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THE CONSERVATION AND HABITAT ECOLOGY OF ANTILLEAN MANATEES  
(TRICHECHUS MANATUS MANATUS) IN THE DROWNED CAYES AREA,  
BELIZE, CENTRAL AMERICA

A Dissertation Presented

by

KATHERINE S. LACOMMARE

Submitted to the Office of Graduate Studies,  
University of Massachusetts Boston,  
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

June 2011

Environmental Biology Program

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Approved as to style and content by:

---

Solange Brault, Associate Professor  
Chairperson of Committee

---

John P. Ebersole, Associate Professor  
Member

---

Ellen M. Hines, Associate Professor  
San Francisco State University, San Francisco  
Member

---

Robert D. Stevenson, Associate Professor  
Member

---

Tian Q. Yong, Assistant Professor  
Member

---

Richard V. Kesseli, Program Director  
Environmental Biology Program

---

Michael P. Shiaris, Chairperson  
Biology Department

## ABSTRACT

# THE CONSERVATION AND HABITAT ECOLOGY OF ANTILLEAN MANATEES (*TRICHECHUS MANATUS MANATUS*) IN THE DROWNED CAYES AREA, BELIZE, CENTRAL AMERICA

June 2011

Katherine S. LaCommare, B.S., University of Michigan, Ann Arbor  
M.S., Purdue University, West Lafayette  
Ph.D., University of Massachusetts Boston

Directed by Associate Professor Solange Brault

The Drowned Cayes area of Belize, Central America is regionally important for the conservation of Antillean manatees in the Caribbean (Lefebvre et al. 2001; Quintana-Rizzo & Reynolds 2008). These islands are increasingly threatened by human activities such as tourism, development and population growth. The objective of this dissertation is to evaluate manatee habitat use and status in this area. The 5 specific objectives are to examine manatee (1) distribution in the Drowned Cayes, (2) use of seagrass beds and forage selection, (3) resting habitat use and selection (4) response to disturbance, and (5) trends in abundance and to suggest a method for monitoring manatees and other sirenians. The principal findings are that manatees utilize all habitat types within the area

to meet a variety of their physiological and behavioral requirements. Some habitat types like seagrass beds and resting holes are clearly important components to the overall seascape. Manatees selectively forage on *Halodule wrightii*. Resting holes and seagrass beds that are adjacent to each other are a particularly important habitat configuration. Manatee habitat use seems to be resilient to mangrove removal, but foraging resources may not. Number of manatees sighted per scan over the duration of this study does not appear to have changed, but our method would not be able to detect a slight decline in abundance. Our survey protocol – point-based scan sampling from a small boat platform - is a relatively inexpensive, effective and repeatable method for monitoring sirenian population trends. By identifying important habitat types, foraging resources and resting areas, this research provides information that wildlife managers can use to promote watercraft guidelines and guide development decisions.

## DEDICATION

To my family – my daughters, Drew and Olivia and my husband Steve - you are an endless source of support and encouragement.

## ACKNOWLEDGEMENTS

This dissertation was written with substantial emotional, intellectual, logistical and financial support.

First and foremost, I thank Caryn Self-Sullivan. Caryn has been a friend, mentor, and inspiration throughout this entire process. Her unwavering support has been a great source of encouragement. This dissertation would not have been completed without her.

My doctoral committee was invaluable in this intellectual endeavor. Solange Brault spent hours with me on the telephone hashing out hypotheses, analyses and interpretations. She has been a mentor, friend, colleague and source of motivation. Rob Stevenson helped me navigate the establishment of this project in an unfamiliar country and field site. John Ebersole, Ellen Hines and Yong Tian provided valuable comments and perspectives on this manuscript. Other biologists that have helped along the way include: Nicole Adimey, Bob Bonde, Robert Ford, Will Heyman, Chris Marshall, Buddy Powell, and Jim Ried. In particular, many Belizean wildlife managers and scientists have provided invaluable background information and advice over the years: Nicole Auil, Earl Codd, Janet Gibson, Wil Maheia, Natalie Rosado, Greg Smith, Angeline Valentine.

A project of this magnitude requires considerable logistical coordination. Gilroy Robinson, our boat captain and lead field assistant, helped with all aspects of the project from bailing out boats to collecting data. His natural history knowledge of the Drowned Cayes was instrumental in establishing our experimental design. His friendship provided a home away from home.



I am thankful to our other numerous field assistants and boat captains. I am particularly appreciative of Dorian Alvarez, whom I have watched grow from a young boy to a young man. He has been a tireless worker. Like his uncle Gilroy, his willingness to help us with anything and everything has been invaluable. His spirit, laughter and sense of fun enlivened our field camp. I am also grateful to Armando 'Pach', Muñoz, Orlando 'Landy' Requena, Jerry Requena, and Mike--local Belizeans who have captained our boats at some point during the project.

Numerous student interns have helped manage volunteers, data, and equipment. Without their willingness to donate their time and talents, this project would not have been possible. I thank: Marie-Lys Bacchus, Sarah Bevins, Leigh Bird, Brian Casey, Seleem Chan, Emma Cook, Jason Dean, Alison Drelich, Haydée Domínguez, Hannah Goorsky, Hoslo Jiwa, Liz Johnstone, Shauna King, Keren Moaney, Maxine Monsanto, Abner Novelo, Randie Oaks Lyn, Karen Petkau, Amanda Port, Pam Quayle, Carly Quisenberry-Dubay, Ryan Roland, Megan Saunders, Rachel Struch, Tom Strang, Samantha Waltjen, Daniel Westby, and Clifton Williams.

Early on, student colleagues helped me navigate the Drowned Cayes environment and volunteer management - Barbara Bilgre, Kecia Kerr, Heidi Petersen, and Kate Schafer.

Data collection would not have been possible without the hundreds Earthwatch Institute and Oceanic Society volunteers. I am grateful for their time and energy.

Numerous institutions and individuals provided financial and in-kind support to this project. For financial support, I would like to thank - the Earthwatch Institute, New England Aquarium - Conservation Action Fund, the Earthwatch Institute – Young

Scientists Award, American Museum of Natural History - Lerner-Gray Marine Research Fund, University of Massachusetts, Boston - Dissertation Improvement Grant, the Oceanic Society and Virtual Explorers. For in-kind support, I would like to thank the Hugh Parkey Foundation for Marine Awareness & Education, Spanish Bay Conservation & Research Center, Mario Guerrero and Manta Ray Charters. For individual in-kind support, I would like to thank Sidney Turton and Teresa Parkey, the former and current owners of Spanish Lookout Caye from which this research is based. Their personal support of this project includes: hospitality, lodging, food, phone use, boat use, internet use, equipment, space and probably numerous details that I have not articulated, but haven't gone unappreciated. Their generosity has been essential to maintaining this project.

Finally, I would like to thank the Forestry and Fisheries Departments of Belize, the Coastal Zone Management Authority & Institute, and Friends of Swallow Caye for granting us research permits.

## PREFACE

During any journey, the unexpected becomes the most rewarding. In 1998 when I was just learning the environment in Belize, just figuring out how to manage volunteers and just formulating my eventual dissertation project, I met Caryn. While spending hours sitting on the bow of a small boat, in the blazing sun, we had long conversations about the challenges of accomplishing research and conservation in a developing nation. It was immediately obvious that we were kindred spirits. These conversations blossomed into a full blown collaboration, the fruits of which culminated in the founding of a nonprofit organization dedicated to supporting manatee and dugong conservation in developing nations, two PhD dissertations and their forthcoming publications. Caryn's dissertation – Conservation of Manatees in the Drowned Cayes Area of Belize – lays the foundation upon which my dissertation builds. She examined the effectiveness of the Swallow Caye Wildlife Sanctuary (SCWS) and confirmed that its establishment is a “triumph of the commons” and that Belize is working to meet the conservation obligations of international agreements. She established that there is not a seasonal fluctuation in the probability of sighting a manatee in the Drowned Cayes and Swallow Caye, but that during the wet season male manatees use the Belize Barrier Reef as a possible travel corridor. She verified that SCWS protects important habitat and suggested that finer scale habitat studies would be important for developing appropriate management guidelines outside of the sanctuary. She determined that 44% of the manatees carry non-lethal boat scars and that the probability of encountering a scarred animal did not vary

between habitat type and years. She also determined, based on presence/absence data, that there was no change in the probability of sighting a manatee from 2001-2004.

My dissertation builds on Caryn's work. It provides a fine scale analysis of habitat use and investigates manatee and seagrass response to disturbance. It further examines our point-based survey design to determine if there was a change in the number of manatees between 2001 and 2007 and conducts a power analysis to examine the statistical power of the data generated by our survey method. The information presented in this dissertation can be used by wildlife managers to establish appropriate and effective conservation guidelines to protect manatees in the area.

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## CHAPTER 1

### INTRODUCTION

The world's oceans are unquestionably in peril (Carlton 2000; Jackson et al. 2001; Murphy & Duffus 1996; Norse 1995; Norse 2005; Thorne-Miller & Catenata 1999; UNEP 2005; Vitousek et al. 1997) and given the extent that human society depends on marine resources (e.g. Jackson et al. 2001; Thorne-Miller & Catenata 1999; UNEP 2005), there is an urgent need to rise to the challenge of conserving them. However, our insufficient understanding about marine species and processes hampers our ability to adequately address the plethora of threats facing them (Malakoff 2003; Norse 1995; Norse 2005; Thorne-Miller & Catenata 1999; UNEP 2005). Success in marine conservation will undoubtedly be driven by our ability to assess and understand marine ecosystems and direct this knowledge toward creative conservation solutions. Sirenians – four species of herbivorous mammals found in shallow, tropical and subtropical, coastal waters around the world - are one of the many threatened elements of marine ecosystems. The Antillean subspecies of the West Indian manatee (*Trichechus manatus manatus*) which is distributed throughout Central America and northeastern South America is no exception (Lefebvre et al. 2001; Quintana-Rizzo & Reynolds 2008). Within this region, the number of manatees in Belize is large in comparison to neighboring countries and the Drowned Cayes area is an important area within the country (Auil 1998; Auil 2004;

Hunter et al. 2010; Lefebvre et al. 2001; Quintana-Rizzo & Reynolds 2008). Because of this, the population of manatees that use these islands may be particularly important to the overall conservation of the subspecies in the region. Concurrently, these Cayes are faced with a variety of human-derived developmental impacts – boat use, mangrove clearing, dredging and resort building. This creates a pressing need to evaluate the status, habitat use and response to disturbance of these manatees so that wildlife managers can establish appropriate conservation and management guidelines.

The objective of this dissertation is to examine manatee habitat use and evaluate manatee status in the Drowned Cayes area of Belize, Central America. There are 5 specific objectives. Chapter 2 examines manatee distribution in the Drowned Cayes, and quantifies manatee habitat use and identifies important habitat area. Chapter 3 examines manatee use of seagrass beds and seagrass resource selection. It will provide further evidence that *Halodule wrightii* is an important food species. Chapter 4 examines manatee resting behavior and resting habitat selection. It will provide evidence of the importance of manatee resting habitat. Chapter 5 examines manatee and seagrass response to disturbance. Chapter 6 examines trends in manatee abundance in the Drowned Cayes and suggests a method for monitoring manatees and other sirenians. This dissertation contributes to the general body of marine mammal biology and conservation biology by increasing our general knowledge of Antillean manatee ecology – specifically on habitat selection, contributing a survey protocol that can be used around the world to monitor sirenians found in convoluted coastal areas and by providing basic ecological information that can be used by local resource managers to improve the protection of a specific population of Antillean manatees.

## Literature Review

### *Range, distribution and status of the Antillean manatee*

West Indian Manatees (*Trichechus manatus*) are found in shallow coastal waters ranging from Georgia on the southeastern coastal United States, throughout the Caribbean, to northeastern South America (Lefebvre et al. 2001; Quintana-Rizzo & Reynolds 2008; Reynolds & Odell 1991). Individuals found in the Greater Antilles and Central and South America belong to the Antillean subspecies (*T. manatus manatus*) (Lefebvre et al. 2001; Quintana-Rizzo & Reynolds 2008), while those found in Florida belong to the Florida subspecies (*T. manatus latirostris*) (Lefebvre et al. 2001; Quintana-Rizzo & Reynolds 2008). However, this nomenclature may be spurious. Genetic analysis identified three distinct mtDNA lineages in *T. manatus*: Florida and the West Indies, the Gulf of Mexico to the Caribbean Rivers of South America, and the northeastern Atlantic coast of South America (Garcia-Rodriguez et al. 1998; Vianna et al. 2006). And Hunter et al. (2010) found that populations within these lineages are isolated.

Within this range, the current distribution of the Antillean subspecies is smaller and more restricted than in the past (Lefebvre et al. 2001; McKillop 1985; Quintana-Rizzo & Reynolds 2008; Thornback & Jenkins 1982). Historical accounts suggest that large-scale reductions occurred in Central and South America in the 17<sup>th</sup> to 19<sup>th</sup> centuries (Jackson et al. 2001; Lefebvre et al. 2001). In the 1600's, manatees were hunted heavily throughout this area to provision ships and by the late 1800's numbers had notably declined (Lefebvre et al. 2001). A similar pattern of abundance and decline has been noted for the Mexican coast and the Yucatan peninsula (Lefebvre et al. 2001) where manatees were used to provision the ships of privateers in the 17<sup>th</sup> century (O'Donnell

1981). Current populations throughout its range are small, fragmented (Lefebvre et al. 2001; Quintana-Rizzo & Reynolds 2008) and faced with a variety of human-related threats such as poaching, habitat loss, chemical contamination, entanglement in fishing/shrimp nets and watercraft collisions (Quintana-Rizzo & Reynolds 2008; USFWS 2001a).

Both national and international agencies recognize this subspecies as imperiled. It is listed as vulnerable to extinction on the IUCN Red List of Threatened Species (Deutsch et al. 2010), as a species of regional concern under the Protocol for Specially Protected Areas and Wildlife (SPA) (Deutsch et al. 2010; Quintana-Rizzo & Reynolds 2008), and is listed in Appendix I of the Convention on International Trade in Endangered Species (CITES) (Inskipp & Gillet 2005). In addition, it is protected by law through domestic legislation in nearly all of the countries within which it exists (Lefebvre et al. 2001; Quintana-Rizzo & Reynolds 2008).

#### *The Antillean manatee in Belize*

Manatees in Belize are relatively abundant when compared to neighboring countries in Central America (Lefebvre et al. 2001; Quintana-Rizzo & Reynolds 2008). This phenomenon has been recognized for some time. Charnock-Wilson conducted interviews, made personal observations and reported that manatees were abundant in the country in the late 1960's (Charnock-Wilson 1968, 1970). In the late 1970's and in the 1980's, aerial surveys continued to document that Belize has a relatively large number of manatees in comparison to other countries in the region (Bengston & Magor 1979; Morales-Vela et al. 2000; O'Shea & Salisbury 1991). More recent aerial surveys

conducted in the 1990's documented that Belize may have about 1,000 individuals (Auil 1998; Auil 2004). This population combined with manatees in southeastern Mexico may be the largest population of West Indian manatees outside of the United States (Quintana-Rizzo & Reynolds 2008).

In Belize, manatees are legislatively protected as an endangered species under the Belize Wildlife Protection Act (Auil 1998) and CITES (Auil 1998). The subspecies is faced with threats similar to those in other Caribbean countries. Boat strikes are the leading source of human-caused manatee mortality (Auil, 1998). Reports of manatee poaching have been made for decades (Quintana-Rizzo & Reynolds 2008). Several reports of poaching were made in the 1990's in the southern portion of the country (Bonde & Potter 1995, Maheia, personal communication) where the recent establishment of a ranger station seems to have abated the threat. In 2006, it was reported that several manatees were slaughtered by Mexican fishers on the northeastern coast (Sweet 2006 cited in Quintana-Rizzo & Reynolds 2008). And finally, coastal development may result in physical habitat destruction and habitat degradation from pollution (Auil 1998).

Within Belize itself, the Drowned Cayes region has long been noted as an important manatee habitat area. Charnock-Wilson (Charnock-Wilson 1968) described manatees generally using drowned cayes, or mangrove islands. He stated that it was common to spot manatees around drowned cayes, their water courses, 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 are a part (Auil 1998; Bengston & Magor 1979; Morales-Vela et al. 2000; O'Shea & Salisbury 1991). Boat surveys conducted since 1999 corroborate that this area is

consistently used by them (LaCommare et al. 2003; LaCommare et al. 2008; Self-Sullivan 2008). In 2002, the Swallow Caye Wildlife Sanctuary was established with the explicit purpose to protect manatees. The sanctuary boundaries include not only Swallow Caye, but also the northern portion of the Drowned Cayes. Analyses of genetic diversity indicate that the population may be isolated from other populations in the country and region (Hunter et al. 2010).

The Drowned Cayes are threatened by human activities such as tourism, development and population growth. Due to their proximity to Belize City, and because these islands lie between the mainland, the reef and developed cayes, manatees may be particularly prone to threats from these sources. Growth in tourism by cruise ships has been particularly dramatic. The number of tourists entering Belize via cruise ships increased from 14,183 visitors per year in 1998 to a peak of 851,436 visitors in 2005 (BTB 2008). Cruise ship visitation remains high. 597,370 cruise ship passengers visited Belize in 2008 (BTB 2008). As tourism has increased, a corresponding increase in boat traffic has also been expected. Although this hasn't been directly measured, there has been an increase in boat registration over this time period (Quintana-Rizzo & Reynolds 2008). Boats pass through the Drowned Cayes when traveling from Belize City to the northern cayes, outer cayes and the reef - popular tourist destinations. An increase in boat traffic increases the risk of manatee/watercraft collisions which are now the leading source of human-caused manatee mortality in Belize (Quintana-Rizzo & Reynolds 2008) and 44% of the manatees sighted in the Drowned Cayes area exhibit scarring from boats (Self-Sullivan 2008). The proximity of these islands to the barrier reef may also result in increased land development that could result in the loss of mangrove habitat. In the last



five years, 3 mangrove islands have been cleared to accommodate new development. And finally, between 2000 and 2009, there has been an 36% increase in the population of Belize City (Brinkhoff 2010). Development in Belize City and along the Belize River is likely to increase 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 (Alves-Stanley et al. 2010; Bengston 1981; Ledder 1986b; Lefebvre et al. 2000; Mignucci-Giannoni 1998; Provancha & Hall 1991). Development of a proposed cause-way from the mainland to adjacent cayes (Auil, personal comment) could further reduce seagrass through increased shading, sedimentation and physical removal (Duarte 2002; Hemminga & Duarte 2000).

#### *General habitat use theory*

Animal habitat is defined as “the resources and conditions present in an area that produce occupancy, including survival and reproduction, of a given organism (Krausman 1999, p.85).” Habitat use is defined as “the way an animal uses these physical and biological resources” to meet life history needs such as foraging and reproducing (Krausman 1999, p.86). Habitat selection is the process by which an animal chooses a component of the habitat (Garshelis 2000; Hall et al. 1997; Johnson 1980; Krausman 1999; Manly et al. 2002) and the disproportionate use of a component in relation to availability is considered evidence of selection (Garshelis 2000; Johnson 1980; Manly et al. 2002). Selection is dependent on scale and is nested in a hierarchy from an animal’s range to individual food items. For instance, the selection of habitat types within a home range is dependent on the availability of habitats within it. Johnson (1980) identified four levels of selection:

*first-order selection* – the geographical range of a species, *second-order selection* – within the geographical range, the home range of an individual or social group, *third-order selection* – within a home range, the specific, chosen and used habitat components, *fourth-order selection* – of these habitat components, how they are specifically used – i.e. if third-order selection determines a foraging site, food items chosen are dependent on availability.

Evaluating habitat use and selection gives some indication of habitat quality and/or importance. Garshelis (2000) defines habitat quality “as the ability of a particular habitat to support population growth (p.113)” and importance refers to its quality in relation to other habitats. An important habitat would have a large contribution to the sustenance of a population or species. Ideally, researchers should identify relationships between an animal’s fitness and habitat characteristics by measuring demographic parameters (Garshelis 2000). However, the difficulty of measuring variation in life history characteristics of slowly reproducing, long-lived organisms in direct relation to habitat selection means that habitat quality and importance is often inferred not measured (Garshelis 2000). It is extremely difficult to measure the demographic response of manatees to various habitat conditions. But, this does not negate the need to understand habitat use and selection patterns.

