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Tidal Cycle Effects on the Occurrence of the Florida Manatee (*Trichechus manatus latirostris*) at the Port Everglades Power Plant

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Abstract

The seasonal distribution of the Florida manatee (*Trichechus manatus latirostris*) is influenced predominantly by feeding locations in the summer and proximity to warm-water refuges during colder months. The tidal cycle may further influence distribution through its impact on manatee movement and foraging. Although the importance of tide on distribution and habitat selection has been acknowledged, it has yet to be studied quantitatively with respect to the manatee population in southeast Florida. The purpose of this study was to examine the effect of the tidal cycle on manatee occurrence at the Florida Power & Light (FPL) Port Everglades Power Plant during the winter. Walking surveys were conducted in Port Everglades during manatee season, 15 November through 31 March 2004 to 2009. The number of manatees in four established locations was noted, and the animals were categorized as calf, juvenile, or adult. Water temperature data were also collected at the sample locations. Because many surveys yielded zero manatees observed, data were analyzed using the zero-inflated negative binomial model. Although the results show no correlation between tidal state and total manatee occurrence, they do suggest that the probability of observing a cow/calf pair is greater during high tide when compared to low and mid-tides ($p < 0.05$). Total manatee occurrence and the presence of cow/calf pairs were both significantly correlated with water temperature ($p < 0.05$). These results are in contrast to those from other locations in Florida and are relevant to the optimal timing of manatee surveys to ensure that all animals using a warm-water refuge are observed and included in population estimates.

Key Words: Port Everglades Power Plant, tide, habitat selection, temperature, Florida manatee, *Trichechus manatus latirostris*

Introduction

Distribution

Manatees are found in the tropical and subtropical regions of the Atlantic Ocean. In particular, the West Indian manatee (*Trichechus manatus*) inhabits the rivers, estuaries, and coastal waters of the mid-Atlantic region of the United States, through the Caribbean Sea and Gulf of Mexico, and south into the coastal regions of northeastern and central-eastern South America. It is the only species that ranges into subtropical and temperate regions. The Antillean manatee (*T. M. manatus*) occupies the species' range from southwestern Texas to South America (Reynolds et al., 2008). The Florida manatee (*T. M. latirostris*) is found in the southeastern United States, primarily in the rivers, estuaries, and coastal waters of Florida (Lefebvre et al., 2001; Deutsch et al., 2003; Laist & Reynolds, 2005a, 2005b; Marine Mammal Commission [MMC], 2006; Florida Fish and Wildlife Conservation Commission [FWC], 2007).

The seasonal distribution of manatees is influenced predominantly by feeding locations in the summer and proximity to warm-water refuges in the winter (Deutsch et al., 2003; Gannon et al., 2007). The lower end of the Florida manatee's thermoneutral zone, or the lowest temperature range at which it does not need to use active metabolism to stay warm, is 20 to 23° C (Irvine, 1983; Reep & Bonde, 2006). This temperature limit coincides with manatee movement patterns. When water temperatures drop below 20° C (Hartman, 1979; Irvine, 1983; Deutsch et al., 2003; Laist & Reynolds, 2005b; Haubold et al., 2006; FWC, 2007; Gannon et al., 2007), manatees congregate around natural and artificial warm-water refuges such as warm-water springs, power plant outfalls, and thermal basins (Irvine, 1983; Laist & Reynolds, 2005a, 2005b; Haubold et al., 2006; MMC, 2006; Edwards et al., 2007; FWC, 2007). Migrating to warm-water refuges reduces the energetic costs of thermoregulation during the cold months (Irvine, 1983).

The Florida manatee is further divided into four subpopulations based on non-winter distribution patterns and the tendency of each to reliably return to the same warm-water refuge(s) (U.S. Fish and Wildlife Service [FWS], 2001; Broward County, 2007). There are two subpopulations on each coast of Florida: the upper St. John's River and the Atlantic subpopulations on the east, and the northwest and southwest subpopulations on the west (FWS, 2001; Laist & Reynolds, 2005a; MMC, 2006; Broward County, 2007). The St. John's River and northwest subpopulations rely primarily on warm-water springs during the winter months. The Atlantic and southwest subpopulations rely predominantly on power plant outfalls, combined with the use of thermal basins by the latter (Laist & Reynolds, 2005a, 2005b; MMC, 2006). One of the most important winter aggregation sites for the Atlantic population of manatees is the Florida Power & Light Company (FPL) power plant in Port Everglades (Reynolds & Wilcox, 1994; Laist & Reynolds, 2005a). The power plant discharges heated water along a canal connecting to the Intracoastal Waterway. Broward County (2007) has designated this canal a critical manatee habitat.

Habitat Selection

Many physical factors other than temperature and food availability have been reported to influence manatee habitat selection, including water depth (Hartman, 1979; Lefebvre et al., 2000, 2001; Jiménez, 2005; Olivera-Gómez & Mellink, 2005), salinity (Hartman, 1979; Lefebvre et al., 2000, 2001; Olivera-Gómez & Mellink, 2005; Gannon et al., 2007), currents (Hartman, 1979; Lefebvre et al., 2001; Jiménez, 2005; Gannon et al., 2007), and tides (Hartman, 1979; Zoodsma, 1991; King & Heinen, 2004; Broward County, 2007). Still, many habitat characteristics have yet to be studied quantitatively in respect to manatee distribution and habitat selection (Jiménez, 2005).

Tides influence the movements of manatees (Hartman, 1979) and, therefore, their distribution. During high tide, manatees may have access to channels that are otherwise too shallow to traverse. Zoodsma (1991) found that during both cold and warm months, manatees in southeastern Georgia traveled more frequently during high and mid-tides than during low tide and rested most often during low and mid-tides.

Tides also influence when and where manatees forage (Hartman, 1979; Zoodsma, 1991). High tide allows manatees to feed upon shoreline vegetation that may otherwise be inaccessible (Hartman, 1979; Zoodsma, 1991). Hartman (1979) observed that the times at which manatees in the Intracoastal Waterway of northeastern Florida would feed were determined by high tide. These animals fed primarily on bank grasses, and they depended on high tide in order to approach the shore. This foraging pattern was also reported by Zoodsma (1991), who found that manatees fed most commonly during high tide.

