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# Characterization of Resting Holes and Their Use by the Antillean Manatee (*Trichechus manatus manatus*) in the Drowned Cayes, Belize

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## Abstract

In the Drowned Cayes area of Belize, manatees (*Trichechus manatus manatus*) are commonly observed resting in depressions in the substrate, locally referred to as *manatee resting holes*. To understand why manatees prefer locations with resting holes, the physical and environmental attributes of the depressions were characterized and diurnal and nocturnal use by manatees at four resting hole sites were documented over two summers. Twelve resting hole sites were compared with 20 non-resting hole sites in the Drowned Cayes, using water depth, substrate type, vegetation, water velocity, salinity, and water temperature. Four resting holes were chosen for repeated diurnal and nocturnal observations, during which sea and weather conditions were recorded in addition to the presence/absence of manatees. Resting holes were significantly deeper and had slower surface water velocity than areas without resting holes. A total of 168 point scans were conducted over 55 d, resulting in 39 manatee sightings over two summers. There was a significant difference in the number of sightings between research years and between day and night scans. Given the large number of resting holes in the Drowned Cayes, many of which are in sheltered areas with slow currents, it is possible that manatees select these spots based on the tranquility of the water and environment. The combination of slow currents, protection from waves, low numbers of boats, and nearby seagrass beds would make these ideal resting areas. These findings have implications for the conservation of important manatee habitat.

**Key Words:** Antillean manatee, *Trichechus manatus manatus*, Belize, resting holes, nocturnal, diurnal, conservation, habitat, sightings

## Introduction

The West Indian manatee (*Trichechus manatus*) is one of only four extant species in the Order Sirenia, which is the only group of herbivorous marine mammals. The species is subdivided into Florida (*T. m. latirostris*) and Antillean (*T. m. manatus*) manatees (Domning & Hayek, 1986). The *2007 IUCN Red List* categorized the species as "vulnerable" and both subspecies as "endangered" (Deutsch et al., 2007).

West Indian manatees inhabit rivers, lakes, lagoons, and coastal marine environments from southeastern North America to northeastern South America, including Central America and the Caribbean (Lefebvre et al., 2001; Deutsch et al., 2007). Within Central America, aerial surveys have indicated that the cayes east of Belize City are important manatee habitat (Auil, 2004). Manatees osmoregulate and thermoregulate behaviorally by moving between activity centers (Deutsch et al., 2007). They can survive in marine environments for extended periods of time; however, a dependence on periodic access to fresh water is presumed (Ortiz et al., 1998, 1999; Deutsch et al., 2003). Thus, when found in marine or coastal environments, they tend to be located near freshwater sources (Powell et al., 1981; Powell & Rathbun, 1984; Rathbun et al., 1990; Olivera-Gomez & Mellink, 2005). Proximity to seagrass beds is another important characteristic in determining manatee habitat preference (Hartman, 1979; Powell et al., 1981; Deutsch et al., 2003). In Chetumal Bay, Mexico, manatee movements were most strongly associated with food distribution (Axis-Arroyo et al., 1998), and in Florida, aerial surveys indicated a strong association between location of manatees and distribution of seagrass beds. Work by Kinnaird (1985) and Provancha & Hall (1991), showed manatee density was positively correlated with seagrass abundance

(*Halodule wrightii* and *Syringodium filiforme*) in the northern Banana River, Florida. Some of the most important manatee food items around the cayes of Belize are turtle grass (*Thalassia testudinum*), manatee grass (*S. filiforme*), and shoal grass (*H. wrightii*) (LaCommare et al., 2008). There is also evidence that resting areas for cows and calves, as well as travel corridors between activity centers, may be critical habitats for manatees (Packard & Wetterqvist, 1986; Deutsch et al., 2007). Major threats to survival of the species include habitat degradation and loss, illegal hunting, boat strikes, entanglement in fishing gear, entrapment in water control structures, pollution, disease, and human disturbance (Deutsch et al., 2007).

