DESCRIPTION, PREVALENCE AND SEVERITY OF GREEN TURTLE FIBROPAPILLOMATOSIS IN THREE DEVELOPMENTAL HABITATS ON THE EAST COAST OF FLORIDA

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Abstract: *Fibropapillomatosis (FP) is a tumor disease that is reported in the hard shelled sea turtle species. The frequency of FP, however, is much higher in green turtles (*Chelonia mydas*) than in any other species. The distribution of this mysterious disease is worldwide, but the etiology is still not understood. We captured 310, 256 and 82 juvenile green turtles by large mesh tangle nets in the Indian River Lagoon (Lagoon), the nearshore reef (Ocean) and the Trident submarine Basin (Port) on the East coast of Florida in 1998 and 1999. FP prevalence at the Lagoon, Ocean and Port study sites were 61.6, 14.8 and 0% respectively. All tumors were examined and measured, and we assigned overall severity of FP (tumor score 0–3) to all turtles that were captured in the three study sites, based on size, number and location of external FP tumors. The range of tumor size is from less than 1 cm to more than 10 cm in length. The number of tumors varies from 1 to as many as 70 among individuals in the Lagoon. Twenty-two of 25 recaptured turtles showed regression of FP tumors by comparison and examination of initial and recapture photographs. The explanation of different FP prevalence in two physically similar sites, the Port and the Ocean, is unknown. One difference between the Port and the Ocean sites is that the Ocean is located closer to the inlets that connect the open ocean to the Indian River Lagoon, where FP prevalence is consistently higher.*

Key Words: green turtle, fibropapillomatosis, Indian River Lagoon

Introduction—Fibropapillomatosis (FP) is a benign tumor disease that is found in the hard-shelled species of sea turtles. It is, however, much more common among green turtles than any other species, for some unknown reason. FP prevalence among strandings of hawksbills, Kemp's ridleys and loggerheads is almost negligible in Florida when it is compared to that of green turtles (Foley et al. 2005). The etiology of FP is still unknown. Possible etiologies of FP involve genetic predisposition, oncogenic viruses, immune suppression, chronic stress, UV light, toxic exposure to chemicals and nutritional deficiencies (Aguirre 1991). Even though the etiology of FP is unknown, it has been experimentally proven to be caused by a transmissible viral agent (Herbst et al. 1995). A novel herpesvirus also is consistently transmitted with the disease phenotype and associated with FP tissue (Herbst et al. 2004, Enel et al. 2005).

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The history of FP in Florida goes back to 1937. The first confirmation of cutaneous fibro-epithelial growths (papillomas, fibromas, fibropapillomas) was reported in captive green turtles that were captured in the Florida Keys in 1937 (Smith and Coats 1938). One year after that confirmation, three diseased animals were found among 200 turtles from the waters south of Key West (Smith and Coats 1938). This was the first incidence of the disease reported in wild animals. In 1938, similar tumors were also found in green turtles captured off Cape Sable, Florida (Lucke 1938). Little or no research into the nature of the disease was done from 1938 to the beginning of the 1980's. As of January 4, 2005, 233 published papers and 60 unpublished reports are listed in the Bibliography of Fibropapillomas in Marine Turtles (Murakawa and Balazs 2005).

The distribution of FP is now worldwide; it is found in all major oceans. However, because of limited human and financial resources, turtle populations are poorly monitored in much of the world (Herbst 1994). There has been a great concentration of FP research in Hawaii and a more limited epizoological study has been done on the wild population of Indonesia (Adnyana et al. 1997). Since 1984, FP turtles have been net captured in the Indian River Lagoon (Lagoon), Florida, but the impact of the disease on the Lagoon green turtles remains unclear. Along with Kaneohe Bay, Hawaii, the Lagoon is one of the few places in the world where FP has been studied for many years. The green turtles found in the Indian River Lagoon are from various nesting beaches in the western hemisphere. The Indian River Lagoon is one of the most important nursery grounds for green turtles in the Atlantic. Juvenile green turtles that survive the post-hatchling stage are the stock that the population depends upon to provide breeding adults in 10 to 20 years (Ehrhart et al. 1986). Therefore, the green turtles in the Indian River Lagoon, a juvenile foraging habitat, constitute a keystone in the recovery of the Florida green turtle (Ehrhart et al. 1986).