Manatees will forage away from their warm-water refuges during the winter months (Hartman, 1979; Zoodsma, 1991; Deutsch et al., 2003; Laist & Reynolds, 2005b; MMC, 2006; Broward County, 2007). This is particularly true for manatees using power plant outfalls because of the lack of vegetation in the area (Broward County, 2007). For example, the manatees that use the FPL Fort Myers Power Plant forage in grassbeds up to 26 km downstream (Laist & Reynolds, 2005b). Likewise, the majority of the seagrass beds available to manatees at the Port Everglades Power Plant are located in Biscayne Bay and Lake Worth, 26 and 64 km away from the power plant, respectively (Reynolds & Wilcox, 1994; Broward County, 2007). In this case, the tidal cycle could affect movement within the waters of the warm-water refuge as well as when the animals are most likely to leave for their foraging excursions.

Manatee population growth is primarily influenced by adult survival, and especially the survival of reproductive females (Runge et al., 2004; Reep & Bonde, 2006), so the study of factors affecting females with calves is of particular importance to manatee conservation (Gannon et al., 2007). Habitat selection and movement during colder months may differ for female manatees with calves (Reep & Bonde, 2006; Gannon et al., 2007). Younger manatees are not able to increase their metabolic rate at low temperatures as adults do, making them more susceptible to the cold (Worthy, 2001). This may affect which warm-water refuge is used or when the cow/calf pair is able to leave the refuge to forage. Females with calves tend to stay closer to warm-water sites than males or females without calves (Reep & Bonde, 2006). Thus, it seems likely that choosing a winter location in close proximity to seagrass beds would be important; however, this is not the case in Port Everglades where many cow/calf pairs have been sighted over 20 km away from the closest foraging location. Port Everglades has even designated a boat slip within the discharge canal as a manatee nursing area due to its high use by female manatees with calves (Broward County, 2007).

Previous studies of the Atlantic population of manatees wintering at the FPL Port Everglades Power Plant have focused on factors such as air temperature and diurnal movements. More manatees were sighted in the morning compared to later in the day (Walsh, 2010), and also during more severe winters, indicated by heating degree days (Goldman, 2010). The objective of our study was to determine whether cow/calf pair and total manatee occurrence at the FPL Port Everglades Power Plant are affected by tidal state. By quantitatively analyzing the importance of tidal state on manatee occurrence, it may be possible to define an optimum tidal state at which to perform aerial studies to better estimate manatee population size at the Port Everglades Power Plant.

Materials and Methods

Study Area

The study was conducted along the Port Everglades Power Plant effluent canal at four sample locations—(1) the Dry Marina, (2) Administration Building, (3) Eller Drive Overpass, and (4) the effluent canal south of the power plant (Figure 1)—based on the observer's accessibility to the canal. The area is a state-designated manatee sanctuary, and the canal connecting the latter three locations is a state-designated No Entry Zone (Broward County, 2007). The water that is discharged from the power plant is generally 10 to 15° C warmer than the adjacent Intracoastal Waterway, which creates an important habitat for manatees during colder months.

Survey Methods

Surveys were conducted by walking to each of the four designated locations during the manatee season (15 November through 31 March) from 2004 to 2009, three times/wk, on average. During the surveys, the number of manatees in each location was noted and categorized based on size as either calf, juvenile, or adult. Calves were defined as being less than half the length of a closely associated adult (Irvine & Campbell, 1978), while juveniles were defined as individuals of intermediate size not in close proximity to an adult (Bengtson & Magor, 1979). The number of cow/calf pairs was recorded. An average of 20 min was spent at each location to allow time for manatees resting on the bottom to surface. The water temperature was recorded with a non-contact laser thermometer at the four set sample locations along the canal during each survey. The present study was conducted from November 2007 through March 2009. Using a tide table for the Port Everglades Turning Basin, sample times were chosen to correlate with the tidal cycle and were categorized as low, mid-, and high tide (mean tidal range is 0.86 m; Pantano, 2011). Surveys occurred early in the day, and sample times were chosen to ensure a similar number of surveys were conducted during each tidal cycle.

Statistical Analysis

Abundance Data—All data from November 2004 to March 2009 were used to show relative manatee abundance by month and by season. In order to correct for incomplete surveys and an unequal number of surveys (per month and/or season), monthly and seasonal indices were used based on the Total Survey Effort (TSE) or the number of

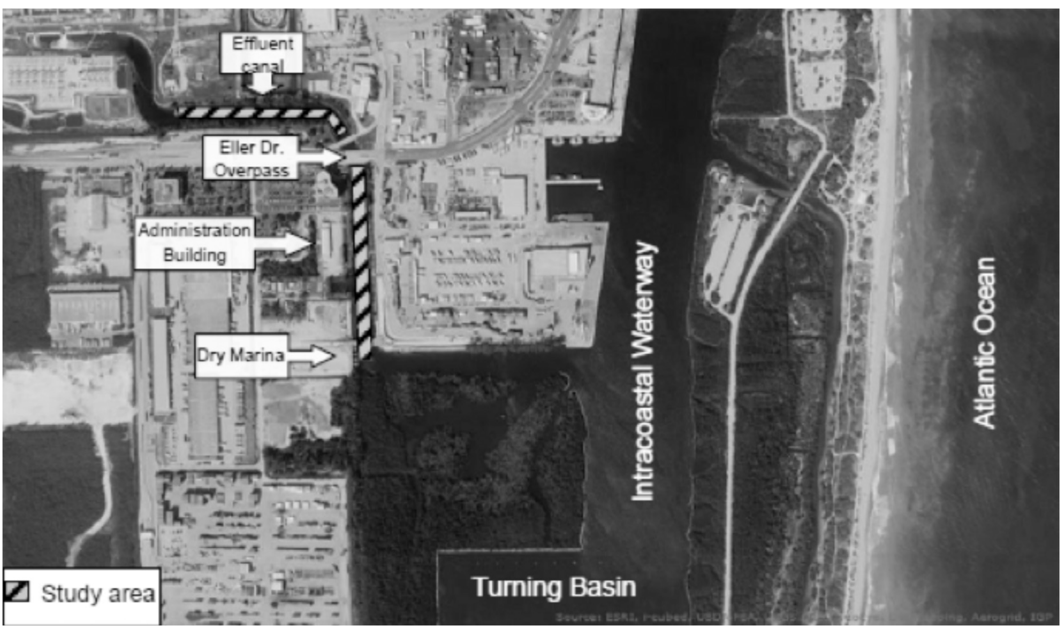

Figure 1. Study area in Port Everglades

surveys completed during a particular time (Nabor & Patton, 1989). The indices standardized the survey effort by distributing the number of sightings over a given time. The total number of manatee sightings in a season was divided by the number of surveys conducted in that season. Likewise, the total number of manatee sightings in a month was divided by the number of surveys conducted in that month. The monthly index was also used to show the relative abundance of adults, juveniles, and calves in each month during each manatee season. The statistical significance of any differences seen in the seasonal index was determined using a likelihood-ratio test. An average water temperature was calculated for each month to show changes in temperature by month and season, which may have affected manatee abundance.