Conservation of this species is dependent on conservation of habitat that meets the requirements described above. Compared to osmoregulation, thermoregulation, and foraging requirements, little is known about manatee resting behavior and the importance of resting habitat for conservation of the species. Hartman (1979) and Bengtson (1981) described Florida manatees as arrhythmic, spending most of their time feeding, resting, idling, cruising, and socializing with no correlation of activity with time of day. The hypothesis that Florida manatees lack a daily activity pattern is supported by two lines of evidence: (1) similar nocturnal and diurnal behaviors (Hartman, 1971) and (2) lack of a pineal body (Ralph et al., 1985; Wally Welker, pers. comm.). Hartman (1979) also found that Florida manatees devoted considerable time to resting behavior with no strict preference for resting sites, which included limestone shelves, oyster bars, and vegetation. However, more recent studies indicated that manatees have a diurnal or nocturnal preference for resting in different areas of Florida. For example, during winter along the Atlantic coast, manatees rested in canals during the day and foraged at night (Deutsch et al., 2003). In Sarasota, they will bottom-rest in deeper areas during the winter when it is colder, and then will switch to surface resting when temperatures increase (Sheri W. Barton, pers. comm.). Along the Gulf Coast during winter months, manatees use the warm water springs in Crystal River to rest at night and often travel downriver to feed on *Ruppia* during the day (Reep & Bonde, 2006). Similar evidence of resting during certain times has been found for other manatee species. Observations of a solitary Amazonian manatee (*T. inunguis*) suggested an activity pattern with the individual sleeping for the first half of the night (Mukhametov et al., 1992). In areas with high instances of hunting, there is evidence that manatees (including the West African manatee, *T. senegalensis*) may have shifted to greater nocturnal activity and a more diurnal resting pattern (Rathbun et al., 1983; Reynolds et al., 1995; Powell & Kouadio, 2006).

Manatees also appear to follow patterns in both resting times and resting sites. During low tides and the dry season in Venezuela and Costa Rica, they often take refuge in holes or channels in the rivers that range from 6 to 12 m in depth (O'Shea et al., 1988; Smethurst & Nietschmann, 1999). Anecdotal observations suggest that manatees in Nicaragua rest in quiet, sheltered, deep water during most of the day, leaving to feed only during the night, early morning, and late afternoon (Jiménez, 2002). In Belize, resting behavior has been correlated with the presence of a "resting hole" (CSS & K. LaCommare, unpub. data), which has also been identified as a significant factor for predicting the presence of manatees at 54 permanent sampling points in the Drowned Cayes during a daytime study (LaCommare et al., 2008). The objectives of this study were to determine what factors influence the use of previously identified resting holes by manatees and whether manatees use the resting holes more often during the day or at night.

## Materials and Methods

*Study Area*

The study was conducted over the summers of 2005 and 2006 in the Drowned Cayes of Belize (located about 15 km east of Belize City at N 17° 28.0', W 88° 04.5'; Figure 1), which are a labyrinth of mangrove islands approximately 13 km long separated by lagoons, coves, and bogues (channels that separate the mangrove cayes both within and between ranges) (Ford, 1991). The ecosystem is marine with an average salinity of 35 ppt, although a few low salinity sites have been identified (CSS, unpub. data). Extensive seagrass beds surround these islands, making them excellent foraging habitats for manatees.

*Characterization of Resting Holes*

For the purpose of this study, a *resting hole* is defined as an area where manatees have consistently been observed in a resting state of behavior. Twelve resting holes in the Drowned Cayes were chosen as a subset of 54 permanent scan-points where manatees have been studied since 2001 (LaCommare et al., 2008). The holes were characterized by depth using a HondexTM digital depth sounder (Forestry Suppliers), substrate (mud or sand), and vegetation (seagrass, algae, none). Water temperature (using a Taylor® classic instant read pocket digital thermometer), salinity (using a WP-84 conductivity-TDS-temperature meter from TPS Pty), and water velocity (using


**Figure 1.** Map of Belize (inset) and the Drowned Cayes in relation to Belize City

a General Oceanics mechanical flowmeter model 2030R from Forestry Suppliers; speed range 10 cm/s to 7.9 m/s) were measured at three points in the water column—surface, mid-water, and bottom—above each resting hole. Latitude and longitude were recorded above the deepest point of each resting hole with a GPS (Garmin® Global Positioning System 12 Personal Navigator®). For comparison, these variables were measured at 20 non-resting hole scan-points.

*Diurnal and Nocturnal Scans*
Four of the 12 resting holes were selected for systematic diurnal and nocturnal scans during the summers of 2005 and 2006: B1Co, 30 CCo, 31 CLa, and 50 GiCr. Two 30-min scans focused around a fixed survey point were conducted at each site daily, once between 1000 and 1500 h, and again between 1900 and 0000 h (sunset occurred ~1900 h). This survey method is referred to as a point scan (Self-Sullivan et al., 2003; LaCommare et al., 2008). The order in which sites were scanned was randomly chosen by the researcher each day. An 8-m fiberglass boat with an outboard engine was used with observers standing in the boat during the scans. As the scan-point was approached, the boat engine was turned off, a long pole used to pull the boat to the scan-point, and the boat tied to the grounded pole. During each point scan, the research team continuously searched for manatees by performing 180° visual scans from different points on the boat and listening for breaths (for detailed point scan methods, see Bacchus, 2007; Self-Sullivan, 2008). Nocturnal scans were performed in the same manner as diurnal scans, with the addition of spotlights to help sight manatees. Data collected during each point scan included manatee sighting (a sighting was defined as detection of one or more manatees during the 30-min scan), sea and weather conditions, tidal state, sea surface temperature (SST), salinity, and air temperature.

