested areas are dominated by Australian pine (*Casuarina* spp.), Brazilian pepper (*Schinus terebinthifolius*), red mangrove (*Rhizophora mangle*), and buttonwood (*Conocarpus erectus*) in the canopy and sawgrass (*Cladium jamaicensis*), swamp fern (*Blechnum serrulatum*), and saltbush (*Baccharis spp*.) in the understory (Gaby et al. 1985).

<u>Moat</u>: The moat was completed in 1969 and is located north of the NW corner of the cooling canals. The moat is comprised of a series of canals that have low, flat banks, which are densely covered with red mangrove, buttonwood, sawgrass, and cattail (*Typha latifolia*). These canals average 4.4 m in depth and 12 m in width. They also exhibit temperatures ranging from 16.0 to 32.5 ^{o}C with a mean of 30.3 ^{o}C. The salinity in these canals ranges from 0 to 4 ppt, with a mean of 1.2 ppt.

<u>Interceptor Ditch</u>: This canal parallels the western edge of the cooling canal system and was completed in 1974. The banks are 3 m high and are composed of limestone rock fill, with large barren areas and some sparse vegetation consisting mainly of Australian pine and other herbaceous cover. The Interceptor Ditch averages 6 m in depth and 9 m in width. The water temperature ranges from 14.0 to 34.5 ^{o}C and averages 27.1 ^{o}C, and salinity ranges from 0 to 14 ppt with a mean of 5.6 ppt.

<u>L-31E</u>: The L-31E borrow canal is located west of the Interceptor Ditch and was completed in 1967. It has flat banks dominated by sawgrass, spike rush (*Eleocharis celluosa*), and cattail. This canal averages 5.4 m in depth and 10 m in width. The water temperature ranges from 18.0 to 39.8 ^{o}C with a mean of 27.2 ^{o}C, and salinity ranges from 0 to 2 ppt and averages 0.45 ppt.

<u>Model Land Canals North and South</u>: This section of the canal system was completed in the 1940's and was incorporated into the cooling canal system. A small section of this canal remains between L-31E and the Interceptor Ditch.

<u>C-107</u>: This canal was completed in 1976. Vegetation along the north-south segment is mainly red mangrove, while sawgrass and Australian pine border the rest of the canal. The average depth of the canal is 2.4 m and the width is 18 m. The water temperature ranges from 16.0 to 33.0 ^{o}C and averages 27.3 ^{o}C, and salinity ranges from 0 to 39 ppt and averages 15.8 ppt.

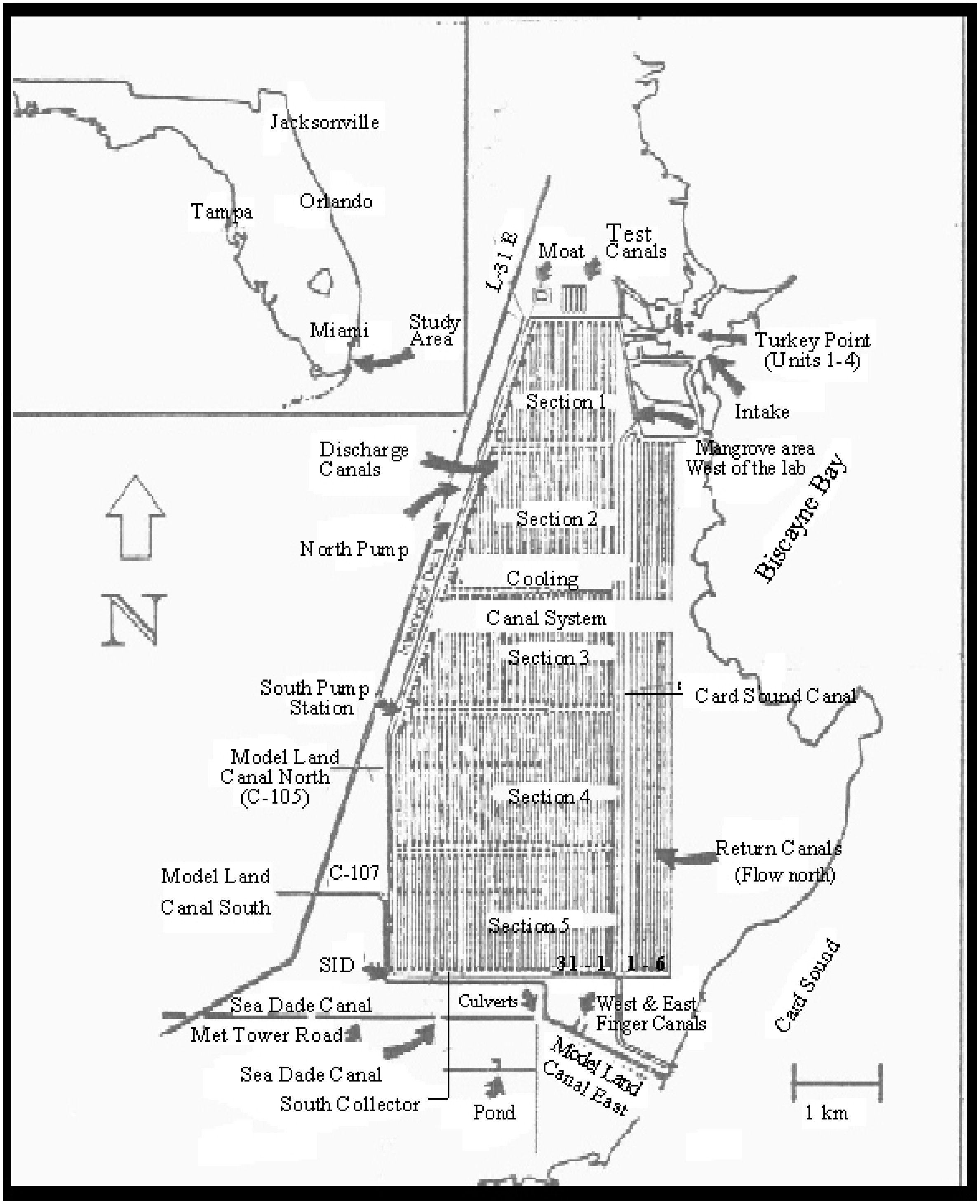


Figure 4. The Florida Power and Light Turkey Point Plant Site, Homestead, FL

Model Land Canal East: This canal was completed in the early 1940s and empties into Card Sound. The northern bank is steep, about 1.5 m in height, and is dominated by Australian pine. The southern bank is flat and covered by red mangroves. Average depth of the canal is 3.9 m and the width is 20 m. The water temperature ranges from 20.0 to 33.0 °C and averages 27.4 °C, and salinity ranges from 0 to 38 ppt with a mean of 20.7 ppt.

Sea Dade Canal: Completed in 1960, this canal is divided into 0.8 km sections by three roads and three mangrove covered earthen plugs. The bank to the north is 0.5 to 1 m high, with Australian pine and buttonwood dominant behind a red mangrove fringe. The southern shore is flat with red mangrove, some sawgrass, and saltgrass (*Distichilis spicata*). The average depth of the canal is 3.8 m, and width is 10 m. The water temperature ranges from 15.5 to 35.7 °C and averages 27.4 °C, and salinity ranges from 0 to 32 ppt and averages 15.4 ppt.

At the Turkey Point site nesting occurs along man-made canal berms throughout the cooling canal system. Sightings of juveniles in the Interceptor Ditch, C-107, and Sea Dade Canal are less consistent than in the cooling canal system and vary from year to year. The percentage of all juvenile sightings that have been in the cooling canal system has remained approximately the same over time. Subadults were observed consistently in all areas. Adults were observed most often in the Interceptor Ditch, followed by the cooling canals, primarily during nesting (Brandt et al. 1995).

North Key Largo and Crocodile Lake National Wildlife Refuge

South of the juncture of U.S. Highway 1 (US 1) and State Road 905, Key Largo is extensively developed, however, north of this intersection, the island is largely undeveloped, with the exception of the Ocean Reef Club at the northern end (Figure 1). Tropical hardwood hammock and mangrove swamp cover most of northern Key Largo. The Atlantic Ocean shore of North Key Largo is mainly jagged, eroded coral bordering marine flats. The Barnes Sound shore consists of extensive swamps of red mangrove, black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemosa*) on deep peat soils.

In the 1920's and again in the early 1970's attempts were made to develop this area, resulting in a series of canals bordered by peat berms. These are the areas where nesting occurs. The Barnes Sound shoreline of Key Largo is completely undeveloped except for the abandoned canals. The mainland shore of Barnes Sound is undeveloped except for a collection of shanties and live-on boats along the mainland portion of Card Sound Road (Moler 1992a).

Immediately south of the Ocean Reef Club lies Crocodile Lake, an extensive maze of shallow (< 1.2 m), mangrove-fringed, saltwater lakes. Card Sound Road bisects two of the lakes. Within this area is a borrow pit from which limerock was extracted for the reconstruction of Card Sound Road in the 1960's.

The salinity in Barnes Sound is slightly lower than seawater (36 ppt), whereas in Crocodile Lake the salinity is strongly influenced by rain and drought. Following periods of rain, the salinity may drop, and during periods of drought, it has risen to 96 ppt. The canals associated with abandoned development had different salinity regimes pre-restoration, some being slightly hypersaline, to one canal that averages between 10 and 20 ppt. (Moler 1992a).

Crocodiles nest along the elevated peat berms, with adjacent canals providing nursery habitat (Moler 1992b). The canal that ranged between 10-20 ppt salinity was an important nursery canal. Juvenile crocodiles were frequently seen in Crocodile Lake, and adults were found along the Barnes Sound shoreline when not near nests.

Everglades National Park and Florida Bay

Florida Bay is very shallow (averaging 1.25 m in depth) and is traversed by broad interconnected mud banks dotted with islands called keys. Mud banks break up deeper water areas into basins, which are interconnected by channels and passes. The mainland coastal plain has very low relief with many creeks, ponds, and small bays. Marl banks line rivers and sand beaches are found on mainland and island shorelines.

Temperature conditions are moderate with mean winter temperatures 7 °C lower than mean summer temperatures. Coastal areas are typically warmer than the interior. Rainfall distribution is bimodal, with peaks in June and in September-October. Salinity in Florida Bay fluctuates with runoff and evaporation. This has particular impact during the dry season, when there is little runoff from inland areas.

Tidal fluctuation in the eastern portion of Florida Bay is minimal because tidal circulation is inhibited by the interconnected mud banks and by the causeway forming US 1. Water levels mainly fluctuate in response to wind, which moves water into and out of the bay. The amount of inland discharge also affects water levels, particularly near the coast (Mazzotti 1983, 1999).

The coastline of Florida Bay is tropical hardwood hammock or stands of red mangrove, black mangrove, and white mangrove, interspersed with sandy beaches. Mangroves surround an extensive network of rivers, creeks, ponds, and lakes. Open water is regularly unvegetated, but widgeon grass (*Ruppia maritima*) covers large areas on a seasonal basis. Higher ground, including sandy beaches along the islands, and high marl river banks support tropical hardwood forests and buttonwood. Wild lime (*Zanthoxylum fagara*), white stopper (*Eugenia foetida*), and Jamaica dogwood (*Piscidia piscipula*) occur here. The understory consists of sea oxeye (*Borrichia frutescens*), nightshade (*Solanum donaium*), and white indigo berry (*Randia aculeata*). Marl flats, which are located behind the beaches and on slightly higher ground than mangroves, are dominated by saltwort (*Batis maritima*), samphire (*Philoxeris vermicularis*), glasswort (*Salicornia virginica*), portulaca (*Sesuvium portulacastrum*), and sea blite (*Suaeda linearis*). These flats often are submerged during the wet season. Salinities are variable, depending upon rainfall and flooding by bay water, and become hypersaline during the dry season (Mazzotti 1983).