Tide Correlation Analysis—Data from the walking surveys conducted between November 2004 and March 2007 that directly coincided with low, mid-, or high tide were included in the tide correlation analysis. In our study, the number of manatees was a function of tide and water temperature. Because the observed data displayed a higher relative frequency of zeros ("excess zeros") than standard count models, we applied a zero-inflated (ZI) count model (Mullahy, 1986; Lambert, 1992). A ZI count model is appropriate when more zeros are observed than the number found with standard Poisson or other baseline count models (Cameron & Trivedi, 1998). The Poisson distribution also assumes that the mean equals the variance; however, the variance is often larger than the mean (overdispersion; Hoffman, 2004). For testing the hypothesis that a modified count model with overdispersion was the adequate specification for the analysis, two specification tests were implemented to alternative models: (1) a likelihood-ratio (LR) test for the overdispersion parameter, α, in the negative binomial (NB) specification against the Poisson model specification, and (2) the Vuong test of the standard count model against the ZI count model. Vuong test statistics were needed to provide the appropriateness of ZI count models against the standard count models (Greene, 2003).

The zero-inflated negative binomial (ZINB) regression expresses the count outcome y as a function of various explanatory variables, x, including water temperature and tide as the following:

$$\varphi(y_i, \theta | X) = \varphi(y_i, B, \gamma | Z_i),$$

where φ is an NB probability density function; i denotes the index for the tide; and y_i is total number of manatees for specific tide i. The dependent count variable, y_i, follows an NB distribution given an independent variable vector X_i, where θ represents a coefficient vector incorporated with the NB probability density function. Z_i represent the explanatory variable water temperature, and B and γ indicate the corresponding coefficients for Z_i.

Cow/Calf Pairs—The effect of tide and water temperature on the occurrence of female manatees with calves was analyzed for sightings between November 2007 and March 2009. Because of the large number of surveys in which zero cow/calf pairs were recorded, a dichotomous dependent variable was created to represent the presence (= 1) or absence (= 0) of cow/calf pairs. A logistic regression model was produced using water temperature and dummy codes for low, mid-, and high tides.

Results

Relative Manatee Abundance

There was a total of 2,116 manatee sightings, including possible resightings, during 161 surveys conducted between 16 November 2004 and 30 March 2009. Average daily water temperatures ranged from 18.25 to 29.72° C. The average monthly water temperatures for the 2006-2007 manatee season were mild and warm compared to the other seasons, with an average change in temperature of only 0.22° C (Figure 2). Water temperatures during the 2008-2009 manatee season exhibited below average values, with a 0.51° C average change in temperature over the 5 mo. A much greater fluctuation in water temperature was seen in other manatee seasons, resulting in average changes in temperature of 1.43° C in 2004-2005, 1.29° C in 2005-2006, and 1.33° C in 2007-2008.

The total number of manatee sightings per survey effort was the same for the 2004-2005, 2006-2007, and 2007-2008 seasons at nine manatees (Figure 3). There was a small increase to 13 manatees for the 2005-2006 season, but a much greater increase during the 2008-2009 season to 32 manatee sightings per survey effort. The results of the LR test showed the 2008-2009 manatee season to have the only significant difference (LR test = 23.0650, $df = 4$, $p < 0.000$; Table 1). The confidence intervals (CIs) do not overlap for the 2008-2009 manatee season—that is, the upper CI for 2004 through 2008 is less than the lower CI for 2008-2009 (Table 1). This illustrates that the only significant difference was found to be during the 2008-2009 manatee season. The large number of manatee sightings per survey effort in the 2008-2009 season corresponds with the most consistently cold water temperatures of all seasons.

The results did not show a particular month in which the number of manatee sightings per survey effort was greatest for all seasons; however, the

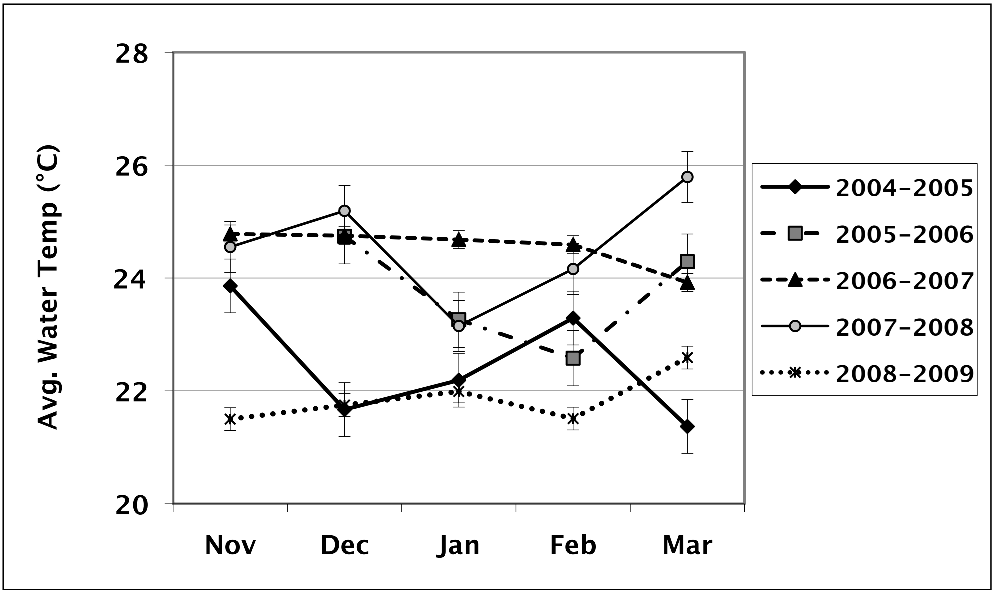

Figure 2. Average monthly water temperatures by manatee season in the FPL Port Everglades Power Plant discharge canal