*Data Analyses*
All statistics were run in *SPSS*, Version 13.0, with $\alpha = 0.05$. Summary statistics were run for resting hole characterizations and data collected during the diurnal and nocturnal scans. The variable "depth" was adjusted to account for tides using predictions from a Belize City tide chart and visually verified via water level marks on the mangrove roots during each scan. The variable "water velocity" was calculated from 5-min rotation counts using the formula provided by General Oceanics:

$$\frac{\frac{\text{Counts} \times 26{,}873 \text{ m/min}}{999{,}999} \times 100 \text{ cm/m}}{5 \text{ min} \times 60 \text{ s}} = \text{Velocity}_{\text{water}} (\text{cm/s}) \quad (1)$$

where 26,873 is the rotor constant, and 999,999 is the maximum number of rotations divided by 5 min and multiplied by 60 s to obtain cm/s.

*T*-tests were used to test for differences in depth and water velocity between areas with and areas without resting holes. Water velocity was ranked to adjust for unequal variances to meet assumptions of normality. *T*-tests were also run to analyze SST and salinity between the two years, and between day and night. Log likelihood ratio tests ($G^2$) were run to test for variance in the number of manatee sightings between the two years and between day and night. A step-wise, logistic regression was used to detect any associations between specific habitat factors and manatee sightings. Factors included location, tide, salinity, SST, day/night, and year.

## Results

*Characterization of Resting Holes*
There was a significant difference in water depth between resting holes and scan-points without resting holes ($t_{(15)} = 4.541$, $p < 0.001$) with a mean difference of 1.5 ± 0.32 m. Mean water depth for resting holes was 3.5 ± 0.30 m ($n = 12$; range: 2.0 to 5.2 m) compared with non-resting hole areas with a mean depth of 2.0 ± 0.12 m ($n = 20$; range: 1.4 to 3.3 m) (Table 1).

Mean surface water velocity for resting holes was 0.89 ± 0.51 cm/s ($n = 10$; range: 0 to 5.20 cm/s). Non-resting hole areas had a mean surface water velocity of 4.26 ± 1.14 cm/s ($n = 20$; range: 0.01 to 17.12 cm/s) (Table 1). These represent a significant difference in surface water velocity between resting holes and areas without resting holes ($t_{(28)} = -2.880$, $p = 0.008$). All of the holes characterized had little or no bottom vegetation. The substrate in and around the resting holes tended to be a silty mixture of mud and sand, which was easily compressed and resuspended. Sparse to abundant vegetation was found proximal to resting holes, usually consisting of shoal grass (*Halodule* sp.), macro algae (*Halimeda* and *Penicillus* sp.), and/or turtle grass. One of the resting holes also had a visible "manatee highway" to and from the hole where manatees swim or paddle along the bottom with their forelimbs and/or torso in contact with the seafloor. This deeper, narrow channel started at the entrance of the small cove containing the resting hole near the mangroves and followed a straight path to the deepest part of the resting hole.

*Diurnal and Nocturnal Scans*
A total of 168 scans were conducted at four resting hole sites during the summer of 2005 ($n = 81$) and the summer of 2006 ($n = 87$). Manatees were sighted during 39 scans—26 times in 2005 and 13 times in 2006 (Figure 2)—representing a significant difference in the number of sightings at these four sites between years ($G^2_{(1)} = 7.01$, $p < 0.01$). Table 2 shows that SST and salinity were significantly different for these four points between years (SST: $t_{(158)} = 3.292$, $p = 0.001$; salinity: $t_{(166)} = 20.629$, $p < 0.001$). There was no significant difference in air temperature between years.

**Table 1.** Descriptive statistics of environmental characteristics of areas without and with resting holes; means are reported with ± 1 SE.