The purpose of this study was to compare the prevalence and severity of FP in three green turtle developmental habitats, the Indian River Lagoon (Lagoon), the nearshore reef (Ocean) and the Trident Submarine Basin (Port) Port Canaveral, that have different physical characters, on the east-central Florida coast. This was accomplished by analyzing the level of severity of the disease in individuals from each of the aggregations. The goal was to assess the overall impact of FP on the status and recovery of the Florida green turtle.

METHODS AND MATERIALS—Juvenile green turtles were captured at three different developmental habitats on the east central coast of Florida (Fig. 1). These habitats differ in terms of ecological and physical characteristics. The Lagoon study site was located about 73 km south of Cape Canaveral and is about 3 km south of Sebastian Inlet (27°49′ N, 80°27′ W). The Lagoon study site is a bay-like expanse of the Indian River Lagoon. The Ocean study site was located in the open ocean east of the barrier island and at approximately the same latitude as the Lagoon study site (Fig. 1). The rate of movement of water, caused primarily by the ebb and flow of tide, is much greater than that at the Lagoon study site. The Port study site, a man-made submarine basin (0.8 km^2), was located close to the mouth of the ship channel, on the north side of Port Canaveral, Brevard County (Fig. 1). We used nets and techniques that are described by Ehrhart and Ogren (1999) at each site. At all study sites, turtles were untangled immediately after they were caught in the nets.

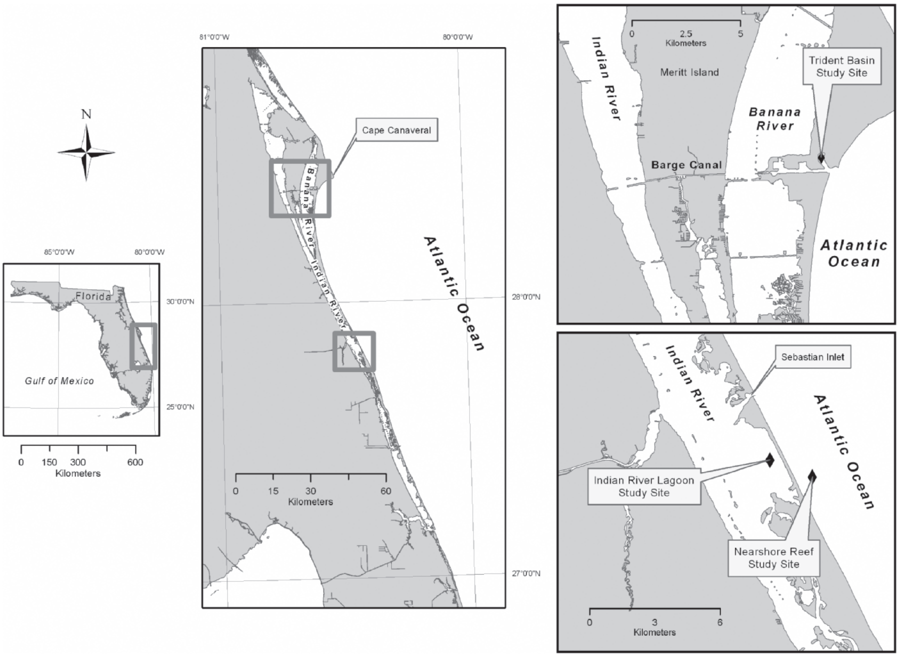

FIG. 1. Location of the Indian River Lagoon (Lagoon), Nearshore Reef (Ocean), and Trident Basin (Port) study sites on Florida's Atlantic Coast.

We examined all green turtles captured at the three study sites for external and oropharyngeal tumors. Histological confirmation of FP tumor was achieved from the Lagoon study site (Jacobson, et al. 1989). The prevalence of FP has remained moderate to high in this study site since the early 1980's (Jacobson, et al. 1989, Hirama 2001). Histopathology diagnosis of FP was not performed in the current study; however there was no doubt that the tumors were FP. For each diseased turtle the locations and sizes of tumors were recorded on a data sheet with four pre-drawn diagrams of turtles: dorsal and ventral views of the entire body and lateral views of the right and left eyes. There were four tumor size (greatest length) categories: Tumor Length (TL)-A$\leq$1 cm, 1 cm$<$TL-B$\leq$4 cm, 4 cm$<$TL-C$\leq$10 cm, 10 cm$<$TL-D (Work and Balazs 1999). The texture of the tumor surface, varying from very smooth to papillose, was observed and noted. After all locations and sizes of tumors were recorded, we assigned subjective overall tumor scores (TS) to all turtles captured in the three study areas. Tumor scores were determined by the size, number, and location of the tumors present (Balazs 1991). The tumor scores were: TS0 – non-diseased, TS1 – mildly afflicted, TS2 – moderately afflicted and TS3 – severely afflicted (Balazs 1991).