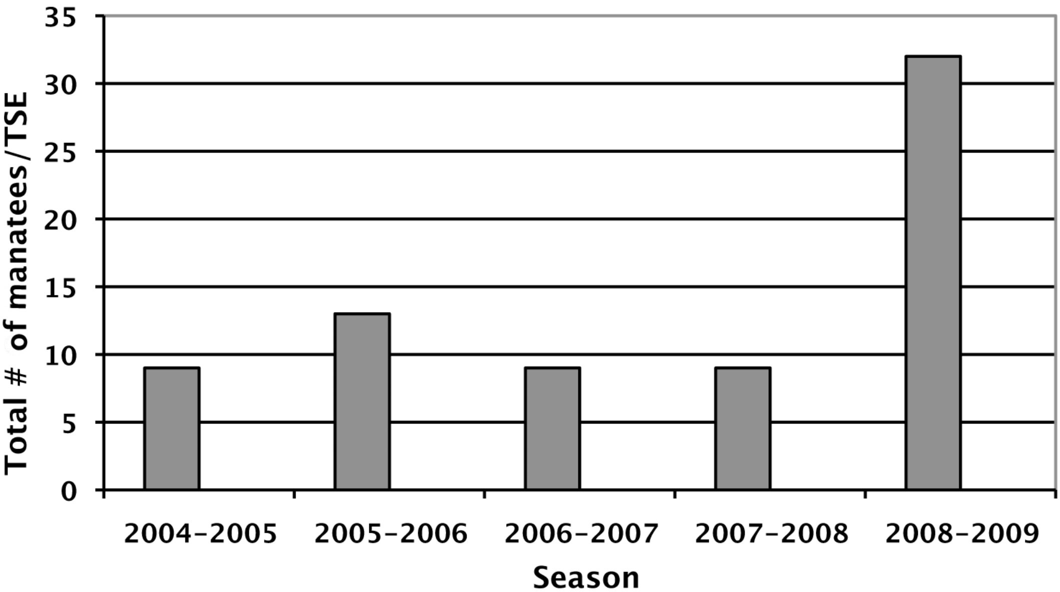

Figure 3. Seasonal index of manatee sightings as total number per survey effort for each manatee season

least number of sightings overall were reported in November and March for all manatee seasons (Figure 4). Except for February and March, there was at least 1 mo for all other manatee seasons in which there were zero sightings per survey. For all seasons, adult manatees were sighted most often (83% of the total count). The number of juveniles and calves varied by month and season but were always less than or equal to the number of adult sightings per survey effort. For the 2004-2005 manatee season, the number of juveniles per survey effort followed the same trend as the number of adults, increasing from December to January and decreasing slightly in February. The number of calves per survey effort remained at one individual during these months and decreased to

Table 1. Frequency table and upper and lower 95% confidence intervals (CI) associated with the seasonal index of manatee sightings, where level is the manatee season, count is the total # of manatees/Total Survey Effort (TSE), and probability is each count divided by the sum of the total

Level	Count	Probability	Lower CI	Upper CI
2004-2005	9	13%	7%	22%
2005-2006	13	18%	11%	28%
2006-2007	9	13%	7%	22%
2007-2008	9	13%	7%	22%
2008-2009	32	44%	34%	56%

zero in March, while the adult and juvenile counts leveled off at one. A similar overall trend was seen in the 2005-2006 manatee season but with a greater number of calves reported than juveniles. The number of juveniles per survey effort remained constant at one individual for December and January, dropping to zero for the remainder of the season. Adults comprised the total number of manatees recorded in March 2006.

The 2006-2007 manatee season was dissimilar to the other four seasons (Figure 4). The number of adults per survey effort decreased from November to December, while the small number of calves remained constant. The number of juveniles increased to one in December from zero in November. The total number of manatees per survey effort decreased from three to zero in January, the month with the highest overall counts in the previous two seasons. All three groups were reported in February, with the adult count reaching 29 individuals, the highest of all previous adult sightings.

There were only adult sightings recorded in November and no manatee sightings per survey effort in December of the 2007-2008 manatee season (Figure 4). The sightings in January were similar to those in January 2005 with adults being the group most represented, followed by juveniles and then calves. The overall counts per survey effort decreased from 14 to five in February, and the adult sightings in March decreased to one, equaling the number of juveniles per survey effort. Calves were only reported in January of this manatee season. The month-to-month fluctuations in number of adult manatee sightings per survey effort for this season seemed to correspond inversely with those seen in the temperature data (Figure 2).

The greatest number of manatee sightings per survey effort was recorded in the 2008-2009 season at 32 manatees (Figure 4). The number of sightings per survey effort in November consisted of only two adults and one juvenile. The overall counts increased in December, with three juveniles and three calves per survey effort. The counts per survey effort of all three groups decreased by one individual in January. As with the 2006-2007 manatee season, the largest number of adult sightings were reported in February rather than in January as seen in the other three seasons. The number of juveniles per survey effort increased by one in February, while the number of calves decreased by the same amount. The sightings per survey effort in March consisted of only two adults. An inverse relationship between number of adult and juvenile manatee sightings and temperature was observed in the month-to-month fluctuations from December to March of this season.

Tide Analysis

Specification Test Results—The specification test results for tide analysis rejected the Poisson specification and rejected the standard count model:

LR test of alpha = 0: $\chi^2(01) = 1{,}259.16$ Pr > = χ^2 = 0.0000

Vuong test of ZINB vs standard NB: z = 0.84 Pr > z = 0.02001

The large χ^2 resulting from the LR test indicated overdispersion, suggesting the use of the NB model. Likewise, the larger statistic for the Vuong test favored the ZI count model over the standard count model. It was concluded that the ZINB model, in which the parent distribution is specified to follow an NB distribution, provided the best fit for the data.

Of the total 161 surveys, 104 were used to analyze the effect of tide and temperature on manatee occurrence. The additional surveys were from previous studies that were not focused on correlating manatee occurrence with tidal state. The total number of manatee sightings for these surveys was 1,508. During 33 of the surveys, zero manatees were seen (i.e., for approximately 32% of the tides, zero manatees were reported).