| | Non-resting hole sites | | | | Resting hole sites | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | Min | Max | Mean ± SE | N | Min | Max | Mean ± SE | Significance |
| Depth (m) | 20 | 1.4 | 3.3 | 2.0 ± 0.12 | 12 | 2.0 | 5.2 | 3.5 ± 0.30 | <0.001 |
| Sea surface temperature (°C) | 20 | 30.1 | 33.8 | 31.1 ± 0.18 | 12 | 28.7 | 35.6 | 31.4 ± 0.50 | NS |
| Surface salinity (ppt) | 19 | 34.0 | 35.4 | 34.5 ± 0.08 | 12 | 29.7 | 35.5 | 34.3 ± 0.46 | NS |
| Surface water velocity (cm/s) | 20 | 0.01 | 17.1 | 4.2 ± 1.14 | 10 | 0.0 | 5.2 | 0.9 ± 0.51 | 0.008 |
| Depth of middle sample (m) | 11 | 1.0 | 1.7 | 1.2 ± 0.07 | 12 | 1.0 | 2.7 | 1.7 ± 0.15 | NS |
| Middle sample sea temperature (°C) | 11 | 30.2 | 31.7 | 30.9 ± 0.13 | 12 | 28.6 | 32.4 | 30.7 ± 0.30 | NS |
| Middle sample salinity (ppt) | 11 | 33.8 | 35.0 | 34.4 ± 0.10 | 12 | 33.7 | 35.5 | 34.8 ± 0.18 | NS |
| Middle sample water velocity (cm/s) | 11 | 0.0 | 24.7 | 5.02 ± 2.33 | 9 | 0.0 | 0.6 | 0.3 ± 0.08 | NS |
| Depth of bottom sample (m) | 20 | 1.3 | 3.4 | 2.0 ± 0.12 | 12 | 1.9 | 5.7 | 3.5 ± 0.32 | NS |
| Bottom sample sea temperature (°C) | 20 | 30.0 | 32.8 | 30.8 ± 0.13 | 12 | 28.6 | 32.4 | 30.5 ± 0.31 | NS |
| Bottom sample salinity (ppt) | 20 | 33.8 | 35.2 | 34.5 ± 0.07 | 12 | 33.8 | 36.4 | 35.0 ± 0.24 | NS |
| Bottom water velocity (cm/s) | 20 | 0.01 | 10.5 | 2.0 ± 0.71 | 10 | 0.0 | 1.2 | 0.3 ± 0.12 | NS |

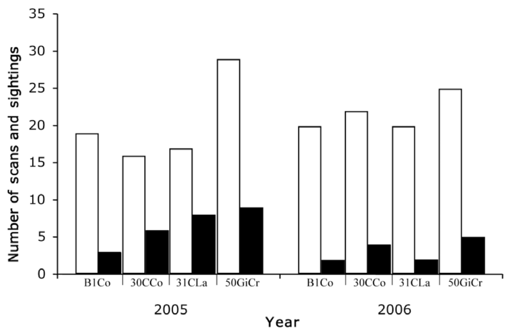


**Figure 2.** Total number of scans (white bars) and sightings (black bars) per year for each location

There were 107 day scans and 61 night scans over both summers, with 34 day sightings and 5 night sightings (Figure 3), resulting in a significant difference in the number of manatee sightings between day and night ($G^2_{(1)} = 13.68$, $p < 0.001$). Table 3 shows that both sea surface and air temperatures were significantly different between day and night, although surface salinity was not significantly different between day and night.

A forward, step-wise logistic regression was conducted to determine which independent variables (location, tide, salinity, SST, day/night, and year) were predictors of manatee presence. The overall model indicated that two variables (day/night and year) were statistically reliable in predicting the presence/absence of manatees (-2 Log Likelihood = 162.326; $\chi^2_{(1)} = 19.206$, $p < 0.001$). The model correctly classified 76% of the cases, although it did this by predicting all cases as "absence." Wald statistics indicated that the variables day/night ($\chi^2_{(1)} = 5.075$, $p = 0.024$) and year ($\chi^2_{(1)} = 5.075$, $p = 0.002$) significantly predicted the presence of manatees. Manatees were more likely to be sighted during the day and in the summer of 2005.

## Discussion

The objectives of this study were to determine what factors influence manatee use of resting holes and whether manatees use the resting holes more often during the day or at night. The results indicate that manatee resting holes are deeper and have slower currents than other sites without resting holes in the Drowned Cayes. Although complicated by the possibility of unequal detection probabilities, manatees likely use resting holes more often during the day than at night.

**Table 2.** Mean ± 1 SE, minimum, and maximum sea surface temperature, salinity, and air temperature per year for all four scan-points

| | 2005 | | | | 2006 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | Min | Max | Mean ± SE | N | Min | Max | Mean ± SE | Significance |
| Sea surface temperature (°C) | 81 | 28.7 | 34.3 | 31.0 ± 0.10 | 86 | 27.2 | 32.9 | 30.5 ± 0.13 | 0.001 |
| Surface salinity (ppt) | 81 | 33.0 | 39.0 | 36.0 ± 0.10 | 87 | 13.0 | 35.0 | 32.0 ± 0.30 | <0.001 |
| Air temperature (°C) | 81 | 27.0 | 32.9 | 31.1 ± 0.14 | 87 | 26.6 | 33.4 | 30.4 ± 0.16 | NS |