#### *Manatee habitat use*

Within their geographic range, Florida and Antillean manatees are found in coastal habitats that have an abundance of vegetation and access to fresh water (Auil 1998; Auil 2004; Lefebvre et al. 2000; Morales-Vela et al. 2000; Olivera-Gomez &

Mellink 2005; Quintana-Rizzo & Reynolds 2008; Reynolds 1999; Spiegelberger & Ganslosser 2005; USFWS 2001a). In Belize and Southern Mexico, they are found all along the coast and generally utilize shallow areas with access to freshwater and vegetation (Auil 2004; Olivera-Gomez & Mellink 2005). In Puerto Rico, high use areas were identified as near shore waters with access to seagrass beds and freshwater. In French Guiana, Nicaragua, Costa Rica and Northeastern Brazil, manatees are found in mangrove estuaries and freshwater lagoons (Borobia & Lodi 1992; De Thoisy et al. 2003; Reynolds et al. 1995; Smethhurst & Nietschmann 1999; Spiegelberger & Ganslosser 2005). Within high use areas, West Indian manatees (*Trichechus manatus manatus*) use specific habitats for particular behaviors such as grassbeds for feeding, open bays and passes for traveling, dredged basins for resting, traveling and milling (Hartman 1979; Koelsch 1997; Self-Sullivan 1999).

#### *Feeding and foraging habits*

Florida manatees are herbivores with a generalized diet (Baugh 1989; Bengston 1981; Hartman 1979; Ledder 1986a; Packard 1981; USFWS 1996; Zoodsma 1991). They eat a wide variety of seagrasses, freshwater vegetation, freshwater emergent vegetation and have even been known to consume benthic macroalgae (Ledder 1986a; USFWS 1996; Zoodsma 1991). Although they eat a variety of aquatic plants, many studies have documented that seagrasses make up the majority of their diet and are the most prevalent food type consumed for individuals that inhabit marine environments (Alves-Stanley et al. 2010; Hartman 1979; Ledder 1986a; Mignucci-Giannoni 1998; Packard 1981). Alves-Stanley et al. (2010) found, based on stable isotope ratios, that

manatees in the Drowned Cayes have a diet that is mostly seagrass. Shoal grass (*Halodule wrightii*), turtle grass (*Thalassia testudinum*) and manatee grass (*Syringodium filiforme*) appear to be the most common seagrasses eaten (Bengston 1981; Ledder 1986b; Quintana-Rizzo & Reynolds 2008; Zoodsma 1991). Although it has been difficult to quantify usage in relation to availability, manatees may prefer *Halodule wrightii* to other seagrasses consumed (Lefebvre et al. 2000).

#### *Seasonal habitat use*

Because manatees have a low heat production and a high thermal conductance, they are poorly adapted to cold water temperatures (Irvine 1983). In Florida, when water temperatures dip below 20°C, they need to seek out warm water refuges to reduce energetic costs and temper the effects of cold water (Irvine 1983). Therefore, Florida manatees utilize different winter and summer habitats (Deutsch et al. 1998; Deutsch et al. 2000; Rathbun et al. 1990; Reid et al. 1991; Reynolds 1999; USFWS 2001a). During the winter, manatees aggregate in warm water areas (Deutsch et al. 1998; Deutsch et al. 2000; Rathbun et al. 1990; Reid et al. 1991; Reynolds 1999; USFWS 2001a) and as water temperatures rise, they disperse to summer habitat which is almost anywhere the water depth is greater than 1-2 meters with access to food and freshwater (Deutsch et al. 1998; Reynolds 1999).

In Belize, water temperatures do not dip below 20°C (Auil 2004; Gibson 1995; LaCommare et al. 2005; USFWS 2001a); therefore, Antillean manatees in Belize do not exhibit similar changes in habitat use in response to temperature (Gibson 1995), but they may shift habitat use in response to wet and dry seasonality (Auil 2004). Auil (2004)

measured a higher than expected probability of sighting manatees in river habitats during the dry season and a reverse distribution during the wet season. But within the Drowned Cayes, Self-Sullivan (2008) found no difference in the seasonal probability of sighting a manatee. However, male manatees may utilize the Belize Barrier Reef as a travel corridor during the wet season when they may be reproductively active and in search of females (Self-Sullivan et al. 2004).

#### *Osmoregulation and freshwater needs*

Nearly every study conducted on manatee habitat use, movement patterns and behavior suggests that manatees seek freshwater (eg. Auil 2004; Deutsch et al. 1998; Deutsch et al. 2000; Lefebvre et al. 2001; Olivera-Gomez & Mellink 2005; Reynolds 1999; Reynolds & Odell 1991; Stith et al. 2004). In Florida they travel from offshore feeding sites to freshwater sources every 4-5 days (Deutsch et al. 2003; Stith et al. 2004). Physiological experiments on captive manatees demonstrate that although they are good osmoregulators (Ortiz et al. 1999; Ortiz et al. 1998) when kept in saltwater and fed seagrass for nine days, they do become susceptible to dehydration (Ortiz et al. 1998).

#### *Movement patterns*

Because travel patterns are individualistic (Deutsch et al. 1998; Deutsch et al. 2000; Rathbun et al. 1990; Reid et al. 1991), it is difficult to make generalizations about Florida manatee movement. However, there are some consistencies that can be summarized. Florida manatees are migratory - many individuals travel over long distances in a short time frame in response to seasonal fluctuations (Deutsch et al. 1998; Deutsch et al. 2000, 2003; Reid et al. 1991; Reynolds 1999; Stith et al. 2004; USFWS

2001a). It is estimated that 85% of the manatees along the Atlantic coast of Florida make long distance migrations between summer and winter areas (Deutsch et al. 1998; Deutsch et al. 2003; Stith et al. 2004). The remainder move to summer habitat adjacent to winter areas or stay in winter areas throughout the year (Deutsch et al. 2003; Stith et al. 2004; USFWS 2001a).

Within season travel is generally not as extensive as between season travel (Deutsch et al. 1998). Although some individuals travel far distances over the course of a few weeks during the summer (Deutsch et al. 1998; Deutsch et al. 2000; Reid et al. 1991; Stith et al. 2004; USFWS 2001a), most manatees exhibit daily movement patterns that consist of moving from secluded areas used for resting and socializing to nearby feeding areas (Deutsch et al. 1998). For example, one animal profiled by Deutsch et al. (1998) traveled from a secluded area where it spent its afternoons to a feeding area three kilometers away where it foraged during the night and in the morning. Stith et al. (2004) noted that manatees will stay at feeding sites for 4-5 days and then travel up to 6-10 km over the course of a single day to freshwater areas where they stay for a day, and then move back to feeding areas.

As discussed above, manatees in Belize and Mexico do not migrate in response to seasonal pressures, but they may travel over long distances while mate seeking (Self-Sullivan et al. 2004, Morales-Vela, personal communication). For manatees that were tracked via satellite tags in Mexico, nearly all of the males travelled to Belize at some point during their tracking period. The greatest distance travelled was 300 km. Only 1 female traveled that distance (Morales-Vela, personal communication) over the same time period. In Southern and Northern Lagoon Belize, a similar pattern of male/female

movement pattern has been observed (Aguirre et al. 2004; Auil 2006). The Belize Barrier Reef may be used as a travel corridor and stop-over sight for manatees. Only male manatees have been identified along the central portion of the reef (Self-Sullivan et al. 2004).

### **Study area**

The Drowned Cayes are a string of mangrove islands 14 km long and 4 km at their widest. They lie 10-15 km east of Belize City and 5 km west of the Belize Barrier Reef (Figure 1.1). As their name implies, they have very little dry land. They almost entirely comprise red mangroves (*Rhizophora mangle*) which grow in standing water. In some areas, where natural soil accretion has occurred, white (*Laguncularia racemosa*) and black mangrove (*Avicennia germinans*) stands have developed. The islands are interspersed with broad channels, narrow inlets, shallow lagoons and quiet coves. The entire complex is surrounded by seagrass beds, and seagrass 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. *Halophila* spp. are present but rare. Water depth is less than 1 meter in some places and is never greater than 6 meters within the study area.

Belize has a wet and dry season with the rainy season generally extending from June to November. In the northern cayes, of which the Drowned Cayes are considered a part of for meteorological purposes, there is an average of 125 rainy days per year with 150 – 180 cm of rain. We measured ambient air and water temperatures, as well as salinities daily throughout the course of this study. Mean air temperatures were lower in

the dry season, 27.6°C, than the wet season, 30°C. Similarly, mean water temperatures were lower in the dry season, 27°C, than the wet season, 30°C.

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

Water temperatures in open water areas range from 23.5°C to 31.6°C with a mean temperature of 28.2°C in the mornings and 29°C in the afternoons. Water temperatures in the highly protected coves within the mangrove islands can reach as high as 34.4°C. Air temperatures ranged from 20.3°C to 32.6°C with a mean temperature of 29°C.

The islands are mostly uninhabited. Local fishermen use a small number of permanent fishing camps that are scattered throughout the islands. There are 3-4 residences. There is a day resort used by cruise ship visitors. A marine research and educational facility is located on the southern-most island of the chain. In 2006 and 2007, two islands were cleared of mangroves presumably for resort development. In 2002, the northern portion of the Drowned Cayes was designated as the Swallow Caye Wildlife Sanctuary. This sanctuary is co-managed for the protection of manatees by the Conservation Division of the Belize Forestry Department and the Friends of Swallow Caye, an NGO.



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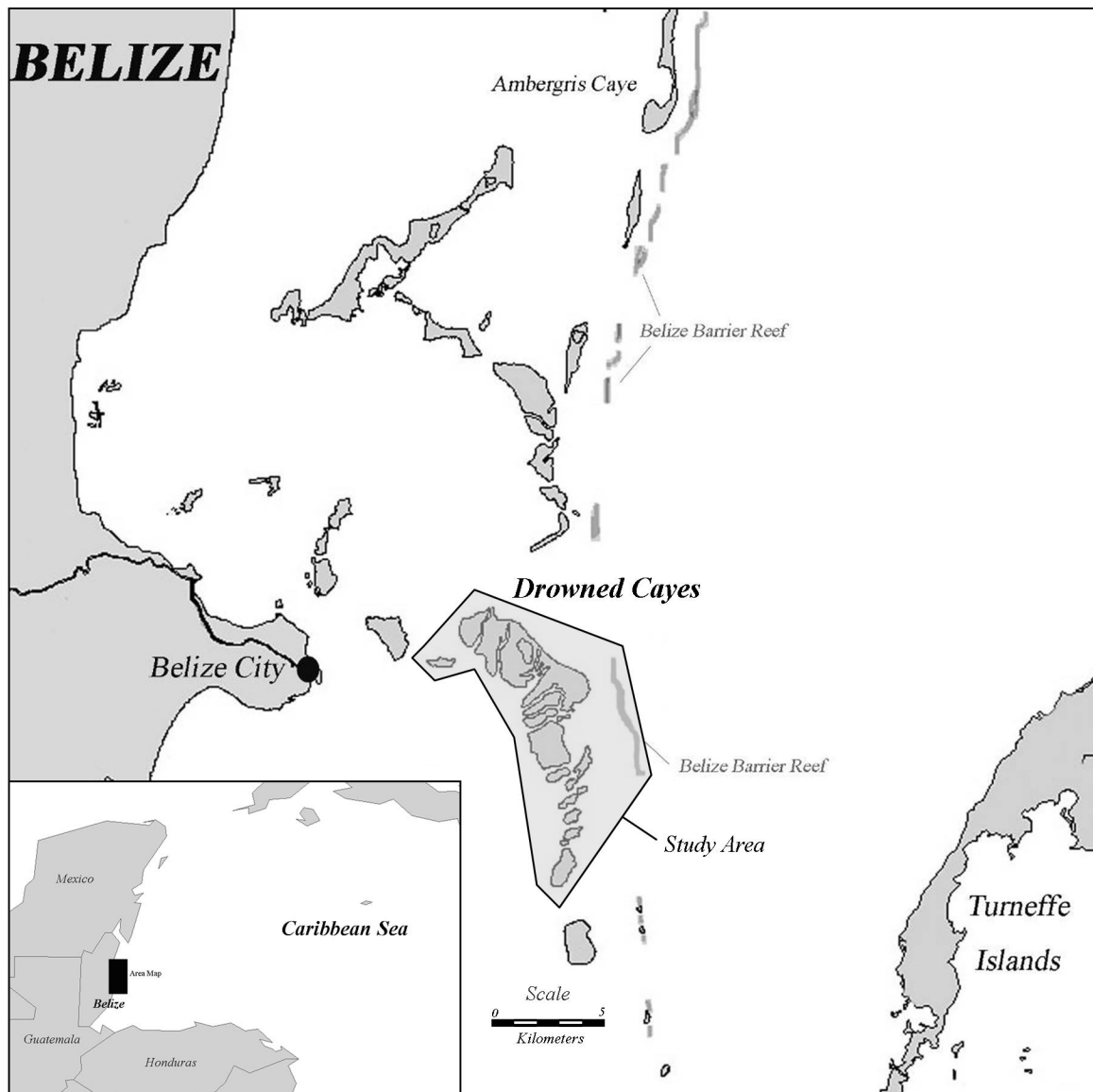


Figure 1.1. Map of the Drowned Cayes and surrounding area.



CHAPTER 2

DISTRIBUTION AND HABITAT USE OF ANTILLEAN MANATEES  
(*TRICHECHUS MANATUS MANATUS*) IN THE DROWNED CAYES AREA OF  
BELIZE, CENTRAL AMERICA<sup>1</sup>

**Abstract.** Belize, Central America has long been recognized as a “stronghold” for Antillean manatees in the Caribbean (O’Shea & Salisbury, 1991). The Drowned Cayes, in particular, have been noted as an important habitat area (Bengston & Magor, 1979; O’Shea & Salisbury, 1991; Auil, 1998; Morales-Vela et al., 2000; Auil, 2004). 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, habitat category interaction with resting hole and grass species present were the most important variables explaining the probability of sighting a manatee (change in log likelihood and p-values = 14.09, 0.015; 23.21, 0.0001; 10.46, 0.015, respectively) and the overall model was a good fit to the data (Hosmer-Lemeshow goodness of fit = 1.486, p = 0.983). The Drowned Cayes clearly constitute a manatee habitat area. Grassflats and cove habitats with resting holes were especially important habitat characteristics (Wald and p-values = 4.14, 0.042; 4.79, p = 0.029, respectively).

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<sup>1</sup> Katherine S. LaCommare, 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.

## **Introduction**

The Antillean subspecies of the West Indian manatee (*Trichechus manatus manatus*) is found in 19 countries throughout the Caribbean, Central and South America (Lefebvre et al., 2001). It is listed as vulnerable to extinction by the IUCN due to greatly reduced numbers, continued exploitation and population fragmentation (IUCN, 2004). However, Belize, Central America has long been recognized as a “stronghold” for Antillean manatees in the Caribbean (O'Shea & Salisbury, 1991). In the 1960's, Charnock-Wilson conducted interviews and personal observations and reported that manatees were abundant within the country (Charnock-Wilson, 1968; Charnock-Wilson, 1970). In the late 1970's, the 1980's, the 1990's, and early 2000's, 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; Morales-Vela et al., 2000; Auil, 2004).

The Drowned Cayes, in particular, are recognized as an important manatee area within Belize. Charnock-Wilson (Charnock-Wilson, 1968) described manatees using drowned cayes, or mangrove islands, in a general sense. He stated that it was common to spot manatees around drowned cayes, their channels, lagoons and surrounding grassbeds. Subsequent aerial surveys have documented high concentrations of manatees in the cayes near Belize City, of which, the Drowned Cayes are a part (Bengston & Magor, 1979; O'Shea & Salisbury, 1991; Auil, 1998; Morales-Vela et al., 2000; Auil, 2004). Boat surveys that have been conducted since 1999 have further corroborated that this area is consistently used by them (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 2004, the number of tourists entering Belize via cruise ships increased from 14,183 visitors per year to 851,436 visitors per year (BTB, 2005). During that same period, there has been 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 may 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, *pers. comm.*). 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; USFWS, 2001).

Because the Drowned Cayes are 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 Method**

### *Study Area*

The Drowned Cayes and Swallow Caye are mangrove islands along the central coast of Belize, 10-15 km east of Belize City and 5 km west of the Belize Barrier reef (Figure 2.1). The Drowned Cayes are a string of islands 14 km long by 4 km at their widest point and comprise almost entirely 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. Where natural soil accretion has occurred, primarily black mangrove and some white (*Laguncularia racemosa*) mangrove stands have developed. 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 being very common. Water depth is less than 1 meter in some places and is never greater than 6 meters within the study area; the tidal range is less than 0.3 meters.

The islands are in a marine environment. In open water areas, salinities range from 35 ppt 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 as low as 30 ppt to 42 ppt. Water temperatures in open water areas range from 23.5°C to 31.6°C with a mean temperature of 28.2°C in the mornings and 29°C in the afternoons. Water temperatures in the highly protected coves within the mangroves islands can reach as high as 34.4°C (Self-Sullivan and LaCommare, *unpublished data*).

The islands are mostly uninhabited. There are a handful of permanent and seasonal residences used by local fishermen scattered throughout the islands and currently 4 tourist resorts used primarily by cruise ship visitors. A marine research and educational facility is located on the southern-most island of the chain. In 2002, the northern portion of the Drowned Cayes and Swallow Caye were designated as the Swallow Caye Wildlife Sanctuary. This sanctuary is co-managed for the protection of manatees by the Conservation Division of the Belize Forestry Department and the Friends of Swallow Caye, a non-governmental organization.

### *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 (Figure 2.1) were established in all habitat types throughout the study area. Habitat types are defined in Table 2.1. These points were randomly sampled during the dry (January, February, March) and wet (June, July, August) seasons from 2001-2004. Surveys were also conducted during the wet season in 2005. Using a mix of experienced observers and

volunteers, 3-13 observers searched for manatees at each point for 30 minutes. These searches are referred to as point scans. As the boat came within 100 meters of each point, observers started scanning for manatees in a 360° 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 2.2).

### *Data Analysis*

**Manatee Distribution--** We mapped manatee distribution within the Drowned Cayes 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, we used presence or absence of manatees 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, we wanted to include the largest number of points in the analysis as possible. In order to do this, we included 20-minute scans in the analysis. To create parity between the 20 and 30-minute scans, we determined presence or absence of the 30-minute scans based on only the first 20-minutes of the sampling duration. This increased our sample size from 613 to 795 scans and allowed us to increase the number of points used in the analysis from 39 to 48.

**Habitat Use--** We used binary logistic regression 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. Because of the large number of zeros (268 zero counts out of 430 samples) and unequal sample sizes across habitat categories, we used manatee presence/absence 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 2.1. A resting hole is a bottom feature that is a distinct, shallow depression in the seafloor. Although they are at least 3-4 meters wide by 3-4 meters 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 seagrasses were found there. There were six categories – none, *Thalassia testudinum* only, *Halodule wrightii* only, *Thalassia testudinum*/*Halodule wrightii* mix, *Syringodium filiforme*/*Thalassia testudinum* mix, and 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). We used the maximum likelihood method to fit the model to the data and a backward stepwise procedure to determine the most parsimonious model. We used the likelihood ratio test and the Wald statistic to determine the significance of the parameters in explaining the variation in the dependent

variable. In order to determine if the model is an adequate fit to the data and to rule out the undue influence of outliers, we used the Hosmer and Lemeshow test and compared observed and expected sighting probabilities (Trexler & Travis, 1993). We created plots of Cook's distances and Studentized residuals versus predicted probabilities to examine the influence of outliers and bias in the data. All statistical analyses were performed using *SPSS* Version 14.0 (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 per scan (n=795). Sighting probabilities for each location ranged from 0 to 0.86 per scan. There doesn't appear to be a distinct spatial pattern of variability in sighting probability (Figure 2.2).

### *Habitat Use*

The probability of sighting a manatee was lowest at the reef (0.17 per scan) and highest on grassflats (0.58 per scan) (Figure 2.3). Results from the logistic regression analysis are shown in Table 2. Habitat category, habitat category interaction with resting hole and grass species present were the most important variables explaining the probability of sighting a manatee. The change in log likelihood for each of these three terms was 14.09 with  $p = 0.015$ , 23.21 with  $p = .0001$  and 10.46 with  $p = 0.015$  respectively. Within habitat categories, grassflats and coves with resting holes both explained a significant portion of the variation in manatee presence (Wald = 4.14 with  $p = 0.042$ , 4.79 with  $p = 0.029$  respectively) (Figure 2.3a, 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  $p = 0.011$ , 6.4, with  $p = 0.011$ ; respectively) (Figure 2.4). The Hosmer and 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 is 0.221 (Table 2.2). The expected sighting probability for each habitat category and seagrass category was very similar to the observed sighting probability further indicating that our model was a good fit to the data (Figure 2.3a, 2.4). Residual plots of change in deviance versus predicted probabilities indicated that samples with a low predicted probability of a presence were poorly fit by the model. In other words, there tend to be manatees present at times and places that would not be predicted by the model.