The effects of low and mid-tides were compared to the effect of high tide on manatee occurrence. The results showed no influence of tide on the number of manatees ($p > 0.05$); however, water temperature had a significant effect ($p < 0.05$). The results suggest that the lower

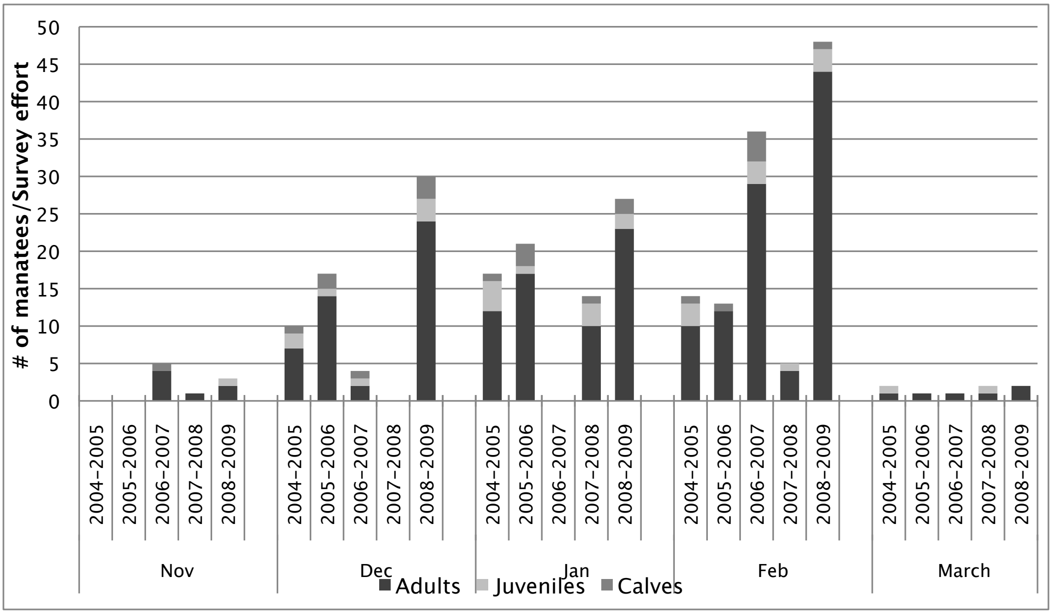

Figure 4. Monthly and seasonal indices of adult, juvenile, and calf manatee sightings as total number per survey effort

the water temperature, the greater the number of manatees—that is, the incidence rate ratio (IRR) is less than one (Table 2; Figure 5). The IRRs in Table 2 represent growth or decline in number of manatees due to a one-unit change in the independent variables, either temperature or tide, holding all else constant (Schweik, 1998).

Cow/Calf Pairs

The number of female manatees with calves ranged from 0 to 14 per survey conducted between November 2007 and March 2009. During 36 of the surveys conducted during this time, zero cow/calf pairs were reported. The probability of observing a cow/calf pair is higher during high tide (57%) when compared to low (27%) and mid-tides (30%) ($p < 0.05$) (Table 3). The odds ratios showed that it is 4.69 (95% CI 1.26 to 27.77) times more likely to have cow/calf pairs in high tide vs low tide, and 6.14 (95% CI 1.18 to 32.05) times more likely to have cow/calf pairs in high tide vs mid-tide. Also, temperature had a significant effect on the number of cow/calf pairs ($p < 0.05$), with the probability of observing a cow/calf pair increasing in warmer water. An increase of 1° C improved the odds of observing a cow/calf pair by 2.08 (95% CI 1.29 to 3.34). Data from the 56 surveys were used to find the probability of observing a cow/calf pair at the recorded water temperatures (Figure 6). Using the secondary y-axis, the probability of observing (= 1) or not observing (= 0) a cow/calf pair can be found for the corresponding water temperatures.

Discussion

Relative Manatee Abundance

Thermal discharges from power plants that were built before the early 1970s allowed the Florida manatee to expand its winter range northward from southern Florida (Laist & Reynolds, 2005b). These industrial warm-water sources have altered seasonal migratory patterns and behavior, and have allowed some manatees to remain in their warm-temperature range for extended periods (Deutsch et al., 2003).

The time at which manatees begin using warm-water aggregation sites, as well as how long they remain nearby, is closely related to winter weather

Table 2. Zero-inflated negative binomial (ZINB) model for the effect of tide and temperature on the number of manatees with high tide as the comparison group

Tide	IRR	Lower 95%	Upper 95%	$p >$ [z]
Temperature	0.78	0.646	0.942	0.010
Low	1.57	0.718	3.457	0.257
Mid	1.27	0.634	2.555	0.496

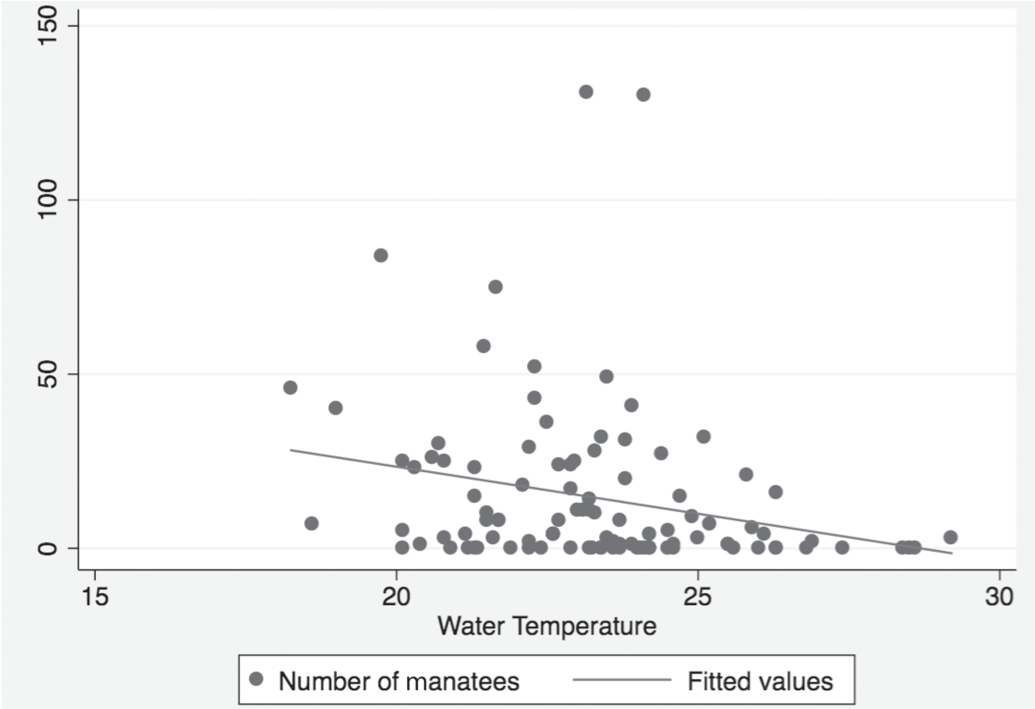

Figure 5. The effect of water temperature on manatee occurrence

Table 3. Probability of observing a cow/calf pair at low, mid-, and high tides

Tide	Probability	Lower 95%	Upper 95%
Low	0.27	0.10	0.50
Mid	0.30	0.12	0.40
High	0.57	0.37	0.77

