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STATUS OF THE AMERICAN CROCODILE (*CROCODYLUS ACUTUS*) AT A POWER PLANT SITE IN FLORIDA, USA

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Abstract. Surveys for distribution and nesting of American crocodiles (*Crocodylus acutus*) were conducted from 1983-1993 at Florida Power & Light Company's Turkey Point power plant site in Homestead, Florida, USA. The number of crocodile nests, hatchlings, and non-hatchlings observed per survey have increased over the 11 year period. The percentage of animals in each size class fluctuated from year to year. It is estimated that 24-30 non-hatchling crocodiles reside on the site. First year survival of hatchlings averaged 8.5% and varied from year to year.

Key Words. American crocodile; *Crocodylus acutus*; Florida; Population ecology; Power plant.

The American crocodile (*Crocodylus acutus*) is a primarily coastal crocodilian that occurs in parts of México, Central and South America, the Caribbean and, at the northern extent of its range, in southern Florida, USA. Historically in Florida, crocodiles occurred as far north as Ft. Myers on the west coast and Lake Worth on the east coast (Fig. 1). Currently, there are three primary crocodile nesting areas in southern Florida: northeastern Florida Bay within Everglades National Park (ENP), North Key Largo (NKL), and Florida Power & Light Company's (FPL) Turkey Point power plant site (TP) in Dade County, Florida (Fig. 1). This paper discusses the status of crocodiles at TP and includes data on survival, nesting, and habitat use based on eleven years (1983 through 1993) of monitoring.

MATERIALS AND METHODS

Turkey Point is a 2388 ha site occupied primarily by cooling canals serving four electrical generating units. These 60 m wide circulating canals comprise a closed-loop system and alternate with 40 m wide earthen berms. Canal water temperature averages 38 C and ranges from 34 to 42 C in summer. Salinity in the cooling canals averages 36 parts per thousand (ppt) and ranges from 15 to 42 ppt depending on seasonal rains (Mazzotti et al. 1986). Eight other non-connecting canals of varying width, depth, and salinity are located adjacent to the cooling canals (Fig. 1; see Gaby et al. 1985 for detailed description). The cooling canal system (CCS), Interceptor Ditch (ID), return canals (RC), Sea-Dade Canal (SDC), and C107 are the areas primarily used by crocodiles, though crocodiles also have been observed in L-31, the test canals, and the moat.

Adult crocodiles were first observed at TP in 1976. In 1978, nesting was discovered when hatchling crocodiles were observed and captured in the cooling canals. Gaby et al. (1985) reported on the status of *Crocodylus acutus* at TP for the period 1978-1981. It was estimated that 17-19 non-hatchling crocodiles occurred at TP (25% adult > 2.25 m, and 75% juvenile and subadult), with a male to female sex ratio of 1:1.3. Four nests were located at TP from 1978-1981, and Gaby et al. (1985) estimated that nests at TP produced nearly 25 hatchlings each year, approximately 10% of the total annual number for

