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Distribution and Habitat Use of Antillean Manatees (*Trichechus manatus manatus*) in the Drowned Cayes Area of Belize, Central America

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Abstract

Belize, Central America, has long been recognized as a stronghold for Antillean manatees (*Trichechus manatus manatus*) in the Caribbean (O'Shea & Salisbury, 1991). The Drowned Cayes area, in particular, has been noted as an important habitat (Bengston & Magor, 1979; O'Shea & Salisbury, 1991; Auil, 1998, 2004; Morales-Vela et al., 2000). It is critical to evaluate habitat use and the relative importance of different habitat types within these cayes because this area is increasingly impacted by human activities (Auil, 1998). The two research objectives for this paper are (1) to document manatee distribution within the Drowned Cayes, Swallow Caye, and Gallows Reef, and (2) to examine habitat use patterns in order to identify habitat characteristics influencing the probability of sighting a manatee. Binary logistic regression was used to examine whether the probability of sighting a manatee varied in relation to several habitat variables. The probability of sighting a manatee across all points was 0.31 per scan (n = 795). Habitat category, seagrass category, and habitat category interaction with resting hole were the most important variables explaining the probability of sighting a manatee. The Drowned Cayes area clearly constitutes a manatee habitat area. Seagrass flats and cove habitats with resting holes were especially important habitat characteristics.

Key Words: distribution, habitat use, Antillean manatee, *Trichechus manatus manatus*, Belize

Introduction

The Antillean subspecies of the West Indian manatee (*Trichechus manatus manatus*) is found in 19 countries throughout the Caribbean, Central America, and South America (Lefebvre et al., 2001). It is listed as vulnerable to extinction by the International Union for the Conservation of Nature and Natural Resources (IUCN) (2004) because of its greatly reduced numbers, continued exploitation, and population fragmentation. However, Belize, Central America, has long been recognized as a stronghold for Antillean manatees in the Caribbean (O'Shea & Salisbury, 1991). In the 1960s, Charnock-Wilson (1968, 1970) conducted interviews and personal observations and reported that manatees were abundant in the country. From the late 1970s to the early 2000s, aerial surveys continued to document that Belize has a relatively large number of manatees in comparison to neighboring countries (Bengston & Magor, 1979; O'Shea & Salisbury, 1991; Auil, 1998, 2004; Morales-Vela et al., 2000).

The Drowned Cayes, Swallow Caye, and Gallows Reef, in particular, are recognized as important manatee areas within Belize. Charnock-Wilson (1968) described manatees using drowned cayes or mangrove islands, in a general sense, stating that it was common to spot manatees around drowned cayes, their channels, lagoons, and surrounding seagrass beds. Subsequent aerial surveys have documented high concentrations of manatees in the cayes near Belize City, of which the Drowned Cayes, Swallow Caye, and Gallows Reef are a part (Bengston & Magor, 1979; O'Shea & Salisbury, 1991; Auil, 1998, 2004; Morales-Vela et al., 2000). Boat surveys that have been conducted since 1999 further corroborated that this area is consistently used by manatees (LaCommare et al., 2003).

This important manatee area may become increasingly threatened by tourism and human population growth (Auil, 1998); growth in tourism by cruise ships has been particularly dramatic. Between 1998 and 2006, the number of tourists entering Belize via cruise ships increased from 14,183 visitors per year to 851,436 visitors per year (Belize Tourism Board, 2007). During that same period, there was an 18% increase in the population of Belize City (Brinkhoff, 2005). Due

to the Drowned Cayes' proximity to Belize City, and because these islands lie between the mainland, the reef, and developed cayes, manatees could be particularly prone to threats from these sources. As tourism increases, a corresponding increase in boat traffic as well as land development is expected. Boats pass through the Drowned Cayes when traveling from Belize City to the northern cayes, outer cayes, and the reef, causing a risk of watercraft collisions with manatees. Watercraft collisions are the leading source of human-caused manatee mortality in Belize (Auil & Valentine, 2004). The proximity of these islands to the barrier reef may result in increased land development that could result in the loss of mangrove habitat. In the last five years, new resort development and expansion have occurred. And finally, development in Belize City and along the Belize River is likely to cause increases in run-off, which may decrease the productivity, biomass, and percent bottom cover of seagrass (Hemminga & Duarte, 2000; Duarte, 2002)—a principal food source for manatees (Ledder, 1986; Provancha & Hall, 1991; Mignucci-Giannoni, 1998; Lefebvre et al., 2000; U.S. Fish and Wildlife Service, 2001).