patterns (Reynolds & Wilcox, 1994; Deutsch et al., 2003). Seasonal manatee migration times and patterns vary depending on the occurrence of cold fronts and the intensity of the cold; however, there is a "typical" pattern in which manatees use the FPL power plants on the east coast (Reynolds & Wilcox, 1994). This generalized pattern consists of manatees migrating south after a drop in air and water temperatures in early winter, with the majority of the animals aggregating at the Port Everglades and Riviera plants by mid-January. The manatees then travel between these two plants and to Hobe Sound and Biscayne Bay to feed during warm periods. The data agree with this pattern for three out of the five manatee seasons which the study covered (i.e., 2004-2005, 2005-2006, and 2007-2008).

For the 2006-2007 and 2008-2009 seasons, however, the number of manatees observed decreased by three animals from December to January. It was in these two manatee seasons that the least temperature fluctuation was experienced, with 2006-2007 being the most consistently warm and mild, and the 2008-2009 season having continuously low temperatures. Results from previous studies have also shown deviations from the typical manatee migration pattern likely related to abnormal winter temperatures. For example, the results from aerial surveys focusing on five FPL power plants between 1982 and 1983 showed very little significance (only 5 of 17 instances) when correlating manatee abundance with air and water temperatures (Reynolds & Wilcox, 1985). This outcome was attributed to a mild winter, with the cold neither intense nor extended enough to cause manatees to form large aggregations. Mild winters also have been associated with low calf numbers at power plants because temperatures are not low enough to urge females with calves to find warm-water refuges (Reynolds & Wilcox, 1994). The results for the 2006-2007 manatee season support these findings, although there was an increase in relative abundance during February. The increase in relative abundance was most likely caused by the only significant drop in temperature during this mild winter.

Weather patterns have been found to affect the migratory timing of manatees in central Florida (Deutsch et al., 2003). This variation in the onset of manatee migrations to their warm-water aggregation sites is apparent in the monthly index. The 2006-2007 and 2007-2008 seasons were the

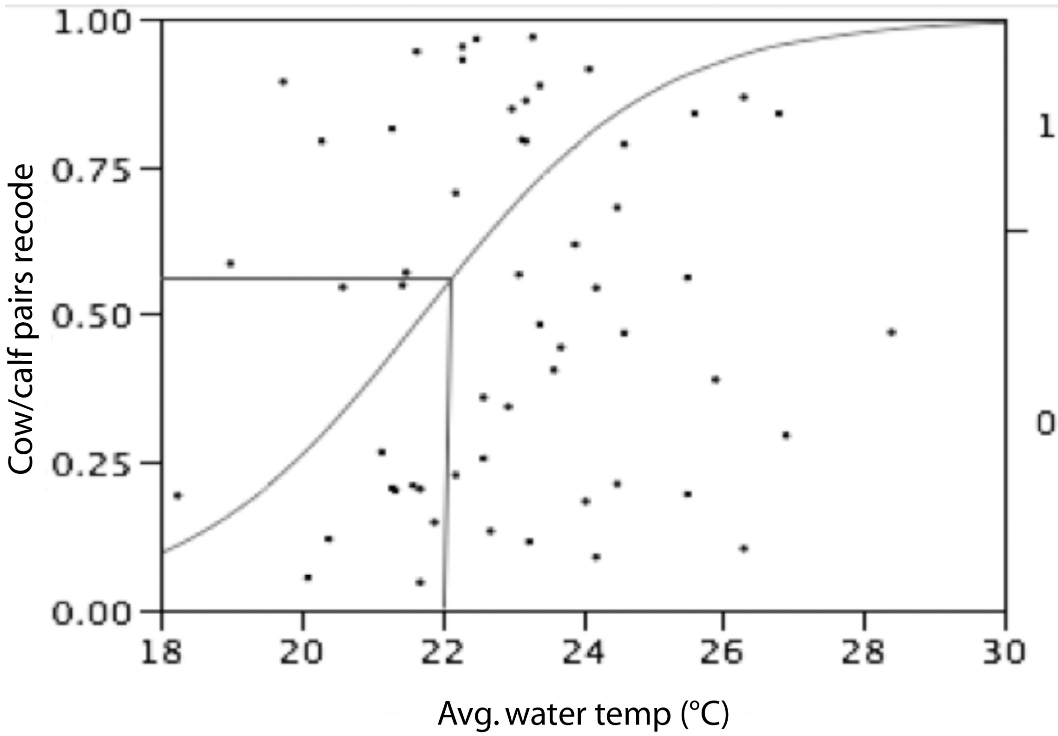

Figure 6. Logistic probability plot showing the probability of observing cow/calf pairs at a particular water temperature, where 0 represents the probability of NOT observing a cow/calf pair and 1 represents the probability of observing a cow/calf pair (*Example shown:* At 22° C, there is a 55% chance of NOT observing a cow/calf pair.)

only manatee seasons in which slightly more manatees were observed in November than in December. For the other three seasons, it is likely that any decrease in temperature during November was tolerable and less severe than that necessary to cause many migrations south.

Deutsch et al. (2003) found that if a cold front occurred toward the end of a mild winter, some of the manatees that had returned from their winter aggregation sites were able to remain in their warm-temperature range. This is likely due to their spring and summer habitat being of such a higher quality than their winter range that it compensated for the energetic costs of migrating long-distance to a heated water source (Deutsch et al., 2003). The only drop in average water temperature greater than 1° C at the end of winter was during the 2004-2005 season. It did not appear that this decrease in temperature caused the manatees to return south because the number of manatees observed in March was comparable across all seasons.

Over all five manatee seasons, the number of calves and juveniles observed remained low compared to the number of adults. The only exceptions were in March 2005 and 2008 in which the number of juveniles observed per survey was equal to the number of adults observed. Calves were not observed during surveys in March of any manatee season. It is possible that juveniles remain at warm-water refuges longer than calves and many adults because they are more susceptible to cold stress (O'Shea et al., 1985). Juveniles may be more prone to cold stress compared to calves because calves have thicker subcutaneous fat layers around the umbilical area, access to energy-rich milk, and the luxury of depending upon their mothers to find them warm-water habitats (Laist & Reynolds, 2005b).