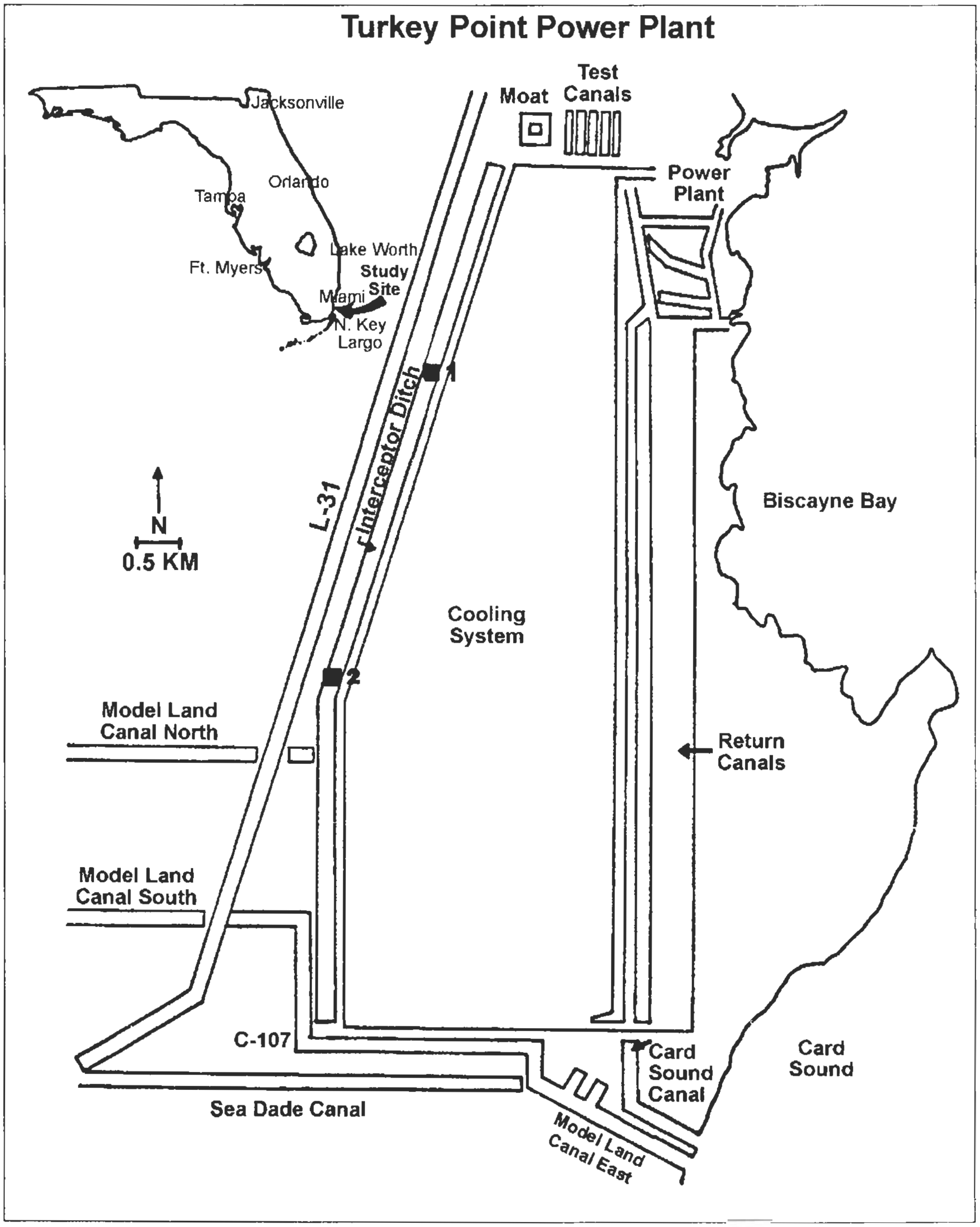

Figure 1. The Turkey Point power plant site, Dade County, Florida. 1=North pump station; 2=South pump station.

Florida. Because of TP's importance as crocodile nesting habitat, FPL established a long-term crocodile monitoring program to insure that the operation and maintenance of the site was compatible with crocodile survival.

Nesting success, juvenile growth, and survival were the factors chosen for monitoring at TP. Population trends were determined by locating and following the fate of nests and hatchlings and by examining the distribution and abundance of different size classes of crocodiles on the site.

Nest surveys were conducted within the cooling canal system from April through August 1984-1993. Berms were searched by day on foot for signs of crocodile activity (trails, tail drags, and digging). Areas of past nesting and recent crocodile activity were searched in an attempt to locate nests before hatching; however, because crocodiles at TP are primarily hole nesters, most nests were found only after hatchlings had been located during night surveys. Night surveys for hatchlings were conducted five nights per week during July and August. If hatchlings were located in an area that had not been identified as a nest site, that area was surveyed on foot the following day to locate the nest. Once a nest was located, it was examined for failed and hatched eggs and the area surrounding the nest was described (soil type, vegetation, distance from shore, and nest type: mound or hole).

Hatchlings were captured by hand or landing net, measured to the nearest mm (snout-vent length [SVL], total length [TL], and head length [HL]), weighed, given an individual mark by clipping scutes (Mazzotti 1983), and released either at the site of capture or in a designated area nearby.