## Discussion

The Drowned Cayes clearly constitute a manatee habitat area. Manatees were sighted at least once at nearly all of the points that we surveyed (48 out of 54 points). There were some points that had particularly high sighting probabilities ( $> 0.5$ ) and these points might be considered “hot spots” within the overall mangrove island complex.

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 (LaCommare et al., *in prep*). It is unlikely that there

were detection biases as a result of habitat types (LaCommare et al., *in prep*). Grassbeds had the highest probability of sighting a manatee and reef points had the lowest. Grassflats 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, we observed manatees feeding, socializing, resting, nursing calves and moving from place to place (Self-Sullivan and LaCommare, *unpublished 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; Ortiz et al., 1999; Reynolds, 1999; Deutsch et al., 2000; Deutsch et al., 2003). We have conclusively identified only one source of hyposaline water (Self-Sullivan and LaCommare, *unpublished 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).

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 our study area -- *T. testudinum*, *H. wrightii*, *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 (LaCommare and Self-Sullivan, *unpublished data*). And, certain areas appear to be more heavily foraged than others (LaCommare and Self-Sullivan, *unpublished data*), perhaps indicating foraging preference.

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 characteristic of important seagrass areas, as well as 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 and LaCommare, *unpublished 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 per 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 our regression model was 0.22, indicating that only 22 percent of the variability in sighting probability was explained by our logistic regression model, our model was a good fit to the data and the variability that we were explaining was the correct variability. Improving our ability to explain variation in sighting probability will provide a better understanding of habitat use. Building a habitat model that includes additional variables is an important follow-up to this analysis and may even be able 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). Manatee habitat use with respect to spatial arrangement of patches and behavior could be important factor determining manatee habitat use patterns.

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Table 2.1. 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	Num. of Points	Description
<b>Lagoon</b>	5	A large open water area totally encompassed within the mangrove islands. The area has a uniform and shallow depth (<3 meters).
<b>Channel</b>	12	An area of deeper water (3-6 meters) that cuts between the mangrove islands. Generally, there is mangrove shoreline on two sides.
<b>Channel Edge</b>	8	An area of deeper water that cuts through areas of shallower water. The point encompasses two habitat types – channel and grassflat. Depth ranges from 1-5 meters. The point may be adjacent to mangrove shoreline on one side or may be in open water.
<b>Grassflat</b>	11	An area of shallow water, < 3 meters, outside of the mangrove islands with a grassy bottom.
<b>Cove</b>	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 – 4 meters.
<b>Reef</b>	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- 4 meters.

Table 2.2. 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, grass species present and habitat category\*resting hole interaction term.

Variables in the Model <i>n=491</i> Nagelkerke R Square = 0.22	Change in -2 Log Likelihood	df	Significance of Change
<b><u>Dependent Variable</u></b>			
Manatee presence/absence			
<b><u>Independent Variables</u></b>			
Sea state (beaufort scale)	0.548	3	NS
Surface salinity (ppt)	1.76	1	NS
Water temperature (°C)	0.108	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*grass species presence	10.84	8	NS

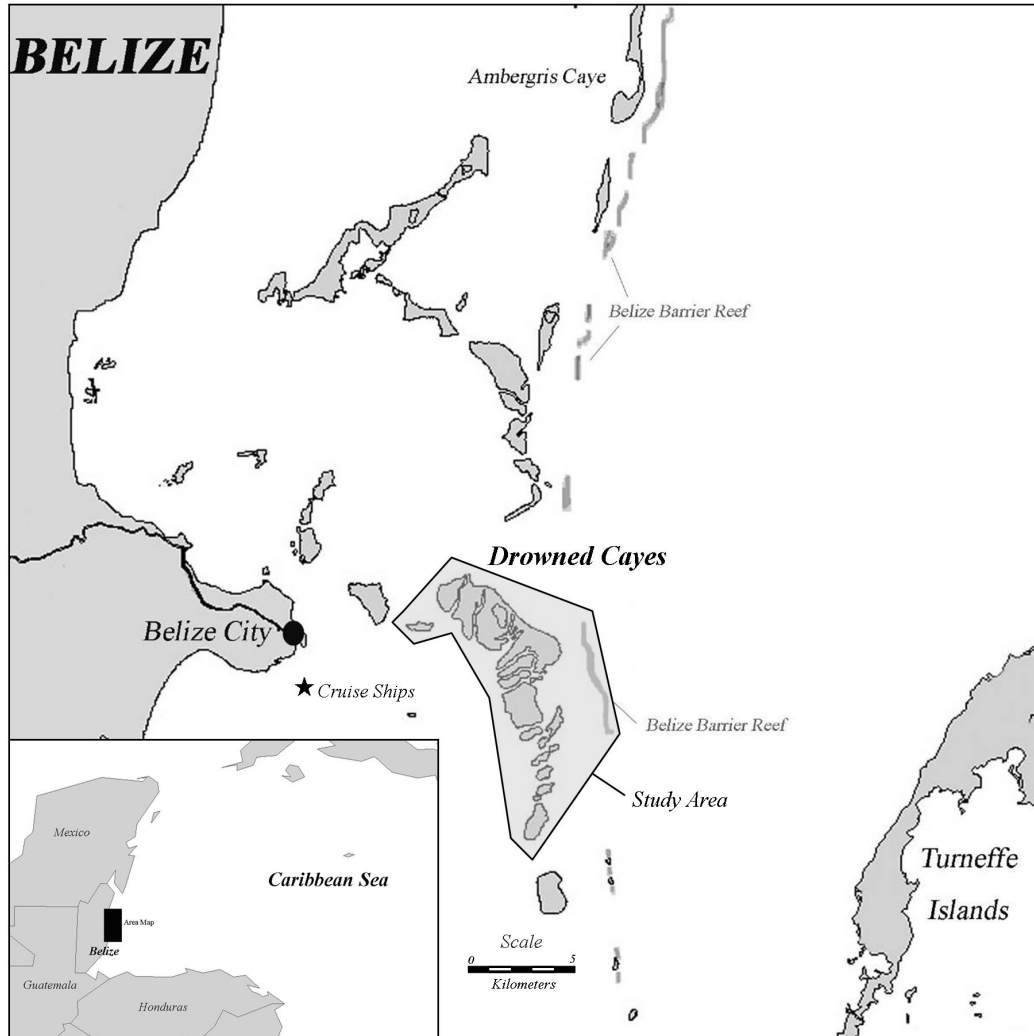


Figure 2.1. Map of the Drowned Cayes and surrounding area.

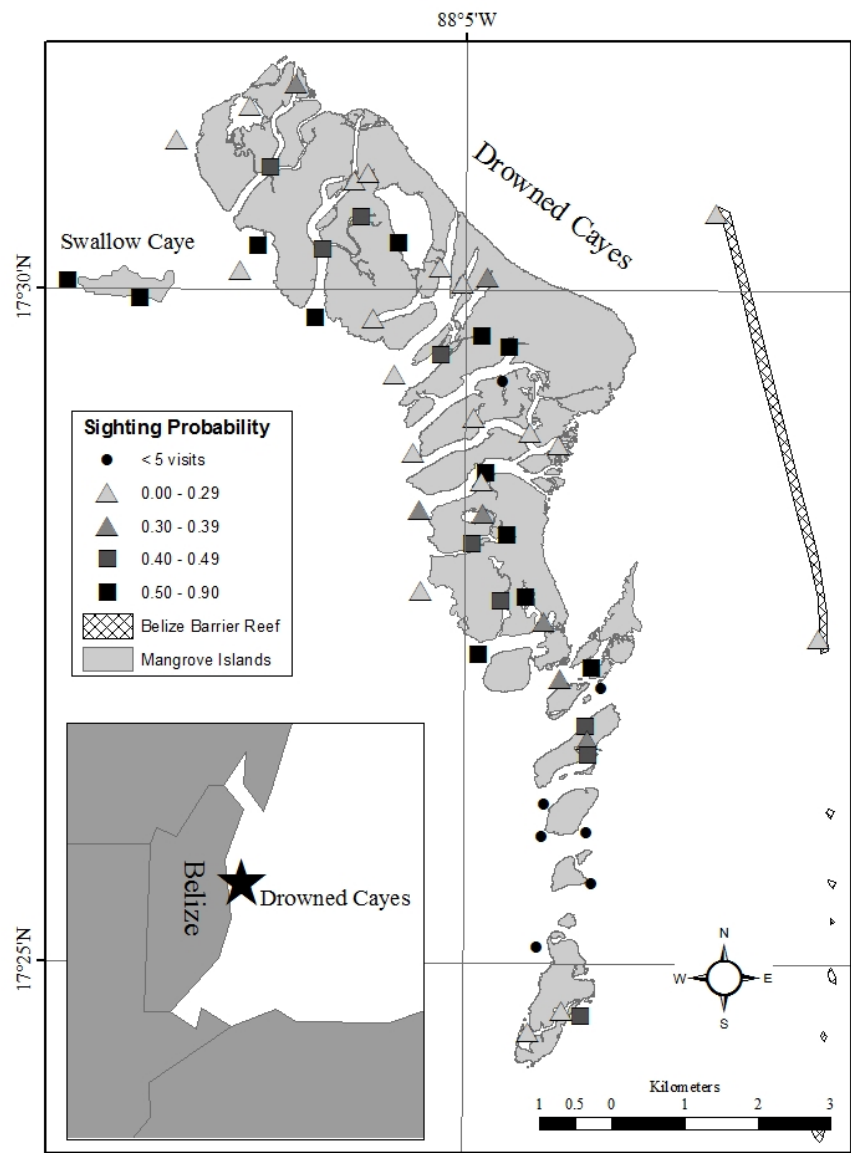


Figure 2.2. Map of manatee sighting probability throughout the Drowned Cayes area ( $n = 795$ ).

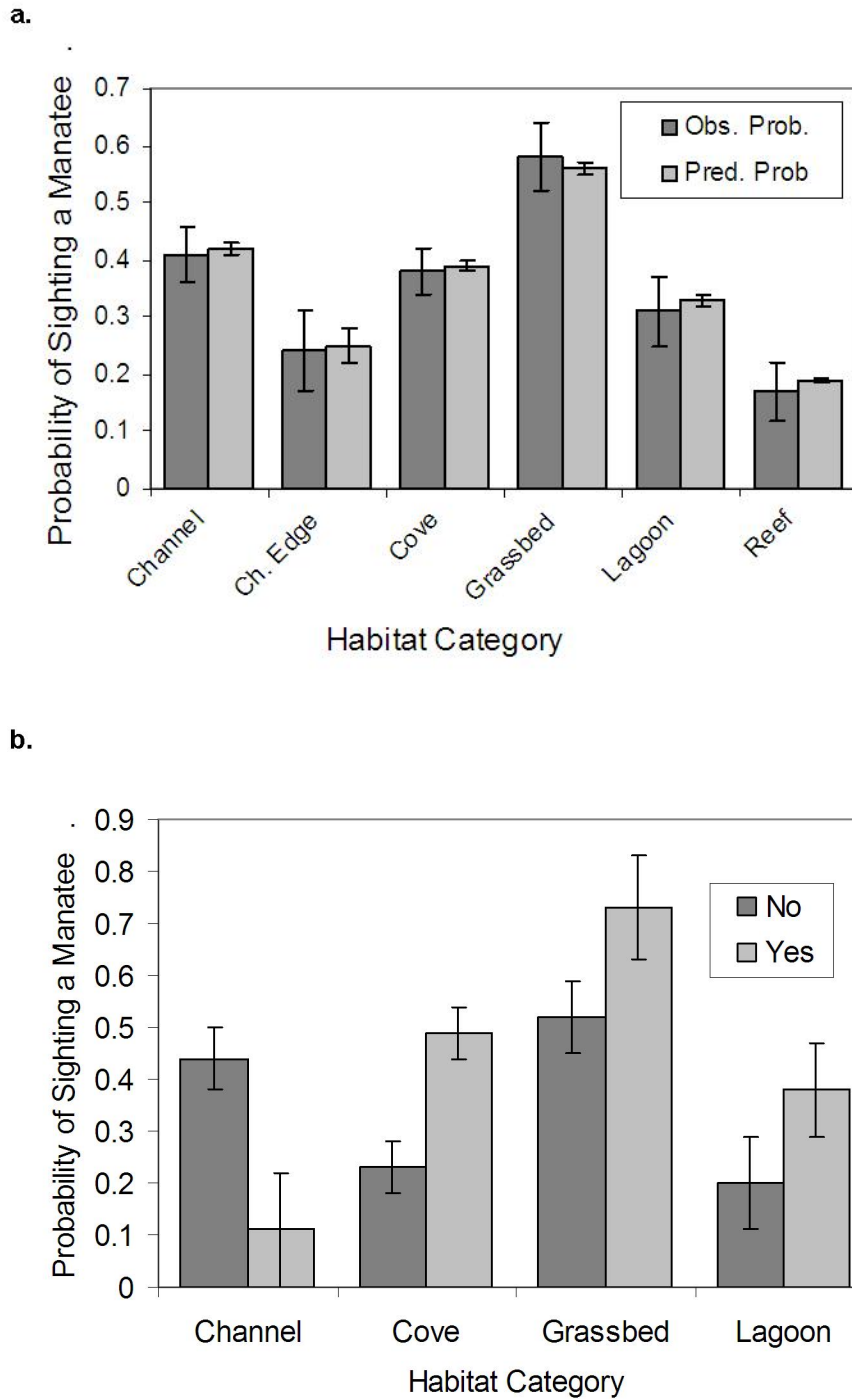


Figure 2.3. a) Observed and predicted probability of sighting a manatee by habitat. b) Observed probability of sighting a manatee by habitat with and without the presence of a resting hole, No= resting hole, Yes = resting hole present, (2001-2005,  $n = 491$ ,  $\pm 1$  s.e.)

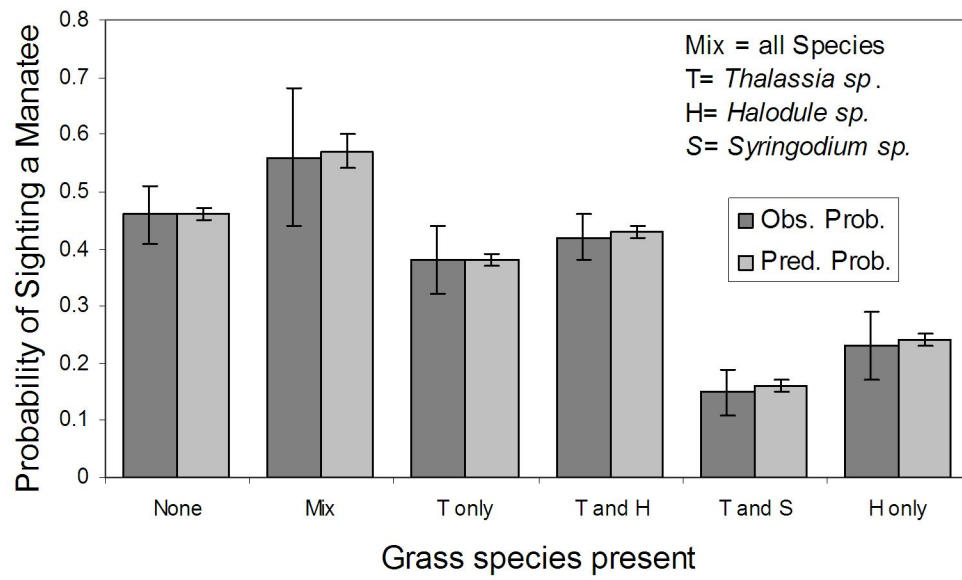


Figure 2.4. Observed and predicted probability of sighting a manatee by seagrass category (2001-2005,  $n = 491$ ).

CHAPTER 3

MANATEE USE OF SEAGRASS BEDS IN THE DROWNED CAYES AREA OF  
BELIZE

**Abstract.** Species select resources in their environment to meet life requirements and individuals presumably select high quality resources over low quality ones (Manly et al. 2002). Selection is inferred when resources are used disproportionately to their availability (Johnson 1980; Manly et al. 2002) which is defined as the quantity of a resource accessible to an animal in a fixed period of time (Manly et al. 2002). Lefebvre et al. (2000) suggested that manatees may select *H. wrightii* in Puerto Rico where they feed on specific patches of this species. However, availability in relation to use was not explicitly measured in that study. The objective of this paper is to determine whether manatees select *Halodule wrightii* as a foraging resource in the Drowned Cayes area of Belize, Central America. We used a nested generalized linear model with a negative binomial distribution and a log-link function to determine whether the number of manatees was dependent on seagrass species present. We also measured the area of *H. wrightii* in relation to *T. testudinum* to measure use in relation to availability. Seagrass beds with *H. wrightii* present had 0.93 mean number of manatees per scan ( $n = 92$ ) and those with just *T. testudinum* had 0.39 mean number of manatees ( $n = 83$ , Wald chi square = 5.248,  $p = 0.022$ ). Within location Mullet Bay Grass Bed (MUGR), manatees fed on the patch of *H. wrightii* that is growing adjacent to or within the larger *Thalassia testudinum* bed. In the Drowned Cayes, manatees appear to selectively forage on *Halodule wrightii*.

## Introduction

Species select resources in their environment to meet life requirements and individuals presumably select high quality resources over low quality ones (Manly et al. 2002). Selection is inferred when resources are used disproportionately to their availability (Johnson 1980; Manly et al. 2002) which is defined as the quantity of a resource accessible to an animal in a fixed period of time (Manly et al. 2002). Resource selection is linked to predation risk (eg. Hebblewhite et al. 2005; Johnson et al. 2002; Rettie 2000), costs of movement (eg. Johnson et al. 2002), forage quality (eg. Hebblewhite et al. 2008; McArt et al. 2009; McLoughlin et al. 2006; Wilmshurst et al. 1999), body mass and ultimately population growth and fecundity (eg. Manly et al. 2002; McLoughlin et al. 2006).

The Antillean subspecies of the West Indian manatee (*Trichechus manatus manatus*) is a long-lived, slow-reproducing herbivore found throughout the Caribbean in shallow, sheltered water with access to freshwater and aquatic vegetation (Reynolds 1999). Although manatees have a generalized diet (Baugh 1989; Bengston 1981; Hartman 1979; Ledder 1986b; Packard 1981; USFWS 1996; Zoodsma 1991), individuals that inhabit marine environments primarily consume seagrass (Alves-Stanley et al. 2010; Hartman 1979; Ledder 1986b; Lefebvre et al. 2000; Mignucci-Giannoni 1998; Packard 1981). Stable isotope analysis of skin samples (Alves-Stanley et al. 2010) and observations of manatees (Self Sullivan and LaCommare, unpublished data) in the Drowned Cayes corroborate that the majority of their diet consists of seagrass. They have been observed feeding on all the species that grow in the area: *Thalassia testudinum*



(turtle grass), *Halodule wrightii* (shoal grass), *Syringodium filiforme* (manatee grass) and *Halophila spp.* (Self-Sullivan and LaCommare, unpublished data). Lefebvre et al (2000) suggested that manatees may select *H. wrightii* in Puerto Rico where they feed on specific patches of this species. However, availability in relation to use was not explicitly measured in that study. Because manatees are protected under national and international law (CEP 1995; Deutsch et al. 2010; USFWS 1996, 2001b) and because forage quality is linked to population health measures such as body mass and fecundity (Deutsch et al. 2010; Manly et al. 2002; McLoughlin et al. 2006), high quality forage resources need to be identified and protected. Once these are identified, conservation plans can target protection through natural area designation, monitoring and pollution abatement schemes.

The objective of this study was to determine whether manatees select *Halodule wrightii* as a foraging resource in the Drowned Cayes area of Belize.

## **Materials and Methods**

### *Study Area*

The Drowned Cayes are a string of mangrove islands 10-15 km east of Belize City and 5 km west of the Belize Barrier Reef along the coast of Belize, Central America (Figure 1.1 – Chapter 1). Aerial and boat surveys over the past several decades have documented that the Drowned Cayes region, which includes Swallow Caye and the Gallows Reef, is a manatee habitat area (Auil 1998; Auil 2004; Morales-Vela et al. 2000) and boat surveys have corroborated the aerial surveys (LaCommare et al. 2008).