In Florida Bay crocodiles primarily occur in mangrove-lined, open water areas that are protected from wind and wave action stretching from US 1 west to Cape Sable (Figure 1). With the exception of female crocodiles visiting nest sites, most sightings of crocodiles occur in water with salinity less than 50% sea water (18 ppt) (Mazzotti 1983, 1999). Areas with creeks, coves, canals, and ponds in close proximity to each other (such as the Taylor River area north of Little Madeira Bay) are riddled with trails connecting the open water areas. Crocodiles avoid areas exposed to wind and wave action and water of higher (>30 ppt) salinities, except during nesting when the search for dry ground takes them to shorelines exposed to Florida Bay. It is probably more appropriate to associate crocodiles with the mangrove headwaters of Florida Bay rather than the bay itself. Crocodiles move into this back-country during fall and winter and remain there until spring. The onset of the summer rains and generally more tranquil waters result in crocodiles moving throughout areas of suitable habitat. In late spring and summer, female crocodiles move into the Bay to visit shoreline-nesting areas (Mazzotti 1983, 1999).

Even in Everglades National Park most of the increase in nesting effort has occurred on artificial surfaces near man-made canals (Figure 1). These canals (Homestead, East Cape, and Buttonwood) were built largely for transportation purposes and connected interior oligohaline systems to the marine conditions in Florida Bay. The resulting saltwater intrusion caused profound changes in the interior ecosystems. In recognition of these unnatural effects, the U.S. National Park Service plugged those canals in the early 1980's. As lower salinity conditions returned north of the plugs, crocodiles began nesting on the high ground found along the canal berms. Initially, these nests were susceptible to depredation by raccoons, but more recently nests along East Cape and Buttonwood canals have been productive. This recent nesting activity in the Flamingo/Cape Sable area of Everglades National Park has resulted in an extension of the historic nesting-range westward along the Florida Bay shoreline (Mazzotti 1999).

Nesting

Mazzotti (1989) defined the optimal nesting habitat requirements for American crocodiles. The most important requirements for nesting success of crocodiles are the presence of elevated, well drained, nesting substrate adjacent to relatively deep (> 1 m) low to intermediate salinity (< 20 ppt) water, protected from the effects of wind and wave action and free from human disturbance. The man-made nesting areas along canal banks (berms) at the Basin Hills area of Crocodile Lake National Wildlife Refuge and the cooling canal system at Turkey Point provide nearly ideal nesting conditions. The exception is the relatively high salinity in the cooling canals proper, although to some extent this has been ameliorated by the creation of oligohaline ponds in the interior of the 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 Everglades National Park are within good nursery habitat but are at low elevation, making them vulnerable to flooding (Mazzotti 1989, 1999). Nests on artificial substrates in the Flamingo/Cape Sable area of Everglades National Park are also in nursery habitat, but are at risk of depredation by raccoons (Mazzotti 1999). Hence, the unwitting creation of man-made nest sites at Turkey Point and on North Key Largo has provided good conditions for nesting, and to some extent has compensated for the 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 its ability to find and use artificial substrates for nesting. In fact, virtually the entire increase of crocodiles nesting in South Florida is due to nesting on artificial substrates in Everglades National

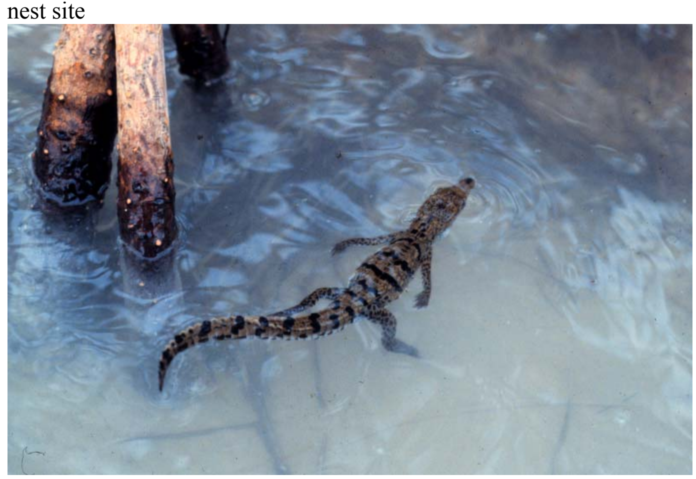
1978. Lori Lagna at Everglades National Park sand beach nest site

1978. Successfully hatched Everglades National Park creek marl nest site

1984. Jim Lindsay and Mike D'Orazio at Turkey Point peat nest site

1984. Laura Brant at Crocodile Lake National Wildlife Refuge peat nest site

1979. Two females nest in Everglades National Park mound nest



1985. Hatchling crocodile swimming near Everglades National Park nest site

1986. Young of the year crocodile in Everglades National Park

2002. Adult crocodile on bank of canal in Florida City

1978. Pond and creek habitat in Everglades National Park

1986. Turkey Point interceptor ditch

1985. Turkey Point cooling canals

1977. Everglades National Park creek habitat

1980. Exposed shoreline Everglades National Park

1979. Aerial view of exposed shoreline showing a nest site in Everglades National Park

1978. Ponds and coves in Everglades National Park

1999. An adult crocodile on a golf course in Miami-Dade County

Park, on North Key Largo, and at the Turkey Point Power Plant.

The most dramatic increase in the number of crocodile nests has occurred at the Turkey Point Power Plant site, where two nests were discovered in 1978 and a maximum of 16 were observed in 1995 and 1996, all on artificial substrates (Figure 5). Turkey Point also has the highest rate of nest success (proportion of all nests laid that produce at least one hatchling) between 1978 and 1999 at 98 % and the lowest annual variability (91-100 %) in success. In Everglades National Park 58 % of all nests were successful (annual success rate varied (33-83 %), and on North Key Largo 48 % of nests laid were successful (0-100 % annual rate). Predation, flooding, and desiccation cause failure of nests in Everglades National Park (Mazzotti 1989), with nests on artificial substrates being prone to predation, sand nests susceptible to desiccation, and nests along creek banks prone to flooding (Mazzotti 1989, 1999). Desiccation is rare in Everglades National Park and occurs only in years of very low rainfall (Mazzotti et al. 1988). In contrast, on North Key Largo desiccation is hypothesized to be the main cause of nest failure (Moler 1992b). Fire ants depredated the three nests lost at Turkey Point (J. Wasilewski pers. comm.).

The number of hatchlings marked is not only a function of how many are produced but also the effort expended on finding them and the rate at which they disperse from the nest (Mazzotti 1999). Hatchlings disperse most rapidly in Everglades National Park and linger near the nest site longest on North Key Largo. The number of hatchlings marked is a minimum estimate of the number of hatchling crocodiles produced from the three nesting colonies in Florida (Figure 5). Seventy-one percent (1915) of hatchling crocodiles marked since 1990 came from the Turkey Point site.

Growth, Survival, and Dispersal

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 or dispersal rates have been associated with areas that pose greater risk to hatchling crocodiles (Mazzotti 1999).

To compare growth rates we used estimates of absolute growth. Changes in total length were used because those data were available for all three nesting colonies. Although absolute survival is difficult to calculate for crocodilians, it is a relatively simple matter to enumerate minimal survival of known age individuals. This is a minimum estimate of survival and does not distinguish among death, dispersal, and wariness. Figure 6 compares the results for the first year of a crocodile's life.

With the lowest survival and growth rates, Everglades National Park is apparently the harshest place for a hatchling crocodile in Florida. Hatchling crocodiles survive best on North Key Largo, but grow a little faster (with more variability) at the Turkey Point Power Plant site. 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 Crocodile Lake National Wildlife Refuge on North Key Largo a critical location for hatchling crocodiles in Florida.

The rate of mortality of hatchling crocodiles is correlated with the distance that hatchlings have to disperse to find nursery habitat (Mazzotti 1999). Nursery habitat can be defined as areas that are protected from wind and wave action and have a low to intermediate salinity regime (0-20 ppt), abundant food, and places to hide from predators. In Florida, estuarine creeks, natural and man-made ponds, and canals meet these habitat requirements. On North Key Largo, nests are adjacent to nursery habitat. At Turkey Point, the distance from nest to nursery can range from meters to hundreds of meters. In Everglades National Park, most hatchlings are produced from shoreline nests, which can be kilometers from nursery habitat. We assume that greater dispersal distance primarily increases the risk to predation, however it may also expose a hatchling crocodile to harsher environmental conditions during transit. For a hatchling crocodile, the surest way to avoid the threat of predation is to outgrow it.

On North Key Largo and at Turkey Point, the creation of canals not only unwittingly created nesting habitat, but also created a productive aquatic environment as evidenced by the growth rates of crocodiles and personal observation (F. J. Mazzotti) of abundant prey items at the two locations. Even so, lower growth rates at both locations have been associated with spatial or temporal patterns of higher salinity (Moler 1992a, Brandt and Mazzotti in prep). In northeastern Florida Bay in Everglades National Park, lower aquatic productivity has been associated with elevated salinities caused by diversion of freshwater for drainage and flood control (J. Lorenz pers. comm.). Although faster growth decreases exposure to the threat of predation by non-crocodilian predators, it also shortens the time it takes to become a subadult crocodile and, hence, a threat to adult crocodiles.