To monitor the distribution of crocodiles at TP and to collect data on hatchling and juvenile survival, night surveys were conducted by airboat, jon boat, canoe, or truck once or twice per week throughout the study area during all seasons from 1983-1993. Animals were located by their eyeshines using a 100,000+ candle power spotlight or with a 4 volt Wheat cap lamp. Location, size estimate, and behavior were recorded when an animal was sighted. Crocodiles < 1 m TL were captured by hand, landing net, or pilstrom tongs. Those 1-2 m TL were captured using self-locking wire nooses. No attempts were made to capture animals > 2 m. Captured animals were measured, sexed (when possible), individually marked, and released at the capture site. Temperature and salinity were recorded for each capture site.

Day surveys for animals in the cooling system and adjacent canals were conducted periodically. Surveys of the ID were used to document seasonal and spatial use of this canal and to look for tail drags and footprints indicating movement of animals from one area to another (crossings). Surveys were conducted by truck before noon (usually < 3 h after sunrise). Estimated size, location, and behavior were recorded for each crocodile sighted; number and direction of tail drags also were recorded.

For analysis of changes in size class distribution, all sightings and captures were coded as: hatchlings < 0.7 m, juveniles 0.71-1.50 m, subadults 1.51-2.25 m, adults >2.25 m, or unknown. To correct for differences in survey effort and biases due to differences in habitat use, results are expressed as crocodiles/survey when comparing the number of crocodiles seasonally within the same area, or average number of crocodiles/survey when comparing the number of crocodiles observed in an area among years. Changes in relative abundance were examined by determining the average exponential rate of increase (r), which is the slope of the least-squares line of:

$$\ln(\text{density indices}) = \text{intercept} + r(\text{time})$$

where the density indices are number of nests/year or average number of crocodiles/survey (Bayliss 1987). The above calculations were computed using data only for crocodiles > 0.70 m.

RESULTS

Fifty-five nests were found from 1984 through 1993. All were hole nests dug into oxidized peat substrates in or near vegetated areas, at an average of 8.1 m from the shorelines (range 3-15 m) of the cooling canals. Median hatching date was 15 July, range was 27 June to 15 August.

The number of nests found per year has increased from two in 1978 (Gaby et al. 1985) to a maximum of 12 in 1992 (Fig. 2). There was no significant change in the number of nests located from 1978-1985. There was a significant increase in the number of nests located from 1986-1993. The average, annual, exponential rate of increase was significantly different than zero and was 0.23, or 23% per year (f=54.67, P<0.01, df=7). At least 25 different nest locations have been used. The number of hatchlings captured each year varied with the number of nests and ranged from 0 -180 during the

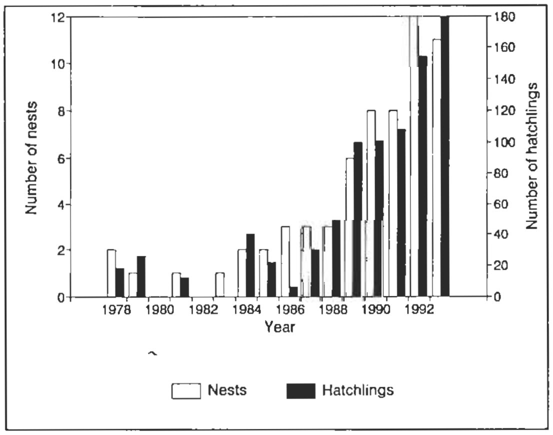

Figure 2. Number of *Crocodylus acutus* nest sites found and hatchlings marked at Turkey Point 1978-1993. 1978-1981 data are from Gaby et al. (1985).

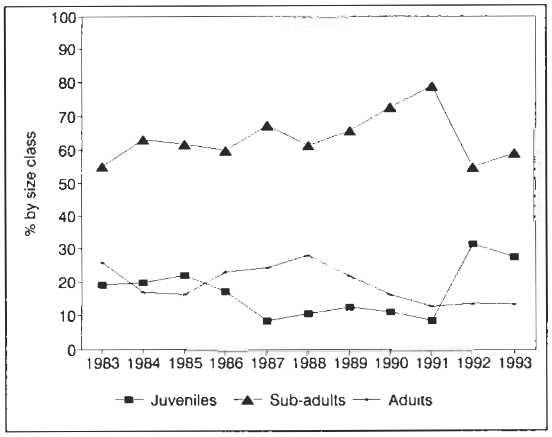

Figure 3. Percentage of three size classes of *Crocodylus acutus* observed during day and night surveys 1983-1993 (juveniles=0.71-1.50 m; subadults=1.51-2.25 m; adults>2.25m).

period of 1983-1993.