This island complex is surrounded by seagrass beds dominated by turtle grass (*Thalassia testudinum*) with shoal (*Halodule wrightii*) and manatee grass (*Syringodium*

*filiforme*) also very common and *Halophila spp.* present, but rare. Most of the seagrass beds are monospecific *T. testudinum*. At Swallow Caye, *H. wrightii* patches tend to be mixed-in with *T. testudinum*. At other locations, *H. wrightii* is found in distinct patches where the water is slightly deeper along the edges of the *T. testudinum*. *S. filiforme* is found mixed-in with *T. testudinum* primarily along the reef. Of the six habitat categories (seagrass beds, coves, lagoons, channels, channel edges and reefs) in the Drowned Cayes area, manatees are found most frequently in seagrass beds (LaCommare et al. 2008).

### *Experimental Design and Data Analysis*

Eleven seagrass beds (Figure 3.1) were sampled from January thru March and June thru August 2001-2004 and from June thru August in 2005 - 2007 using a 20-minute point sampling survey design (referred to as point scans) conducted from a small watercraft – see chapters 2 and 6 for a detailed description of the survey method. For each 20-minute point scan, number of manatees, distance and a directional vector to manatees, and manatee behavior was recorded. Distance to the manatees was measured using a Bushnell Yardage Pro 500®. Direction was determined using a hand-held compass. Seagrass species presence was determined by snorkeling the sample area. At location Mullet Bay seagrass bed (MUGR), *H. wrightii* patches were mapped by recording the latitude and longitude of the edge of the patch using a global positioning system (GPS) receiver. For each confirmed observation of feeding, approximate manatee locations were mapped using the distances and vectors that were recorded during sightings. Maps were created using ArcMap 9.3 (ESRI 2008). We standardized the size of our sampling circle – making them effectively an equal area - based on histograms of

boat-to-manatee distance (LaCommare, unpublished data). Since 99% of all sightings, with measured distances, were within 150 meters (LaCommare, unpublished data), area of the sampling circles was equalized by removing from the analysis sightings with known distances greater than 150 meters. Sample circles were mapped in ArcMap 9.3 (ESRI 2008) by creating 150 meter radius buffers around our scan points.

At 6 of our point locations, only *T. testudinum* was present. Five of our point locations had both *T. testudinum* and *H. wrightii*. We used a nested generalized linear model with a negative binomial distribution and a log-link function to determine whether the number of manatees was dependent on seagrass species present. Negative binomial distribution was the most appropriate distribution to use for our over-dispersed (variance greater than the mean) Poisson-distributed response variable – number of manatees. The generalized linear model was also appropriate for our categorical predictor variables (Agresti 1996; Quinn & Keough 2002) - seagrass bed category (*T. testudinum* only and *H. wrightii* present) and locations nested within seagrass bed category. Our null hypotheses are that the mean number of manatees per scan is equal among locations within seagrass bed category and that the mean number of manatees per scan is equal among seagrass bed category. Statistical analyses were performed using *SPSS* version 17.0 (SPSS, 2008).

The disproportionate use of a habitat component in relation to availability is evidence of selection (Garshelis 2000; Johnson 1980; Manly et al. 2002). We used ArcMap 9.3 (ESRI 2008) to map and measure the area in square kilometers of the *H. wrightii*, *T. testudinum* and manatee feeding at 2 locations. This gives us a measure of use in relation to availability by allowing us to compare the area of *T. testudinum* to *H.*

*wrightii* within our sample circle and to examine manatee feeding behavior. We weren't able to complete this analysis for all 5 locations due to permit restrictions. The mapped *H. wrightii* patch at SLCW allows us to examine manatee feeding in relation to a known *H. wrightii* patch, but doesn't give us a measure of use versus availability because the patch is outside of the 150 meter radius of our sample circle (see Figure 3.4).

## Results

Between 2001 and 2007, 175 20-minute point scans were conducted between 2001 and 2007 at the eleven seagrass sites in our study area. Number of manatees sighted per 20-minute scan ranged from 0 – 4 with a mean of 0.67 manatees per scan. Mean number of manatees per scan per location ranged from 0 at location BAW ( $n = 6$ ) and HUMO ( $n = 3$ ) to 1.73 at location SWCS ( $n=22$ ). Due to heterogeneity in our data, we rejected our null hypothesis that the number of manatees was equal among locations within seagrass bed category (Wald chi-square = 20.109,  $p = 0.005$ ). The parameter estimates indicate that SWCS, SCW and GMO have a significantly higher number of manatees than MUGR (Wald chi-square = 13.293, 6.752, 3.562,  $p < 0.0001$ , 0.009, 0.059 respectively; Table 3.1, Figure 3.2). And, locations GIGR and LHOS have a significantly higher number of manatees than DMO (Wald chi-square = 4.287, 5.908,  $p = 0.015$ , 0.38 respectively) and BAW and HUMO have a significantly lower number of manatees (Wald chi-square = 0.0001,  $p = 1.000$ , Table 3.1, Figure 3.2).

We rejected our null hypothesis that the number of manatees was equal among seagrass bed categories (Wald chi square = 5.248,  $p = 0.022$ ). Seagrass beds with *H.*

*wrightii* present had 0.93 mean number of manatees per scan ( $n = 92$ ) and those with just *T. testudinum* had 0.39 mean number of manatees ( $n = 83$  - Figure 3.2).

At MUGR, there were 0.05 km<sup>2</sup> of *Thalassia testudinum* and 0.003 km<sup>2</sup> of *Halodule wrightii*. *H. wrightii* comprised only 7% of the seagrass bed habitat, but 100% of the observed manatee feeding occurrences (four of four observations - Figure 3.3). The *H. wrightii* patch at SLCW was outside of the 150 m radius, so we don't have a measure of availability for each, but for one of two feeding occurrences at SLCW, the manatee was feeding on the patch of *H. Wrightii* just outside of the circle radius (Figure 3.4).

## Discussion

In the Drowned Cayes, manatees utilize seagrass beds that have *Halodule wrightii* present over locations with just *Thalassia testudinum*. However, there was significant heterogeneity in the manatee sightings among locations within seagrass category, indicating other factors might be important for seagrass bed selection. Among locations with *H. wrightii* present, locations SWCS, SCW and GMO had a higher number of manatees than MUGR. SWCS and SCW also have resting holes which is an important variable in determining manatee habitat usage (see Chapters 2 and 4).

Within MUGR, based on our observations, manatees seem to feed on the patch of *H. wrightii* that is growing adjacent to or within the larger *Thalassia testudinum* bed indicating that manatees select *H. wrightii* over *T. testudinum*.

Nutritional factors such as percent nitrogen, soluble carbohydrates and neutral detergent fiber (a measure of cellulose concentration) often determine dietary preference

(Bjorndal 1980; Iongha et al. 1994; White 1983). The grass blades of *T. testudinum* and *H. wrightii* growing in the Caribbean have similar values of proximate constituents – ash, protein, carbohydrates and fiber (Dawes 1986). However, because Dawes (1986) only measured seagrass blades and manatees are known to consume rhizomes (Lefebvre et al. 2000; Packard 1984) which also contain soluble carbohydrates (Hemminga et al. 1995), this study may not be a good benchmark for manatee nutrition. Whole plant proximate analysis is more illuminating. This analysis hasn't been completed on plants in the Caribbean but has been conducted on similar species growing in the Pacific. *Halodule uninervis* had a higher nitrogen and lower fiber concentration in comparison to *Thalassia hemprichii* which has higher carbohydrate concentration because of its larger proportion of roots and rhizomes. However, because of the high fiber content of *T. hemprichii* dugongs may not be able to access the nutrients in these plants making them of lower nutritive value (Aragones 1996).

In terrestrial ungulates, a higher quality diet can increase nutrient intake, improve body condition and increase fecundity (White 1983, Robbins 1993). In northern ungulates – reindeer (*Rangifer tarandus tarandus*), caribou (*Rangifer tarandus grantii*) and muskoxen (*Ovibos moschatus*) – 10-20% changes in the forage digestibility resulted in a 200% increase in weight gain which translated into 35% increase in the probability of conception. In Rocky Mountain and captive elk (*Cervus elaphus*), increases in forage availability resulted in earlier parturition, faster growth of calves and mothers, higher conception rates of cows and higher survival rates of calves (Cook et al. 2004; Cook et al. 2001). In contrast, female elk in northern Canada who fed on an overgrazed range with

poor nutritional quality, had smaller fat reserves, insufficient lactation and smaller, lighter calves (Crête & Huot 1993).

Forage quality probably has a similar effect on manatee body mass and fecundity. Therefore, protecting high quality forage should be an objective in conservation and management plans. Once identified, these resources should become a high priority for protection within marine protected areas and/or other management guidelines (i.e. watercraft or development restrictions). For instance, manatees are known to shift habitat use in response to boat traffic (Smethurst & Nietschmann 1999). If increases in boat traffic along and through the Drowned Cayes results in manatees shifting their habitat from high quality forage sites to lower quality forage sites, manatees may spend less time foraging at high quality resources which could ultimately be detrimental to manatee health. Establishing watercraft guidelines around high quality resources could alleviate watercraft/manatee conflicts.

*H. wrightii* monitoring programs should also be established to ensure its persistence within the Drowned Cayes. Because seagrass nutrient levels are known to fluctuate in response to light, sediment and detrital fluctuations (e.g. Dawes 1986; Dawes & Lawrence 1980; Evrard et al. 2005; Hemminga & Duarte 2000; Hemminga et al. 1995; Pirc 1989), monitoring should include changes in nutrients and proximate constituents.

And finally, more research should be done to understand the nutritional ecology of manatees. Full nutritive value studies should be conducted on *T. testudinum*, *H. wrightii* and *Syringodium filiforme* in the Drowned Cayes and Caribbean. Digestive studies should evaluate nutrient absorption rates and attempts should be made to link manatee diet quality to lactation, parturition, body mass and fecundity through longitudinal studies.



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Table 3.1. Results of our nested generalized linear model relating number of manatees (dependent variable) to seagrass category and locations nested within seagrass category (independent variables,  $n = 175$ ). Seagrass categories: *T. testudinum* only and *H. wrightii* present. Parentheses indicate nested variable.

Variables in the Model <i>n</i> = 175	Wald Chi-square	df	Significance
<b>Dependent variable</b>			
Number of manatees			
<b>Independent variables</b>			
<u>Seagrass Presence Category</u>	5.248	1	0.022
<u>Location (Grass)</u>	20.109	7	0.005
Location ( <i>T. testudinum</i> only)			
DMO* ( <i>n</i> = 21)			
BAW ( <i>n</i> = 8)	0.0001		NS
GIGR ( <i>n</i> = 32)	4.287		0.038
HUMO ( <i>n</i> =3)	0.0001		NS
LHOS ( <i>n</i> = 15)	5.908		0.015
SUMO ( <i>n</i> = 6)	2.652		0.105
Location ( <i>H. wrightii</i> only)			
MUGR* ( <i>n</i> = 27)			
GMO ( <i>n</i> = 14)	3.562		0.059
SCW ( <i>n</i> = 21)	6.752		0.009
SLCW ( <i>n</i> = 8)	1.144		NS
SWCS ( <i>n</i> = 22)	13.293		<0.0001

\*Reference subcategory

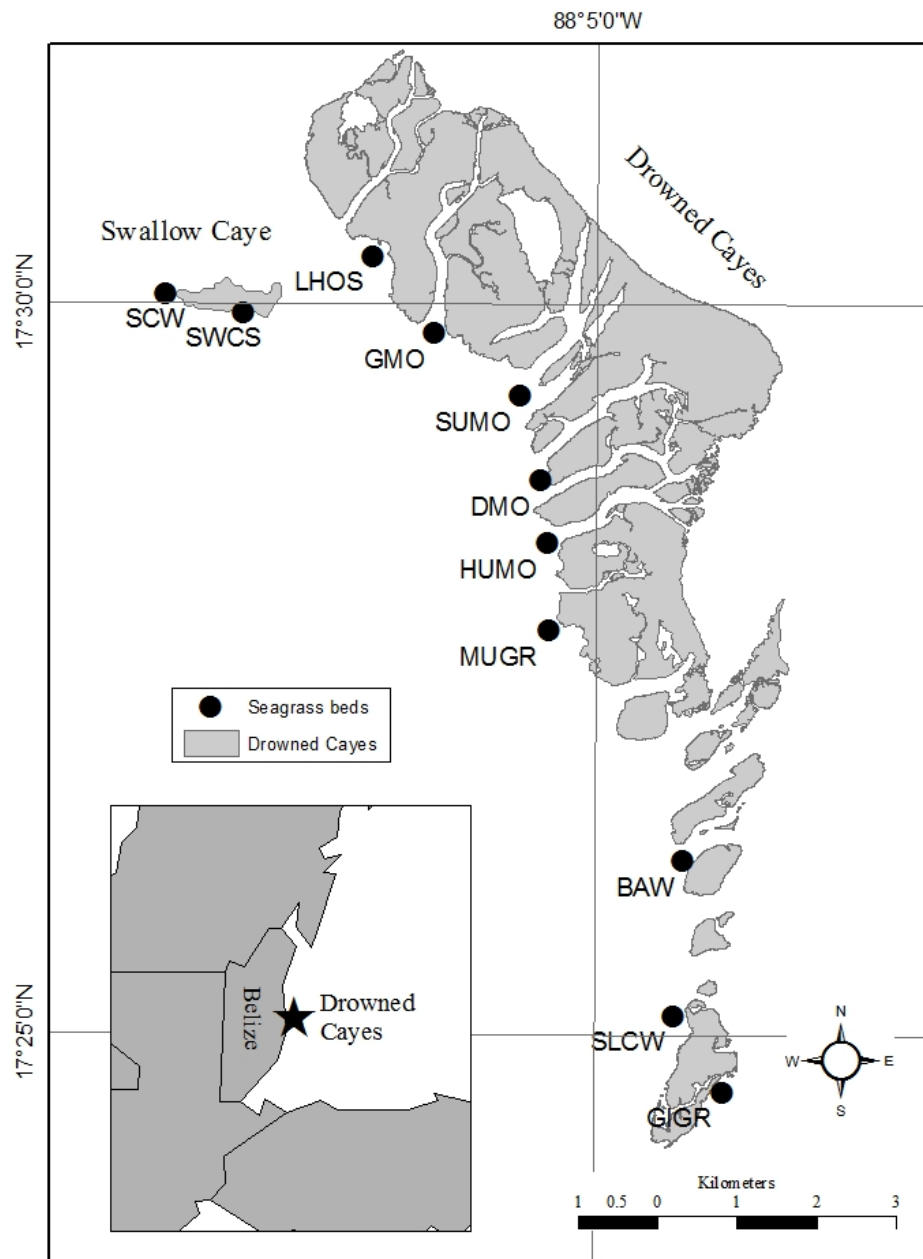


Figure 3.1. Map of seagrass beds and seagrass sample locations.

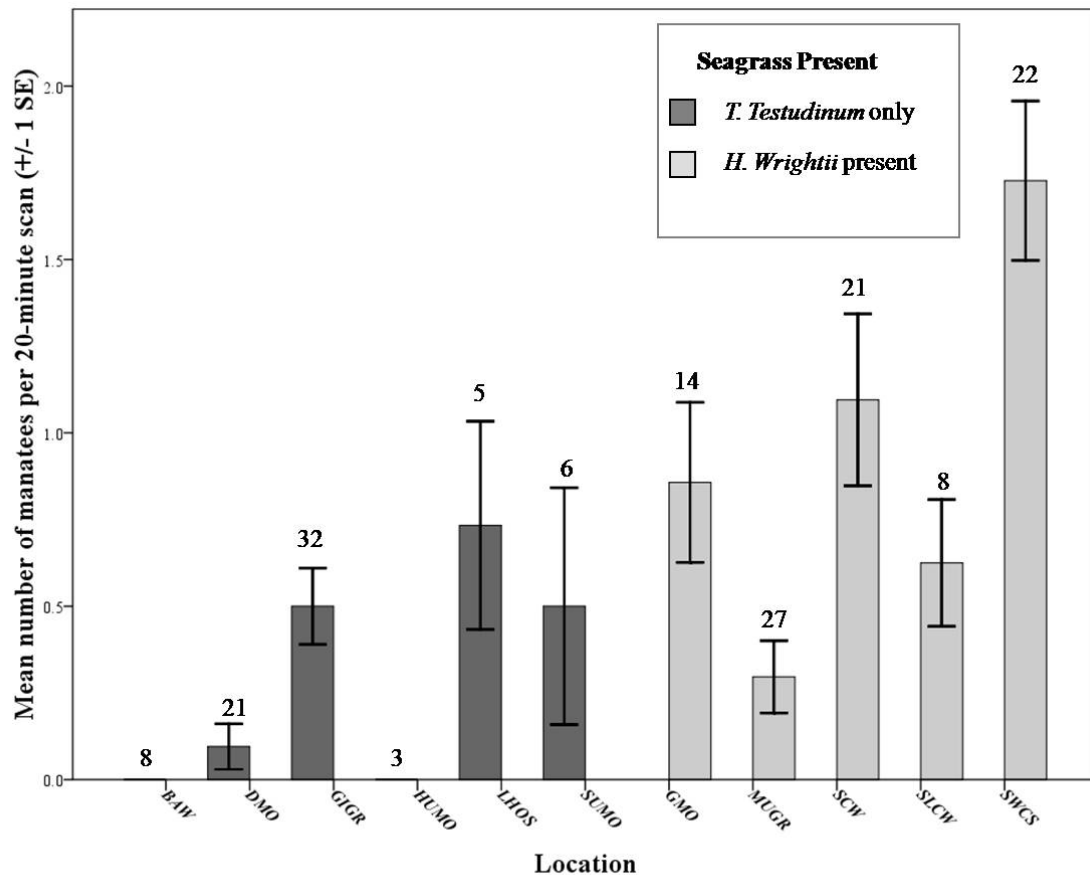


Figure 3.2. The number of manatees was not equal among locations within seagrass bed category (Wald chi-square = 20.109,  $p = 0.005$ ). SWCS, SCW and GMO have a significantly higher number of manatees than MUGR (Wald chi-square = 13.293, 6.752, 3.562,  $p < 0.0001$ , 0.009, 0.059). LHOS and GIGR have a significantly higher number of manatees than DMO (Wald chi-square = 5.908, 4.287,  $p < 0.015$ , 0.038, 0.059). The number manatees was not equal among seagrass bed category (Wald chi square = 5.248,  $p = 0.022$ ). Numbers above bars are the sample sizes for each location. Error bars:  $\pm 1$  S.E.



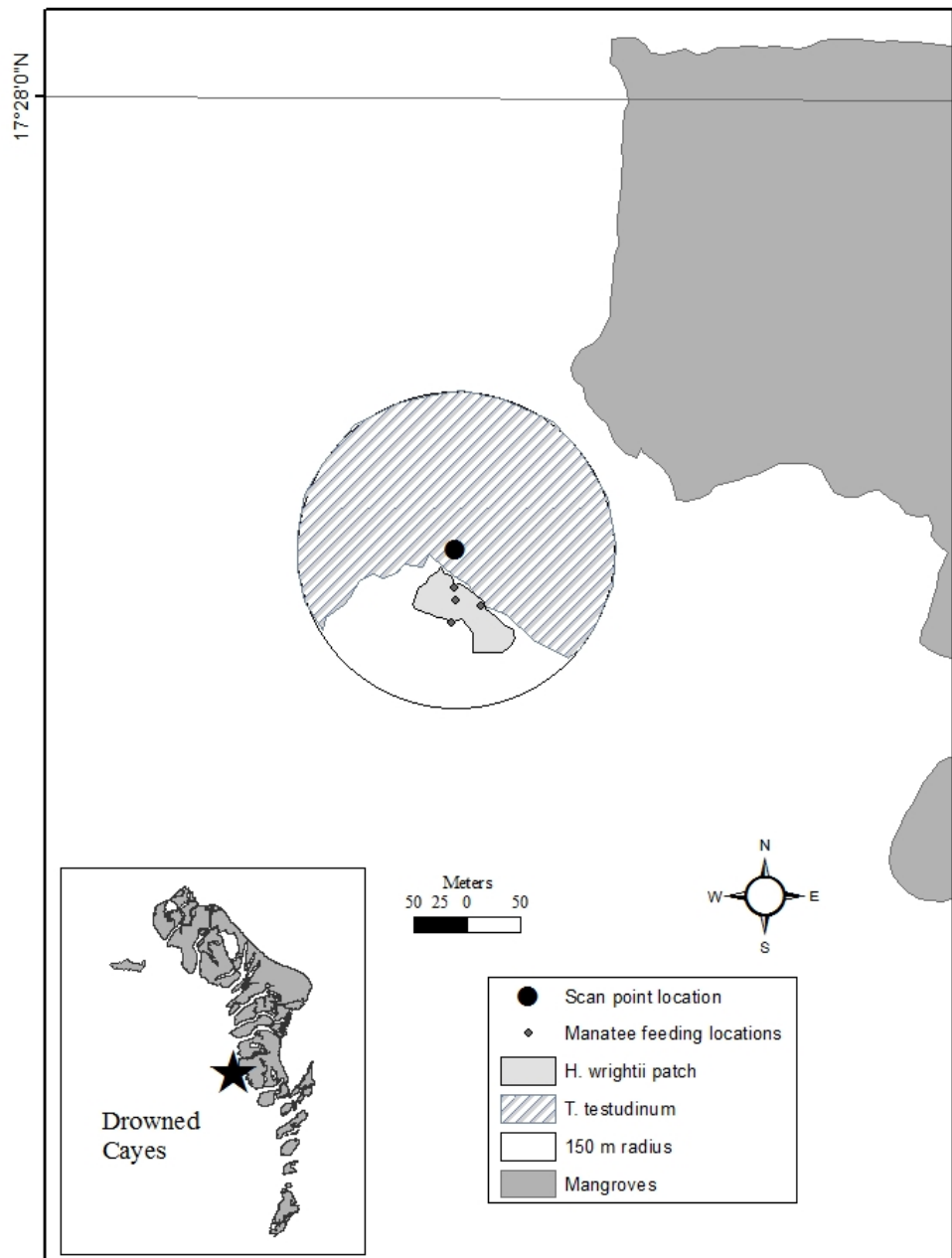


Figure 3.3. Manatee feeding locations in relation to the *H. wrightii* patch at seagrass bed MUGR.