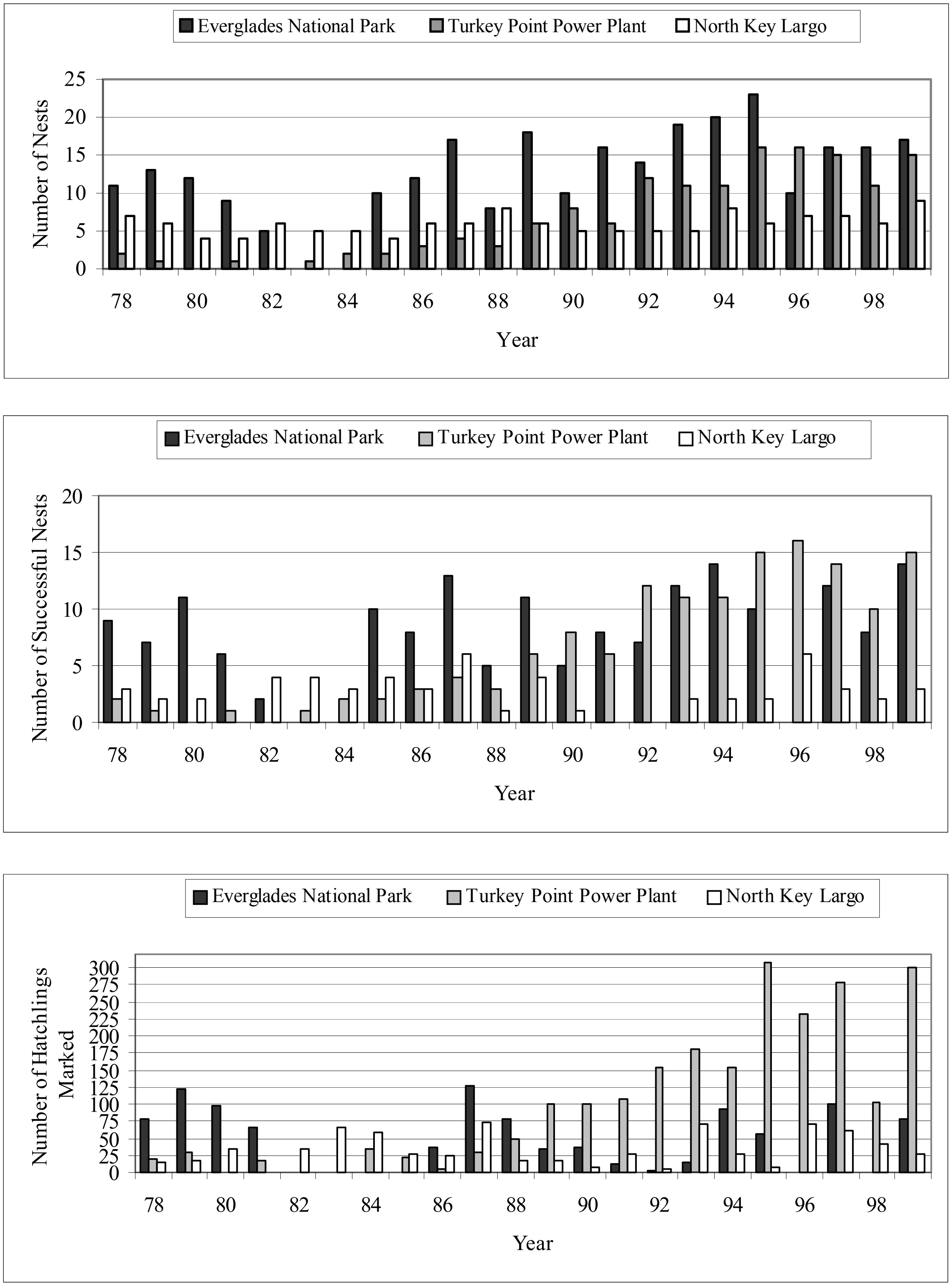


Figure 5. Summary of the total number of crocodile nests, successful nests, and hatchlings marked for the three nesting colonies in South Florida. Data are from Mazzotti (1989, pers. obs.) for Everglades National Park, Gaby et al. (1985), Brandt et al. (1995) and Wasilewski (pers. comm.) for Turkey Point, and Moler (1992b, pers. comm.) for North Key Largo.

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.

It is important to remember that cumulative annual minimum survival is a direct enumeration of crocodiles known to have survived for at least 12 months. Missing crocodiles could have died, dispersed, or simply be too wary to be observed. At Turkey Point, where adult crocodiles are concentrated around nesting and courting areas, fast growing crocodiles would have to disperse quickly to survive. Table 3 is a direct enumeration of crocodiles that have dispersed from one nesting colony to another. Fifty-five percent of all crocodiles marked have come from Turkey Point, whereas only 35% of the dispersing crocodiles have come from there; indicating that mortality is occurring on-site or they are staying on site. Likewise, 26% of marked crocodiles came from Everglades National Park but only 10% have dispersed to adjacent areas and none since 1986. In contrast only 18% of marked crocodiles have originated from Crocodile Lake National Wildlife Refuge, but this location accounts for 55% of the crocodiles that have dispersed from nest sites.

Crocodiles have dispersed from all three natal sites to other sites. However, no crocodiles have been captured from Everglades National Park since 1986 (Table 3) and no crocodiles 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 1990's in Biscayne Bay and Card Sound by Mazzotti and Cherkiss (1998) and in the Flamingo and Cape Sable areas (Mazzotti 1999). This is correlated with an increased predation of beach nests in northeastern Florida Bay. Since the 1950's beach nests have been the most productive natural sites in Everglades National Park. An increase in nest failure combined with low survival and growth rates may currently be limiting crocodiles in northeastern Florida Bay.

Relative Risk Assessment

Table 4 summarizes the relative risks for crocodiles at the three nesting colonies in South Florida. Overall there is little difference between Turkey Point and North Key Largo. In terms of hatching success and growth and survival of hatchling crocodiles, the Turkey Point

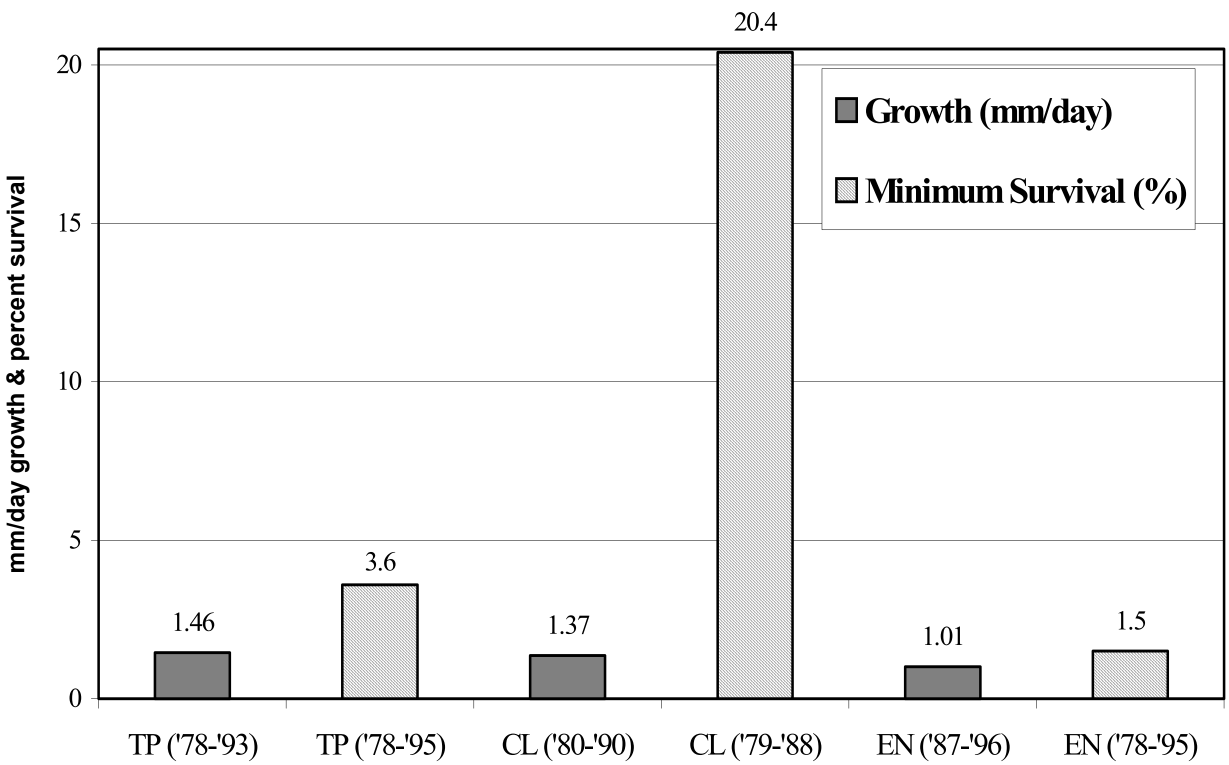


Figure 6. Growth and survival of the American crocodile in South Florida. Data are from Moler (1992b), Mazzotti (1999), and Brandt et al. (in prep). Location abbreviations include: TP – Turkey Point Power Plant, CL – Crocodile Lake National Wildlife Refuge, and EN – Everglades National Park.

Table 3. Dispersal of crocodiles from the three nesting colonies in South Florida. Data are from Mazzotti (pers. obs.) for UF, Wasilweski (unpublished data) for TP, and Moler (unpublished data) for FWC captures.

Orig. Cap. Date	Recap. Date	Orig. Capture	Recap. By	Orig. TL_CM[1]	Recap. TL_ CM	Original Location	Recapture Location	S/DL/DR[2]
ND[3]	06/06/78	TP[4]	FWC[5]	ND	184.50	ND	ND	00/01/69
1978	06/06/81	UF[6]	FWC	28.50	100.70	Mud Creek	US 1 Mainland	03/357/00
ND	07/07/82	TP	FWC	ND	226.00	ND	ND	00/01/69
ND	ND	TP	FWC	ND	130.50	ND	ND	00/08/39
11/13/85	ND	UF	TP	ND	95.00	Everglades Nat. Park	Turkey Point Cooling Canal	ND
07/29/86	ND	UF	TP	ND	102.00	Everglades Nat. Park	Turkey Point Cooling Canal	ND
ND	02/05/85	FWC	TP	ND	71.00	ND	Test Canals	ND
ND	02/10/88	FWC	TP	ND	111.50	ND	Return Canals	ND
ND	08/23/88	FWC	TP	ND	113.00	ND	Canal Cooling System	ND
ND	01/12/89	FWC	TP	ND	116.30	ND	Return Canals	ND
ND	08/28/91	FWC	TP	ND	199.00	ND	South Collector Turkey Point	ND
ND	12/29/92	TP	FWC	29.20	47.30	Turkey Point Power Plant	Card Sound Road, mainland	ND
ND	06/29/95	TP	FWC	ND	184.00	Turkey Point Power Plant	Bayfront Park	ND
ND	02/07/96	FWC	UF	ND	77.00	ND	Joe Bay	03/04/678
ND	12/28/96	FWC	UF	ND	90.20	ND	NE Joe Bay	00/23/678
ND	01/29/97	FWC	UF	ND	91.00	ND	NE Joe Bay	00/23/678
ND	01/30/97	FWC	UF	ND	266.50	ND	Key Largo	00/25/58
07/11/94	04/30/97	TP	FWC	104.50	170.50	Turkey Point Power Plant	ND	07/08/469
07/31/85	10/24/97	FWC	UF	28.20	285.00	Basin Hills	Card Sound Canal	08/01/18
1990	02/27/98	TP	FWC	ND	268.00	Turkey Point Power Plant	Black Point Marina	ND
07/11/94	02/03/99	TP	FWC	104.50	197.00	Turkey Point Power Plant	ND	07/08/469
ND	06/02/99	FWC	UF	ND	168.90	ND	CLNWR[7] Shoreline, Barnes Sound	00/56/28
07/31/89	10/18/99	FWC	UF	29.50	211.00	ND	CLNWR Shoreline, Barnes Sound	00/35/68
06/27/84	12/20/99	FWC	UF	53.80	245.00	ND	Deering Bay	06/07/78
01/11/98	02/12/00	FWC	UF	42.50	81.20	Basin Hills Entrance	Turkey Point Canal Card Sound	04/13/28
ND	03/01/00	FWC	UF	ND	164.90	ND	Joe Bay	03/04/678
08/05/93	11/10/00	FWC	UF	29.40	188.40	Basin Hills North	Manatee Bay	00/67/48
08/09/82	02/21/01	FWC	UF	34.90	273.20	ND	Card Sound Canal	05/01/28
ND	09/26/01	TP	FWC	ND	191.00	ND	Angler Club	07/09/09
07/08/93	12/18/01	TP	UF	23.80	198.20	Turkey Point Power Plant	3rd Canal N of Convoy Pt.	07/08/269
ND	02/21/01	TP	UF	ND	52.10	ND	CLNWR Shoreline, Barnes Sound	310/06/09

[1]TL_CM - Total length in centimeters
[2]S/DL/DR - Scutes clipped (Single/Double Left/Double Right)
[3]ND - No Data
[4]TP - Florida Power and Light, Turkey Point Power Plant
[5]FWC - Florida Fish and Wildlife Conservation Commission
[6]UF - University of Florida
[7]CLNWR - Crocodile Lake National Wildlife Refuge

Power Plant site is the least risky for crocodiles. The primary question at Turkey Point is what is happening to all of the hatchling crocodiles tagged on the site. Low relative risk to hatchling crocodiles may be offset by higher juvenile and subadult mortality. The high survival of hatchling crocodiles at Crocodile Lake National Wildlife Refuge compensates for relatively poor nesting success. The proximity of nursery habitat to nesting habitat has been correlated to the high survival rate for North Key Largo hatchlings. Maintaining the proximity of nursery habitat to nesting habitat should be an important management goal for the Crocodile Lake National Wildlife Refuge. Low growth and survival of hatchling crocodiles in Everglades National Park has been associated with elevated salinities and long distance dispersal. Both elevated salinities and a compression of isohalines towards the mainland, away from shoreline nests, have been the result of water management practices (Smith et al 1989, McIvor et al. 1994) upstream to Florida Bay. Hence, an ecosystem restoration goal for crocodiles in Florida Bay should be to restore the quantity, timing, and distribution of freshwater flow to a more natural pattern (Mazzotti 1999). Sea level rise poses a risk for nest sites in Everglades National Park that has not been addressed.