Because the Drowned Cayes area is an important manatee area within the country and because the islands are increasingly affected by human activities, it is critical to improve our understanding of how manatees utilize this area. Evaluating animal habitat use and the relative importance of habitat types informs habitat management and conservation (Garshelis, 2000). The two research objectives for this paper are (1) to document manatee distribution within the Drowned Cayes, Swallow Caye, and Gallows Reef, and (2) to examine habitat use patterns in order to identify habitat characteristics influencing the probability of sighting a manatee.

Materials and Methods

Study Area

The Drowned Cayes and Swallow Caye are mangrove islands along the central coast of Belize, 10 to 15 km east of Belize City and 5 km west of the Belize Barrier Reef (Figure 1). The Drowned Cayes are a string of mostly uninhabited islands that are 14 km long by 4 km at their widest point and are almost entirely comprised of red (*Rhizophora mangle*) and black (*Avicennia germinans*) mangrove stands. There is very little dry land, and the islands are interspersed with broad channels, narrow inlets, shallow lagoons, and protected coves. The entire complex is surrounded by seagrass beds; seagrass also grows in varying densities on the bottoms of the channels, lagoons, and coves. Turtle grass (*Thalassia testudinum*) is the predominant species with shoal (*Halodule wrightii*) and manatee grass (*Syringodium filiforme*) also very common. Water depth is less than 1 m in some places and is never greater than 6 m within the study area; the tidal range is less than 0.3 m. In 2002, the northern portion of the Drowned Cayes and Swallow Caye were designated as the Swallow Caye Wildlife Sanctuary.

The islands are in a marine environment. In open water areas, salinities range from 35 to 40 ppt (mean salinity is 37 ppt), making the environment slightly hypersaline. Within the mangrove island complex, salinities have greater fluctuations as a result of larger run-off, evaporation, and tidal influences. Therefore, within the channels, coves, and lagoons of the mangrove islands, salinities can range from 30 to 42 ppt.

Survey Design

A point sampling survey design was devised for a small boat platform to quantify manatee distribution and habitat use. Fifty-four permanent points were established in all habitat types throughout the study area (Figure 2). Habitat types are defined in Table 1. These points were randomly sampled during January, February, March, June, July, and August from 2001 to 2004. Surveys were also conducted in June, July, and August 2005. Using a mix of experienced observers and volunteers, three to 13 observers searched for manatees at each point for 30 min. These searches are referred to as point scans. As the boat came within 100 m of each point, observers started scanning for manatees in a 360º circle around the boat. The boat was then anchored in position using a pole. For each scan, the number of manatees and habitat characteristics were recorded. The latter consisted of habitat category, presence of a resting hole, presence and type of seagrass, temperature, salinity, and sea state (Table 2).

Data Analysis

Manatee Distribution—Manatee distribution was mapped within the Drowned Cayes area by calculating the probability of sighting a manatee for each point. Since most of the scans had no manatees and because location sample sizes were unequal, presence or absence of manatees was used to calculate the probability of sighting a manatee. Points that were visited less than five times were excluded from this analysis. This map is a snapshot of the overall variation in distribution throughout the study area. To provide the most comprehensive map of distribution, the largest number of points possible was included in the analysis. To do this, 20-min scans were included in the analysis. To create parity between the 20- and 30-min scans, presence or absence of the 30-min scans was determined based on only the first 20 min of the sampling duration. This increased the sample size