We weighed and obtained straight carapace length (SCL) of all turtles from the three study sites. The mean SCL of TS0-3 were compared and tested by a Kruskal-Walis test followed by Dunn's multiple comparison test. A regression analysis between total number of FP tumors on the body and condition factor (body weight/SCL^3) was performed. Similar analyses of size and FP prevalence relationships were conducted by dividing all captured turtles into size groups (30–34.9, 35–39.9, 40–44.9, 45–49.9, 50–54.9, 55–59.9 and over 60 cm). We compared the median sizes of tumors with (n=28) and without (n=651) necrotic tissue using a Mann Whitney-U test. Another relevant null hypothesis, purporting no difference in the frequency of ocular tumors between Lagoon and Ocean turtles, was tested by Chi-square.

Forty-one green turtles that had been at large in the Lagoon for at least 10 months were recaptured and examined for change in FP status. Green turtles recaptured at intervals of less than

10 months were excluded from the analysis because their rates of change were negligible in the short-term. In the present study, numbers and sizes of tumors at the initial and second captures were examined and compared by use of tumor drawings and photographs. The recaptured turtles were considered as regressed when the numbers of tumors were reduced by 30% or more with reduction of existing tumor sizes at second capture. The 41 turtles were divided into four categories based on the FP status change, as follows.

1) No FP present at the first capture, and the turtle was not afflicted at the second capture.
2) No FP at the first capture, but the turtle was afflicted by the disease at the second capture.
3) FP present at the first capture, and by the second capture the tumors showed regression clearly.
4) FP present at the first capture, and the tumors showed progression of FP.

In order to examine seasonal differences in FP prevalence, we tested TS for each season, Summer (June, July and August), Fall (September, October and November), Winter (December, January and February) and Spring (March, April and May) by Chi-square. We also tested the annual FP prevalence in 1996 through 1999 in the Lagoon study site for correlation with temperature, salinity and pH by use of the Spearman rank correlation coefficient. The annual FP prevalence in the Lagoon from 1984 to 2000 and the Ocean from 1996 to 1999 were examined by regression analysis attempting to quantify the trend in FP prevalence during these periods of time. Statistical analyses in this study were performed using the Prism program.

A Wilcoxon rank sum test was used to test the null hypothesis that there was no difference in mean SCL of FP regressed (n=49) and non-regressed (n=49) green turtles in the Indian River Lagoon. Regression was determined by the appearance of the tumors. Regressing tumors exhibited a smooth surface; the texture of the skin was essentially the same as normal healthy skin. The active FP tumors had a broccoli-like, papillose texture. This method of determination of regression was confirmed by the status change of turtles recaptured in the Indian River Lagoon. Tumors that showed a decrease in size at the second capture had smooth skin on the surface.

RESULTS—The appearance of the tumors varied from smooth to cauliflower-like with small spiny projections. FP tumors are found mostly on the soft skin tissue, around the neck or at the base of flippers, but they were observed occasionally at the seams between carapace and plastron scutes. They also were found commonly on and around the eye. The color of tumors can be white to pinkish, red, gray, purple or black. The size of tumors varied from less than 1 cm to more than 10 cm, and the number of tumors per turtle varied from 1 to as many as 70. There were no turtles with oropharyngeal tumors in any of the study sites.

Indian River Lagoon (Lagoon) Green Turtles—The numbers of individuals evaluated as TS0, TS1, TS2 and TS3 were 119 (38.4%), 100 (32.3%), 62 (20.0%) and 29 (9.3%) respectively in the Lagoon. The mean SCLs of Lagoon green turtles by TS were: TS0 = 50.7 cm, TS1 = 43.3 cm, TS2 = 40.7 cm, TS3 = 41.2 cm. Based on a Kruskal-Walis test followed by Dunn's multiple comparison test, the median SCL of non-diseased (TS0) green turtles was significantly larger than that of diseased turtles (TS1, 2 and 3). The highest FP prevalence was in the 35–39.9 cm size class (Fig. 2). The mean number of tumors increases as the severity of TS increases (Table 1). A regression test showed that there was a significant relationship ($p=0.03687$, $r^2=0.02452$)