Recovery of the American Crocodile in Florida

When crocodiles were declared an endangered species by the USFWS, five factors were cited as the primary factors that prompted listing (Federal Register 40:44140). Progress towards addressing these factors can be assessed with the information collected in this report.

Destruction, Modification, or Curtailment of Habitat or Range

There are more crocodiles in more places today than there were in 1975 when crocodiles were declared endangered. Crocodiles now occur in most of the habitat that remains for them in southern Florida. Most of the remaining habitat is currently protected in public ownership or engaged in support of energy production. In these areas, destruction of habitat has not been an issue. However, questions of potential modification of habitat through continued alteration of freshwater flow due to upstream development, and potential curtailment of range due to relocation of crocodiles, need to be addressed. Crocodiles provide a unique opportunity to integrate habitat enhancement for an endangered species with ecosystem restoration and management. Crocodiles will benefit from restoration of freshwater flow into their estuarine habitat and will be harmed by diversion or restriction of flow. Quantity, timing, and distribution of flow are very important. When possible, freshwater flows should be directed through the fringing mangrove swamps rather than discharged through canals. The adequacy of regulatory mechanisms to protect or to help restore the hydrological integrity of crocodile habitat is discussed below. With the increase in crocodile presence comes an increase in interactions between crocodiles and humans. The presence of a crocodile in Florida tends to surprise people. A lack of tolerance for the presence of crocodiles by at least

Table 4. Relative risks for crocodiles at three nesting colonies in South Florida. One represents the least risk and three indicates the greatest risk.

Location	Growth	Hatchling Survival	Nesting	Dispersal	Total
Turkey Point	1	2	1	2	6
Crocodile Lake	2	1	3	1	7
Everglades	3	3	2	3	11

some humans has been expressed consistently. In no instance has aggressive behavior by crocodiles towards humans been observed. At some locations the occurrence of crocodiles has resulted in unacceptable risk to the individual crocodiles or to humans. The combination of surprise and intolerance has contributed to the relocation of at least 25 crocodiles, 2 of which have returned, one twice (Table 5). The crocodile that returned twice to Deering Bay returned the first time from C-111 within 30 days, and from Collier Seminole State Park across the state within 10 months. The ecological impacts of relocation are unknown. The existing policy for dealing with crocodiles is reactive to each individual situation. 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.

Over-utilization for Commercial, Sporting, Scientific, or Educational Purposes

Crocodiles are not being poached for hides or meat. Crocodiles have been killed or injured accidentally or maliciously (Table 6), but not for sport. Crocodiles in northeastern Florida Bay/North Key Largo are being exploited as an ecotourism attraction by at least one organized tour operation. The location and frequency of tours is unknown but there is no evidence of any impacts from this operation. Crocodiles required for scientific or educational purposes can be obtained legally from captive-breeding operations.

Disease or Predation

There is no evidence that disease has ever been a problem for crocodiles in Florida. Although tracks of raccoons and large wading birds have been regularly interspersed among hatchling crocodile locations, no instances of predation have been directly observed. On one occasion a blue crab (*Callinectes sapidus*) was caught in the act of drowning a hatchling crocodile (Mazzotti 1983). J. Wasilewski (pers. comm.) found microchips that he had implanted in small crocodiles at the Turkey Point site in stomachs of larger crocodiles at the same location. This may at least partially explain why so many hatchling crocodiles have been marked at Turkey Point, and so few have dispersed from the site to surrounding areas.

Fire ants have depredated crocodile nests at Turkey Point and consumed a partial clutch in Everglades National Park. Predation on nests by raccoons has been documented for the Everglades National Park nesting colony but not for the Key Largo or Turkey Point colonies. The rate of predation on nests in Everglades National Park has been variable (Figure 7) since the early 1970's. When nests on artificial substrates were first discovered, they seemed very susceptible to predation (Mazzotti 1999). Now they appear to be similar to natural nests. Since 1998, beach nest sites have been especially vulnerable to raccoon predation. If the trend continues, relatively high predation of beach nests is of concern because most of the hatchlings in ENP have been produced by beach nest sites. Environmental contamination was not considered a listing factor for crocodiles in 1975. Contaminants were evaluated from eggs in Everglades National Park during the early and late 1970's and the early 1980's and from the Turkey Point Power Plant site in the early 1980's (Hall et al. 1979, Stoneburner and Kushlan 1984, ABI 1987). Both organochlorine and heavy metals were tested. In no case were exceptional levels reported.

Inadequacy of Existing Regulatory Mechanisms

Because malicious attacks on crocodiles or nests have been rare, the 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 controversial. Regulatory mechanisms that protect crocodile habitat from modification also have been of concern.

Since most of the available habitat for crocodiles is under public ownership, the adequacy of regulatory mechanisms to protect crocodile habitat from direct loss is not an issue. However, development of areas adjacent to, or in proximity to, crocodile habitat creates two problems that are challenging regulatory mechanisms. First, the ability of regulatory mechanisms to protect the integrity of freshwater flows to the mangrove estuaries making up crocodile habitat is questionable at best. For example, regulatory decisions regarding the "eight-and-a-half square mile area" 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. Outside of the protective levee and the urban services boundary in Miami-Dade County, and known to be prone to flooding, it would have seemed that county, state, and federal wetland regulatory programs would have limited

Table 5. Relocation information for the American crocodile in South Florida. Data are from Dean (unpublished data).

Record	Date	Location Taken From	Relocated To	Length (cm)	Sex	Comments
1	11/25/91	Cocoa	Proposed release Collier County			Trapped by FWC trapper
2	10/05/92	Near Homestead Airport	Barnes Sound			Displaced by Hurricane Andrew
3	03/09/94	Deering Bay	C-111	278	M	Held at Metro Zoo for 6 weeks prior to release
4	10/28/94	Bonita Springs	Mullock Creek	151		Lee County, released 8 miles from capture site
5	01/19/95	Dania	C-111 Canal	167	F	Previously marked by Paul Moler
6	06/29/95	Bayfront Park	Turkey Point	184	F	Previously marked by Joe Waselewski at Turkey Point
7	12/20/96	Snapper Creek Canal	Turkey Point	144	M	Not previously marked
8[A]	02/27/98	Black Point Marina	C-111 Canal	268	M	Held for 45 days, tagged 8 yrs earlier at TP, (same animal as below)
9[B]	04/21/98	Deering Bay	C-111 Canal	220	F	Held at Metro zoo 45 days, returned to original site 30 days post-release
10	08/17/98	Naples Beach	Collier Seminole Park	242		Unmarked
11	02/12/99	Deering Bay	Collier Seminole Park	232	F	Was recaptured at Deering Bay on 12/20/99
12	03/17/99	Black Point Marina	Collier Seminole Park	283	M	(Same animal as above)
13	06/19/00	Fisher Island	C-111 Canal	225	F	Biscayne Bay
14	09/26/00	Dade County	C-111 Canal	126		Recovered from rehabilitation, treated for eye injury
15	11/11/00	Ocean Reef Drive	Barnes Sound	250	F	Blind in left eye, released near CLNWR, Key Largo
16	02/02/01	Deering Bay	Collier Seminole Park	260	F	No Info
17	05/07/01	Dinner Key Marina	C-111 Canal	187	F	No Info
18	08/02/01	Bayfront Park	C-111 Canal	91		No tail
29	09/17/01	Biscayne Bay	Aerojet Canal	32		Found in swimming Pool
20	09/26/01	Angler Club	Harrison Tract	191	M	Found in swimming pool, Marked (scutes DR9,DL9,S7)
21	12/05/01	Jupiter Beach		121	F	Being held and analyzed for origin
22	12/05/01	Jupiter Beach Inlet		106	M	Being held and analyzed for origin
23	12/06/01	Boca Raton Inlet		152	F	Being held and analyzed for origin
24	12/18/01	Delray Beach Inlet		159	F	Nuisance, being held and analyzed for taxonomy

[A]Record #8 was a 268cm total length male that was captured at Black Point Marina, held at Metro Zoo for 45 days, and then released at the C-111 Canal in Barnes Sound. The crocodile returned to the point of original capture and was then taken on 3/17/99 and released in Collier Seminole State Park in Naples. There has not been a confirmed second return of the crocodile, but an animal of similar size has been observed in the same location as the original capture (Cherkiss pers. obs).

[B]Record #9 was a 220cm total length female that was captured at the Deering Bay golf course, held at Metro Zoo for 45 days and then released at the C-111 Canal in Barnes Sound. The crocodile returned to the point of original capture within 30 days and was taken on 2/12/99 to Collier Seminole State Park in Naples and released. The same crocodile was then recaptured again at Deering Bay on 12/10/99 at a total length of 245cm.

Table 6. Mortality information for the American crocodile from 1971-2001. Data are from Klett (unpublished data) and Dean (unpublished. data).