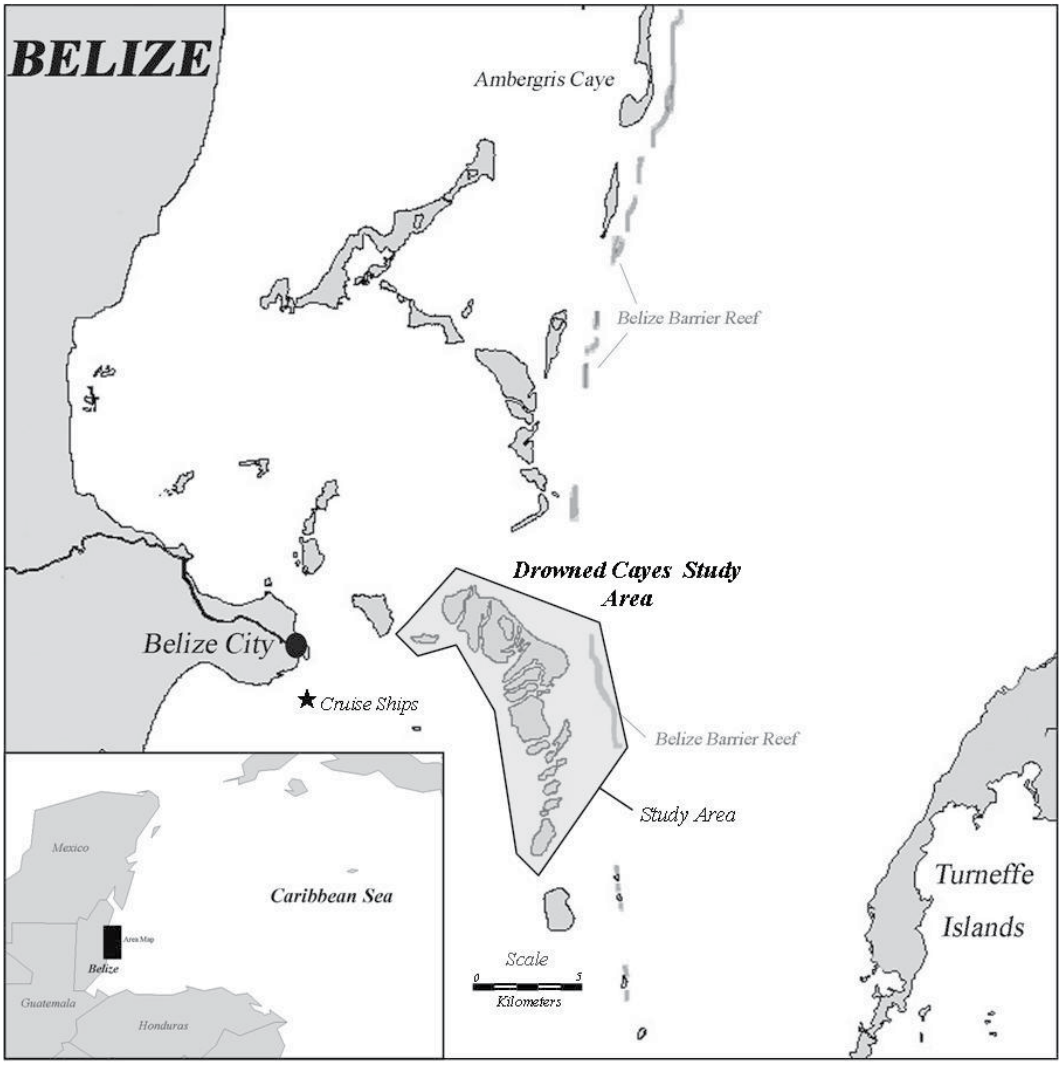

Figure 1. Map of Drowned Cayes and surrounding area (*Source:* British Admiralty Navigation Chart No. 522, Belize City and Approaches, 1989)

from 613 to 795 scans and increased the number of points used in the analysis from 39 to 47.

Habitat Use—Binary logistic regression was used to examine whether the probability of sighting a manatee varied in relation to several habitat variables—habitat category, presence of a resting hole, presence and type of seagrass, temperature, salinity, and sea state. Due to the large number of zeros (268 zero counts of 430 samples) and unequal sample sizes across habitat categories, manatee presence/absence was used rather than the number of individual manatees sighted during each scan to calculate the probability of sighting a manatee. Habitat category was determined by placing each point into one of six categories based on mangrove shoreline features and the depth profile of the particular point. These habitat categories were qualitatively assigned and are mutually exclusive. It is recognized that not all points fit neatly into these designations. A complete description of each category is given in Table 1. A resting hole is a bottom feature that is a distinct, shallow depression in the seafloor. Although they are at least 3 to 4 m wide by 3 to 4 m long, they can be larger and are not necessarily regularly shaped. In some cases, they appear to be natural features that are maintained by manatee use; in other cases, they may have been created by manatee use. Seagrass category connotes whether seagrass was present at a particular point and, if so, what species of seagrass were found there. There were six categories: (1) none, (2) *Thalassia*