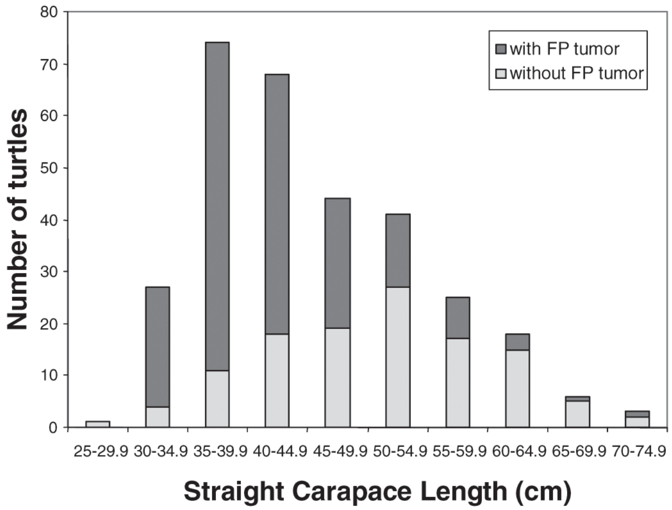

FIG. 2. Number of green turtles that captured in 1998 and 1999 with (TS1, 2, 3) and without (TS0) FP tumors in different size (straight carapace length) classes from the Indian River Lagoon study site, Indian River County, Florida. The percentage of turtles with FP tumors in each size group is presented.

between the overall number of tumors and body weight/(SCL) ^{3}. The prevalence of ocular (on and around eye) tumors was 47.6% (93 of 191) among FP turtles. The average number and size of ocular tumors was 2.6 ± 1.3 (range: 1–6, n=93) and 0.9 ± 0.5 cm (range: 0.1–2.7 cm, n=235). The regression analysis showed that there was no significant correlation ($p=0.28734$, $r^2=0.013465$) between the volume of ocular tumors, ($V_{sphere} = 4/3*pi*radius^3$) per individual and weight/$(SCL)^3$ ratio. The tumors with necrotic tissue (mean length: 4.6±2.0 cm, range: 1.4–10.0 cm, n=28) were significantly bigger ($p<0.0001$) than those without necrotic tissue (mean length: 1.8±1.2 cm, range: 0.2–9.4 cm, n=651) by a Mann Whitney-U test. During the study period, we observed nine cases of FP turtle entanglement in fishing line (5-TS3; 3-TS2; 1-TS1). None of the 119 TS0 turtles showed any involvement with monofilament.

Among 25 green turtles with FP at initial capture, 22 (88%) showed regression of FP clearly by the second capture. Twenty one FP turtles showed a reduction of tumor number by 50%. The FP turtle that had 21 tumors presented complete absence of the disease after 1560 days. Also, 88% of the turtles that showed regression were TS1 at initial capture. None of the turtles that were recaptured had been assigned TS3 at initial capture.

The minimum and maximum of annual FP prevalence were 28% and 72% from 1984 to 2000 in the Lagoon. The mean and standard deviation over that period was 49.2 ± 12.0%. There was no significant increase or decrease in annual FP prevalence from1984 to 2000 by linear regression analysis.

TABLE 1. Mean number of tumors by tumor size class and tumor scores for green turtles with FP in the Indian River Lagoon, Indian River County, Florida. The mean number of tumors among all FP turtles is 23.4 ± 17.8 (n=19) in the Indian River Lagoon.

	FP Severity Score		
Tumor Size Class (cm)	Mildly Afflicted Tumor Score 1	Moderately Afflicted Tumor Score 2	Severely Afflicted Tumor Score 3
Tumor Length (A) ≤1	6.8 ± 8.1	13.9 ± 10.0	11.2 ± 8.4
1 < Tumor Length (B) ≤4	4.8 ± 5.0	19.3 ± 10.2	23.0 ± 13.9
4 < Tumor Length (C) ≤10	0.1 ± 0.4	2.1 ± 1.8	5.9 ± 4.3
10 < Tumor Length (D)	0.0	0.0 ± 0.2	0.6 ± 0.9
Mean Number of Tumors	11.9 ± 11.1 (n=100)	35.3 ± 14.4 (n=62)	40.6 ± 14.0 (n=29)

Spearman rank correlation tests reveal that there is no significant correlation between annual FP prevalence and water temperature (r_s=0.8, p=0.3333), salinity (r_s=−0.4, p=0.7500) and pH (r_s=−0.2, p=0.9167) from 1996 to 1999.