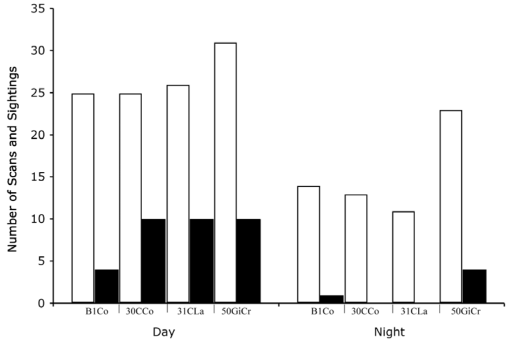


**Figure 3.** The number of scans (white bars) and sightings (black bars) during diurnal (left) and nocturnal (right) scans for each location

*Characterization of Resting Holes*

Sites with resting holes were located in dead end bogues, lagoons, and coves close to the mangroves with little current and calm sea state. Water depth was greater and surface velocity was lower at resting holes than at scan-points without resting holes. However, comparison of water velocity between resting holes could not be made because measurements within resting holes were all less than 10 cm/s, which was the lower threshold for the flowmeter. Slow current and calm waters may enable manatees to rest without exerting energy to hold their position. These results support previous studies that reported manatees are found in areas sheltered from high currents, surf, and wind (Hartman, 1979; Powell et al., 1981; Lefebvre et al., 2001; Jiménez, 2005; Olivera-Gomez & Mellink, 2005).

Although there was no seagrass growing in the resting holes themselves, many seagrass beds were nearby. This would facilitate a short distance of travel for manatees between resting sites and feeding sites in calm waters. Given their large body mass and dependence on a low-energy, low-protein diet, manatees must spend a large proportion of their time feeding to meet metabolic requirements. Manatees tend to feed from 5 to 8 h/d, consuming about 7% of their body weight in wet vegetation (Hartman, 1979; Bengtson, 1983; Etheridge et al., 1985). Manatees may choose foraging strategies that allow them to maximize food intake while minimizing energy output. Similar studies in the Drowned Cayes indicated that sightings of manatees were most probable near resting holes and seagrass beds (LaCommare et al., 2008). The more familiar an animal is with locations of essential resources, the more efficient it will be in energy acquisition since this reduces searching time (Deutsch et al., 2003).

Manatees were frequently encountered at three of the four previously identified resting holes within the Drowned Cayes. All four holes were located in protected coves or lagoons with minimal current, making it likely that manatees choose these areas because of the quiet conditions and create, or at least maintain, resting holes at these sites. Although previously categorized as a resting hole (LaCommare et al., 2008), the scan-point B1Co was likely not being used as a resting site in the summers of 2005 and 2006; it had a uniform 1.5 m depth, with patches of shoal grass and no depression. However, there were many feeding scars and forelimb marks where manatees had dug into the mud to eat seagrass roots and rhizomes. Only one manatee was observed resting at this site in the summer of 2005, and no manatees were observed resting in the cove during the summer of 2006. This may indicate that manatee use of particular resting holes changes over time.

Although manatees frequently used known resting holes, there was no evidence that manatees intentionally excavated or maintained the holes. Our current hypothesis is that they make use of natural depressions at these sites. The substrate in the holes is primarily uncompacted silt with high interstitial space, which is easily stirred-up as manatees rise off the bottom to surface for breaths. By resting regularly in the same place, the presence and vertical movement of a manatee during breathing cycles could easily deepen and maintain the depression.

However, we do not yet know if individual manatees return to preferred holes exclusively or if resting hole use is indiscriminate. Also, it is unknown how manatees learn about the presence

**Table 3.** Descriptive statistics for sea surface temperature, surface salinity, and air temperature during day and night scans of four locations

| | Day | | | | Night | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | Min | Max | Mean ± SE | N | Min | Max | Mean ± SE | Significance |
| Sea surface temperature (°C) | 106 | 27.2 | 34.3 | 30.9 ± 0.12 | 61 | 28.6 | 31.8 | 30.4 ± 0.10 | 0.001 |
| Surface salinity (ppt) | 107 | 13.0 | 39.0 | 34.0 ± 0.30 | 61 | 28.0 | 37.0 | 34.0 ± 0.30 | NS |
| Air temperature (°C) | 107 | 26.6 | 33.4 | 31.5 ± 0.12 | 61 | 27.4 | 32.0 | 29.4 ± 0.08 | <0.001 |

of these specific resting holes. In Florida, individual manatees show strong site fidelity to warm-season and winter ranges where manatee mother-calf pairs have been tracked remotely over time (Deutsch et al., 2003). Use of specific sites, initially with their mothers and then as independent subadults, has demonstrated natal philopatry to specific warm-season and winter ranges as well as to migratory patterns and travel routes among sites. Similarly, Antillean manatees may learn of specific resting holes as dependent calves and return to these same areas as adults.