Date	Location	Length (cm)	Sex	Comments
09/01/71	Lake Surprise, Key Largo	250		Source of info uncertain, included in memo summary
04/01/74	Crocodile Lake Area	45		Source of info uncertain, included in memo summary
03/01/75	Crocodile Lake Area	120		Source of info uncertain, included in memo summary
08/01/75	Card Sound Rd., mainland	100		Source of info uncertain, included in memo summary
06/01/77	Card Sound Rd, mainland	50		Source of info uncertain, included in memo summary
1975-1977	Card Sound Rd., Croc lake	280+		Source of info uncertain, included in memo summary
08/01/80	US 1, MM 115	125		Source of info uncertain, included in memo summary
06/01/81	US 1, MM 110	125		Source of info uncertain, included in memo summary
02/01/82	US 1 MM 113	280+		Source of info uncertain, included in memo summary
08/09/83	US 1, North Key Largo			
03/01/86	US 1, east side of Lake Surprise		F	Gravid, 28 eggs
04/04/86	US 1, MM 111			
06/29/86	Turkey Point			Nest destruction in maintenance, 2 eggs destroyed, 6 re-buried
05/04/88	US 1, at Dade/Monroe co. line		F	Road-kill, adult, tail had been removed, 31 shelled eggs present
10/26/89	Monroe County			Road-kill, juvenile
05/03/90	Card Sound Rd.	212		Road-kill
08/02/90	North Key Largo			Salvaged one dead hatchling and 22 non-viable eggs
10/23/90	US 1, MM 108.5	160	M	Road-kill
06/08/91	near microwave tower			Road-kill reported by Jeanne Parks, no details
06/12/91	Card Sound Rd., Dade County			Road-kill
06/17/91	North Key Largo			Road-kill reported by Jeanne Parks, no details
12/27/91	US 1, North of Jewfish Creek			Road-kill reported by CRSP employee
04/20/92	US 41 Port of the Isles, Collier Co.	333	F	Road-kill
05/22/92	Card Sound Rd., Monroe Co.	242		Road-kill
06/08/92	Card Sound Rd.	151		Road-kill
06/26/92	US 1, MM 114.5, Dade Co.	270		Road-kill
10/24/94	Card Sound Rd.		M	Road-kill, adult
10/25/94	Card Sound Rd.	278	M	Road-kill
06/13/95	Card Sound Rd. PP69	90		Marked by Paul Moler
01/06/96	CR-905, PP 89	~212		Hit by car and crawled off into woods on west side of road
02/13/96	Card Sound Rd. PP77			Road-kill called in by commuting ORC employee
04/02/97				Found by J. Wasilewski, FPL, no more details
05/20/97	Key Largo			Illegal capture with set hook, animal died (pled or convicted)
08/21/98	Turkey Point Land Utilization, Dade Co.	246	F	Numbered (TP-150, 9RD, 1RD, 5S) no cause of death
06/09/99	Turkey Point Plant	137	F	Cause of death unknown
06/14/99	Card Sound Rd.	136		Road-kill
12/07/99	Turkey Point Plant	208.2		Appeared killed by another croc, badly decomposed
01/04/00	US 1, MM 112	220		Road-kill, sex unknown, pelvis and head smashed (scutes DR37, DL3, S1)(Steve Klett)
06/15/00	CR-905, PP185	154	M	Road-kill, unmarked, good physical condition (Steve Klett)
07/23/00	Card Sound Road, PP70	94	F	Road-kill, (scutes DR78,DL23,S3), within footprint of old crocodile fence (Steve Klett)
08/15/00	Card Sound Road, PP70	91		Unmarked, animal within footprint of old crocodile fence (Steve Klett)
10/29/00	US 1, MM 107.4 (PP B071)	217	M	Marked (scutes DR59,DL5,S4?)end of tail missing at 4th scute (Steve Klett)
04/19/01	US 1 @ Jewfish Creek (PPB074)	273		Road-kill, unmarked, animal in good physical condition (Steve Klett)
05/06/01	US 1, between MM 106 & 108	256	F	Unmarked, animal appeared in good health and contained 23 eggs
14/06/01	Manatee Bay Marina, MM112.7	~242		Marked (scutes DR8, DL3,S6), jaw broken & wrapped in gill netting
08/10/01	CR 905 (C9,PP84) in water at culvert	220	M	Possible road-kill, (Scutes clipped-DR269,DL9,S5)(Steve Klett)
09/11/01	US 1, MM115	~90		Called in by Dave Roudebush
10/20/01	US 1, MM 112.5, near County line,	249		Road-killed, unmarked, not salvaged or officially reported.
11/15/01	Turkey Point Power Plant	90		Road-killed, unmarked (from Bob Bertleson)

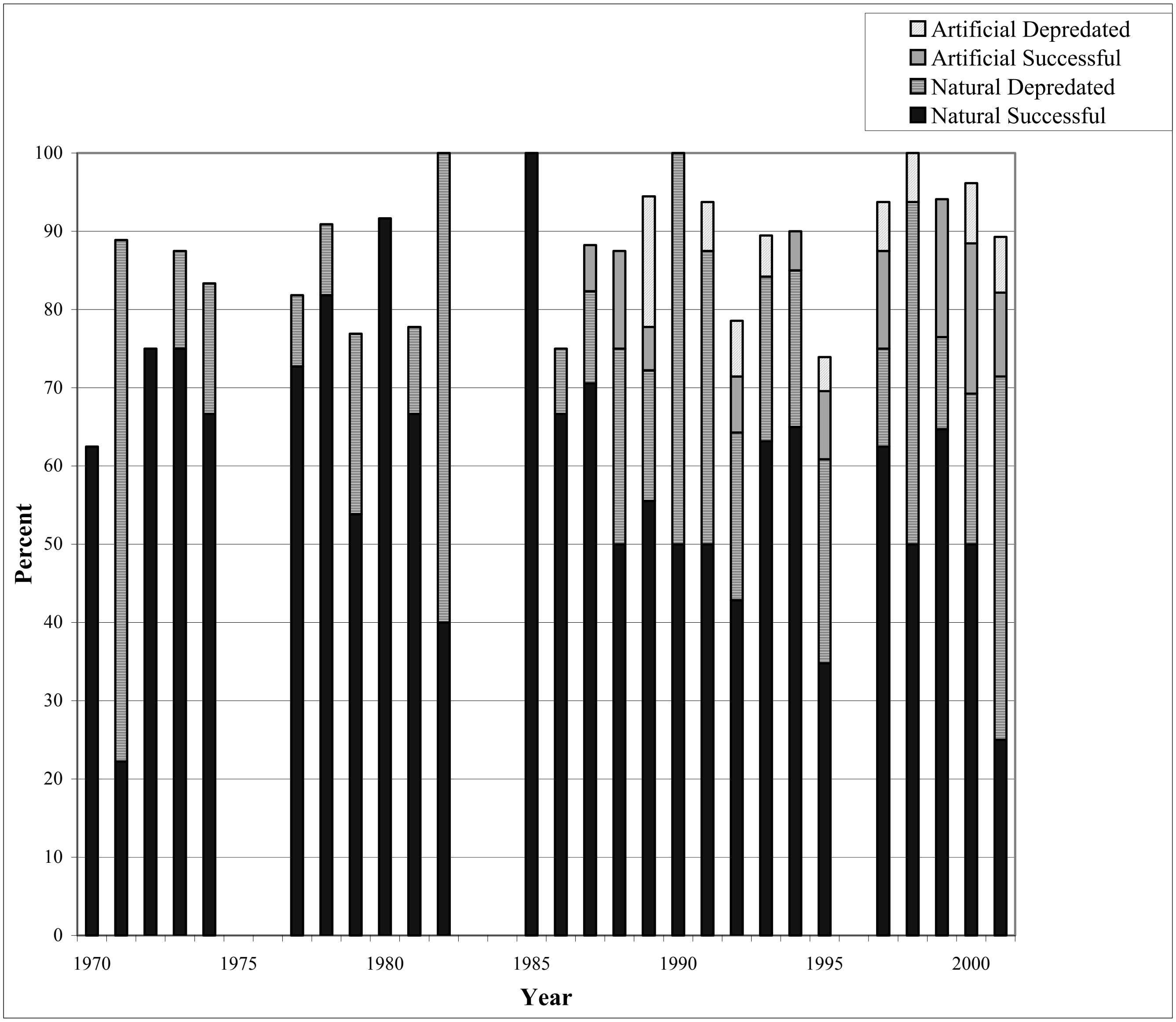


Figure 7. American crocodile nesting success and predation on artificial and natural substrates in Everglades National Park over a 30 year period.

development in the eight-and-a-half square mile area. Instead, political decisions have resulted in a flood mitigation plan that will promote more development, and likely more requests for increased flood protection.

Second, the manner of development (creation of finger canals and ponds for drainage 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 Everglades National Park, nest sites have been created in areas remote from human activity. The same is not true of 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. This promotes interactions between humans and crocodiles. Crocodiles regularly show up in areas where residents are not knowledgeable of the non-aggressive 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 in the media. Crocodiles have been relocated (Table 5) more in response to intolerance than to legitimate threats to human or crocodile safety. Increased interactions between the American crocodile and humans in South Florida are becoming a major conservation issue for this endangered species, and regulatory approval of projects that will enhance habitat conditions for crocodiles in areas of human activity will exacerbate this growing problem. The challenge for regulatory mechanisms is how to encourage projects to enhance habitat conditions for crocodiles while increasing human understanding of their natural history and endangered status. A proactive program for dealing with the increasing incidence of human/crocodile interactions is needed.

Hence, we conclude that existing regulatory mechanisms cannot protect crocodiles from intolerance, relocation, and continued modification to their habitat. Examples of the ability of regulatory mechanisms to protect endangered species are rare. For example, existing laws have failed to protect individual manatees from regular collisions with boats (Miami Herald, 8 March 2002, 9b) and have failed to protect panthers from loss of habitat due to conversion to more intensive land uses (Kautz et al. 2002).

Other Natural or Man-made Factors

Collisions with automobiles continue to be the major documented cause of mortality of crocodiles in Florida (Table 6). Most of these collisions have occurred on US 1 or SR 905 (Card Sound Road) in southernmost Dade and northern Monroe County. Despite these mortalities, nesting effort on North Key Largo has remained constant, even increasing slightly (Figure 5).

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 is limiting growth, survival, and abundance of crocodiles in historical flow-ways, we further hypothesize that these factors, in combination with increased predation on beach nest sites, may be preventing northeastern Florida Bay from becoming a source nesting colony for crocodiles in Florida.

Seven hurricanes or tropical storms have passed through crocodile habitat since crocodiles were declared endangered in 1975 (Table 7). Hurricanes and tropical storms have not proved to have a catastrophic effect on crocodiles. The best evidence for this is that Hurricane Andrew made a direct hit on the Turkey Point Power Plant site on 24 August 1992 with no immediate or lasting impact. On the other hand, hard freezes have been reported in the past to cause mortality of crocodiles (Mazzotti 1983). Four crocodiles were found dead after the Christmas freeze of 1989. We hypothesize that freezing temperatures limit the range of crocodiles in Florida, but not the abundance of crocodiles within the range.

The potential effects of sea-level rise on crocodiles have not been evaluated. This should be of concern because of the 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 been adversely affected by sea-level rise (Simmons and Ogden 1998). All of the potential crocodile-nesting habitat should be identified and mapped. A forecasting model should be developed to evaluate the spatial and temporal patterns of nesting habitat loss in response to sea-level rise.

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

Restoration Success Criteria

Do historic and current patterns of nesting, relative distribution and abundance, growth, and survival of crocodiles provide any clues for restoration of Florida Bay? Water management practices have changed the natural patterns of freshwater inflow to Florida Bay (McIvor et al. 1994). Taylor Slough was a major source of freshwater for central and northeastern Florida Bay. During the wet season, freshwater would pool behind a series of marl and sand berms along the north shore of the Bay. Restricted by berms, freshwater would flow into northeastern Florida Bay through Taylor Slough and into the central Bay primarily through McCormick Creek. Potentially large amounts of water would continue to flow into the 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 hatchling growth. Historical flow patterns probably also pushed isohalines farther out into the Bay, reducing the distance hatchlings would have to disperse to find suitable nursery habitat. Less freshwater in Florida Bay means that crocodiles would not only grow more slowly, but also have to disperse farther. Both factors negatively impact survival

Table 7. Hurricanes and tropical storms impacting crocodile habitat in South Florida 1975-2001.

Year	Name	Storm/Hurricane	Location/Path	Severity[1]/Impact
1999	Irene	Hurricane	From Key West north through Florida Bay and southeast Florida	Category 1, severe flooding
1998	Georges	Hurricane	Moved west-northwest from Cuba through Key West and Florida Bay	Category 2, moderate rainfall
1992	Andrew	Hurricane	Moved due west over extreme South Florida	Category 4, severe flooding and wind damage
1987	Floyd	Hurricane	Moved east-northeast over Florida Bay, Biscayne Bay, South Florida	Category 1/Tropical Storm, moderate rainfall/wind damage
1981	Dennis	Hurricane	Passed from south to north-northeast over Florida Keys, southern Florida	Tropical Storm, heavy rainfall, light flooding
1979	David	Hurricane	Northwest from Haiti to Palm Beach, passing east of South Florida	Tropical Storm conditions in Florida Bay
1976	Dottie	Tropical Storm	Formed northwest of Key West, drifting east-northeast over South Florida	Tropical Storm, moderate rainfall

[1]Hurricanes are rated in intensity on the Saffir-Simpson Hurricane Scale. This scale rates hurricanes by their wind speed, barometric pressure, storm surge height, and damage potential.

and the suitability of shoreline and island nest sites. The hypothesis is that in northeastern Florida Bay, the combination of saline water and long distance dispersal limits hatchling growth and survival.