Although the overall number of calves and juveniles observed was low (< 5 recorded per survey effort), it is interesting to note that it varied by season as to which group was observed more. In other words, the number of calves recorded was never higher than the number of juveniles in one month and lower in another month of the same manatee season.

Tidal Cycle Effects

Our results did not indicate that the overall manatee occurrence was affected by the tidal cycles at the Port Everglades Power Plant. Tidal cycle influences the time and location to which manatees are able to travel and forage (e.g., Hartman, 1979; Zoodsma, 1991). This suggests that foraging locations used by manatees wintering in southeast Florida are not restricted during certain tide levels. Manatees are also able to access the heavily used locations within Port Everglades during all tidal stages. Manatees were observed using a shallow lagoon in the northern part of a mangrove forest in the Port but only during high tide. So, with State approval, the area was dredged to provide the necessary depth to be used during all stages of the tidal cycle (Broward County, 2007). Distributional surveys have since recorded manatee use of the lagoon year-round in addition to the heavy winter use, possibly as an important mating location (Broward County, 2007).

Cow/Calf Pairs

It is likely that demography influences manatee habitat selection and distribution. Although the causes are unclear, female manatees with dependent calves have different criteria for selecting habitats than other demographic groups (Gannon et al., 2007). The results showed that the number of female manatees observed with calves increased during high tide, although tide was not found to affect the southeastern population of Florida manatees as a whole. This may be related to the cow/calf pairs traveling with the tidal current to conserve energy or possibly making use of the discharge canal's warmer temperatures. While this particular finding has not been reported, previous studies have also found other differences between female manatees with and without calves such as in feeding and migratory times, and migratory patterns (see Rathbun et al., 1990; Zoodsma, 1991; Flamm et al., 2005).

While the total number of manatees was found to increase at colder water temperatures, the probability of observing a cow/calf pair increased in warmer water. This finding may be due to the location of the majority of cow/calf pairs within the effluent canal when colder water temperatures were experienced. It is possible that they moved closer to the power plant where the heated water is discharged and were not observed because the area was inaccessible during walking surveys.

Based on the results of our study and the examples provided, it is evident that all Florida manatee populations, and groups within those populations, do not respond to environmental factors and habitat characteristics in the same way. In order to protect the species, it is important to study the factors that contribute to its recovery and conservation on a quantitative level. Of particular importance is the study of factors affecting female manatees with dependent calves. One of the three criteria outlined by the Florida Manatee Recovery Plan to classify the Florida manatee as threatened rather than endangered is that the average percentage of adult females with dependent calves in winter is at least 40% (FWS, 2001); however, it is difficult to get an accurate determination of manatee abundance due to survey biases (Wright et al., 2002; Jiménez, 2005; Reep & Bonde, 2006). By studying specific environmental and habitat variables that affect manatee distribution, improved research methods for determining manatee abundance may be developed.

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Literature Cited

Bengtson, J. L., & Magor, D. (1979). A survey of manatees in Belize. *Journal of Mammalogy*, *60*(1), 230-232. http://dx.doi.org/10.2307/1379785

Broward County. (2007). *Broward County manatee protection plan*. Plantation, FL: Broward County Environmental Protection Department, Biological Resources Division. Retrieved 11 January 2012 from www.broward.org/Manatees/Documents/broward_mpp_v1.1.pdf.

Cameron, A. C., & Trivedi, P. K. (1998). Regression analysis of count data. *Econometric Society Monograph* (No. 30). Cambridge, UK: Cambridge University Press.

Deutsch, C. J., Reid, J. P., Bonde, R. K., Easton, D. E., Kochman, H. I., & O'Shea, T. J. (2003). Seasonal movements, migratory behavior, and site fidelity of West Indian manatees along the Atlantic coast of the United States. *Wildlife Monographs*, *151*, 1-77.

Edwards, H. H., Pollock, K. H., Ackerman, B. B., Reynolds III, J. E., & Powell, J. A. (2007). Estimation of detection probability in manatee aerial surveys at a winter aggregation site. *Journal of Wildlife Management*, *71*, 2052-2060. http://dx.doi.org/10.2193/2005-645

Flamm, R. O., Weigle, B. L., Wright, I. E., Ross, M., & Aglietti, S. (2005). Estimation of manatee (*Trichechus manatus latirostris*) places and movement corridors using telemetry data. *Ecological Applications*, *15*, 1415-1426. http://dx.doi.org/10.1890/04-1096

Florida Fish and Wildlife Conservation Commission [FWC]. (2007). *Florida manatee management plan*. Tallahassee: FWC.

Gannon, J. G., Scolardi, K. M., & Reynolds III, J. E. (2007). Habitat selection by manatees in Sarasota Bay, Florida. *Marine Mammal Science*, *23*, 133-143. http://dx.doi.org/10.1111/j.1748-7692.2006.00096.x

Goldman, J. M. (2010). *Seasonal aggregations of the Florida manatee* (Trichechus manatus latirostris) *in the Port Everglades and intracoastal regions of Fort Lauderdale, Florida* (Unpublished master's thesis). Nova Southeastern University, Fort Lauderdale, FL.

Greene, W. G. (2003). *Economic analysis* (4th ed.). Upper Saddle River, NJ: Prentice Hall.

Hartman, D. S. (1979). *Ecology and behavior of the manatee (*Trichechus manatus*) in Florida* (Special Publication 5). Pittsburgh, PA: American Society of Mammalogy.

Haubold, E. M., Deutsch, C., & Fonnesbeck, C. (2006). *Final biological status review of the Florida manatee (*Trichechus manatus latirostris*)*. St. Petersburg: Florida Fish and Wildlife Conservation Commission.

Hoffman, J. P. (2004). *Generalized linear models: An applied approach*. Boston: Pearson Publishing.