Hatchling size analyses were based on measurements from 786 hatchlings captured within five days of hatching during 1984-1993. Hatchlings averaged 26.5±1.9 cm TL (*n*=786), 13.4±1.0 cm SVL (*n*=778), and 59.4±9.9 g (*n*=785). TL of hatchlings differed significantly among 27 different nests with > nine hatchlings (Kruskal-Wallis, *h*=358.2, $P<0.01$, *df*=488) as did SVL (*h*=361.1, $P<0.01$, *df*=488). Mean TL ranged from 23.0±0.41 to 30.5±0.42.

First year minimum known alive survival of hatchlings varied from 0% in 1988 to 33% in 1986 ($\bar{x}$=8.5%). Minimum known alive survival to 36 months averaged 5.9% for 1984-1990 hatchlings, with a range of 0-16.7% (Table 1). Low survival was associated with high salinity. This is illustrated by two groups of hatchlings from 1984, when a nest was found in the return canals (Fig. 1). Because this nest was close to the intake of the generating units, the hatchlings (*n*=18) were relocated to an area in the southwestern portion of the system adjacent to the freshwater ID. Twelve of the 18 relocated hatchlings survived for at least six months. During the same year, 16 hatchlings were left near their nest site in the hypersaline cooling canal system. These animals had the lowest growth rate of crocodiles at TP (pers. obser. 1993), and none were captured more than three months after hatching.

The 1847 surveys (860 day and 987 night) conducted from 1983-1993 resulted in 4658 sightings of crocodiles. Of these, 2691 were made during the day and 1967 at night. The majority (58%) of day surveys were of the ID while the majority (60%) of the night surveys were of the CCS and RC. Other areas were surveyed nearly equally during the day and night. The average number of crocodiles observed per night survey was highest in March and June and lowest in October and January. The average number of crocodiles observed during day surveys was highest in January and February. Adults and subadults were observed more often during day surveys. Adults were observed at a rate of 0.69 ± 0.27 crocodiles/survey during the day compared to 0.07 ± 0.04 crocodiles/survey at night (paired *t*-test, *t*=7.98, $P<0.01$, *df*=10). Subadults were observed at a rate of 2.13 ± 1.08 crocodiles/survey during the day and 0.48 ± 0.16 crocodiles/survey at night (*t*=5.48, $P<0.01$, *df*=10). Hatchlings were observed significantly more at night (0.87 ± 0.69 crocodiles/survey at night compared to 0.07 ± 0.09 crocodiles/survey during the day; paired *t*-test, *t*=-3.67, $P<0.01$, *df*=10). There was no significant difference in the number of juveniles observed during the day than observed at night. The percentage of sightings in each size class has fluctuated from year to year (Fig. 3).

The average exponential annual rate of increase (r) for the mean number of non-hatchling crocodiles observed per survey for day and night surveys from 1983-1993 combined, was significantly different from zero (*f*=52.79, $P<0.05$, *df*=10; Fig. 4) and was 0.09 or 9%. This indicates that, based on all surveys, the average number of non-hatchlings observed per survey has increased since 1983. The regression of

TABLE 1. Number of *Crocodylus acutus* known to be alive at 1-4 years of age from clutches from 1984-1992. Percent is percent of the hatchlings surviving to that age class.

Year	# Hatchlings	1 yr (%)	2 yr (%)	3 yr (%)	4 yr (%)
1984	34	2(5.9)	2(5.9)	2(5.9)	2(5.9)
1985	21	3(14.3)	2(9.5)	2(9.5)	0(0)
1986	6	2(33.3)	1(16.7)	1(16.7)	1(16.7)
1987	30	4(13.3)	2(6.7)	2(6.7)	1(3.3)
1988	49	0(0)	0(0)	0(0)	0(0)
1989	100	3(3.0)	0(0)	0(0)	0(0)
1990	101	5(5.0)	1(1.0)	1(1.0)	—
1991	108	2(1.8)	0(0)	—	—
1992	154	1(0.6)	—	—	—
	Mean %	8.5%	5.0%	5.9%	4.3%

the average number of non-hatchling crocodiles observed per night survey and year was not significantly different from 0, indicating no significant increase from 1983-1993 based only on night surveys, while the average exponential rate of increase for day surveys was significant (f=25.95, P<0.05, df=10; r=0.18).