*Diurnal and Nocturnal Use of Resting Holes*

There was a significant difference in the number of sightings of manatees between day and night. Although spotlights were used to increase the probability of detection during night scans, we acknowledge the increased potential for observer error during nocturnal scans. However, this potential was further reduced by increased vigilance during night scans, both visually and aurally. To increase successful detection and maintain consistency in effort, the same researchers and assistants were used for all night scans during this study.

Despite concerns over detectability, these data suggest that manatees used resting holes more frequently during the day than at night in the Drowned Cayes. These results are consistent with observations in Florida where manatees leave the warm water refuge of Blue Spring in the late winter afternoons to feed all night, returning to the refuge in the morning (Bengtson, 1981; Rathbun et al., 1990). However, the animals abandoned the diurnal resting behavior in Blue Spring when water temperatures warmed in the spring. If use of resting sites is driven more by resources than a daily activity pattern, perhaps manatees use the resting holes in the current study area during the day when human activity on the water is high, then leave at night to feed in nearby seagrass beds or travel to freshwater sites. Interviews with local people indicated a similar pattern in Nicaragua where manatees rest in deep, quiet waters during the day and move to shallow waters to feed during late afternoon, night, and early morning, presumably to avoid hunting predation (Jiménez, 2002).

Another possible reason for different resting hole uses during the day and night is the need for fresh water. Behavioral, ecological, and physiological evidence suggest that manatees require fresh or low salinity water for osmoregulation when living in a marine environment and feeding exclusively on seagrasses (Hartman, 1979; Powell & Rathbun, 1984; Ortiz et al., 1998, 1999). A lack of fresh water for extended periods leads to dehydration, although manatees may be able to osmoregulate via oxidation of fat for short periods of time (Ortiz et al., 1999). In Puerto Rico, where manatees are primarily observed in marine habitats, Powell et al. (1981) noted that 85.8% of manatee sightings were within 5 km of freshwater sources. Those authors also reported anecdotes by local fisherman indicating that manatees often visited nearby rivers to drink water. In aerial surveys in Belize, a higher number of manatees have been observed in near-shore habitat (e.g., estuary, lagoon, and river) than in cay habitat, with one of the highest numbers recorded from the Belize River (Auil, 2004). Also, more manatees were sighted in near-shore habitat during the dry season (November to May), and more manatees were sighted in the cay habitat during the wet season (May/June to November) (Auil, 2004).

Similar to the situation in Ten Thousand Islands, Florida (Butler et al., 2003; J. P. Reid, pers. comm.), manatees in the Drowned Cayes travel to the Belize River, the closest source of substantial fresh water (about 12 to 15 km away) during the dry season (Auil, 2004). Manatees may also be traveling to the Belize River on a shorter time frame. Since boat traffic, both on the river and between the river and the cayes, is much higher during the day, manatees that travel from the Drowned Cayes to the river at night may reduce the probability of being struck by boats. This hypothesis is supported by studies in Florida and Costa Rica, where manatees have been known to avoid areas of high boat traffic, changing their behavioral state and moving out of a geographical area in response to approaching vessels (Buckingham et al., 1999; Smethurst & Nietschmann, 1999; Miksis-Olds, 2006).

There was a significant difference in sightings between the two summers with twice as many manatees seen in the summer of 2005 than in the summer of 2006. The reasons for this are unclear, but longer-term data for all 54 scan-points detected no significant difference in the probability of encountering manatees over the period of 2001 to 2004, even as a result of season (Self-Sullivan, 2008). There was a significant difference in water temperature and salinity for the four scan locations between these two summers, with 2005 being warmer and more saline. However, the difference in temperature (0.5° C), although significantly different between years, is relatively small and probably not significant to manatees given what is known about their range. A similar situation occurred with day and night SST with only a 0.5° C difference. Although manatees can sense water temperature and salinity differences (Deutsch et al., 2003), the differences in the temperature readings in this study seem small enough to insignificantly affect manatee habitat choices. Salinity was 36 ppt in 2005 and 32 in 2006. Although this difference is fairly small, this may indicate a slightly more rainy summer season, which might have some impact on the probability of manatee presence at the four resting holes studied. Even though manatees were not seen as often in the summer of 2006, this does not necessarily mean that they used the Drowned Cayes habitat less frequently but rather that they were not detected as often at the particular resting holes being studied.