A Wilcoxon rank sum test showed that there was a significant difference (p=0.0218) in mean SCL between FP regressing and non-regressing green turtles in the Lagoon. The turtles with regressing tumors were larger than the turtles with non-regressing tumors.

Nearshore Reef (Ocean) Green Turtles—Thirty-eight of 256 (14.8%) green turtles that were caught over near shore reefs in 1998 and 1999 had FP. The average SCL of the Ocean turtles was 43.9 cm. There was no significant difference in average SCL between non-FP (42.0 cm) and FP (47.6 cm) individuals by a t-test (p=0.0728). The average number and standard deviation of tumors per FP turtle at the Ocean site was 4.7 ± 12.6. There was a significant difference in the number of tumors per individual between FP turtles on the Ocean and the Lagoon (p<0.0001, Mann Whitney-U test). Only two of the Ocean FP turtles (0.8%) were ranked as TS2; all other diseased animals (n=36) were evaluated as TS1. Twelve of 38 (31.6%) diseased individuals exhibited ocular tumors. The mean and standard deviation of ocular tumors per diseased turtle was 0.5 ± 1.1. There was a difference in the frequency of ocular tumors in the Lagoon and Ocean green turtles (χ^2=3.738, p=0.0532). The frequency of ocular tumors was higher in the Lagoon than in the Ocean site.

Trident Submarine Basin (Port) Green Turtles—We captured 82 different green turtles in the Port during this study period. At this study site, no evidence of FP has been observed. FP prevalence has remained at 0% since the study of the aggregation began at this site in 1993. Port green turtles were significantly smaller (younger) than turtles from the Lagoon and Ocean sites (Redfoot 1997).

DISCUSSION—In the Lagoon, diseased turtles (TS1-3) were found to be significantly smaller than non-diseased turtles. In the Lagoon turtles, the prevalence of FP decreases as the size of the animal increases (Fig. 2). A slightly different relationship between size and FP severity has been observed in the past at the Lagoon. The intermediate size green turtles were more frequently and more severely afflicted than small and large size groups (Ehrhart 1991). There is no confirmed explanation for this discrepancy between the Lagoon data in 1991 and 1998–1999. The sample size of diseased turtles in the past study (n=41) was much smaller than that of the present study (n=191), and that may be the reason for the inconsistency. It is also possible that the relationship between size and severity of disease in the Lagoon has changed over seven to eight years.

The relationship between size and FP prevalence seen in Lagoon turtles is essentially opposite to that seen in studies of other green turtle populations. For instance, in Indonesia and Kaneohe Bay, Oahu, Hawaii, the FP prevalences increase as the size of turtles increases, then they gradually decrease. The peaks of the FP prevalences in Indonesia and Kaneohe Bay, Hawaii were at curved-carapace-length = 85 cm (Adnyana et al. 1997) and SCL = 60–70 cm (Balazs 1991), respectively. In Pala'au, Molokai, Hawaii, the prevalence of FP increased as the size of turtles increased (Chaloupka and Balazs 2005); the prevalence was highest in the largest size categories, SCL = 90–100 cm (Balazs 1991). Together with the absence of oropharyngeal tumors, this is another major difference between Florida and Hawaiian green turtles.

In a similar study conducted in Indonesia (Adnyana et al. 1997), the sizes of tumors were not described, so a direct comparison of FP severity with Lagoon turtles is not possible. Nevertheless, the Indonesian study did quantify the number of tumors per diseased turtle and that provides the basis for a subjective comparison. Overall FP prevalence was 21.5% among Indonesian individuals. The mean tumor number in the Indonesian FP green turtles was 5 $\pm$ 4.1 (range 1 to 29; n=949), far fewer than the 23.7 $\pm$ 17.9 (range 1 to 70; n=191) observed in the Lagoon individuals. Only 12.6% (120 of 949) of the Indonesian diseased turtles had more than 10 tumors per individual (Adnyana et al. 1997). In the Lagoon study site, 69.1% (132 of 191) of FP individuals exhibited more than 10 tumors on their bodies.