Irvine, A. B. (1983). Manatee metabolism and its influence on distribution in Florida. *Biological Conservation*, *25*, 315-334. http://dx.doi.org/10.1016/0006-3207(83)90068-X

Irvine, A. B., & Campbell, H. W. (1978). Aerial census of the West Indian manatee, *Trichechus manatus*, in the southeastern United States. *Journal of Mammalogy*, *59*, 613-617. http://dx.doi.org/10.2307/1380237

Jiménez, I. (2005). Development of predictive models to explain the distribution of the West Indian manatee *Trichechus manatus* in tropical watercourses. *Biological Conservation*, *125*, 491-503. http://dx.doi/org/10.1016/j.biocon.2005.04.012

King, J. M., & Heinen, J. T. (2004). An assessment of the behaviors of overwintering manatees as influenced by interactions with tourists at two sites in central Florida. *Biological Conservation*, *117*, 227-234. http://dx.doi/org/10.1016/j.biocon.2003.07.001

Laist, D. W., & Reynolds III, J. E. (2005a). Florida manatees, warm-water refuges, and an uncertain future. *Coastal Management*, *33*, 279-295. http://dx.doi/org/10.1080/08920750590952018

Laist, D. W., & Reynolds III, J. E. (2005b). Influence of power plants and other warm water refuges on Florida manatees. *Marine Mammal Science*, *21*, 739-764. http://dx.doi/org/10.1111/j.1748-7692.2005.tb01263.x

Lambert, D. (1992). Zero-inflated Poisson regression with an application to defects in manufacturing. *Technometrics*, *34*, 1-14. http://dx.doi.org/10.2307/1269547

Lefebvre, L. W., Reid, J. P., Kentworthy, W. J., & Powell, J. A. (2000). Characterizing manatee habitat use and seagrass grazing in Florida and Puerto Rico: Implications for conservation and management. *Pacific Conservation Biology*, *5*, 289-298.

Lefebvre, L. W., Marmontel, M., Reid, J. P., Rathbun, G. B., & Domning, D. P. (2001). Status and biogeography of the West Indian manatee. In C. A. Woods & F. E. Sergile (Eds.), *Biogeography of the West Indies: Patterns and perspectives* (2nd ed., pp. 425-474). Boca Raton, FL: CRC Press. http://dx.doi.org/10.1201/9781420039481.ch22

Marine Mammal Commission (MMC). (2006). *Marine Mammal Commission annual report to Congress 2006*. Washington, DC: MMC.

Mullahy, J. (1986). Specification and testing of some modified count data models. *Journal of Econometrics*, *33*, 341-365. http://dx.doi/org/10.1016/0304-4076(86)90002-3

Nabor, P., & Patton, G. W. (1989). *Aerial studies of the West Indian manatee* (Trichechus manatus) *from Anna Maria Florida to northern Charlotte Harbor including the Myakka River: Recommended habitat protection and manatee management strategies* (Technical Report Number 134). Sarasota, FL: Mote Marine Laboratory.

Olivera-Gómez, L. D., & Mellink, E. (2005). Distribution of the Antillean manatee (*Trichechus manatus manatus*) as a function of habitat characteristics, in Bahía de Chetumal, Mexico. *Biological Conservation*, *121*, 127-133. http://dx.doi/org/10.1016/j.biocon.2004.02.023

O'Shea, T. J., Beck, C. A., Bonde, R. K., Kochman, H. I., & Odell, D. K. (1985). An analysis of manatee mortality patterns in Florida, 1976-81. *Journal of Wildlife Management*, *49*, 1-11. http://dx.doi.org/10.2307/3801830

Pantano, A. A. (2011). *Item 19*. Retrieved 26 August 2011 from http://bcs.dep.state.fl.us/env-prmt/broward/issued/0299432_Port_Everglades_Inlet/002-BE/Application/Attachments.

Rathbun, G. B., Reid, J. P., & Carowan, G. (1990). Distribution and movement patterns of manatees (*Trichechus manatus*) in northwestern peninsular Florida. *Florida Marine Research Publications*, *48*, 33.

Reep, R. L., & Bonde, R. K. (2006). *The Florida manatee: Biology and conservation*. Gainesville: University Press of Florida.

Reynolds III, J. E., & Wilcox, J. R. (1985). Abundance of West Indian manatees (*Trichechus manatus*) around selected Florida power plants following winter cold fronts, 1982-1983. *Bulletin of Marine Science*, *36*, 413-422.

Reynolds III, J. E., & Wilcox, J. R. (1994). Observations of Florida manatees (*Trichechus manatus latirostris*) around selected power plants in winter. *Marine Mammal Science*, *10*, 163-177. http://dx.doi.org/10.1111/j.1748-7692.1994.tb00258.x

Reynolds III, J. E., Powell, J. A., & Taylor, C. R. (2008). Manatees: *Trichechus manatus, T. senegalensis,* and *T. inunguis*. In W. F. Perrin, B. Würsig, & J. G. M. Thewissen (Eds.), *Encyclopedia of marine mammals* (2nd ed., pp. 682-691). San Diego: Academic Press.

Runge, M. C., Langtimm, C. A., & Kendall, W. L. (2004). A stage-based model of manatee population dynamics. *Marine Mammal Science*, *20*, 361-385. http://dx.doi.org/10.1111/j.1748-7692.2004.tb01167.x

Schweik, C. (1998). Social norms and human foraging: An investigation into the spatial distribution of *Shorea robusta* in Nepal. In C. Gibson, M. McKean,

& E. Ostrom (Eds.), *Forest resources and institutions* (Forests, Trees and People Programme, Working Paper No. 3, pp. 87-109). Rome, Italy: Food and Agriculture Organization (FAO).

U.S. Fish and Wildlife Service [FWS]. (2001). *Florida manatee recovery plan (*Trichechus manatus*)* (3rd rev.). Atlanta, GA: FWS.

Walsh, K. (2010). *Diurnal movements of the Florida manatee,* Trichechus manatus latirostris*, in the Port Everglades effluent canal* (Unpublished master's thesis). Nova Southeastern University, Fort Lauderdale, FL.

Worthy, G. (2001). Nutrition and energetics. In L. A. Dierauf & F. M. D. Gulland (Eds.), *CRC handbook of marine mammal medicine* (2nd ed., pp. 791-828). Boca Raton, FL: CRC Press. http://dx.doi.org/10.1201/9781420041637.ch36

Wright, I. E., Reynolds III, J. E., Ackerman, B. B., Ward, L. I., Weigle, B. L., & Szelistowski, W. A. (2002). Trends in manatee (*Trichechus manatus latirostris*) counts and habitat use in Tampa Bay, 1987-1994: Implications for conservation. *Marine Mammal Science*, *18*, 259-274. http://dx.doi.org/10.1111/j.1748-7692.2002.tb01032.x

Zoodsma, B. J. (1991). *Distribution and behavioral ecology of manatees in southeastern Georgia*. Washington, DC: U.S. Department of the Interior, National Park Service.

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