During the 1983-1993 period, 66 individual non-hatchling crocodiles (17 male, 29 female, 20 unknown sex) were captured. The total number of individuals captured per survey increased up to 1986 and has fluctuated since then. Based on the number of individuals captured, number sighted in the ID in one day, and the number of nests, it is estimated that 24-30 non-hatchling crocodiles reside on the Turkey Point site.

The sex ratio for 1983-1993 was 1:1.7 (male:female, 64% female) which does not differ from a 1:1 sex ratio (χ^2, P<0.05). The percentage of females captured has fluctuated between 33% of all sexed animals (1990) and 100% (1984 and 1993). Juveniles were observed in the cooling canals in all years and in the return canals in 1986 and 1988-1993. Sightings of juveniles in the ID, C107, and SDC are less consistent and vary from year to year. The number of sightings of juveniles in the CCS decreased up until 1992 and then increased in 1993. The percentage of all juvenile sightings that have been in the CCS has remained approximately the same (Figs. 5, 6). Subadults were observed consistently in all areas. Adults were observed most often in the ID, followed by the cooling canals, primarily during nesting (April-August).

DISCUSSION

The number of crocodile sightings at TP has increased since Gaby et al.'s (1985) 1978-1981 study. Part of this reflects an increased awareness of the crocodiles' presence on the property, and part is due to an actual increase in the population. Gaby et al. (1985) estimated the population to consist of 17-19 individuals in 1978-1981. By 1985 the popula-

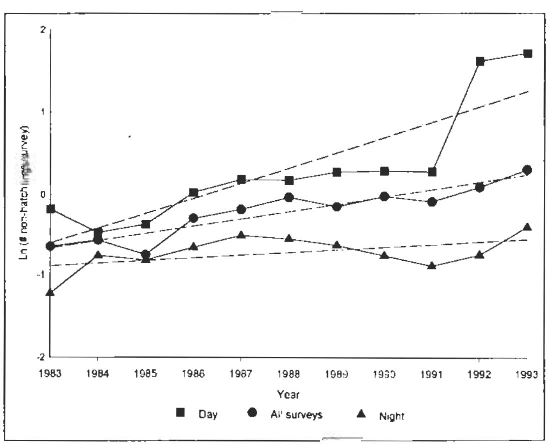

Figure 4. Natural log average number of non-hatchling *Crocodylus acutus* observed per survey in all areas of Turkey Point from 1983-1993. Regressions of Ln number vs. year for day and all surveys were significantly different from zero (see text).

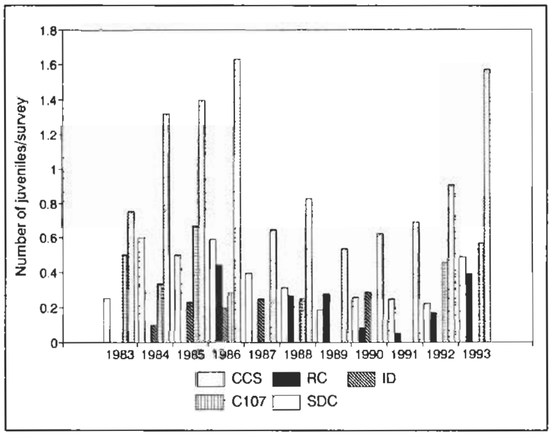

Figure 5. Number of juvenile *Crocodylus acutus* observed per night survey in the major canals at Turkey Point 1983-1993.

tion was estimated at 18-22 non-hatchling crocodiles with a seasonal peak of approximately 50 individuals immediately after hatching (pers. obser. 1985). Currently it is estimated that 24-30 non-hatchling crocodiles occur at TP. At least 12 breeding females have used the site (12 nests in 1992). The increase in the number of nests observed could be due in part, to a greater search effort over the years, but it also indicates an increase in reproductive effort. In 1986 and 1987, nests containing small infertile eggs were found, suggesting the presence of first-time nesters (Ferguson 1985). This suggests that the increase in the number of nests is in part, a result of younger animals becoming sexually mature on the site. Animals from off-site also may be locating and selecting this area as suitable nesting habitat. Animals marked in 1978 and 1979 should now be sexually mature and may be returning to the site to nest.