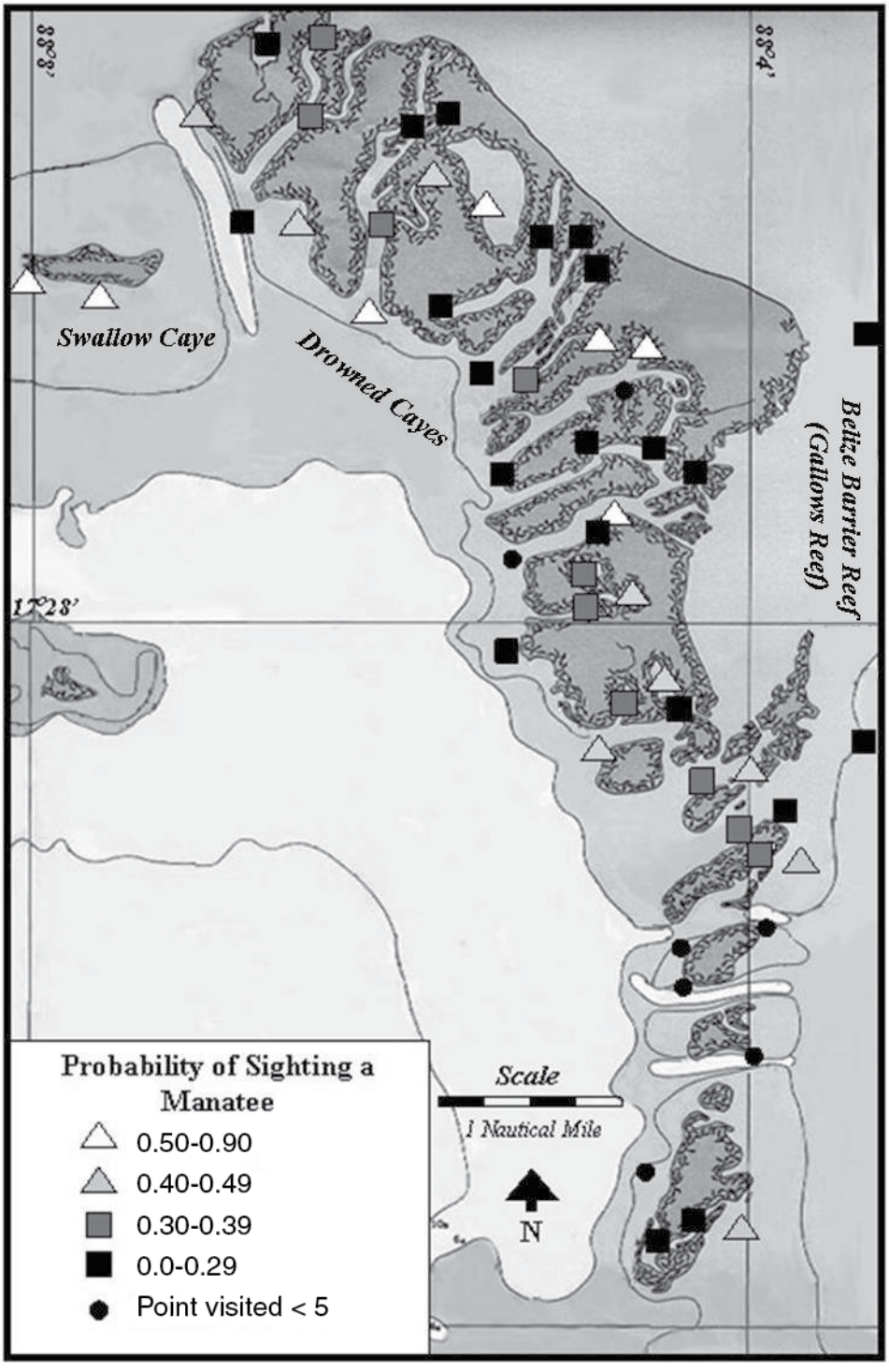

Figure 2. Map of manatee sighting probability throughout the Drowned Cayes study area (n = 795) (*Source:* Defense Mapping Agency Chart, Belize City Harbor, 1996)

Table 1. List and description of habitat categories used in the logistic regression analysis; number of points equals the number of points in each habitat category type. Description is the definition of the habitat category type.