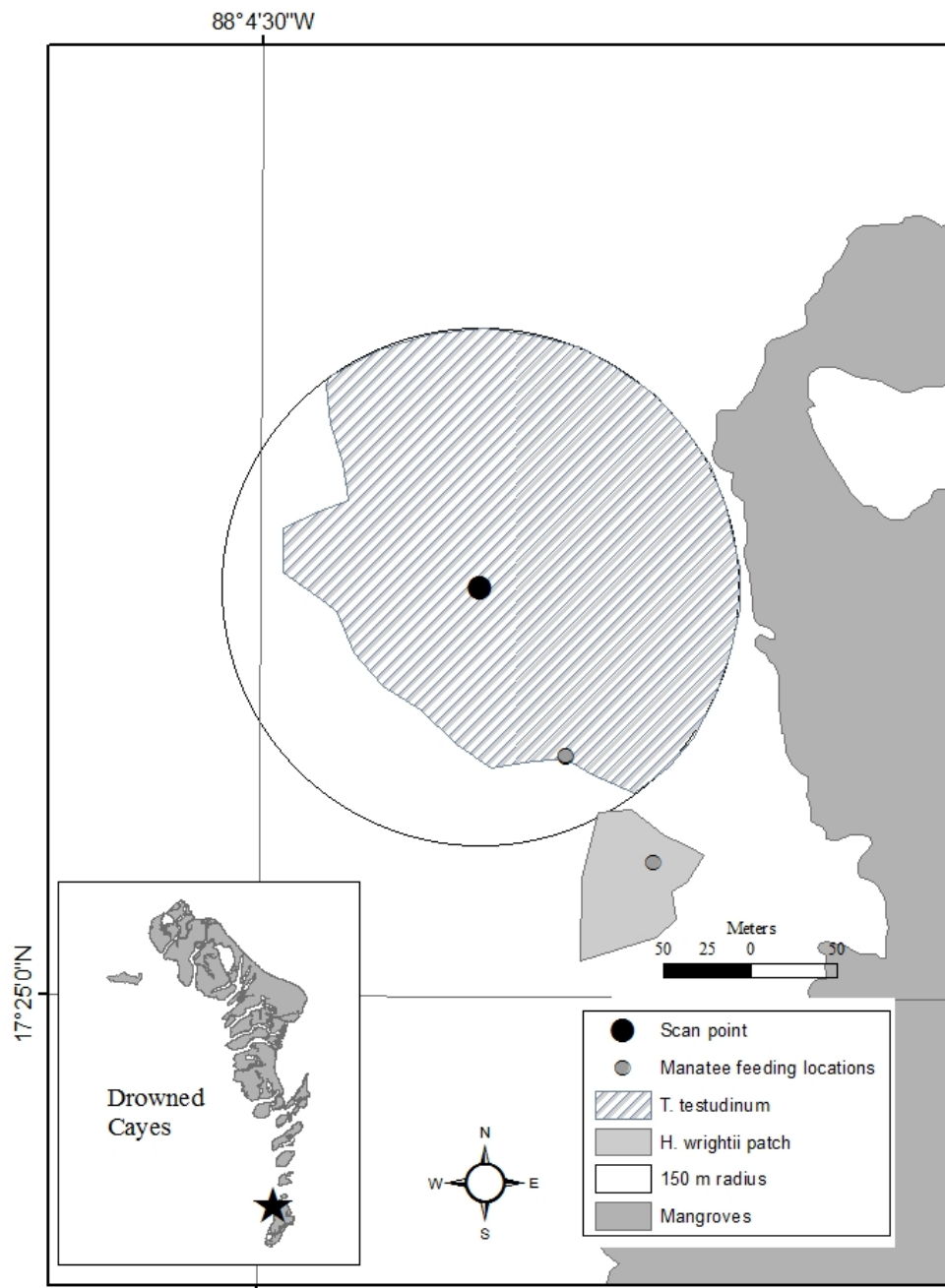


Figure 3.4. Manatee feeding locations in relation to the *H. wrightii* patch at seagrass bed SLCW

## CHAPTER 4

### MANATEE USE OF RESTING HOLES IN THE DROWNED CAYES AREA OF BELIZE

**Abstract.** Many environmental features constitute the essential components of an animal's habitat and determine occupancy, survival and fecundity of a species. Suitable habitat is a mixture of patches for all essential activities and activities are segregated between these elements (Myserud & Ims 1998b). Although West Indian manatees (*Trichechus manatus manatus*) use specific habitats for particular behaviors such as seagrass beds for feeding, open bays and passes for traveling, dredged basins for resting, traveling and milling (Hartman 1979; Koelsch 1997; Self-Sullivan & LaCommare Unpublished data), they spend a considerable portion of their time resting and feeding. Manatee foraging and travelling habitat has been well studied (e.g. Deutsch et al. 2003; Hartman 1979; LaCommare et al. 2008; Lefebvre et al. 2000; Morales-Vela et al. 2000). Manatee resting habitat has not (Bacchus et al. 2009; LaCommare et al. 2008). The objective of this paper is to examine manatee use of resting holes in the Drowned Cayes area of Belize. We used a nested generalized linear model with negative binomial distribution and a log-link function to determine whether the number of manatees was dependent on resting-hole location category. There was heterogeneity in our data and the number of manatees was not equal among locations within resting-hole category (Wald chi-square = 22.889,  $p = 0.018$ ). But, overall, resting holes categorized as adjacent to seagrass beds had a significantly higher mean number of manatees than resting holes categorized as lagoons (Mean Difference = 0.78,  $p = 0.004$ ) and a marginally significant higher mean number of manatees than resting holes categorized as enclosed (Mean Difference 0.54,  $p=0.56$ ). Manatees use resting-hole locations that are adjacent to seagrass beds more heavily than enclosed resting holes or resting holes within lagoons.

## Introduction

A myriad of environmental features constitute essential animal's habitat and determine occupancy, survival and fecundity of a species. Habitat is defined as the abiotic and biotic components in a given area (Hall et al. 1997; Krausman 1999) and specific components – i.e. food, cover, water – fulfill different life history and physiological requirements (eg. Morrison et al. 2006). Suitable habitat must contain a mixture of patches for all essential activities and activities are segregated between these elements (Mysterud & Ims 1998b). Habitat selection – how animals allocate their time with respect to patches – is determined largely by availability, cost and benefits (Charnov 1976; Hall et al. 1997; Krausman 1999; MacArthur & Pianka 1966; Mysterud & Ims 1998b). Because cost and benefits differ between habitat components, animals balance trade-offs that affect how they choose habitat. For example, patches used for foraging are often segregated from patches used for protection from predators. Therefore, foraging patches are sometimes risky in relation to predation (Mysterud & Ims 1998b). Numerous organisms such as fish, insects, small mammals, ungulates, birds and dugongs have been shown to make trade-offs in habitat use and use lower quality foraging habitat in the presence of predation (see Mysterud & Ims 1998b for references; Wirsing et al. 2007).

West Indian manatees (*Trichechus manatus manatus*) use specific habitats for particular behaviors such as seagrass beds for feeding, open bays and passes for traveling, dredged basins for resting, and traveling (Hartman 1979; Koelsch 1997; Self-Sullivan & LaCommare Unpublished data). They have a feeding-resting-feeding behavioral rhythm (Deutsch et al. 2003; Horikoshi-Beckett & Schulte 2006) and spend a considerable

portion of their day resting (Deutsch et al. 2003; Hartman 1979). Manatee foraging and travelling habitats have been well studied (e.g. Deutsch et al. 2003; Hartman 1979; LaCommare et al. 2008; Lefebvre et al. 2000; Morales-Vela et al. 2000), but resting habitats have not (Bacchus et al. 2009; LaCommare et al. 2008). Many studies have noted where manatees tend to rest – dredged basins in Florida (Hartman 1979; Koelsch 1997), sheltered, deep water areas in Nicaragua (Smethurst & Nietschmann 1999), resting holes in Belize (see Bacchus et al. 2009; LaCommare et al. 2008 and Chapter 2 for a definition of resting hole), but no authors have examined how manatees select resting areas. Bacchus et al. (2009) characterized resting-hole site depth, substrate, presence of vegetation, water temperature, salinity and water velocity to non-resting hole areas. She found that resting holes were deeper and had a slower water velocity than non-resting holes. She did not document differential manatee use, nor consider proximity of resting holes to other habitat.

Terrestrial ungulates, like manatees, subsist on a low quality food source and alternate between feeding and resting behaviors (Mysterud & Østbye 1995). High quality resting places – bedding sites – were those that provided adequate protection from predators, thermal cover and were proximal to foraging areas (Canon & Bryant 1997; Mysterud 1996; Mysterud & Ims 1998a; Mysterud & Østbye 1995; Ockenfels & Brooks 1994; Strohmeyer et al. 1999). Likewise, optimal foraging sites tend to be adjacent to cover and bed-sites (Mysterud & Østbye 1995). For example, Stuwe and Hendrichs (1984) found that roe deer (*Cervus elaphus*) sought feeding sites that were within 400 meters of bed-sites.

We expect manatees to choose resting areas that are adjacent to feeding locations because they have to travel less between resting and feeding areas. Travel is an energetic cost and animals will allocate time spent in various activities in a manner that optimizes net energy gains and losses.

The objective of this paper is to examine manatee use of resting holes in relation to proximity to seagrass beds and level of enclosure by mangrove shorelines to examine optimal resting habitat.

## **Methods**

### *Study Area*

The Drowned Cayes are a string of mangrove islands that lie along the central coast of Belize, 10-15 km east of Belize City and 5 km west of the Belize Barrier reef (Figure 1.1 – Chapter 1). The islands comprise red (*Rhizophora mangle*), black (*Avicennia germinans*) and white (*Laguncularia racemosa*) mangrove stands. Because red mangroves grow in standing water, the islands consist of very little dry land. They are interspersed with broad channels, narrow inlets, shallow lagoons and protected coves. The entire complex is surrounded by seagrass beds. There are 14 manatee resting holes throughout the area (Figure 4.1).

### *Experimental Design and Data Analysis*

The 14 resting-hole locations (Figure 4.1) were sampled from January thru March and June thru August in 2001-2004 and from June thru August in 2005 - 2007 using a 20-minute point sampling survey design (referred to as point scans) conducted from a small

watercraft – see chapters 2 and 6 for a detailed description of the survey method. For each 20-minute point scan, the number of manatees sighted was recorded.

We allocated each resting-hole location to one of three mutually exclusive categories: adjacent to seagrass beds, lagoon or enclosed by mangrove shoreline (see Figure 4.1). Resting-hole sites adjacent to seagrass beds are in open water areas surrounded by seagrass. Seagrass beds are outside of the mangrove islands and have a uniformly shallow (<3m) seagrass bottom (3 locations). Lagoons are large open water areas within the mangrove island complex with a seagrass bottom, although, the seagrass growing at location CLA is very sparse (3 locations). Enclosed areas are resting-hole sites at the end or off to the side of narrow channels, surrounded by mangroves on three sides (8 locations).

We used a nested generalized linear model with negative binomial distribution and a log-link function to determine whether the number of manatees was dependent on resting-hole location category. Negative binomial distribution was the most appropriate distribution to use for our over-dispersed (variance greater than the mean) Poisson-distributed response variable – number of manatees. The generalized linear model was also appropriate for our categorical predictor variables (Agresti 1996; Quinn & Keough 2002). Our dependent variable is number of manatees per 20-minute scan. Our predictor variables are resting-hole category (adjacent to seagrass bed, enclosed, lagoon) and location nested within resting-hole category. Our null hypotheses are that the mean number of manatees per scan is equal among locations within resting-hole category and among resting-hole category.

We used pairwise comparisons to test the hypothesis that mean number of manatees would be higher for those locations categorized as adjacent to seagrass beds than those locations categorized as lagoons or enclosed by mangroves ( $p = .05$ , Bonferroni adjusted). Statistical analyses were performed using *SPSS* version 17.0 (SPSS 2008)

## Results

Between 2001 and 2007, 301 20-minute point scans were conducted between 2001 and 2007 at the 14 resting-hole locations. Number of manatees sighted per 20-minute scan ranged from 0 – 5 with an overall mean of 0.75 manatees. Mean number of manatees per scan per location ranged from 0.18 at location GICR ( $n = 22$ ) to 1.73 at location SWCS ( $n=22$ ). Due to heterogeneity in our data, we rejected our null hypothesis that the number of manatees was equal among locations within resting-hole category (Wald chi-square = 22.889,  $p = 0.018$ ). The parameter estimates indicate that SWCS had a marginally significant higher number of manatees than LHOS (Wald chi-square = 3.2,  $p < 0.074$ ; Table 4.1, Figure 4.2). Locations CCO, ESP, F1EN, HECO had significantly higher number of manatees than GICR (Wald Chi-square = 4.756, 10.066, 7.740, 6.565,  $p = 0.029, 0.002, 0.005, 0.010$  respectively, Table 4.1, Figure 4.2).

We rejected our null hypothesis that the number manatees was equal among resting-hole category (Wald chi square = 12.386,  $p = 0.002$ ). Resting holes categorized as adjacent to seagrass beds had a significantly higher mean number of manatees than resting holes categorized as lagoons (Mean Difference = 0.78,  $p = 0.004$ ) and a



marginally significant higher mean number of manatees than resting holes categorized as enclosed (Mean Difference 0.54,  $p=0.056$ ).

## Discussion

Manatees use resting-hole locations that are adjacent to seagrass beds more heavily than other types of resting holes. Like terrestrial ungulates, they allocate a considerable portion of their time to resting and alternate between resting and feeding (Deutsch et al. 2003; Hartman 1979). Hartman (1979) noted that manatees may rest up to twelve hours per day with individual resting bouts lasting 2-4 hours. They may need long periods of inactivity to conserve energy and digest food because they subsist on a low quality food source (Larkin et al. 2007), have a relatively low (Irvine 1983), and have a long gut retention time (Larkin et al. 2007). Choosing resting areas adjacent to foraging areas would conserve energy by reducing travel time.

There was significant heterogeneity within the adjacent and enclosed resting-hole location categories indicating additional factors may influence habitat use. Within the adjacent category, SWCS had a significantly higher number of manatees than LHOS. This location also has *Halodule wrightii* present – the seagrass species on which manatees selectively forage. The adjacency of a resting hole, seagrass bed and the presence of *H. wrightii* may make this location particularly important manatee habitat.

Within the enclosed category, location CCO, ESP, F1EN and HECO had a significantly higher number of manatees than BACO. Location ESP had the highest mean number of manatees and is one site within the study area where we have recorded low salinity levels (<20 ppt) indicating the possible presence of a freshwater source.

However, we have not definitively located a freshwater seep or spring at this location. Physiological experiments on captive manatees demonstrate that although they are good osmoregulators (Ortiz et al. 1999; Ortiz et al. 1998) when kept in saltwater and fed seagrass for nine days, they become susceptible to dehydration (Ortiz et al. 1998). In addition, nearly every study conducted on manatee habitat use, movement patterns and behavior suggests that manatees seek out freshwater (eg. Auil 2004; Deutsch et al. 1998; Deutsch et al. 2000; Lefebvre et al. 2001; Olivera-Gomez & Mellink 2005; Reynolds 1999; Reynolds & Odell 1991; Stith et al. 2004). If there is a freshwater source at this location, it is highly likely that it would be heavily utilized by manatees.

Additional sources of heterogeneity in resting hole use could be the result of the proximity to seagrass resources other than the seagrass growing in the seagrass beds. The diversity, biomass, percent cover and density of seagrass vary considerably on the bottom of the channels throughout the mangrove islands. We have observed manatees feeding on *T. testudinum* and *Halophila spp.* that grows along the banks of the mangrove shoreline and in patches on the bottom where it is sufficiently shallow for light to reach the seagrass (Self-Sullivan and LaCommare, unpublished data). Both HECO and CCO, sites with high numbers of manatees, are in close proximity (< 500 m) to seagrass patches growing in adjacent channels.

The presence of humans and watercraft may also influence habitat use. Manatees are known to shift behavioral activities as well as habitat use in response to human activity (Sorice et al. 2003). At Crystal River in Florida manatees tended to leave when boats arrived (Wooding 1997), avoided boats as the number of boats increased (Buckingham et al 1999) and increased the use of protected areas as number of boats and

swimmers increased (King 2002). Most seagrass beds in the Drowned Cayes are subject to watercraft usage and the three resting-holes (LHOS, SCW, SWCS) adjacent to seagrass beds are within the Swallow Caye Wildlife Sanctuary where human/boat/manatee interactions are controlled (Self-Sullivan 2008).

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Table 4.1. Results of our nested generalized linear model relating number of manatees (dependent variable) to resting-hole category and locations nested within resting-hole category (independent variables,  $n = 175$ ). Resting-hole categories: enclosed, lagoon, adjacent to seagrass bed. Parentheses indicate nested variable.