West Indian manatee populations must deal with environmental changes on a daily (e.g., tides, currents, weather, human activity levels), seasonal (e.g., rainfall, temperature), and generational basis as human development continues to dramatically alter their habitats throughout the Caribbean (Deutsch et al., 2007). Although little is known about habitat use in the population over long periods of time, changes in habitat use by manatees have been observed at Swallow Caye in the Drowned Cayes of Belize, presumably as a result of increased human disturbance. When tour operators began and then ended a "swim-with" program at Swallow Caye, manatee use of the resting hole decreased during the program but increased again when the program was discontinued (Self-Sullivan, 2008). For generations of manatees, the undeveloped Drowned Cayes have provided a safe haven within a short distance of essential fresh water from the Belize River.

Between 2001 and 2004, there was an exponential increase in cruise ship tourism in Belize. In 2001, there were 48 cruise ships with 48,116 passengers; in 2002, there were 200 ships with 319,690 passengers, representing a 584% growth; in 2003, there were 315 ships with 575,196 passengers, an 80% growth from 2002; and in 2004, there were 406 ships with 851,436 passengers, which is a 49% growth from 2003 (Belize Tourism Board, 2006). Although cruise ship numbers have leveled-off since 2005, the impact of cruise ship tourism remains above the 2003 level with a continued increase in development and human disturbance of manatee habitat in the Drowned Cayes area. Manatee mortality rate near Belize City is relatively high (Auil, 2004). This might be due to the increase in boat traffic as passengers are ferried from the ships by tender boats and are taken on tours to the reef, around the Drowned Cayes, and to small sandy cayes in the area (Self-Sullivan, 2008). Also, there has been an increase in development of some of the other cayes in the Drowned Cayes, causing increases in boat traffic in these areas with the potential to cause siltation that may destroy the seagrass beds that the manatees feed on.

The implications of our findings should be taken into consideration by conservation managers who are concerned with development in the Drowned Cayes. Conservation strategies designed to protect manatees should include preservation of low-energy, secluded areas where manatees can continue to maintain resting holes near seagrass beds. Results of the current study not only increase understanding of manatee resting habitats but provide necessary data for decisionmakers and wildlife managers to establish limits of acceptable change within the Drowned Cayes area and other strategies for the conservation of manatee habitat in Belize.

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## Literature Cited

Auil, N. E. (2004). *Abundance and distribution trends of the West Indian manatee in the coastal zone of Belize: Implications for conservation.* Master's thesis, Texas A&M University, College Station. 83 pp.

Axis-Arroyo, J., Morales-Vela, B., Torruco-Gomez, D., & Vega-Cendejas, M. E. (1998). Variables asociadas con el uso de habitat del manatí del Caribe (*Trichechus manatus*), en Quintana Roo, México (Mammalia). *Revista de Biologia Tropical*, *46*, 791-803.

Bacchus, M-L. C. (2007). *Characterization of resting holes and use by the Antillean manatee (*Trichechus manatus manatus*).* Master's thesis, Loma Linda University, CA. 84 pp.

Belize Tourism Board. (2006). *Cruise arrivals by month.* Retrieved December 2006 from www.belizetourism.org.

Bengtson, J. L. (1981). *Ecology of manatees (*Trichechus manatus*) in the St. Johns River, Florida.* Ph.D. dissertation, University of Minnesota, Minneapolis. 126 pp.

Bengtson, J. L. (1983). Estimating food consumption of free-ranging manatees in Florida. *Journal of Wildlife Management*, *47*, 1186-1192.

Buckingham, C. A., Lefebvre, L. W., Schaefer, J. M., & Kochman, H. I. (1999). Manatee response to boating activity in a thermal refuge. *Wildlife Society Bulletin*, *27*, 514-522.

Butler, S. M., Reid, J. P., & Stith, B. M. (2003). *Detailed movements and habitat use patterns of radio tagged manatees in the western Everglades.* Poster presentation at the 15th Biennial Conference on the Biology of Marine Mammals. Greensboro, NC.

Deutsch, C. J., Self-Sullivan, C., & Mignucci-Giannoni, A. A. (2007). *Trichechus manatus*. In *2007 IUCN red list of threatened species.* Gland, Switzerland: International Union for Conservation of Nature and Natural Resources.

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.

Domning, D. P., & Hayek, L. C. (1986). Interspecific and intraspecific morphological variation in manatees (Sirenia: *Trichechus*). *Marine Mammal Science*, *2*, 87-144.

Etheridge, K., Rathbun, G. B., Powell, J. A., & Kochman, H. I. (1985). Consumption of aquatic plants by the West Indian manatee. *Journal of Aquatic Plant Management*, *23*, 21-25.

Ford, R. E. (1991). Toponymic generics, environment and culture history in pre-independence Belize. *Names*, *39*, 1-25.

Hartman, D. S. (1971). *Behavior and ecology of the Florida manatee,* Trichechus manatus latirostris *(Harlan), at Crystal River, Citrus County.* Ph.D. dissertation, Cornell University, Ithaca, NY. 285 pp.