Habitat category	Number of points	Description
Lagoon	5	A large open water area totally encompassed within the mangrove islands; the area has a uniform and shallow depth (< 3 m).
Channel	12	An area of deeper water (3 to 6 m) that cuts between the mangrove islands; generally, there is mangrove shoreline on two sides.
Channel edge	8	An area of deeper water that cuts through areas of shallower water; the point encompasses two habitat types: (1) channel and (2) seagrass bed. Depth ranges from 1 to 5 m. The point may be adjacent to mangrove shoreline on one side or may be in open water.
Seagrass bed	11	An area of shallow water, < 3 m, outside of the mangrove islands with a seagrass bottom.
Cove	16	An area of very protected water that is at the end of a channel or off to the side of a channel; it is nearly enclosed by mangroves and has shoreline on at least three sides. Depth ranges from 0.6 to 4 m.
Reef	2	This is an open water area on the back reef portion of the Belize Barrier Reef; there are no mangrove islands in the vicinity, and depth ranges from 1.5 to 4 m.

Table 2. Description and assessment of the model relating the presence/absence of manatees to habitat variables for the Drowned Cayes study area (n = 491, Nagelkerke R-Square = 0.22); significant variables were habitat category, seagrass category, and habitat category*resting hole interaction term. Backward stepwise procedure and log-likelihood function were used to determine the most parsimonious model. Hosmer and Lemeshow Goodness of Fit $\chi^2 = 3.757$, $p = .878$.

Variables in the model	Change in -2 log likelihood	df	Significance of change
Dependent variable			
Manatee presence/absence			
Independent variables			
Sea state (Beaufort scale)	0.55	3	NS
Surface salinity (ppt)	1.76	1	NS
Water temperature (°C)	0.11	1	NS
Habitat category	14.09	5	0.015*
Resting hole	1.27	1	NS
Seagrass category	23.21	5	0.0001*
Habitat category*resting hole	10.46	3	0.015*
Habitat category*seagrass category	10.84	8	NS

NS = Not significant, * = significant

testudinum only, (3) *Halodule wrightii* only, (4) *T. testudinum*/*H. wrightii* mix, (5) *Syringodium filiforme*/*T. testudinum* mix, and (6) a mix of all three. Sea state was based on the Beaufort scale.

Logistic regression accommodates both continuous and categorical predictor variables (Trexler & Travis, 1993; Floyd, 2001). Maximum likelihood method was used to fit the model to the data, and a backward stepwise procedure was used to determine the most parsimonious model. The likelihood ratio test and the Wald statistic were used to determine the significance of the parameters in explaining the variation in the dependent variable. To determine if the model was an adequate fit to the data and to rule out the undue influence of outliers, the Hosmer-Lemeshow test was used and observed and expected sighting probabilities were compared (Trexler & Travis, 1993). Plots of Cook's distances and Studentized residuals vs predicted probabilities were used to examine the influence of outliers and bias in the data. All statistical analyses were performed using *SPSS*, Version 13.0 (SPSS, 2004).

Results

Distribution Within the Drowned Cayes

Manatees were sighted throughout the study area. The probability of sighting a manatee across all

points was 0.31/20-min scan (n = 795). Sighting probabilities for each location ranged from 0 to 0.86/scan. Swallow Caye had the highest probability of sightings among its points, and the Gallows Reef points had the lowest probability of sightings. There does not appear to be a distinct spatial pattern of variability in sighting probability among the Drowned Cayes points (Figure 2).

Habitat Use

The probability of sighting a manatee was lowest at the reef (0.17/scan) and highest on seagrass flats (0.58/scan) (Figure 3). Habitat category, seagrass category, and habitat category interaction with resting hole were the most important variables explaining the probability of sighting a manatee (Table 2). The change in log likelihood for each of these three terms was 14.09 with p = 0.015, 23.21 with p = 0.0001, and 10.46 with p = 0.015, respectively. Within habitat categories, seagrass flats and coves with resting holes both explained a significant portion of the variation in manatee presence (Wald = 4.14 with p = 0.042 and 4.79 with p = 0.029, respectively) (Figures 3A & B). There was only one scan point categorized as a channel with a resting hole. The low sample size of this category type may explain why channels with resting holes had an opposite trend to other habitat types. Scan points with just *T. testudinum* and *S. filiforme* present or with just *H. wrightii* present had a significantly lower probability of sighting a manatee than other seagrass categories (Wald = 6.50 with p = 0.011 and 6.4 with p = 0.011, respectively) (Figure 4). The Hosmer-Lemeshow chi-square goodness of fit was 1.486 with a p-value of 0.983, indicating that the overall model was a good fit to the data, and the Nagelkerke R-Square was 0.221 (Table 2). The expected sighting probability for each habitat and seagrass category was very similar to the observed sighting probability further indicating that the model was a good fit to the data (Figures 3A & 4). Residual plots of change in deviance vs predicted probabilities indicated that samples with a low predicted probability of a presence were poorly fit by the model. In other words, manatees tended to be observed more often than predicted by the model at places where the probability of sighting a manatee was low.