The number of crocodiles resident at TP appears to be leveling off, and this would be expected for a population reaching stability, perhaps as a site approaches carrying capacity. Fluctuations in the percentage of sightings by size class have been greatest for subadults and smallest for adults. Given the stable number of adults observed, the increase in nesting suggests that some animals nesting at TP are probably occupying other habitats during most of the year. Gaby et al. (1985) speculated that crocodiles may not use an adjacent fresh water canal (L-31) because of the presence of alligators. An alternate explanation is that prior to 1982, the low density of crocodilians at TP allowed them all to remain in preferred habitats. Since 1981, however, the number of crocodiles in L-31 has increased from zero to at least four. The distribution of sightings of crocodiles within the cooling canals also has expanded, with more sightings occurring in the return canals and northern portions of the system. It may be that the cooling canals, with their higher salinities, are only marginal crocodile habitat, to which subadults are being displaced (Messel et al. 1982). The observed fluctuations in subadult numbers may be the result of animals searching for suitable habitat and then being displaced by adults during the breeding/nesting season. Gaby et al. (1985) observed that crocodiles of different size classes used habitats available on the TP site differently, with the majority of adult sightings in the ID and the majority of juvenile and subadult sightings in the brackish canals (C107 and SDC). The patterns of distribution observed in this study were similar, with adults being observed most often in the ID, subadults in all areas, and juveniles primarily in the CCS, but also in the surrounding canals. The decrease in the number of juveniles observed throughout the site up to 1992 may be due to interactions with an increasing number of subadults, high juvenile mortality, or increase in human activity within the system; or it might reflect changes in the availability of suitable juvenile habitat within the cooling canals.

Crocodylus acutus prefer sheltered areas such as undercut banks and mangrove snags and roots that are protected from wind and wave action (Mazzotti 1983). The cooling canals at TP are protected from wind and wave action, and during the early 1980s,

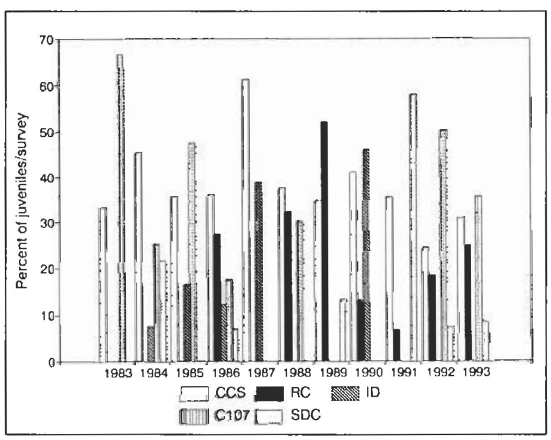

Figure 6. Percentage of all individual *Crocodylus acutus* observed per night survey in the major canals at Turkey Point 1983-1993 that were juveniles.

most of the system had vegetated canal banks. In 1984, however, a 10-year program was initiated to restore the canals to the design efficiency. As part of this canal maintenance operation, all vegetation was removed from all berms not designated as crocodile nest site sanctuaries. This eliminated potential cover sites for crocodiles. In addition to removing potential cover, these maintenance activities, along with an increase in night surveys, increased the amount of human disturbance within the cooling canals (Fig. 7). Combined with the growth in the number of subadult crocodiles, this increase in human activity may have displaced juveniles that would normally have resided in the system to suitable habitat elsewhere. Maintenance activities are ending and it will be interesting to see if the number of juveniles observed in the cooling system changes.