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

Jiménez, I. (2002). Heavy poaching in prime habitat: The conservation status of the West Indian manatee in Nicaragua. *Oryx*, *36*, 272-278.

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.

Kinnaird, M. F. (1985). Aerial census of manatees in northeastern Florida. *Biological Conservation*, *32*, 59-79.

LaCommare, K. S., Self-Sullivan, C., & Brault, S. (2008). Distribution and habitat use of Antillean manatees (*Trichechus manatus manatus*) in the Drowned Cayes area of Belize, Central America. *Aquatic Mammals*, *34*(1), 35-43.

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. Wood & F. E. Sergile (Eds.), *Biogeography of the West Indies: Patterns and perspectives* (2nd ed.) (pp. 425-474). Boca Raton, FL: CRC Press.

Miksis-Olds, J. L. (2006). *Manatee response to environmental noise.* Ph.D. dissertation, University of Rhode Island, Narragansett. 228 pp.

Mukhametov, L. M., Lyamin, O. I., Chetyrbok, I. S., Vassilyev, A. A., & Diaz, R. P. (1992). Sleep in an Amazonian manatee, *Trichechus inunguis*. *Experientia*, *48*, 417-419.

Olivera-Gomez, L. D., & Mellink, E. (2005). Distribution of the Antillean manatee (*Trichechus manatus manatus*) as a function of habitat characteristics, in Bahia de Chetumal, Mexico. *Biological Conservation*, *121*, 127-133.

Ortiz, R. M., Worthy, G. A. J., & Byers, F. M. (1999). Estimation of water turnover rates of captive West Indian manatees (*Trichechus manatus*) held in fresh and salt water. *Journal of Experimental Biology*, *202*, 33-38.

Ortiz, R. M., Worthy, G. A. J., & MacKenzie, D. S. (1998). Osmoregulation in wild and captive West Indian manatees (*Trichechus manatus*). *Physiological Zoology*, *71*, 449-457.

O'Shea, T. J., Correa-Viana, M., Ludlow, M. E., & Robinson, J. G. (1988). Distribution, status, and traditional significance of the West Indian manatee *Trichechus manatus* in Venezuela. *Biological Conservation*, *46*, 281-301.

Packard, J. M., & Wetterqvist, O. F. (1986). Evaluation of manatee habitat systems on the northwestern Florida coast. *Coastal Zone Management Journal*, *14*, 279-310.

Powell, J. A., & Kouadio, A. (2006). *Trichechus senegalensis.* In *2007 IUCN red list of threatened species.* Gland, Switzerland: International Union for Conservation of Nature and Natural Resources.

Powell, J. A., & Rathbun, G. B. (1984). Distribution and abundance of manatees along the northern coast of the gulf of Mexico. *Northeast Gulf Science*, *7*, 1-28.

Powell, J. A., Belitsky, D. W., & Rathbun, G. B. (1981). Status of the West Indian manatee (*Trichechus manatus*) in Puerto Rico. *Journal of Mammalogy*, *62*, 642-646.

Provancha, J. A., & Hall, C. R. (1991). Observations of associations between seagrass beds and manatees in east central Florida. *Florida Scientist*, *54*, 87-98.

Ralph, C. L., Young, S., Gettinger, R., & O'Shea, T. J. (1985). Does the manatee have a pineal body? *Acta Zoologica*, 66, 55-60.

Rathbun, G. B., Powell, J. A., & Cruz, G. (1983). Status of the West Indian manatee in Honduras. *Biological Conservation*, *26*, 301-308.

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*, 1-33.

Reep, R. L., & Bonde, R. K. (2006). *The Florida manatee: Biology and conservation.* Gainesville: University Press of Florida. 189 pp.

Reynolds, J. E., Szelistowski, W. A., & Leon, M. A. (1995). Status and conservation of manatees *Trichechus manatus*

*manatus* in Costa Rica. *Biological Conservation*, *71*, 193-196.

Self-Sullivan, C. (2008). *Conservation of Antillean manatees in the Drowned Cayes area of Belize.* Ph.D. dissertation, Texas A&M University, College Station. 129 pp.

Self-Sullivan, C., Smith, G. W., Packard, J. M., & LaCommare, K. S. (2003). Seasonal occurrence of male Antillean manatees (*Trichechus manatus manatus*) on the Belize Barrier Reef. *Aquatic Mammals*, *29*(3), 342-354.

Smethurst, D., & Nietschmann, B. (1999). The distribution of manatees (*Trichechus manatus*) in the coastal waterways of Tortuguero, Costa Rica. *Biological Conservation*, *89*, 267-274.