Mazzotti and Brandt (1995) described the habitat suitability of crocodiles based on salinity regimes. Their criteria (0-20 ppt - most suitable, 20-40 ppt - intermediate suitability, and > 40 ppt – least suitable) were based on a combination of field and laboratory data. In the lab crocodiles grow best when the salinity is less than 50 % seawater (18 ppt) and lose mass when exposed to salinity greater than 40 ppt, unless freshwater is provided periodically (Mazzotti 1983, Gaby et al. 1985). In the field, lower growth and survival rates have been associated with higher salinities (Brandt et al. 1995, Moler 1992a). We hypothesize that crocodiles that grow faster are also in better condition (relatively fatter) than crocodiles that grow more slowly.

Relative distribution and abundance of crocodiles also reflects these salinity patterns. Within an area, most crocodiles occur at the lower end of the available salinity gradient (Mazzotti 1983, Brandt et al. 1995, Mazzotti and Cherkiss 1998). 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 or juveniles presumably avoiding adults. We hypothesize that restriction of freshwater flow into an estuary would decrease the relative density of crocodiles and that restoring or enhancing freshwater flow would increase relative density. The increase in crocodiles and crocodile nests on the freshwater side of Buttonwood Canal after it was plugged provides anecdotal support for this hypothesis.

Based on this, the ecosystem restoration goal 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 the early dry season flow (October to January) from Taylor Slough to Florida Bay.

Measurable objectives of success would be:

1. A fluctuating mangrove back-country salinity that rarely exceeded 20 ppt in northeastern Florida Bay;
2. An increase in relative density and condition of crocodiles in areas of restored freshwater flow;
3. Increased growth and survival of hatchling crocodiles to levels observed in other nesting colonies in Florida; and
4. Continued increase in nesting effort and success.

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 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.

Standard Protocols for Monitoring

Field Sampling

To provide the necessary information to assess the status of the population and for adaptive assessment of ecosystem restoration projects on the endangered American crocodile, the minimum effort for monitoring should include nesting effort and success, and growth and survival of crocodiles. Crocodile nesting effort and success should be determined by searching known and potential nesting habitat during April and May (effort), and July and August (success) for nesting activity (tail drags, digging, or scraping) or the presence of eggs or hatchlings. When nests are located, their vegetation, substrate, distance from shore, dimensions (lXwXh) and salinity of adjacent waters should be recorded (see data collection below). Hatched eggshells or hatchling crocodiles are evidence of successful nests. The number and causes of egg failure should be noted whenever possible.

Distribution, growth, survival, relative abundance, and habitat relations of crocodiles should be assessed by standard survey and capture efforts.

The following data collection and database management protocols should be followed whenever possible:

Data Collection

More than 4000 crocodiles have been marked and more than 500 nests have been located since 1978 in research and monitoring programs in South Florida. This has been a cooperative effort among different organizations and individuals. Methods and standards of collecting data have varied by time period and individual. An example of problems caused by these differences is the inability to individually identify 20 of the 31 dispersing crocodiles in Table 3. Reasons for the inability to identify recaptured crocodiles included not recording the mark, recording the mark in error (at capture or recapture), or crocodiles that were given subcutaneous microchips, but not a unique mark.

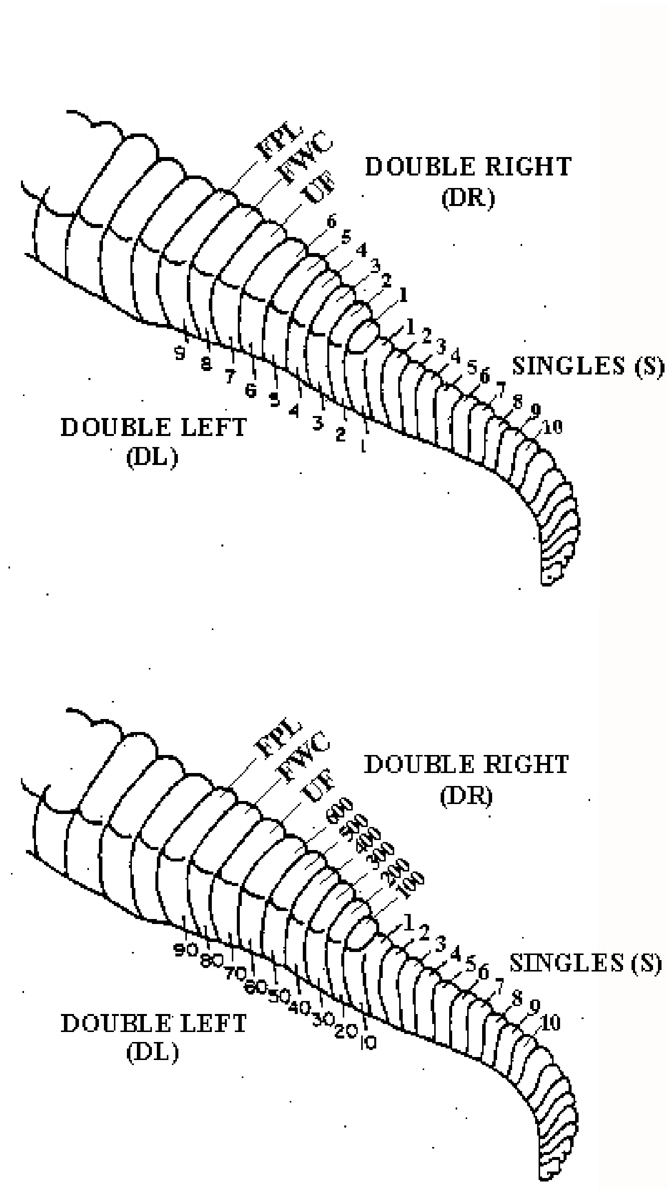


Figure 8. Scute configurations used by the Florida Fish and Wildlife Conservation Commission (top) and the University of Florida (bottom).

To reduce the discrepancies between data sets we recommend that the following standard methods of data acquisition be required as part of the permitting process.

Location

The location of crocodile sightings, captures, or nests should be recorded with a global positioning system (GPS) or on a map, chart, or aerial photograph of appropriate scale. If a GPS is used, the coordinates should be collected in Latitude and Longitude or

Universal Transverse Mercator (UTM), and the projection recorded as part of the metadata.

Marking

Figure 8 presents two variations of the same marking method currently in use by FWC and UF. We recommend that all sites use this method. Further, we recommend that the following maxims also be followed; "count twice, cut once" when marking the animal and "count twice and then again" when recording the mark on the data sheet.

Sex Determination

Sex is determined by examining the cloaca for presence of a penis or clitoris. A probe or speculum is generally required for crocodiles less than 60 cm.

Measuring

The following measurements should be taken whenever the opportunity presents itself.

1. **Total Length (TL):** the measurement is taken from the tip of the snout to the tip of the tail along a straight line, measured in centimeters (cm).
2. **Snout-Vent Length (SVL):** the measurement is taken from the tip of the snout to the posterior end of the cloacal vent in a straight line, measured in centimeters (cm).
3. **Weight:** measured in grams (g) or kilograms (kg).
4. **Head Length (HL):** measured in centimeters, from the tip of the snout to center of posterior end of skull, on the dorsal side.
5. **Tail Girth (TG):** measured in centimeters, the circumference of the tail at the 3rd scute row posterior of the rear legs.

Nesting

In addition to recording the location of the nest as described above, the following data should be collected to describe the environment and fate of nests.

1. **Vegetation:** type of vegetation (e.g., mangrove or hammock) surrounding the nest.
2. **Substrate:** nest material.
3. **Distance from water:** measured in meters (m).
4. **Nest dimensions:** length, width, and height, measured in centimeters (cm).
5. **Fertility:** when needed, fertility can be determined early in incubation by the presence of an opaque band on the egg (Mazzotti 1986).
6. **Success/Failure:** a nest is successful when one egg hatches. The number of hatched shells and failed eggs should be counted and the cause of egg failure recorded whenever possible. However, it should be noted that the number of hatched shells present provides only a minimum estimate of the number of hatchlings produced.

Environmental Measurements

The following parameters have been shown to be correlated with the ability to observe crocodiles in Florida (Mazzotti 1983, 1999)

1. **Salinity:** measured in parts per thousand (ppt)
2. **Air Temperature:** measured in degrees Celsius
3. **Water Temperature:** measured in degrees Celsius
4. **Habitat:** described as artificial or natural pond, canal, creek, cove, exposed shoreline, or other dominant feature
5. **Vegetation:** described by the dominant species or group of species.

Database Management

Currently the data for this project is in Microsoft Excel format; it is our recommendation that future data should be entered into Microsoft Access. Access was chosen due to its ability to be interchangeable with most spreadsheet and database management programs, as well as its ability to perform statistical analyses. In addition, metadata should accompany all files and include the following: name of the person(s) who collected and entered the data, the period over which the data were collected, the location(s) where the data were collected, location of the raw data, an explanation of any fields or abbreviations that might need explaining, relevant GPS information (e.g., projection), contact information for the person(s) who may be contacted with any questions pertaining to the files, and quality assurance/quality control procedures.

Conclusions

There are more crocodiles and nests in more places today than in 1975, when the American crocodile was declared an endangered species. This evidence of progress towards recovery of the American crocodile population in South Florida has been attributed to a matrix of natural and man-made habitats that together meet all the life stage requirements necessary for this species (Mazzotti and Cherkiss 1998, Mazzotti 1999). The reoccurrence of crocodiles in areas in Biscayne Bay, where they had been absent for over 20 years, 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.

The 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 CERP purposes, provide a net enhancement of the pattern of freshwater flow to the adjacent estuary.

It is important to recognize that an increase in the presence of crocodiles will exacerbate the growing problem of interactions between humans and crocodiles. The challenge of integrating a recovering population of the American crocodile with an ever-increasing use of coastal areas by humans will require a proactive education program. This will be the final challenge in the successful recovery of this once critically endangered species.

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Appendix 1. Metadata and abbreviations for the Florida Fish and Wildlife Conservation Commission data files.

Florida Fish and Wildlife Conservation Commission

Data Collection and Management

Florida Fish and Wildlife Conservation Commission, (FWC) formerly Florida Game and Freshwater Fish Commission files.

- Data collected by Paul Moler of the FWC.
- Data collected during the period 1979 – 1999.
- Data collected on site at the Crocodile Lake National Wildlife Refuge (CLNWR) on North Key Largo or anywhere throughout the range of the American crocodile in South Florida.
- Data entered and proofed by Paul Moler of the FWC.

Paul Moler
Florida Fish and Wildlife Conservation Commission
4005 South Main St.
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352-955-2230 (phone)

Capture File (FWC CAP)

Text (including column titles) should all be in capital letters.
The following is an explanation for each of the fields.

- **CLIP-** By the clipping of tail scutes in a prescribed manner, each crocodile was given an individual identification number.

- **OWNER (DR)**- Represents the institution responsible for marking the crocodile, where DR is the double right tail scute. An eight in this field means that Paul Moler or someone under his supervision marked the crocodile (Figure 1).

- **S/DL/DR-** Represents the specific tail scutes that were cut on each individual. The S stands for the single row of scutes, DL and DR represent the double left and right rows of tail scutes, respectively (Figure 1).
  Ex. Clip=000206 and was caught by FWC. The eighth (8) double right scute would be cut to denote this. To represent the #000206 the sixth (6) double right scute, second (2) double left scute and no single scutes would be cut.