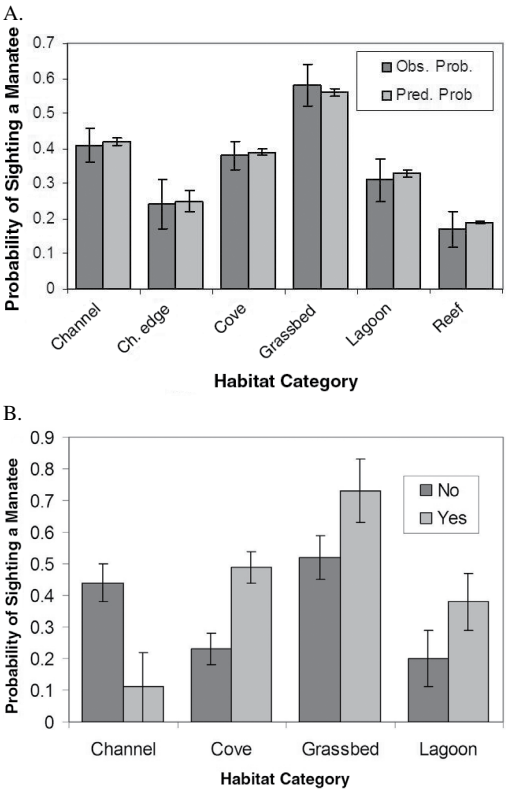

Figure 3. (A) Observed and predicted probability of sighting a manatee per 20-min scan by habitat; (B) Observed probability of sighting a manatee per 20-min scan by habitat with and without the presence of a resting hole; No = no resting hole, Yes = resting hole present (2001 to 2005, n = 491, ± 1 SE).

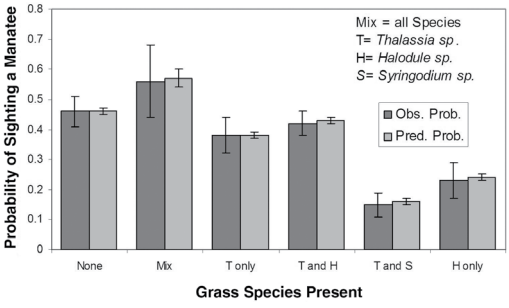

Figure 4. Observed and predicted probability of sighting a manatee per 20-min scan by seagrass category (2001 to 2005, n = 491)

Discussion

The Drowned Cayes area clearly constitutes a manatee habitat area. Manatees were sighted at least once at nearly all of the points that were surveyed (47 out of 54 points). There were some points that had particularly high sighting probabilities (≥ 0.5/20-min scan), and these points might be considered "hot spots" within the overall mangrove island complex. These points should be given particular consideration in management plans in terms of tourist activities, development, and watercraft traffic.

Based on the logistic regression procedure, habitat category was one of the three most important variables explaining variation in sighting probability across the Drowned Cayes. Variability in sighting conditions between habitat types did not result in differences in detection probability. It is unlikely that there were detection biases as a result of habitat types (LaCommare et al., unpub. data). Seagrass beds had the highest probability of sighting a manatee, and reefs had the lowest. Seagrass flats may be a particularly important habitat category, indicating the importance of the Drowned Cayes as a feeding area.