<b>Variables in the Model</b> <i>n = 301</i>	<b>Wald Chi-square</b>	<b>df</b>	<b>Significance</b>
<b>Dependent variable</b>			
Number of manatees			
<b>Independent variables</b>			
<u>Resting-hole category</u>	12.386	1	0.002
<u>Location (Resting-hole category)</u>	22.889	11	0.018
Location (enclosed)			
BACO* ( $n = 20$ )			
CCO ( $n = 27$ )	4.756		0.029
ESP ( $n = 21$ )	10.066		0.002
F1EN ( $n = 25$ )	7.740		0.005
G1EN ( $n = 21$ )	2.092		NS
GICR ( $n = 22$ )	0.878		NS
HECO ( $n = 33$ )	6.565		0.010
SU3 ( $n = 10$ )	0.963		NS
Location (lagoon)			
MALA* ( $n = 22$ )			
STLA ( $n = 21$ )	0.672		NS
CLA ( $n = 20$ )	0.551		NS
Location (adjacent to seagrass bed)			
LHOS* ( $n = 15$ )			
SCW ( $n = 22$ )	0.645		NS
SWCS ( $n = 22$ )	3.200		0.074

\*\* Reference Category

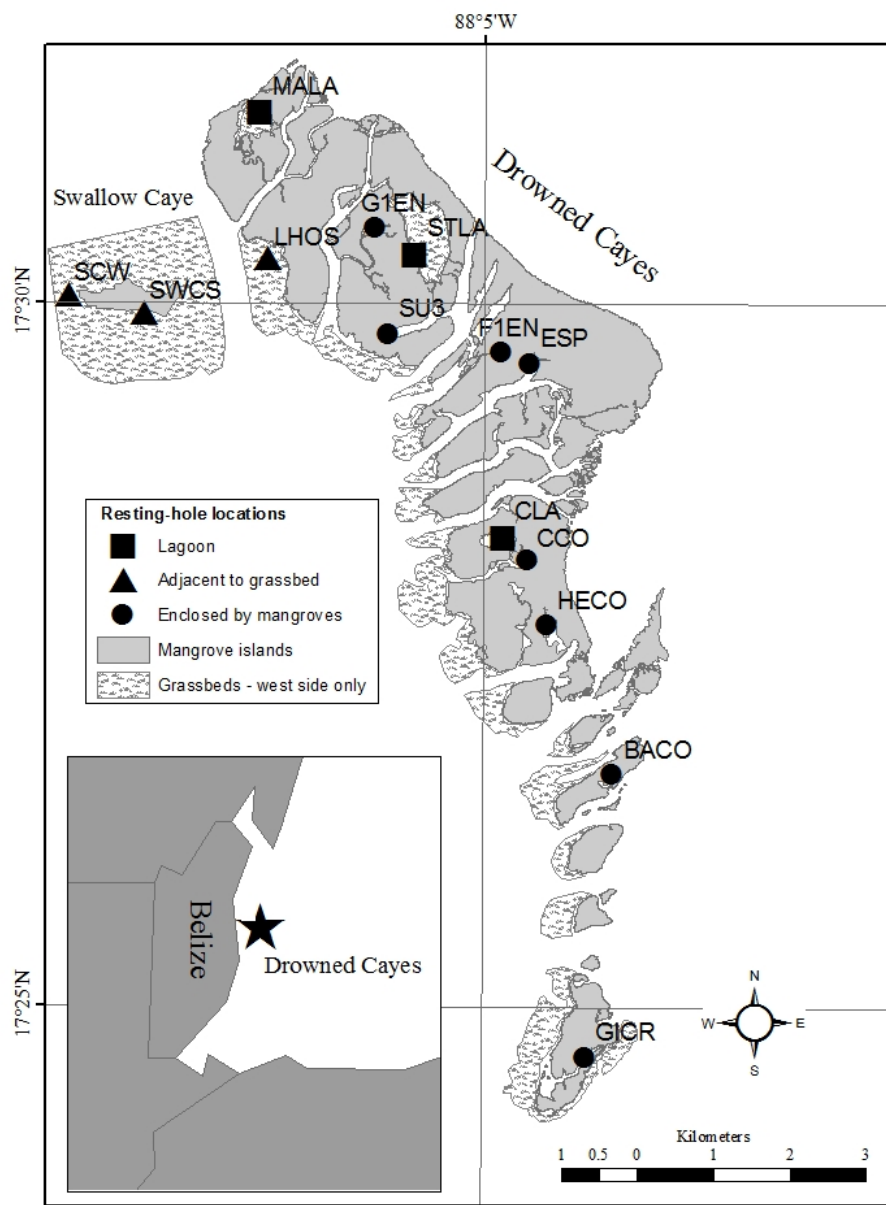


Figure 4.1. Map of the Drowned Cayes with resting-hole locations and seagrass beds.

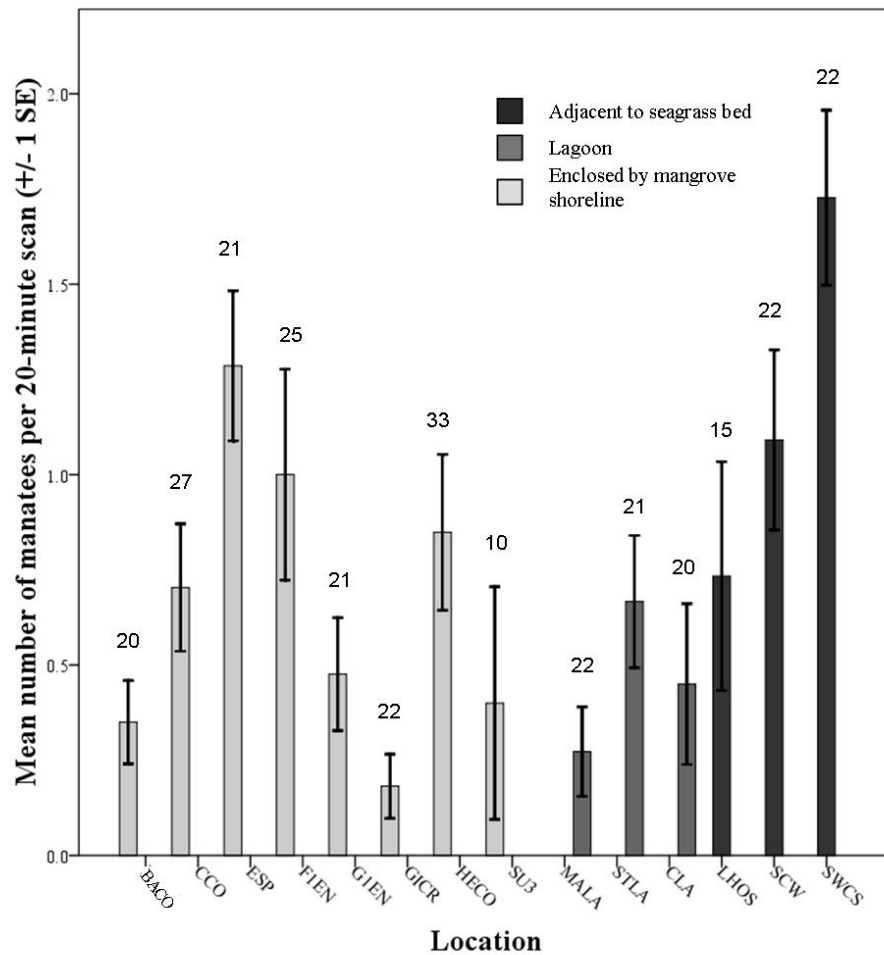


Figure 4.2. Number of manatees was not equal among resting-hole categories (Wald chi square = 12.386,  $p = 0.002$ ). Resting holes categorized as adjacent to seagrass beds had a significantly higher mean number of manatees than resting holes categorized as lagoons (Mean Difference = 0.78,  $p = 0.004$ ) and a marginally significant higher mean number of manatees than resting holes categorized as enclosed (Mean Difference 0.54,  $p = 0.056$ ). The parameter estimates indicate that SWCS had a significantly higher number of manatees than LHOS (Wald chi-square = 3.2,  $p < 0.074$ ). And, locations CCO, ESP, F1EN, HECO had a marginally significantly higher number of manatees than BACO (Wald Chi-square = 4.756, 10.066, 7.740, 6.5653.137,  $p = 0.0770.029, 0.002, 0.005, 0.010$  respectively Figure 3.2). Numbers above bars are sample sizes for each location. Error bars:  $\pm 1$  S.E.

## CHAPTER 5

### MANGROVE CLEARING AND BOTTOM DREDGING: HOW IS ANTILLEAN MANATEE (*TRICHECHUS MANATUS MANATUS*) HABITAT USE AFFECTED BY COASTAL DEVELOPMENT IN BELIZE?

**Abstract.** – The Antillean subspecies of the West Indian manatee (*Trichechus manatus manatus*) is a conspicuous component of the tropical coastal environment that comprises three principal ecosystems: mangroves, coral reefs, and seagrass. Removal of mangroves may alter adjacent seagrass and coral reef systems by changing sediment bacterial diversity, macrofaunal diversity, pore water nutrients, fish abundance, sedimentation rates, and algal biomass (Granek 2006). Because manatees rely heavily on seagrass (Alongi 2002; Auil 1998; Lefebvre et al. 2000; Mignucci-Giannoni 1998; Reid et al. 1999; USFWS 2001b), they may be negatively impacted by mangrove deforestation. The objective of this chapter is to determine how mangrove removal alters (1) seagrass characteristics such as density and percent bottom cover, (2) water transparency and (3) manatee habitat use. We determined the number of manatees, measured percent bottom covered by seagrass, counted seagrass shoot density and measured water transparency at three locations – one disturbed site (AGR) and two control sites (MUGR, DMO) – within the Drowned Cayes before and after a disturbance event. The mean number of manatees at location AGR did not decline after the disturbance (Likelihood = 0.036,  $df = 1$ ,  $p = 0.849$ ). There was a significant difference in mean water transparency before/after the disturbance ( $F = 6.889$ ,  $df = 2$ ,  $p = 0.012$ ) and a significant interaction between location and disturbance ( $F = 6.889$ ,  $df = 2$ ,  $p = 0.012$ ). AGR is the only location with a significant decline in mean water transparency after the impact event, but there was also a downward trend at MUGR. There were significant differences in mean percent bottom cover before/after disturbance ( $F = 18.548$ ,  $df = 1$ ,  $p = 0.001$ ) and a marginally significant interaction between location and disturbance ( $F = 3.025$ ,  $DF = 2$ ,  $p = 0.060$ ). AGR was the only location that had a significant decline in mean percent cover after the impact event. There was also a downward trend at DMO. This study highlights the importance of water quality and seagrass monitoring at potential development locations as well as already disturbed sites to assess the impact of disturbance to the seagrass and to manatees.

## Introduction

The Antillean subspecies of the West Indian manatee (*Trichechus manatus manatus*) is a conspicuous component of the tropical coastal environment which comprises three principal ecosystems: mangroves, coral reefs and seagrass. Mangroves may be the keystone habitat in this trio because when mangroves are removed adjacent systems - coral reefs and seagrass - are highly altered through changes in sediment bacterial diversity, macrofaunal diversity, pore water nutrients, fish abundance, sedimentation rates, and algal biomass (Granek 2006). Mangrove forests are also highly threatened; one-third of the global extent has been removed in recent decades (Alongi 2002). Manatees may be detrimentally affected by mangrove deforestation because they utilize mangrove watercourses and graze on seagrass growing alongside it (Alongi 2002; Auil 1998; LaCommare et al. 2008; Lefebvre et al. 2000; Mignucci-Giannoni 1998; Reid et al. 1999; USFWS 2001b).

The spatial propinquity of mangroves, seagrass and coral reefs has led many researchers to examine their ecological connections (see Ogden & Gladfelter 1983). More attention has been given to the linkages between coral reefs and mangroves, (e.g. Granek 2006) and coral reefs and seagrass (e.g. Mumby et al. 2004; Nagelkerken et al. 2002) than to the connectivity between mangroves and seagrass because of the ontogenetic and daily habitat shifts of reef fishes - many of which are commercially important species. The connection between mangroves and seagrass ecosystems is no less important.

Mangroves and seagrass are coupled through the bidirectional exchange of dissolved organic matter (DOM), particulate organic matter (POM), nutrients and sediment filtering (Bouillon et al. 2004; deBoer 2000; Hemminga et al. 1995; Hemminga et al. 1994; Hogarth 1999; Lee 1995; Slim et al. 1996). The relative amount of mangrove-derived carbon moving through the seagrass system is debated. Several authors have determined that the input of mangrove litter to an intertidal seagrass system was small (de Boer 2000; Lee 1995), but Bouillon et al. (2004) found that the contribution of mangrove organic matter to seagrass has been underestimated by previous studies and re-asserts the importance of mangrove detritus in seagrass systems. Spatially, the input of mangrove derived carbon in seagrass diminishes quickly with distance from the mangrove fringe (Bouillon et al. 2004; deBoer 2000).

Despite the clear exchange of organic matter between mangroves and seagrass, the importance of mangrove derived carbon on seagrass production and nutrient content is unclear. Some studies have shown that the influx of POM to seagrass from neighboring mangroves resulted in increases in leaf production or nutrient content in the adjacent seagrass (Hemminga et al. 1995). Other studies have shown that seagrass adjacent to mangrove communities have a higher nutrient content and greater primary production than seagrass further from the mangrove fringe (Koch & Madden 2001). If the presence of mangroves increases the nutrient content and productivity of seagrass, then the linkage between these systems could be particularly important to manatees.

These systems are also linked by the sediment filtering capacity of mangroves. Estuarine mangroves trap between 15-40% of riverine sediment (Kathiresan 2003; Victor et al. 2004), and during high tides, mangroves are known to trap suspended sediment

present in coastal waters (Furukawa et al. 1997; Wolanski et al. 1998). The sediment trapping capacity of mangroves is important because sedimentation and increased turbidity can reduce photosynthetic activity and disrupt seagrass growth (Granek 2006).

Although it is well recognized that these systems are linked, the question still remains: what is the impact of mangrove removal on these neighboring systems and manatee habitat use? Few studies have examined the impact of mangrove removal on either seagrass or coral reef systems. Granek (2002) determined that after mangroves were removed from areas at Turneffe Atoll in Belize sedimentation increased on adjacent patch reefs. She also found that algal biomass was higher in the waters adjacent to mangrove removal (Granek 2002). Others have found sediment bacterial diversity, macrofaunal diversity and pore water nutrients decreased after deforestation (Fondo & Martens 1998; Johnstone 1998; Sjöling et al. 2005). Fish abundance was lower in cleared areas in Kazi Bay, Kenya (Huxham et al. 2004). Studies have not investigated how seagrass might be impacted by mangrove removal but a decrease in seagrass growth can be hypothesized as a result of an increase in sedimentation, an increase in algae, and a loss of POM and DOM.

Manatees use mangrove areas to meet a variety of behavioral and physiological needs. They are found travelling, resting, socializing, and nursing in and among mangrove water courses (Charnock-Wilson 1968, 1970; Hartman 1979; USFWS 1996). In addition, West Indian manatees in the Drowned Cayes of Belize have been sighted feeding on the seagrass growing in close proximity to the mangroves (LaCommare and Sullivan, unpublished data). Mangrove removal may affect manatee habitat use due to the loss of habitat or from detrimental impacts to neighboring seagrass. If the amount or

quality of seagrass growing in close proximity to the mangroves deteriorates as a result of disturbance to the mangroves then manatee visitation may decrease. However, if the seagrass is unaffected by the nearby changes, then manatee habitat use may remain unchanged.

The objective of this study is to determine how seagrass characteristics - density and percent bottom cover, water transparency and number of manatees might change as a result of mangrove removal.

## **Methods**

### *Study area*

The Drowned Cayes are a string of mangrove islands along the central coast of Belize that lie 10-15 km east of Belize City and 5 km west of the Belize Barrier Reef (Figure 1.1 – Chapter 1). In recent years, several of these islands have been cleared in preparation for resort development. Mangrove clearing, channel dredging and island filling occurred in 2006 at location AGR - a manatee high-use location (LaCommare et al. 2008). Mangroves were cleared from a 9.75 acre island adjacent to this protected water course. Two small channels on either side of the island were dredged to accommodate boat traffic and the island was filled with the dredged material (Figure 5.1). This location has been monitored for manatees since 2000. There has been a 50% probability of sighting manatee during a 20-minute scan at this point prior to clearing and dredging (LaCommare et al. 2008). When manatees were sighted and their behavior discernible, there was a 55% probability that they were feeding on the turtle grass (*Thalassia*



*testudinum*) that grows monospecifically in the area (Sullivan and LaCommare, unpublished data).

#### *Experimental design and data analysis*

We conducted a before/after – control/impact study to determine if mangrove removal affected manatee habitat use and seagrass characteristics at one impacted location – AGR and two control locations – MUGR and DMO. These control locations were chosen because we had collected seagrass and manatee data at these places prior to the disturbance event.

We counted manatees using a point sampling survey design (referred to as point scans) conducted from a small watercraft – see chapters 2 and 6 for a detailed description of the survey method. Point scans were conducted at AGR, MUGR and DMO (Figure 5.1), from 2001-2005 (before impact) and then again in 2007 (after impact) to determine whether manatee occurrence and habitat use changed as a result of the disturbance. Spatial autocorrelation of the sites is not likely a problem because they are 0.5 to 2 km apart; they are separated by channels; MUGR and AGR are separated by mangrove islands.

We used a generalized linear model with negative binomial distribution and a log-link function to determine whether the number of manatees was dependent on location (control/impact) and disturbance (before/after impact). The negative binomial distribution is the most appropriate distribution to use for an over-dispersed (variance greater than the mean) Poisson distributed response variable - number of manatees (Agresti 1996; Quinn & Keough 2002). Manatee sighting data from the control locations

were pooled because preliminary heterogeneity testing indicated that manatee count frequencies were not significantly different between these locations and therefore could be pooled ( $G = 1.478$ ,  $p = .224$ ) (McDonald 2009).

We measured percent cover and density of turtle grass with a systematic random sampling design (Ramsey and Schafer 2002) within the impacted location AGR and control locations MUGR and DMO in 2000 - 2002 (before impact) and again in 2007 (after impact). Percent bottom covered with seagrass was measured using a 1 x 1 meter square divided into 100 smaller squares with white twine. Within each smaller square grass shoot presence was recorded. Percent bottom covered with seagrass was determined based on the number of smaller squares occupied within the 1 x 1 meter frame. Density of turtle grass was determined by counting the total number of shoots within a 0.25 by 0.25 meter frame. Water transparency was measured at the point location using a 20 cm Secchi disk deployed horizontally in the water column from either the bow or stern of the boat.

We used a general linear multivariate model (MANOVA) to determine whether dependent variables - mean percent cover, turtle grass shoot density and water transparency varied between independent variables – location (AGR, MUGR, DMO) and disturbance (before/after impact). MANOVA was chosen because it allowed us to consider several dependent variables simultaneously and accounts for possible correlation among them (Zar 1999). An arcsine transformation was performed on percent cover to normalize the distribution (Zar 1999). A priori contrasts tested the hypothesis that mean percent cover and shoot density at AGR would be lower than MUGR and DMO both before and after the impact due to manatee grazing at this site ( $p = 0.025$ ). Box's M and

Levene's statistics were used to test whether the data met the assumptions of equality of covariances and variances, respectively.

## Results

A total of 97 point scans were conducted at the three locations during the five years of sampling. The mean number of manatees sighted was 0.48 per 20 minute scan. Zero manatees were sighted during 66% of the scans; one manatee was sighted during 23.7% of the scans; 2-4 manatees were sighted during all other scans. When behavior was discernable, manatees were feeding 54% of the time and travelling 22% of the time. The number of manatees was higher at AGR than in the control sites (mean number of manatees = 0.73 per scan and 0.21 per scan,  $n = 48$  and  $49$ , respectively; Likelihood ratio = 9.247,  $df = 1$ ,  $p = < 0.002$ ). The number of manatees was independent of disturbance (Likelihood = 0.379,  $df = 1$ ,  $p = 0.538$ ) and the interaction term between location and disturbance was not significant (Likelihood = 0.036,  $df = 1$ ,  $p = 0.849$ , Figure 5.2).

The overall MANOVA determined that a significant amount of the variation was explained by location (Pillai's Trace  $F = 4.022$ ,  $df = 3$ ,  $p = < 0.002$ , AGR,  $n = 20$ ; DMO,  $n = 11$ ; MUGR,  $n = 13$ ), before/after disturbance (Pillai's Trace  $F = 8.358$ ,  $df = 3$ ,  $p = 0.0001$ , before,  $n = 18$ ; after,  $n = 26$ ) and the interaction terms (Pillai's Trace  $F = 2.608$ ,  $df = 3$ ,  $p = 0.024$ ,  $n = 44$ ).

Mean water transparency did not differ between locations ( $F = 0.713$ ,  $df = 2$ ,  $p = 0.497$ ,  $n = 44$ ) or before/after the disturbance ( $F = 6.889$ ,  $df = 2$ ,  $p = 0.012$ ). The interaction term between location and disturbance was significant ( $F = 3.737$ ,  $df = 2$ ,  $p = 0.033$ ) due to after-impact declines in transparency at disturbed location AGR and control

location MUGR. Mean water transparency decreased to 5.9 feet after the disturbance at AGR and 9.1 feet at MUGR. Mean water transparency increased to 10.2 feet at control location DMO (Figure 5.3). The mean Secchi depth corresponds to 10% of surface irradiance (SI).

Mean turtle grass shoot density differed significantly between locations ( $F = 9.116$ ,  $df = 2$ ,  $p = 0.001$ ,  $n = 44$ ), but not before/after the disturbance ( $F = 2.296$ ,  $df = 2$ ,  $p = 0.138$ ). A priori contrasts indicate that shoot density of turtle grass at impact site AGR (27 shoots per  $1/4\text{m}^2$ ,  $n = 20$ ) was less than that at control location MUGR (47 shoots per  $1/4\text{m}^2$ ,  $n = 11$ ; contrast estimate = 22.096,  $p < 0.0001$ ). The mean shoot density for AGR (27 shoots per  $1/4\text{m}^2$ ,  $n = 20$ ) was not less than mean shoot density for DMO (34 shoots per  $1/4\text{m}^2$ ,  $n = 11$ ) (contrast estimate = 9.949,  $p = 0.070$ ). The interaction term between location and disturbance was not significant (Figure 5.4).