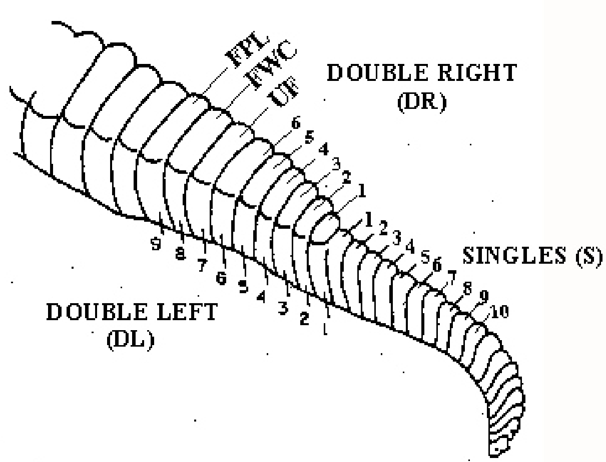

Figure 1. Scute configuration used with FWC captures.

- **TOE_TAG-** This method of marking was not used by the FWC, therefore this field will have no data (ND).

- **DATE**- The date the crocodile was captured.
- **HATCHLING-** A yes or no indicates whether or not the animal captured was a hatchling.
- **RECAPTURE-** A yes or no indicates whether or not the animal has been previously captured.
- **HATCH_DATE-** If present, this indicates the hatching date.
- **LOCATION-** This denotes the specific location where the crocodile was captured.
- **TL_CM**- Total length (TL), measured in centimeters, from the tip of the snout to the tip of the tail on the ventral side.
- **SVL_CM**- Snout vent length (SVL), measured in centimeters, from the tip of the snout to the posterior end of the cloacal vent.
- **MASS_G**- Total weight of the crocodile, measured with a Pesola scale and recorded in grams.
- **AIR-** Temperature of the air at the site of capture, measured in degrees Celsius.
- **WATER-** Temperature of the water surface, at the site of capture, measured in degrees Celsius.
- **SALINITY-** Salinity of the water surface, measured with a hand refractometer on a scale of 0–100 ppt (parts per thousand).
- **SEX-** Determined by probing the cloaca.
- **NEST-** If present, represents the nest the crocodile hatched out of.
- **COMMENTS-** Information that was recorded at the time of capture, this can include physical characteristics of the animal captured and/or environment.

Nest File (FWC_NEST)

- **YEAR**- Year the nest was active.
- **LOCATION-** Location of the nests monitored. For this file all nests are from CLNWR.
- **TOTAL # NESTS-** Total number of nests observed in a particular year.
- **# Successful Nests-** Number of successful nests in a particular year.
- **# Hatchlings Marked-** Number of hatchlings marked in a particular year, from all nests.
- **Owner-** Represents who found and monitored the nests. The following codes were used for each of the institutions involved in monitoring: Frank Mazzotti (University of Florida), 7, Paul Moler (Florida Fish and Wildlife Conservation Commission), 8 and at the Turkey Point Power Plant, 9.

Florida Fish and Wildlife Conservation Commission (FWC) Abbreviations

ABBREVIATION	STANDS FOR
BHH	BASIN HILLS
BHM	BASIN HILLS MAIN
BHN	BASIN HILLS NORTH
BHS	BASIN HILLS SOUTH
CNL	CANAL

Florida Fish and Wildlife Conservation Commission (FWC) Abbreviations cont.

ABBREVIATION	STANDS FOR
CRL	CROCODILE LAKE
CSC	CARD SOUND CANAL
CSR	CARD SOUND ROAD
DAN	DANIA
DOR	DEAD ON ROAD
DRB	DEERING BAY
ENT	ENTRANCE
OCR	OCEAN REEF
SCC	SNAPPER CREEK CANAL
SHO	SHORELINE
TPP	TURKEY POINT

Appendix 2. Metadata and abbreviations for the Turkey Point Power Plant data files.

Turkey Point Power Plant

Data Collection and Management

Turkey Point Power Plant (TP) files
- Data collected by Joe Wasilewski.
- Data collected during the period 1978 – 1997.
- Data collected on site at the Florida Power and Light Turkey Point Power Plant Facility in Homestead, FL.
- Data entered and proofed by various employees of the Florida Power and Light Company.

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Capture File (TP_CAP)

Text (including column titles) should all be in capital letters.
The following is an explanation for each of the fields.

- **CLIP-** By the clipping of tail scutes in a prescribed manner, each crocodile was given an individual identification number. This is true for captures during the period from 1978 to 1997. From 1997 to the present this field corresponds to a numbered pit tag that was inserted under the skin. In addition to the pit tag, each crocodile was also scute clipped with a cohort mark, denoting the year it was first marked (Figure 1).

- **OWNER (DR)**- Represents the institution responsible for marking the crocodile, where DR is the double right tail scute. A nine in this field means the crocodile was marked by an individual from the Turkey Point Power Plant (Figure 1).

- **S/DL/DR-** Represents the specific tail scutes that were cut on each individual. For the years from 1978 – 1997 the S stands for the single row of scutes, DL and DR represent the double left (10's) and double right (100's) rows of tail scutes, respectively. From 1997 on, the DL, DR and S scutes represent the cohort (year) the crocodile was captured and marked (Figure 1).

Ex.1 from 1979-1997, clip=355 was caught by the Turkey Point staff, the ninth (900)double right scute would be cut to denote this. To represent the #355 the third (300) double right scute, fifth (50) double left scute and the fifth (5) single scute would be cut. Ex.2 for animals captured from 1997 on, cohort 1997, the ninth (90) DL, ninth (900) DR and the seventh (7) S would be cut.

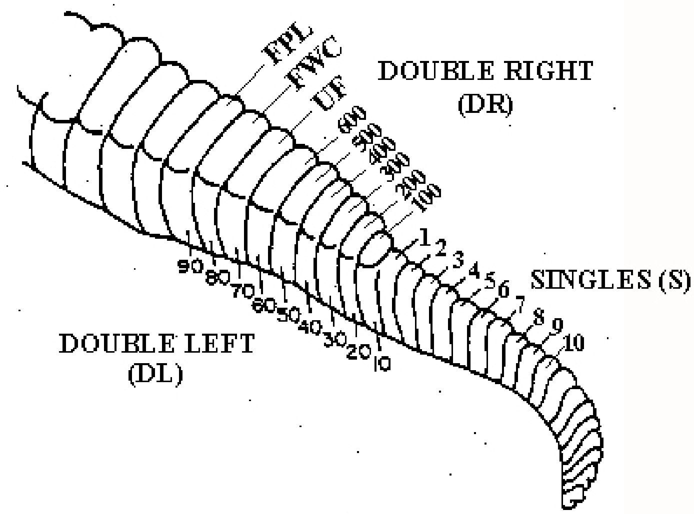

Figure 1. Scute configuration used with FPL captures.

- **TOE_TAG-** This method of marking was not used by TP, so this field will have no data (ND).
- **DATE**- The date the crocodile was captured.
- **HATCHLING-** A yes or no indicates whether or not the animal captured was a hatchling.
- **RECAPTURE-** A yes or no indicates whether or not the animal had been previously captured.
- **HATCH_DATE-** If present, this indicates the hatching date.
- **LOCATION-** Denotes the specific location where the crocodile was captured. For this database, the abbreviations are read as follows. Example: B26SXN5, would be read as Berm 26 section 5.
- **TL_CM**- Total length (TL), measured in centimeters, from the tip of the snout to the tip of the tail, on the ventral side.
- **SVL_CM**- Snout vent length (SVL), measured in centimeters, from the tip of the snout to the posterior end of the cloacal vent.
- **MASS_G**- Total weight of the crocodile, measured with a Pesola scale and recorded in grams.
- **AIR-** Temperature of the air at the site of capture, measured in degrees Celsius.
- **WATER-** Temperature of the water surface, at the site of capture, measured in degrees Celsius.
- **SALINITY-** Salinity of the water surface, measured with a hand refractometer on a scale of 0–100 ppt (parts per thousand).
- **SEX-** Determined by probing the cloaca.
- **NEST-** If present, this represents the nest the crocodile hatched out of.
- **COMMENTS-** Information that was recorded at the time of capture, this can include physical characteristics of the animal captured and/or environment.

Nest File (TP_NEST)

- **NEST ID**- Nests are given an identification number, this corresponds to either the year the nest was monitored or the location of the nest.
- **OWNER-** Represents who found and monitored each nest. The following codes were used for each of the institutions involved in monitoring: Frank Mazzotti (University of Florida), 7, Paul Moler (Florida Fish and Wildlife Conservation Commission), 8 and at the Turkey Point Power Plant, 9.
- **YEAR-** The year the nest was active.
- **LOCATION-** The location of the nest site. For this database, the abbreviations are read as in the following. Example: B26SXN5, would be Berm 26 section 5. The berms are numbered from 1 - 31 counting from right to left.
- **FATE-** Indicates the fate of the nest. The following were used to represent a successful (S) nest, a failed (F) nest and a depredated (P) nest.

Florida Power and Light Turkey Point (TP) Abbreviations

ABBREVIATION	STANDS FOR
B	BERM
BAY	BISCAYNE BAY
BSI	BOY SCOUT ISLAND
CNL	CANAL
C106	C-106
C107	C-107
CANA	OTHER CANALS
CCS	CANAL COOLING SYSTEM
CSC	CARD SOUND CANAL
DC	DISCHARGE CANAL
EFC	EAST FINGER CANAL
GC	GRAND CANAL
ISL	ISLAND
ID	INTERCEPTOR DITCH
L31	L-31
LSP	L-SHAPED POND
MISC	MISCELLANEOUS
MLCN	MODEL LAND CANAL NORTH
MLCS	MODEL LAND CANAL SOUTH
MLLE	MODEL LAND CANAL EAST
MOAT	MOAT
MTC	MET TOWER CANAL
MTR	MET TOWER ROAD

Florida Power and Light Turkey Point (TP) Abbreviations cont

ABBREVIATION	STANDS FOR
NC	NORTH COLLECTOR
NEST	NEST SITE SURVEY
NPS	NORTH PUMP STATION
NTC	NORTH TEASE CANAL
PDC	PALM DRIVE CANAL
POC	POINT OF CAPTURE
RC	RETURN CANALS
S20A	S-20-A
SANCT	SANCTUARY AREA
SC	SOUTH COLLECTOR
SDC	SEA-DADE CANAL
SID	SOUTH INTERCEPTOR DITCH
SPS	SOUTH PUMP STATION
STC	SOUTH TEASE CANAL
SXN	SECTION
TC	TEST CANALS
TUR	TURTLE POINT
WFC	WEST FINGER CANAL
YOY	YOUNG OF YEAR

Appendix 3. Metadata and abbreviations for the University of Florida data files.

University of Florida

Data Collection and Management

University of Florida (UF) files

- Data collected by Frank Mazzotti, Michael Cherkiss, and Geoff Cook of UF.
- Data collected during the period 1978 – 2000.
- Data collected throughout South Florida, primarily from Everglades National Park.
- Data entered and proofed by Michael Cherkiss and Geoff Cook of UF.

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Capture File (UF_CAP)

Text (including column titles) should all be in capital letters.
The following is an explanation for each of the fields:

- **CLIP-** By the clipping of tail scutes in a prescribed manner, each crocodile was given an individual identification number. The individual identification numbers for the UF captures follow a counting format. For the period 1978 – 1979 marking was done according to the illustration below (Figure 1). Starting in 1980 scutes were cut in a different configuration, which is currently in use today (Figure 2).