One probable reason for the lack of recaptures of TS3 turtles longer than 10 months from initial capture is that they constitute a very small proportion (<10%) of the Lagoon aggregation. Another possibility is that survivorship of TS3 individual may be reduced relative to TS1 and 2. A separate hematology study showed that the TS3 Lagoon turtles suffered anemia of chronic disease (Hirama 2001).

It is encouraging that 70.7% of green turtles in the Lagoon were either TS0 or 1 during the two-year duration of this study. A similar pattern was seen in Hawaiian green turtle populations (Work and Balazs 1999) and, although tumor scores were not assigned to turtles in the Indonesian study (Adnyana et al. 1997), a similar trend was clearly discernable in their results.

There was no correlation between the ocular tumor volume and condition factor (body weight/SCL^3) in the Lagoon study site. This result suggests that there is little or no effect of ocular tumors on the general health of Lagoon turtles. This result does not agree with the commonly-held view about the effects of ocular tumors. Other workers have suggested that ocular tumors have a large effect on the overall condition of FP turtles; obstruction of vision is thought to be a threat to wild populations of green turtles by affecting their ability to feed or swim (Jacobson et al. 1989; Balazs 1991; Jacobson et al. 1991). In the Hawaiian Islands (1990–1998), 78% of stranded and necropsied FP turtles had tumors around the eyes (Murakawa et al. 2000). Ten of 14 (71.4%) stranded green turtles with lesions from Oahu, Hawaii, had either complete or partial obstruction of vision due to the presence of ocular tumors (Aguirre et al. 2002). Ocular tumors affected the health of turtles adversely in Indonesian FP turtles (Adnyana et al. 1997). This discrepancy between effects of ocular tumors in Florida and Pacific green turtles is unexplained.

The biggest difference in FP expression between Hawaii and Florida was prevalence of oropharyngeal tumors among FP turtles. In Florida, there were only two records of FP turtles with small oropharyngeal tumors out of thousands of stranded green turtles (Florida Sea Turtle Stranding and Salvage Network data: 1980–2005). None were seen in this study. The fact that Florida FP green turtles lack the oropharyngeal tumors may explain the apparent lower level of concern about the impact of the disease on Florida green turtles as compared to those of the Hawaiian population. Forty percent of live turtles at Kaneohe Bay, Hawaii (1989–1997) and 74% of stranded and necropsied turtles (1990–1998) exhibited oropharyngeal tumors (Balazs et al. 2000; Murakawa et al. 2000). Oropharyngeal tumors in Hawaiian green turtles were invasive and seriously reduced survival and increased susceptibility to stranding (Aguirre et al. 2002). Oropharyngeal tumors are believed to present the greatest threat to the turtle's well-being (G. Balazs, pers. comm.). There is little doubt that FP turtles with oral tumors have a reduced chance to survive in the wild.

In the present study, we found that only large tumors had necrotic tissue. It is possible that these pedunculate growths drag along the bottom of the Lagoon, becoming abraded and more susceptible to infection. Necrotic tissue was also observed on large tumors in the Hawaiian Islands (Aguirre et al. 1998). The degraded water quality in the Lagoon may also be contributing to the infection of FP tumors. In contrast, turtles kept in the hygienic conditions of the Living Seas Aquarium in Orlando, Florida showed improvement of their necrotic tumors after one and a half months in captivity (Ehrhart et al. 1986). In the Indonesian population, 60% of FP turtles had necrotic and ulcerated tumors (Adnyana et al. 1997). In that study, the abrasion was caused by the turtles moving around within an abattoir, while being kept out of water for a period of two to three weeks (Adnyana et al. 1997). Green turtles with FP tumors seem to be susceptible to fishing line entanglement. Fishing line and other gear entanglement also appeared to be more likely in FP afflicted Hawaiian turtles (Balazs 1986). This anthropogenic phenomenon constitutes another way in which FP debilitates and threatens the survival of green turtle populations in the wild.

Statistical analysis showed that there was no significant trend in annual FP prevalence between 1984 and 2000 in the Lagoon study site. The prevalence of FP was not stable in Mosquito Lagoon (about 100 km north of the Lagoon study site) aggregation in four cold stun events. None of the green turtles that were immobilized during severe cold spells of 1977 and 1981 exhibited the disease (Ehrhart 1991). In 1985, however, 29% of 145 green turtles stunned by cold water presented FP, and it declined to 1.6% in 1989 (Witherington and Ehrhart 1989). No consistent trend was observed in the annual FP prevalence between 1989 and 1997 in Kaneohe Bay, Hawaii, where the range was 42 to 65% (Aguirre et al. 1998). There appears to be no strong increase or decrease of FP prevalence in Florida and Hawaii.