Mean percent cover differed significantly between locations ( $F = 8.398$ ,  $df = 2$ ,  $p = 0.001$ ,  $n = 44$ ). A priori contrasts indicate that the mean percent cover for AGR (65.59 percent per  $\text{m}^2$ ,  $n = 20$ ) was less than MUGR (85.96 percent per  $\text{m}^2$ ;  $n = 13$ ; contrast estimate = 24.203,  $p < 0.0001$ ), but not less than DMO (68.31 percent per  $\text{m}^2$ ,  $n = 11$ ; contrast estimate = 11.638,  $p = 0.064$ ). There were significant differences in mean percent cover before/after disturbance ( $F = 18.548$ ,  $df = 1$ ,  $p = 0.001$ ) and the interaction term between location and before/after disturbance was marginally significant ( $F = 3.025$ ,  $df = 2$ ,  $p = 0.060$ ) due to a significant decrease in percent cover at impact location AGR (before = 85 % per  $\text{m}^2$ , after = 58% per  $\text{m}^2$ , Figure 5.5).

Box's M test rejected the equality of covariance matrices (Box's M = 69.99,  $p = 0.015$ ) signifying the variances of the dependent variables are not equal across groups.

Levene's test, which allows us to explore this more thoroughly, indicates that the error variance of turtle grass shoot density is not equal across locations ( $F = 3.394$ ,  $p = 0.012$ ). The shoot densities at AGR and DMO are lower and more variable than at MUGR. However, MANOVA is robust against inequality of covariances and variances (Quinn & Keough 2002).

## Discussion

The *Thalassia testudinum* growing at impact site AGR are probably stressed, but not dying from low light conditions created by sediment run-off from the cleared and filled neighboring island. Light is imperative for the growth and survival of seagrass (Hemminga & Duarte 2000) and a decrease in light availability is known to impact seagrass growth, architecture and physiology (Czerny & Dunton 1995; Erftemeijer & Lewis 2006; Kraemer & Hanisak 2000; Onuf 1996). Experiments that have exposed *T. testudinum* to severe, chronic light reduction – 10% of surface irradiance (SI) - have demonstrated that plants will begin to slow their growth and show signs of stress after just 1 month and will die after 10-18 months depending on the severity and periodicity of the shading. When this species was experimentally subject to severe, but periodic light limitations (less than 8% SI for less than 3 weeks) - which closely resemble natural pulsed run-off events – it was found to be both resistant and resilient to change (Kraemer & Hanisak 2000). Leaf carbohydrates concentrations and other physiological indicators did decrease, slightly, during reduced light exposure, but returned to normal shortly after shading was removed (Kraemer & Hanisak 2000). At AGR, percent bottom covered by seagrass did decrease significantly after a 6-10 month time frame. The mean Secchi

depth after disturbance was 5.9 feet – 10% SI. The average depth of this location is 6.7 feet. The turtle grass growing here is probably subject to pulsed shading episodes that drop incident light below 10% SI. The extent, duration and timing of our water transparency sampling were inadequate to determine the degree and periodicity of light reductions. Although it is possible that *T. testudinum* growing at the site has been impacted by decreases in water transparency, additional sampling is necessary to determine the extent of light reductions and impact to turtle grass growth and physiology.

It is not clear if the percent cover of turtle grass at the site will continue to decline. In Laguna Madre, Texas, seagrass distribution did not begin to change until two years after the chronic appearance of a brown tide which caused a light reduction – to a mean 15% SI - over the seagrass beds growing there (Onuf 1996). Since the fill from the island adjacent to AGR continues to be exposed to wind, rain and tidal influences, sedimentation persists. Therefore, reduced water transparency is also persistent. It is possible that the seagrass in the area is still being exposed to chronic and periodic light reductions which could cause continued declines in the percent bottom covered by *Thalassia testudinum* and shoot density.

Percent bottom covered by seagrass and shoot density also decreased at DMO, but not significantly. An explanation for this is not clear – 3 possibilities exist. (1) Manatee foraging increased. (2) There were localized changes in sedimentation and seagrass growth patterns. (3) Larger scale water quality changes are occurring throughout the Drowned Cayes. There is no evidence to suggest that there was an increase in the number of manatees or a change in manatee feeding patterns at seagrass bed DMO between 2002 and 2007 (LaCommare, unpublished data). Further research would need to

be done to test the second and third alternative hypotheses. One complication of this study was that DMO and MUGR are physiographically different from AGR. AGR is surrounded by mangrove shoreline; DMO and MURGR are not. In order to further differentiate the second and third alternative hypotheses, additional control sites should be chosen and examined.

AGR is an important foraging site within these islands (LaCommare et al 2008). Water transparency declines may have decreased percent bottom cover of *T. testudinum* growing there, but manatee habitat use does not appear to have changed. In Florida and Puerto Rico, manatees exhibit site fidelity to foraging locations (Koelsch 1997; Reid et al. 1999) which may explain why manatees may have continued to use this specific place even if the seagrass was degraded. However, without continued monitoring at AGR, it is not clear whether percent bottom covered by seagrass will continue to decline or if manatee habitat use may eventually change as a result of this development. Therefore, it is important to continue monitoring this site to assess the impact to seagrass and manatees.

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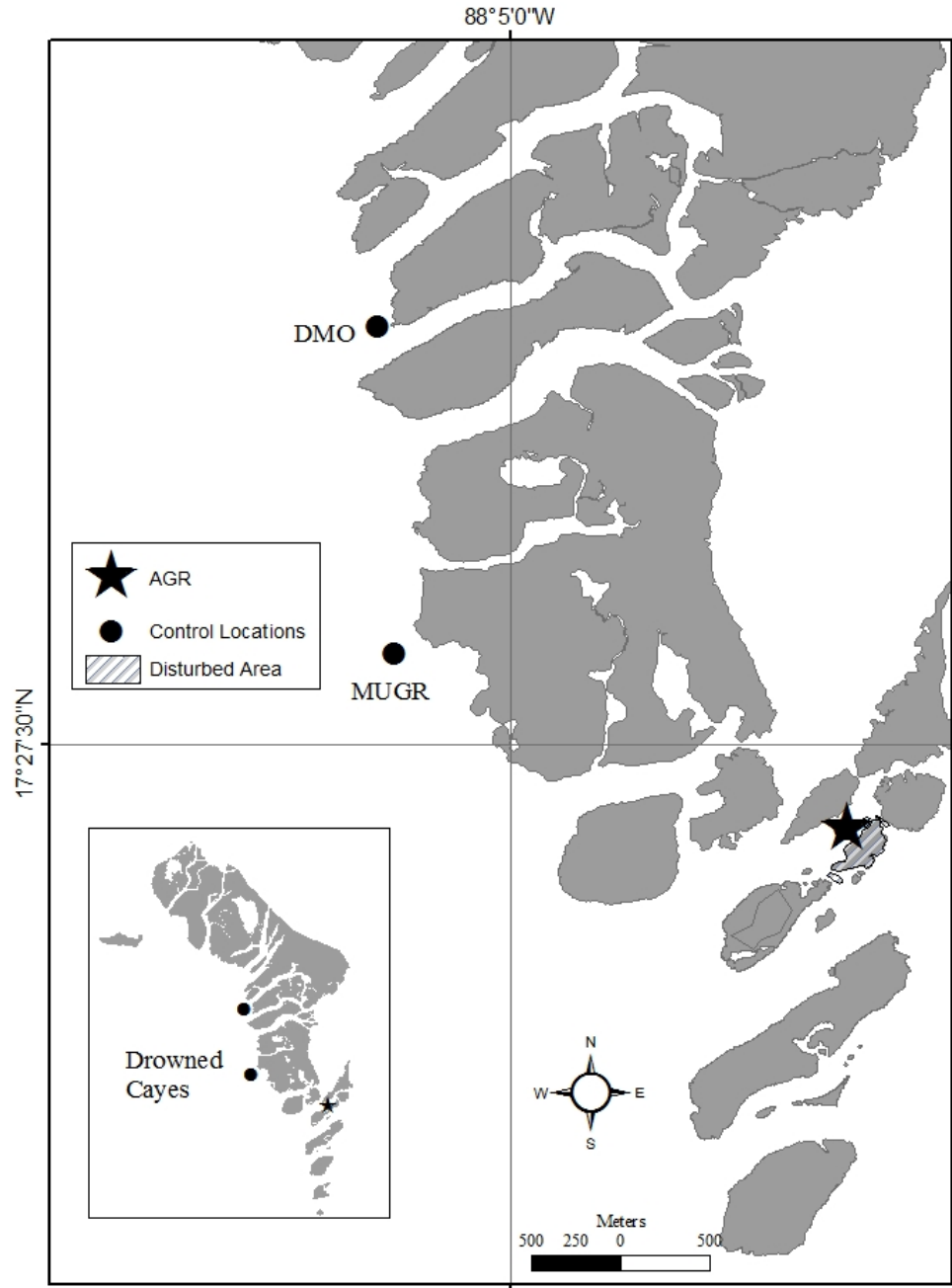


Figure 5.1. Map of the Drowned Cayes and sampling sites

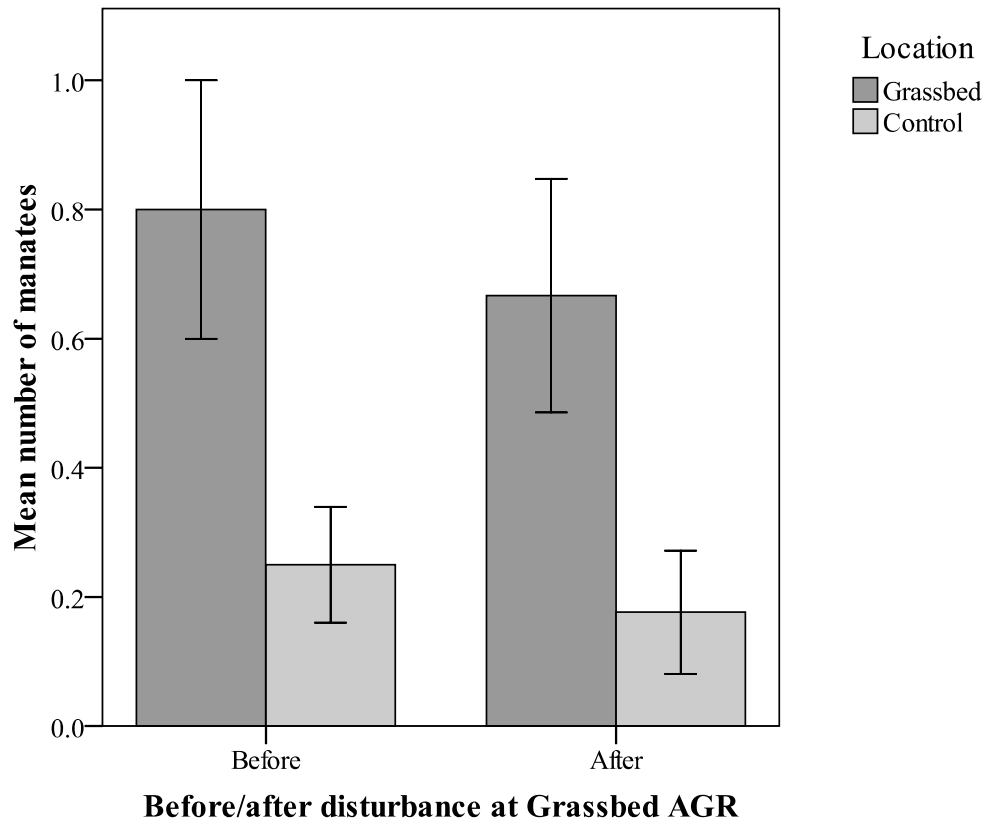


Figure 5.2. There was no significant decrease in the number of manatees sited at location AGR after the disturbance. Number of manatees was dependent on location (Likelihood ratio = 9.247,  $df = 1$ ,  $p = < 0.002$ ), but independent of year (Likelihood = 0.379,  $df = 1$ ,  $p = 0.538$ ). There was no interaction between location and year (Likelihood = 0.036,  $df = 1$ ,  $p = 0.849$ ).  $n = 97$  Error bars:  $\pm 1$  SE

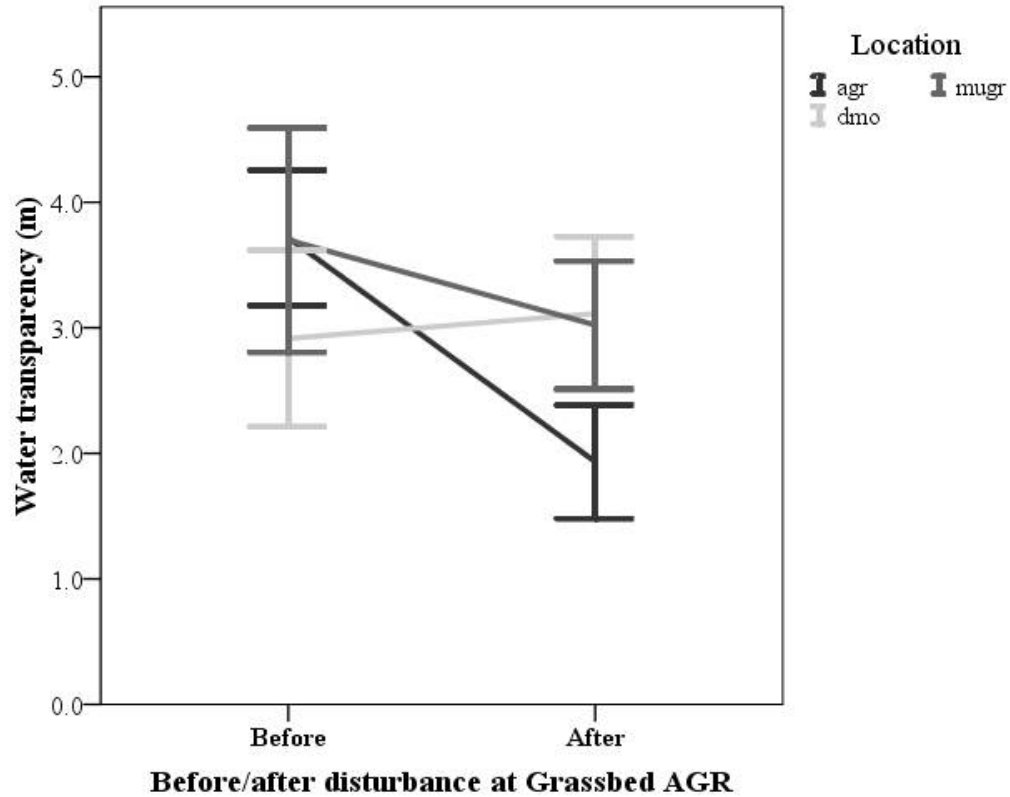


Figure 5.3. The interaction term between location and before and after disturbance was significant due to a significant decrease in mean water transparency at impact location AGR ( $F = 3.737$ ,  $df = 2$ ,  $p = 0.033$ ). Mean water transparency between locations were not significantly different ( $F = 0.713$ ,  $df = 2$ ,  $p = 0.497$ ,  $n = 44$ ); Mean water transparency before/after the disturbance was significant ( $F = 6.889$ ,  $df = 2$ ,  $p = 0.012$ ). Error bars: 95% CI

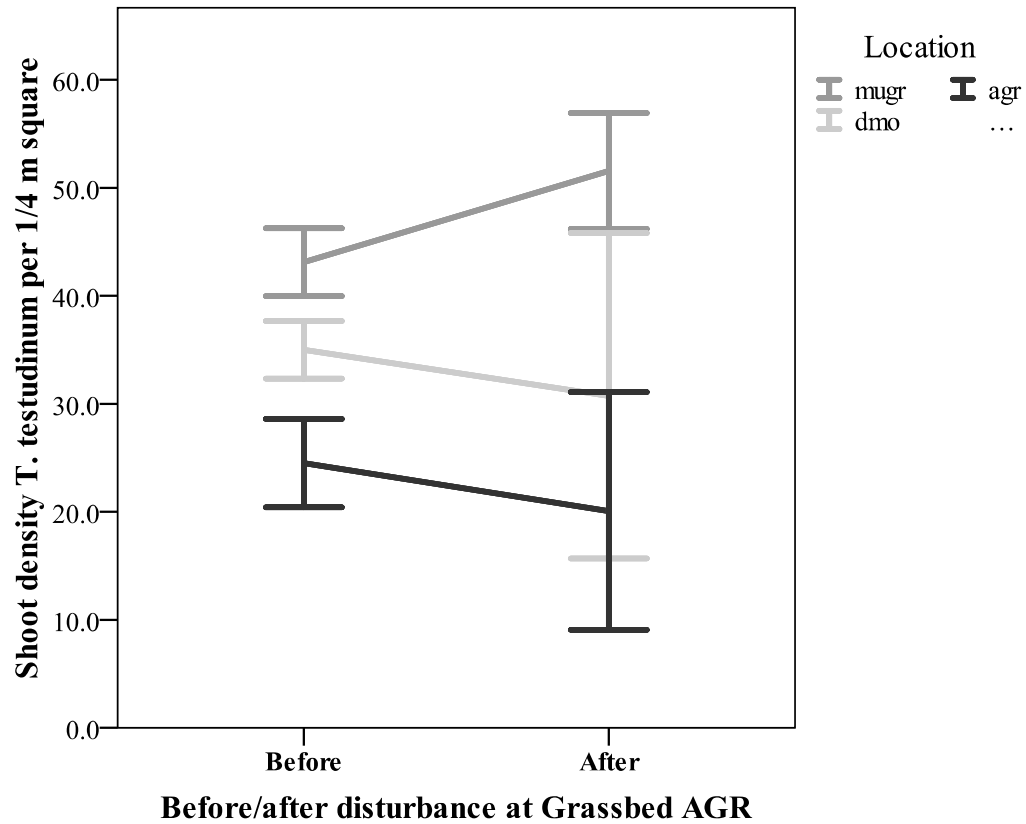


Figure 5.4. Mean turtle grass shoot density per  $\frac{1}{4}$  m square was significantly different between locations ( $F = 9.116$ ,  $df = 2$ ,  $p = 0.001$ ,  $n = 44$ ), but not before/after disturbance ( $F = 2.296$ ,  $df = 2$ ,  $p = 0.138$ ). The mean shoot density for AGR was less than shoot density for MUGR (contrast estimate = 22.096,  $p < 0.0001$ ). Mean shoot density of AGR was not less than that for DMO (contrast estimate = 9.949,  $p = 0.070$ ). The interaction term was not significant. Error bars: 95% CI

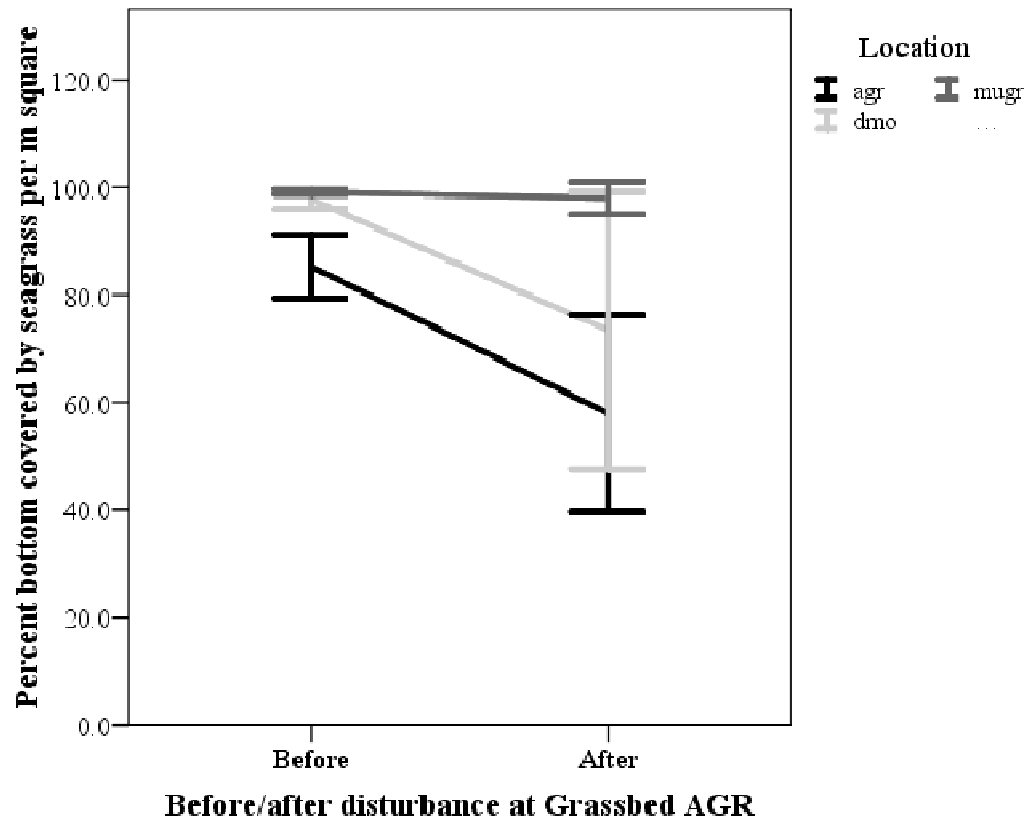


Figure 5.5. The interaction term between location and disturbance was marginally significant ( $F = 3.025$ ,  $df = 2$ ,  $p = 0.060$ ) due to a significant decrease in the mean percent cover after the disturbance event at impact location AGR. Mean percent cover was significantly different before/after the disturbance ( $F = 18.548$ ,  $df = 1$ ,  $p = 0.001$ ) and there were significant differences in mean percent cover between locations ( $F = 8.398$ ,  $df = 2$ ,  $p = 0.001$ ,  $n = 44$ ). A priori contrasts indicate that the mean percent cover for AGR was significantly smaller than the mean percent cover for MUGR (contrast estimate = 24.203,  $p < .0001$ ). Error bars: 95% CI

## CHAPTER 6

### A BOAT-BASED METHOD FOR MONITORING SIRENIANS: ANTILLEAN MANATEE CASE STUDY

**Abstract.** All four extant species in the order Sirenia are vulnerable to extinction and accurate monitoring is a critical step in evaluating the conservation and management needs of these species. We devised a relatively low cost, effective survey method for monitoring West Indian manatees (*Trichechus manatus manatus*) in Belize, Central America. The four objectives for this paper are (1) to evaluate a count-based population index derived from a boat-based survey method, (2) to examine trends in manatee abundance in the Drowned Cayes area, (3) to conduct a power analysis using simulation techniques to explore our ability to detect a trend and the ramifications of survey structure on trend detection. We used a boat-based point survey design to monitor manatee occurrence by counting the number of manatees sighted during a 20-minute period at designated locations throughout the Drowned Cayes area. We used a generalized linear model to determine whether number of manatees observed per 20-minute scan changed from 2001 - 2007. Following Taylor and Gerrodette (1993) and Gibbs (1998, 2000), we used a simulation technique to determine statistical power - the ability to detect potential declines of 10%, 25% or 50% over 15 years and for various sampling regimes. There was no change in the mean number of manatees sighted per scan from 2001 to the 2007 (Likelihood Ratio Chi-Square = 1.566, df = 1,  $p = 0.212$ ,  $B = -0.003$ ). Our ability to detect a trend ranged from 6 to 100% depending on the level of decline, scan duration, number of points surveyed and number of surveys. This survey protocol is a practical and repeatable way to examine population trends of sirenians around the world.