However, manatees did utilize all habitat categories. Manatees use the entire area and many of its components to meet a variety, but probably not all, of their physiological and behavioral requirements. During the course of this study, manatees were observed feeding, socializing, resting, nursing calves, and moving from place to place (Self-Sullivan & LaCommare, unpub. data). Even resources that are used at a low frequency may be important components of the manatees' overall habitat. For instance, the reef may be a seasonally important travel corridor and stopover site for male manatees during the mating season (Self-Sullivan et al., 2004). Behavioral and physiological studies indicate that manatees probably need regular access to freshwater sources to survive (Reynolds & Odell, 1991; Ortiz et al., 1998, 1999; Reynolds, 1999; Deutsch et al., 2000, 2003). Only one source of hyposaline water (refractometer measurements ranged from 10 to 17 ppt) has been conclusively identified (Self-Sullivan & LaCommare, unpub. data) within the Drowned Cayes, which may be used for osmoregulation. Manatees may also be traveling from the Drowned Cayes to freshwater sources several kilometers away as they do in Florida (Deutsch et al., 2003). Management plans should recognize the importance of protecting a variety of habitat types.

Seagrass is clearly an important component of the Drowned Cayes habitat. Seagrass category was an important variable explaining the probability of sighting a manatee. It contributed the largest improvement in model fit, and the parameter was highly significant. Specifically, sites that had a mix of *T. testudinum* and *S. filiforme* or sites with just *H. wrightii* present had a significantly lower probability of sighting a manatee than the other seagrass categories—no seagrass, a mix of all three species, just *T. testudinum*, or a mix of *T. testudinum* and *H. wrightii*.

How this relates to manatee foraging and feeding is not clear. The three most common species in the study area—*T. testudinum*, *H. wrightii*, and *S. filiforme*—are present in the manatee diet in both Florida and Puerto Rico (Packard, 1984; Ledder, 1986; Provancha & Hall, 1991; Mignucci-Giannoni, 1998; Lefebvre et al., 2000; USFWS, 2001). The relative importance of these species in their diet is not fully understood in these places. In Indian River Lagoon, Florida, and in Puerto Rico, "manatees fed most often on the most frequently encountered seagrass" (Lefebvre et al., 2000, p. 295). In Indian River Lagoon, this was *H. wrightii*, and in Puerto Rico, this was *T. testudinum* (Lefebvre et al., 2000). However, in both locations, it is possible that manatees return to specific *H. wrightii* beds to feed on them (Lefebvre et al., 2000). Both *T. testudinum* and *H. wrightii* appear to be important food resources in the Drowned Cayes based on observations of feeding manatees, and certain areas appear to be more heavily foraged than others (LaCommare & Self-Sullivan, unpub. data), perhaps indicating foraging preferences.

While certain types of seagrass sites, as well as species, may be particularly important to manatees in the Drowned Cayes, fully understanding manatee foraging will involve examining the extent of feeding behavior in particular places, specific physical and biological characteristics of important seagrass areas, and the juxtaposition of these areas to other important resources.

Habitat category interacting with resting hole was also an important variable explaining variation in sighting probability. Cove habitats with resting holes were the most significant subcategory. Cove habitats are extremely sheltered places found at the end of narrow channels or off to the side of larger channels. In the Drowned Cayes, resting holes are a feature of the bottom topography and are associated with resting manatees (Self-Sullivan & LaCommare, unpub. data). In Florida, manatees often use secluded places for feeding, resting, mating, and calving (USFWS, 2001). This appears to be true in the Drowned Cayes as well. The presence of a resting hole was a key feature distinguishing which particular cove area was utilized (0.25 to 0.49/scan increase in sighting probability). It is unclear at this point if the resting hole was the reason manatees used the site or if the resting hole depression is a result of repeated manatee use.

While the Nagelkerke R-Square for the regression model was 0.22, indicating that only 22% of the variability in sighting probability was explained by the logistic regression model, the model was a good fit to the data, and the variability explained was the correct variability. The ability to explain variation in sighting probability will provide a better understanding of habitat use. Building a habitat model that includes variables that describe the spatial configuration and characteristics of habitat is an important follow-up to this analysis and

may even provide insight into habitat selection and preferences. Habitat use is dependent on behavior, and suitable habitat must include a variety of patch types or components so that animals can meet their essential behavioral and physiological requirements (Mysterud & Ims, 1998). In addition, habitat use, selection, and preferences are affected by habitat heterogeneity (Johnson, 1980; Li & Reynolds, 1994; Kie et al., 2002). Heterogeneity can be defined in terms of number, proportion, spatial arrangement, shape, and contrast between patches and patch types (Kie et al., 2002). Analyses examining manatee habitat components in these terms and with respect to behavior could be important in understanding manatee habitat use patterns.

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