- **OWNER (DR)**- Represents the institution responsible for marking the crocodile, where DR is the double right tail scute. A seven in this field means that Frank Mazzotti or someone under his supervision marked the crocodile (Figure 2).

- **S/DL/DR-** Represents the specific tail scutes that were cut on each individual. The S stands for the single row of scutes, DL and DR represent the double left (10's) and right (100's) rows of tail scutes (Figure 2). Ex. Clip=355 and was caught by UF/National Park Service. The seventh (700) double right scute would be cut to denote this. To represent the #355 the third (300) double right scute, the fifth (50) double left scute and the fifth (5) single scute would be cut as well. The tenth (10) single scute was cut to denote numbers that are in the one thousands.

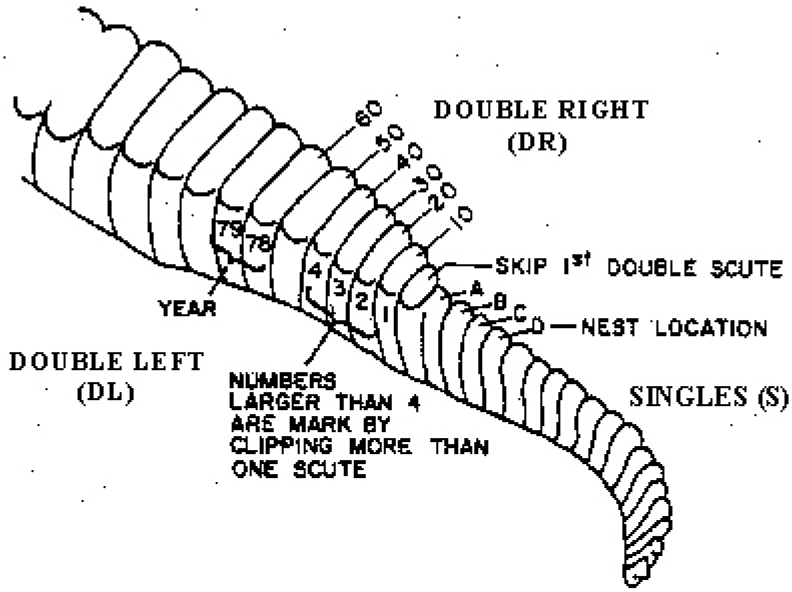

Figure 1. Scute configuration used with UF captures for 1978 – 1979.

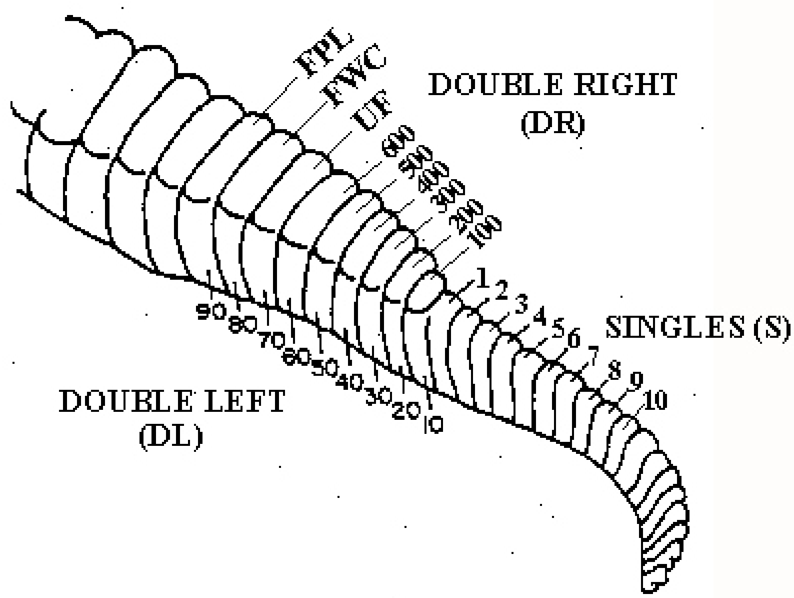

Figure 2. Scute configuration used for UF captures 1979 to the present.

- **TOE_TAG-** Originally crocodiles were marked with an external numbered tag in the webbing of the foot in addition to the cutting of scutes. However, this no longer occurs and therefore no data (ND) will be present in this field for most of the capture database.

- **DATE**- The date the crocodile was captured.

- **HATCHLING-** A yes or no indicates whether or not the animal captured was a hatchling.

- **RECAPTURE-** A yes or no indicates whether or not the animal had been previously captured.

- **HATCH_DATE-** If present, this indicates the hatching date.
- **LOCATION-** This indicates the specific location where the crocodile was captured.
- **TL_CM**- Total length (TL), measured in centimeters, from the tip of the snout to the tip of the tail, on the ventral side.
- **SVL_CM**- Snout vent length (SVL), measured in centimeters, from the tip of the snout to the posterior end of the cloacal vent.
- **MASS_G**- Total weight of the crocodile measured with a Pesola scale and recorded in grams.
- **AIR-** Temperature of the air at the site of capture, measured in degrees Celsius.
- **WATER-** Temperature of the water surface, at the site of capture, measured in degrees Celsius.
- **SALINITY-** Salinity of the water surface, measured with a hand refractometer on a scale of 0–100 ppt (parts per thousand).
- **SEX-** Determined by probing the cloaca.
- **NEST-** If present, this represents the nest the crocodile hatched out of.
- **COMMENTS-** Information that was recorded at the time of capture, this can include physical characteristics of the animal captured and/or environment.

Nest File (UF_NEST)

- **NEST ID**- Nests are named for their location.
- **OWNER-** Represents who found and monitored each nest. The following codes were used for each of the institutions involved in monitoring: Frank Mazzotti (University of Florida), 7, Paul Moler (Florida Fish and Wildlife Conservation Commission), 8 and at the Turkey Point Power Plant, 9.
- **YEAR-** The year the nest was active.
- **LOCATION-** The location of the nest site.
- **FATE-** Indicates the fate of the nest. The following were used to represent a successful (S) nest, a failed (F) nest and a depredated (P) nest.

Helicopter Survey Files (UF_HELI)

- **DATE-** The date of the helicopter survey.
- **TIME-** The time of the survey.
- **LOCATION-** The specific location of the survey.
- **SIZE (m)-** The size of the crocodile observed, in meters.

- **TYPE OF SURVEY-** Type of transportation used for the survey.
- **HABITAT-** A description of the specific habitat surveyed.
- **AIR TEMP (C)-** Temperature of the air at the site of the survey, measured in degrees Celsius.
- **H20 TEMP (C)-** Temperature of the water surface, at the site of the survey, measured in degrees Celsius.
- **WAVES (cm)-** Height (top of wave to bottom of trough) of the waves, estimated in centimeters.
- **SALINITY (ppt)-** Salinity of the water surface, measured with a hand refractometer, on a scale of 0–100 ppt (parts per thousand).
- **H20 DEPTH (m)-** Depth of the water at the survey site measured in meters.
- **COMMENTS-** Any information that was recorded at the site of the survey.

Egg File (UF_EGG)

- **DATE**- The date of the nest survey
- **NEST**- The specific location of the nest
- **LENGTH** (mm)- Length of the egg in millimeters
- **WIDTH**(mm) – Width of the egg in millimeters.
- **WEIGHT (g)-** Weight of the egg in grams.
- **SALINITY (ppt)-** Salinity of the water surface, measured with a hand refractometer, on a scale of 0–100 ppt (parts per thousand).
- **H20 TEMP (C)-** Temperature of the water adjacent to the nest, measured in degrees Celsius.
- **H20 DEPTH (cm)-** Water depth adjacent to the nest, measured in centimeters.
- **WAVES -** Wave action
- **WIND SPEED (mph)-** Wind speed, measured in miles per hour and direction.
- **COMMENTS-** Any information that was recorded at the site of the nest.
- **COLLECTOR-** Individual who collected data.

Univerisity of Florida (UF) Abbreviations

ABBREVIATION	STANDS FOR
AHP	ARGYLE HENRY POND
ALB	ALLIGATOR BAY

University of Florida (UF) Abbreviations cont.

ABBREVIATION	STANDS FOR
BBB	BLACK BETSY BEACH
BBH	BLACK BETSY HOLE
BBK	BLACK BETSY KEY
BBP	BLACK BETSY POINT
BDI	BIRD ISLAND
BRL	BEAR LAKE
BRR	BEAR LAKE ROAD
BRS	BARNES SOUND
BWC	BUTTONWOOD CANAL
CAS	CAPE SABLE
CCB	COCOA BEACH
CCP	COCOA POINT
CDC	CARD SOUND CANAL
CDS	CARD SOUND
CHB	CHAPMAN FIELD BORROW PIT
CHC	CHAPMAN FIELD CANAL
CHF	CHAPMAN FIELD
CLB	CLUBHOUSE BEACH
CLK	CLUB KEY
CNL	CANAL
COB	COOT BAY
CRK	CREEK
CRL	CROCODILE LAKE NATIONAL WILDLIFE REFUGE
CTB	CAT TRACK BEACH
CUL	CUTHBERT LAKE
DAL	DALRYMPLE'S
DCO	DAVIS COVE
DCR	DAVIS CREEK
DES	DEAD STORK
DRB	DEERING BAY
DRK	DEER KEY
E	EAST
EAK	EAGLE KEY
ECA	EAST CAPE
ECC	EAST CAPE CANAL
ECD	EAST CREEK POND
ECP	EAST CAPE PLUG
ECR	EAST CREEK
FLB	FLAMINGO BOAT BASIN
FLM	FLAMINGO
FLP	FOX LAKE POND

University of Florida (UF) Abbreviations cont.

ABBREVIATION	STANDS FOR
FPH	FAN PALM HAMMOCK
HDC	HOMESTEAD CANAL
HOL	HOLE
JOB	JOE BAY
KEL	KEY LARGO
LAK	LAKE KEY
LFL	LITTLE FOX LAKE
LMA	LITTLE MADEIRA BACK
LMB	LITTLE MADEIRA BAY
LME	LITTLE MADEIRA BEACH
LMM	LITTLE MADEIRA BEACH MOUND
LMP	LITTLE MADEIRA BAY POINT
LMS	LITTLE MADEIRA POINT SHORE
LNS	LONG SOUND
LPM	LITTLE MADEIRA POINT MOUND
MAA	MARCO AIRPORT
MAB	MANATEE BAY
MCA	MILITARY CANAL
MDF	MIDDLE FOX
MGC	MANGROVE CREEK
MGP	MONTGOMERY PROPERTY
MID	MID
MRP	MRAZEK POND
MUB	MUD BAY
MUC	MUD CREEK
MUL	MUD LAKE
N	NORTH
NE	NORTH EAST
NW	NORTH WEST
RUK	RUSSELL KEY
S	SOUTH
SCC	SNAPPER CREEK CANAL
SDM	SOUTH DADE MARINA
SE	SOUTH EAST
SHO	SHORELINE
SHP	SHARK POINT
SNB	SNAG BAY
SNC	SNOOK CREEK
SNP	SNIPE POINT
SW	SOUTH WEST
TAR	TAYLOR RIVER

University of Florida (UF) Abbreviations cont.

ABBREVIATION	STANDS FOR
TAS	TAYLOR SLOUGH
TCI	TROUT COVE ISLAND
TCO	TROUT COVE
TCR	TROUT CREEK
TLU	THE LUNGS
TPC	CARD SOUND TURKEY POINT CANAL
W	WEST
WEL	WEST LAKE
WLP	WEST LAKE POND
WLR	WEST LAKE ROAD
YOY	YOUNG OF YEAR