No significant association between seasons and TS was found in the present study. Subjectively, however, the prevalence of TS3 decreases in the winter and spring months. Among the three physical data sets (temperature, salinity, and ph), correlation with temperature produced the lowest p-value ($p=0.3333$).

Green turtles at the Ocean site exhibit lower prevalence, severity of FP and mean number of tumors per turtle compared to those of the Lagoon; therefore, the impact of the disease is less severe on the Ocean assemblage. No FP turtles were seen at the Ocean study site over a period of eight years through the summer of 1997. Since 1997 FP prevalence has been quite low in the Ocean population compared to that of the Lagoon population and has remained relatively stable. A similar observation has been made at the Island of Molokai, Hawaii where 0% prevalence of FP was seen between 1982 and 1985 and only one FP turtle was caught in 1985 and 1987 (Balazs 1991). In 1988, the frequency went up to 5%; and then to 10% and 25% in 1989 and 1990 (Balazs 1991). There are several ways to interpret the observed increase in FP prevalence in the reef assemblage. It may be that:

1) Diseased turtles were there prior to 1997 but went undetected because of small sample size. There was a significant difference ($p=0.0121$) in average annual captures between the period prior to 1997 (27, range: 8–51) and after 1997 (102, range 50–202). A binomial test was used to determine the probability of capturing no diseased turtles prior to 1997 with a sample size of 27. The probabilities that FP went undetected were 10.5 and 0.2% if real prevalence was 8 and 21% (the lowest and highest FP prevalence), respectively. Therefore, it is unlikely that FP turtles were there in the Ocean study site between 1989 and 1996.
2) FP turtles that contracted the disease in another area (for instance, Indian River Lagoon) began moving to the Ocean site at a greater rate. If the

diseased turtles captured on the Ocean after 1997 were there as the result of increased emigration from the Lagoon, it seems likely that the overall rate of recapture of Lagoon-tagged turtles on the Ocean would also rise; however, such a trend has not seen in this study site. Since 1989 there have been only two records of green turtles tagged in the Lagoon and recaptured at the Ocean site. Two green turtles tagged on the Ocean were recaptured in the Lagoon. Two other green turtles that were tagged at the Port were recaptured in the Lagoon. It appears that green turtles in the different habitats are mixing to a certain extent. The rate of emigration of Lagoon turtles, however, remains unclear.

3) The trend is real and represents a true expansion of the epizootic to the Ocean population in the late 1990's.

While the high prevalence of FP in the Lagoon and its absence at the Port are clear, the data collected from 1989 to 2000 are not yet sufficient to provide an understanding of the pattern of FP prevalence in the Ocean aggregation. This site requires careful monitoring of FP prevalence in the future to see if it increases, becomes stable or even decreases over the years. Moreover, seasonal variation in FP at the Ocean site remains unclear. All netting effort was expended during the summer months (late May to mid August) at the Ocean study site, because sea state is unacceptably rough and water clarity is very poor in the winter months.

The complete absence of FP at the Port is in stark contrast to the situations in the Lagoon and Ocean aggregations. A similar situation is seen in the Hawaiian Islands, where there are also open-water aggregations that are entirely free of FP. The disease is highly prevalent in the windward Hawaiians but among 500 turtles captured and examined in the Leewards between 1982 and 1987, no evidence of FP was observed (Balazs 1991). On the west coast of the Island of Hawaii at Kiholo Bay, none of 140 turtles examined expressed the disease (Balazs 1991).

At the present time it is not possible to know with certainty what differentiates these habitats. Speculatively, however, it can be pointed out that the Port is situated very close to the mouth of Port Canaveral; the habitat, therefore, is quite oceanic (Fig. 1). Large swells from the Atlantic roll directly into the mouth of the basin so that the flush rate is much greater than that of the Lagoon. Environmental pollutants are a major factor in the quality of aquatic environments and greatly affect sea turtles (Aguirre 1991). Aguirre et al. (1994), however, did not find any evidence of environmental contaminants in 19 juvenile green turtles from Kaneohe Bay, Hawaii. No similar study of environmental contaminants in Lagoon green turtles has been done, but agricultural and residential pollutants enter the Indian River Lagoon with stormwater runoff (Woodward-Clyde Consultants 1994). The entire basin has experienced substantial intensification of land use and human occupation, particularly in the central and south Indian River Lagoon (Sigua et al. 2000). Water management districts, counties and various organizations are involved in restoring the Indian River Lagoon system. It will be interesting to see if FP prevalence decreases as lagoon restoration proceeds.