Because of low growth rates and low survival of hatchlings in the cooling system, it was decided that the relocation of hatchling crocodiles from areas of potentially adverse conditions (areas of high salinity and/or high plant or maintenance activity) would continue. The policy of moving hatchlings from the hypersaline portions of the system to lower salinity areas has probably increased hatchling survival and may have contributed to the observed increase in crocodiles at TP. Survival of hatchlings and yearlings is variable among years, and survival of different age/size classes has been impossible to determine, since hatchlings disperse off site and may not be recaptured until they return to the system as adults. Average annual survival for hatchlings (8.5%) is lower than that reported for alligators in a cooling reservoir in South Carolina (52%, Brandt 1989), alligators in north-central Florida (19%; Woodward et al. 1987), *C. porosus* (38-46%, Messel et al. 1982), crocodiles on NKL (20.4%, P. Moler, pers comm. 1993), but higher than for crocodiles in ENP (<5%, pers. obser. 1984). However, because it is impossible to distinguish between death and dispersal, the low observed survival rates also may reflect movement of juveniles and subadults to habitats adjacent to those surveyed. There is some evidence for this because two 1979 hatchlings were recaptured in the study area after periods of 10 and 12 years. In addition, animals from NKL have been captured at TP and in ENP (pers. obser. 1990), and an animal from TP has been captured on the mainland side of Barnes Sound (P. Moler, pers. comm. 1990), demonstrating that animals do move from site to site. Since animals > 2 m have not been regularly captured at TP, it is not possible at this time to quantify long-term crocodile survival and use of the site by non-nesting animals. However, we do know that TP is important for the overall survival of crocodiles in Florida. It provides nesting habitat for approximately one third of the known nesting crocodiles in Florida. Because of the abundance of suitable nest sites (high ground in a relatively undisturbed area), it is expected that the number of crocodiles nesting at TP will continue to increase.

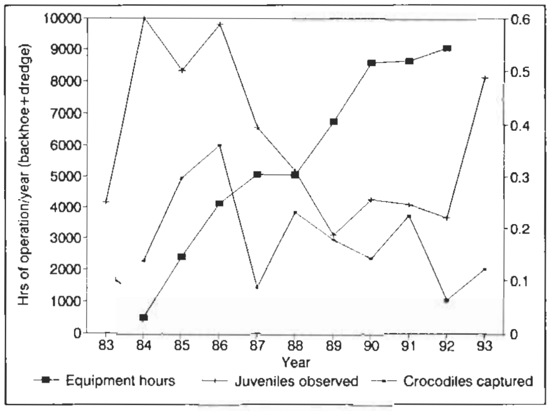

Figure 7. Number of juvenile *Crocodylus acutus* observed per survey, number of non-hatchlings captured per survey and yearly hours of operation of equipment used for cooling canal restoration.

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LITERATURE CITED

Bayliss, P. 1987. Survey methods and monitoring within crocodile management programmes. In: *Wildlife Management: Crocodiles and alligators.* (Ed. by G.J.W. Webb, S.C. Manolis, and P.J. Whitehead), pp. 157-175. Surrey Beatty & Sons Pty Limited, Austrailia.

Brandt, L.A. 1989. Status and ecology of the American alligator (*Alligator mississippiensis*) in Par Pond, Savannah River Site. Unpubl. M.S. Thesis, Department of Biological Sciences, Florida International University, Miami, Florida, USA.

Ferguson, M.J.W. 1985. Reproductive biology and embryology of the crocodilians. In: *Biology of the Reptilia*. Vol 14, (Ed. by C. Gans, F. Billet and P.F.A. Maderson), pp. 329-491. John Wiley and Sons, New York, New York.

Gaby, R., M.P. McMahon, F.J. Mazzotti, W.N. Gillies and J.R. Wilcox. 1985. Ecology of a population of *Crocodylus acutus* at a power plant site in Florida. *J. Herpetol*, **19**, 189-198.

Mazzotti, F.J. 1983. The ecology of *Crocodylus acutus* in Florida. Unpubl. Disser., Department of Biology, The Pennsylvania State University, University Park, Pennsylvainia, USA.

Mazzotti, F.J., B. Bohnsack, M.P. McMahon and J.R. Wilcox. 1986. Field and Laboratory observations on the effects of high temperature and salinity on hatchling *Crocodylus acutus*. *Herpetologica*, **42**, 191-196.

Messel, H., G.C. Vorlicek, A.G. Wells and W.J. Green. 1982. Status and dynamics of *Crocodylus porosus* populations in the tidal waterways of northern Australia. *IUCN Publ. (N.S.) Suppl. Paper*. pp. 127-173.

Woodward, A. R., T.C. Hines, C.L. Abercrombie and J.D. Nichols. 1987. Survival of young American alligators on a Florida lake. *J. Wildl. Manage*, **51**, 931-937.