Just why FP has appeared in low frequency (8–21%) at the Ocean site in recent years but has remained completely absent in the Port aggregation is an interesting epizootiological question. The Trident Basin (Port) is located about 500 m west of the mouth of Port Canaveral. Physical characteristics (water quality, temperature, salinity, etc.) of the Port are very similar to those of the Ocean habitat. One difference between the Port and the Ocean study sites is that the Ocean is located closer to the inlets that connect the Indian River Lagoon system to the open sea. It may be that diseased turtles captured over the Ocean study site actually contracted the disease while they were in the Indian River Lagoon system and moved out to the open sea through an inlet, such as Sebastian Inlet, Fort Pierce Inlet or St. Lucie Inlet. These turtles, once in the open sea, could move north and south along the extensive worm rock system. For example, we recaptured a green turtle originally captured at the St. Lucie Power Plant, about 90 km south of the Ocean study site. The Port study site is located at Port Canaveral, about 80 km north of Sebastian Inlet. Port Canaveral is connected to the Indian River Lagoon system by the Barge Canal, a narrow, man-made waterway that is fitted with a lock that greatly restricts movement between the lagoon and port (Fig. 1). It is doubtful that a significant number of Indian River Lagoon green turtles are able to gain access to Port Canaveral by navigating the Barge Canal lock. Therefore, "as the turtle swims", the Port is far removed from the area we regard as the primary source of FP infection, the Indian River Lagoon. It is entirely possible that a green turtle could move along the coast or traverse the Barge Canal lock and enter the Trident Basin, but in more than 10 years of study and with more that 300 green turtles examined there is no evidence that such movements are common in the prevailing pattern of green turtle life history on the east central Florida coast. There are no records of FP north of 29° North latitude (Ponce de Leon Inlet; Teas 1991; Foley et al. 2005). The distances between the Port and Sebastian Inlet, Fort Pierce Inlet and St. Lucie Inlet are about 70 km, 147 km and 184 km, respectively. The distances between the Ocean site and Sebastian Inlet, Fort Pierce Inlet and St. Lucie Inlet are about 3 km, 80 km and 117 km, respectively.

That the TS1 and TS2 turtles with regressing tumors were significantly larger than turtles with no evidence of regression suggests that, as they grow older, many of them overcome the disease. The tendency for large juvenile Florida green turtles to regress their tumors has been noted previously (Ehrhart et al. 1986). It can be speculated that younger, non-diseased, green turtles enter the lagoon system from the pelagic life stage and develop FP after a short residence in this habitat (Ehrhart et al. 1986). Ehrhart (1991) thought that about half of the juvenile turtles that enter the lagoon contract the disease by the time they reach 7 kg body mass. When we started capturing FP turtles in the Indian River Lagoon in the 1980's, the impact of FP at the population level was not clear. Because such a large proportion of this aggregation of endangered animals is involved, the impact of this disease was thought to hold "disastrous potential" (Ehrhart et al. 1986). It needs to be recognized, however, that "the effect of FP on sea turtle population dynamics is not well understood" (Herbst and Klein 1995) and that "there are no reliable estimates of mortality or depressed reproductive rates attributable to the disease for any sea turtle populations…" (Chaloupka and Balazs 2005). In Florida, for example, green turtle nesting has been increasing significantly over the past 15 years (Florida Index Nesting Beach Survey data). Also, the slope of CPUE rates in the IRL indicates that relative density of the juvenile green turtle population has risen sharply over the past 20 years (Ehrhart and Redfoot this volume).

Certainly, FP has negative but difficult-to-quantify effects on the green turtles in the Indian River Lagoon. However, the high prevalence of tumor regression coupled with the indirectly related indicators of the condition of the Florida population suggest that FP may not be the serious impediment to green turtle recovery once thought. Many aspects of FP disease and its population-wide impact are poorly understood. Further epizootiological research, providing a comparative approach to the discrepancy between Florida and Hawaiian green turtles, should help to clarify our understanding of FP.

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