## **Introduction**

All four extant species in the order Sirenia are vulnerable to extinction due to small population sizes, population declines, fragmentation and continued exploitation (Deutsch et al. 2010; Lefebvre et al. 2001; Marsh & Lefebvre 1994). They are listed on the IUCN Red List (Deutsch et al. 2010) and protected by CITES (CITES 2010), the SPAW protocol (CEP 2010), the Memorandum of Understanding on the Conservation and Management of Dugongs (CMS 2010), the U. S. Endangered Species Act (USFWS 2001a), and other national and international wildlife protection laws (see Quintana-Rizzo & Reynolds 2008). For many populations of these species, little information exists on their status (e.g. Hines et al. 2005a; Lefebvre et al. 2001; Marsh & Lefebvre 1994; Quintana-Rizzo & Reynolds 2008). A preliminary step in determining conservation status, effects of exploitation and improving management decisions is monitoring (Gibbs 2000; Gibbs et al. 1998; Marsh & Trenham 2008; Martin et al. 2006) - the process of gathering data to draw inferences about population abundance changes over time (Yoccoz et al. 2001). Monitoring is listed as a key objective in most manatee and dugong conservation and management plans (eg. Auil 1998; CEP 1995; USFWS 2001a).

As others have pointed out,” the need for high quality data is clear, the means for getting it is not (Dawson et al. 2008, p. 20; USFWS 2001a),” especially for small populations of marine mammals that live in complex coastal and riverine habitats – conditions that constrain survey designs (see Dawson et al. 2004; Dawson et al. 2008; Dick & Hines in prep; Hines et al. 2005b; Williams & Thomas 2009). A well designed monitoring program requires two key components: a reliable population index and a

powerful statistical analysis. Indices are the proxy for population abundance (Caughley 1977; Gibbs 2000; Kindberga et al. 2009) and are based on the premise that systematic surveys will detect the same proportion of the population over time. Thus, changes in the number of animals detected reflect changes in population size (Gibbs 2000). To be a good surrogate to population size, an index must have a positive, constant relationship between the surrogate and actual abundance (Gibbs 2000; Gibbs et al. 1998; Williams & Thomas 2009), 2) and a constant detection probability over habitat, sighting conditions and time (Anderson 2001; Gibbs 2000; Gibbs et al. 1998; Thompson 2004; Williams & Thomas 2009).

Detecting trends in abundance depends on statistical power (Gerrodette 1987; Gibbs 2000; Gibbs et al. 1998; Taylor & Gerrodette 1993) and an effective monitoring program must generate data that can be statistically analyzed to detect trends (Gibbs 2000; Gibbs et al. 1998). Both the accuracy of the population index and sampling structure – number of plots, survey frequency, scan duration, number of years – will impact the ability to detect changes in population abundance. Power analysis, through simulation techniques, is the process used to determine the statistical power of an index and sampling regime (Gerrodette 1987; Gibbs 2000; Gibbs et al. 1998; Taylor & Gerrodette 1993).

Most populations of sirenians are found in developing nations where monitoring funds are scarce. To be valuable, monitoring methods must be sound, repeatable and inexpensive (Aragones et al. in press; Aragones et al. 1997; Dick & Hines in prep; Hines et al. 2005a; Williams & Thomas 2009). This paper introduces a low cost and repeatable boat-based method for monitoring sirenians. We used this method on West Indian

manatees (*Trichechus manatus manatus*) in the Drowned Cayes area of Belize, Central America and examined trends in manatee abundance from 2001-2007. Using simulations, we conduct a power analysis to determine trend detection ability and the ramifications of sampling structure on trend detection.

## **Materials and Methods**

### *Study area*

The Drowned Cayes including Swallow Caye are a string of mangrove islands -14 km long by 4 km wide - along the central coast of Belize, 10-15 km east of Belize City and 5 km west of the Belize Barrier reef (Figure 1.1 – Chapter 1). The study area also encompasses two points along the Belize Barrier Reef. Prior to this study, aerial and boat surveys documented this area has a consistent population of manatees (Auil 2004; Bengston & Magor 1979; Morales-Vela et al. 2000; O'Shea & Salisbury 1991, Self-Sullivan and LaCommare, unpublished data).

### *Survey design*

We devised a point-based survey design to monitor manatee occurrence by counting the number of manatees sighted during a 20-minute period at designated locations throughout the Drowned Cayes area (Figure 6.1). We marked with a global positioning system (GPS) 54 permanent points throughout the study area and used a small (20-25 ft) skiff to survey the points on a regular basis. To minimize boat and engine-noise disturbance to the manatees, we maneuvered the boat with a pole when we were within 100 meters of the exact point location. During this time, 3 - 13 observers started scanning for manatees. Three experienced observers were on the boat at all times. The number of inexperienced,

but trained observers, ranged from 0 to 10. Once anchored in position with the pole, observers searched for manatees in a 360° circle around the boat. From 2001-2007, we conducted these searches, called point scans, 4 - 8 times per year during two-week survey sessions and sampled the points without replacement for the two-week period. Since not all points could be surveyed in one day, we divided the study area into 8 zones with 4 – 6 points each. Each day, we randomly chose the survey zone and starting point and then surveyed 4 – 5 points.

#### *Index and detection probability*

Our population index is the number of manatees sighted per 20-minutes per point. A valid population index must have a constant, linear relationship with manatee abundance. Two conditions can violate this relationship. When using call indices (indices that rely on animal calls such as frog calls or bird songs) or presence/absence data (Gibbs 2000; Gibbs et al. 1998), high population densities have an asymptotic relationship between the index and abundance. Low population densities can have threshold below which animals will not be detected (Gibbs 2000; Gibbs et al. 1998).

We are assuming that our index has a constant, linear relationship with manatee abundance and that this assumption is justifiable because we are not using presence/absence data or call indices. Since we are evaluating population declines rather than population increases, we are more concerned with the problem of a bottom threshold than population saturation. This point-based method has been successfully utilized to locate and count small and sparse populations of manatees in Volta Lake, Ghana, Estero Hondo, Dominican Republic, and Lake Ossa, Cameroon (Self-Sullivan, personal

communication; Dominquez, personal communication) indicating that manatees can be detected with this method at low population densities.

The relationship of the index to the actual number of animals counted is also a function of detection probability (Anderson 2001; Gibbs 2000; Gibbs et al. 1998; Thompson 2004; Williams & Thomas 2009) – the ability to detect an animal when it is present (MacKenzie & Royle 2005). There are three classes of variables that impact this: observers, environment and the species behavior. For each point scan, we counted the number of manatees and recorded variables that might influence detection probabilities. We used a generalized linear model (GLM) with a negative binomial distribution and a log-link function to determine whether the number of manatees sighted was influenced by sighting conditions. The negative binomial distribution was the most appropriate distribution to use for our over-dispersed (variance is greater than the mean) Poisson-distributed response variable – number of manatees (Agresti 1996; Quinn & Keough 2002). Our predictor variables are: number and experience of observers (number of volunteers and total number of observers), environmental conditions (sun glare - yes/no, precipitation -dry/light rain/heavy rain, cloud cover -clear/scattered clouds/partly cloudy/overcast, Beaufort sea state -0/1/2/3, swell height -in 0.15m increments), and manatee behavior (disturbed/feeding/resting/social/travel/ undetermined - Table 6.1). We did not take into account seasonality because previous analyses indicate that there is no difference in seasonal sighting probability (LaCommare et al. 2005; Self-Sullivan 2008).

### *Trends of manatee counts in the Drowned Cayes*

We used a GLM with negative binomial distribution and a log-link function to determine whether there was a change in the number of manatees per 20-minute scan from the first survey period in 2001 – to the last survey period in 2007. 42 survey periods were conducted over 79 months from 2001-2007. Each survey period was numbered from 1 to 79 based on the month in which the survey occurred and time of survey was included in the model as a covariate.

### *Power analysis of trend data*

We used simulations - following Taylor and Gerrodette (1993) and Gibbs (1998, 2000) - to determine the statistical power of our ability to detect a trend. We fit a negative binomial distribution to our manatee count data from our 20-minute scans for the whole 2001 - 2007 period. Using the parameters from this distribution, we generated a random array of the number of manatees for 28 sample points for each of 6 two-week survey periods per year. The potential number of manatees sighted was truncated at 5 since we only had 1 sighting with greater than 5 manatees in 7 years. We chose this sampling regime because this most closely resembled our annual survey structure from 2001 – 2007. We repeated this process for 15 “years”. Then using a GLM with a negative binomial and a log-link function, we examined whether we could detect a decline in the number of manatees over that 15 year period. We generated our random array and ran our GLM 1000 times to determine our ability to detect each of three potential linear declines in the number of manatees at the end of these 15 years: slight (10%), moderate (25%) and precipitous (50%). These declines are equivalent to a 0.7%, 1.7% and 3.6% annual decrease in the

number of manatees sighted per 20-minute scan (Table 6.2). Taylor et al. (2007) defined a precipitous decline in marine mammal abundance as a 50 percent decline after 15 years.

#### *Power analysis of sampling design*

Survey structure affects variability in detection probability and therefore statistical power (Gibbs 1998, 2000). Number of plots, sampling frequency, sampling interval and scan duration interact to influence statistical power and needs to be considered when designing a monitoring protocol. These factors also influence the cost of monitoring. Therefore, determining the most efficient experimental design can be critical to carrying out an effective monitoring program. In the field, we sampled approximately 28 of our 54 points during two-week survey periods, 4-8 times per year. Each point was scanned for a 20-minute duration. A fraction of the point scans were scanned for 30 minutes. This increased the likelihood of sighting a manatee or additional manatees during any one point scan (LaCommare and Self-Sullivan, unpublished data), but decreased the number of points that could be sampled in any one day and during a two-week survey period. How does a 30-minute scan duration with fewer samples impact our ability to detect a trend? Using data that we collected from our 30-minute scans, we generated new negative binomial distribution parameters and a new random array of the number of manatees for 21 sampling points per two-week survey period for 6 survey periods per year and repeated our power analysis as described above (Table 6.2).

In the Drowned Cayes, 28 out of 54 point scan locations have a greater than 30% probability of sighting a manatee (Chapter 2, LaCommare et. al, 2008). Would restricting our survey protocol to locations with a higher sighting probability yield a

greater ability to detect a trend? We generated new negative binomial distribution parameters using our manatee count data from 2001 - 2007 from locations with a greater than 30% probability of sighting a manatee (Chapter 2, LaCommare et. al 2008). Using these parameters, we generated a new random array of the number of manatees for 28 sampling points for 6 two-week survey periods. We repeated our power analysis as described above. From that distribution, we also created an array of the number of manatees for 8 two-week survey periods with both 28 and 21 points (Table 6.2).

## **Results**

We conducted 960 20-minute scans during 42 survey periods from 2001 - 2007. The number of manatees sighted per scan ranged from 0 to 6. Mean number of manatees sighted per scan was 0.54 (0.89 SD) (Figure 6.2 Mean number of manatees per survey period ranged from 0.21 to 1.08 manatees per 20-minute scan. Yearly averages ranged from 0.33 manatees per 20-minute scan in 2002 to 0.71 manatees per 20-minute scan in 2001 (Figure 6.3).

### *Index and encounter probability*

The number of manatees sighted per scan was not affected by sighting conditions (overall Likelihood Ratio Chi-Square = 6.626, df = 21,  $p = 0.999$ ,  $n = 216$ ). None of the individual factors or covariates had a significant influence on the number of manatees sighted per scan (Wald Chi Square ranged from 0.034 to 3.631, df ranged from 1-7,  $p$ -values ranged from 0.494 to 0.973). Of all of the subcategories, only social behavior increased the mean number of manatees sighted at a marginal level of significance (Wald Chi Square = 3.082,  $p = 0.079$ ,  $n = 5$ ). None of the other subcategories had a significant



effect ( $p$ -values ranged from 0.494 to 0.999, Table 6.1). We observed very few instances of social behavior (LaCommare and Sullivan, unpublished data). We did not include it as an offset variable in our trend model because it was not clear if the mean number of manatees was greater when social behavior was present or if social behavior increases detectability (LaCommare and Sullivan, unpublished data).

#### *Trends of manatee counts in the Drowned Cayes*

There was no change in the mean number of manatees sighted per scan from the first survey period in 2001 to the last survey period in 2007 (Likelihood Ratio Chi-Square = 1.56,  $df = 1$ ,  $p = 0.212$ ,  $B = -0.003$ , Figure 6.3).

#### *Power Analysis*

Using a 20-minute scan duration, 28 points per two-week survey period, and 6 two-week periods, we were able to detect a 10% decline in number of manatees within a 15 year time frame 10% of the time, a 25% decline 51% of the time and a 50% decline 100% of the time (Table 6.2).

#### *Power Analysis of sampling design*

Using a 30-minute scan duration, 21 points per two-week survey period, and 6 two-week periods, we were able to detect a 10% decline in number of manatees after a 15 year time frame 8% of the time, a 25% decline 34% of the time, a 50% decline 99% of the time (Table 6.2).

Using a 30-minute scan duration, 28 points per two-week survey period, an average of 6 two-week periods per year and choosing only locations that had a greater than 30% probability of sighting a manatee, we were able to detect a 10% decline in

manatees after a 15 year time frame 11% of the time, a 25% decline 57% of the time, a 50% decline 100% of the time (Table 6.2). The power to detect a trend if we fielded 8 two-week survey periods and sampled 28 points per period was 16, 71 and 100% (Figure 6.4, Figure 6.5, Table 6.2) and the power to detect a trend if we fielded 8 two-week survey teams and sampled only 21 points was 14, 60 and 100% (Table 6.2).

## **Discussion**

We did not detect a change in manatee abundance in the Drowned Cayes area of Belize between 2001 and 2007. Although we have a limited ability to detect moderate or slight declines, our power analysis indicates that we would be able to detect a precipitous decline after 15 years of surveys. Taylor et al. (2007) found that most marine mammal monitoring programs had a low power (0-50%) to detect precipitous declines in abundance. Hatch (2003) suggested that a 90% power to detect a 50% decline over 10 years as a good benchmark for seabirds. Our survey design yielded a 100% power to detect a precipitous decline after 15 years and a 51% probability of detecting a moderate decline.

Although our monitoring protocol would be able to detect a precipitous decline, even slight declines in manatee abundance should trigger conservation actions because small populations are susceptible to extinction over short time horizons (Williams & Thomas 2009). This raises the question: “what is an ecologically significant population trend (Seavy & Reynolds 2007)?” In the case of manatees, Marmontel (1997) determined through a population viability analysis for Florida manatees, starting with a population of 2000 individuals, a 10% increase in adult mortality or a 10% decrease in

reproduction could lead to an annual rate of population decrease of 0.6% and 1% respectively and extinction within 1000 years. This is roughly equal to our slight and moderate declines and our monitoring program has a limited ability to detect slight declines.

Our index – number of manatees per 20 minutes of scan effort per location - is a good proxy to manatee abundance. However, there is considerable debate regarding the validity of population indices in comparison to population estimates - the former characterized as estimating relative abundance, the latter absolute abundance (see Thompson 2004; Williams & Thomas 2009). Several authors caution against the use of indices in favor of more robust estimating procedures such as distance sampling or mark-recapture procedures (e.g. Anderson 2001; Williams & Thomas 2009). Yet, as long as the population index is linearly related to absolute abundance and detection probabilities are constant over space and time, count-based indices are valid (Skalski et al. 1983; Thompson 2004; Williams & Thomas 2009). Based on our analysis of possible influences on detection probability, we feel confident that the relationship between our index and population abundance is constant over conditions and time because observer experience, environmental conditions and manatee behavior do not significantly influence number of manatees sighted. But, validation studies should be conducted to confirm that our index has a linear and constant relationship to actual manatee abundance and does not have either saturation or threshold levels beyond which trends cannot be detected.

Survey structure - number of plots, sampling frequency, sampling interval and scan duration - affects variability in detection probability, statistical power (Gibbs 1998,

2000). It also affects monitoring costs. Survey structure needs to be considered when designing a monitoring protocol. Choosing points that had a greater than 30% probability of sighting a manatee, 30-minute scan duration and visiting 28 points per survey period, 8 times per year yielded the best power, 71% and 100%, for moderate and precipitous declines after 15 years. We would be able to detect a precipitous decline after just 10 years, but detecting a moderate decline 90% of the time may take 20 years. None of our sampling regimes had significant power to detect slight declines.

Species behavior and severely limited resources hamper the ability to conduct robust estimating procedures on Antillean manatees and other sirenians in developing nations (Aragones et al. in press; Aragonés et al. 1997; Dawson et al. 2008; Dick & Hines in prep). Using 30-minute point scans from a small boat platform is an effective and repeatable method for monitoring manatees and dugongs around the world. Distance sampling requires the ability to consistently measure the distance from the observer to the animal using a range finder, reticulated binoculars or spotting scope (Buckland et al. 2001). Sirenians often surface very briefly and only expose their nose to the surface when breathing. In our study, even the best trained observers captured distances only 10% of the time (LaCommare and Sullivan, personal observation). Mark-recapture methods are equally challenging. Because manatees in Belize (and other developing nations) are not scarred by boats to the same extent as manatees in Florida, photo-identification of manatees in Belize requires underwater video capturing techniques. This involves considerable time and effort by the observer and does not always yield individual identification due to lack of natural markings and/or poor visibility (LaCommare and Sullivan, personal observation). Like distance sampling, photo-

identification requires considerable observer training. Equipment and observer training may price monitoring programs out of reach of most wildlife and conservation agencies in developing nations (Aragones et al. in press; Aragones et al. 1997). When management agencies utilize locals (e.g. local fishermen) in conservation and monitoring programs, boat surveys are appropriate because they require little training (Aragones et al. in press; Self-Sullivan 2008).

To ensure the greatest success in a monitoring program, pilot studies are highly recommended (Aragones et al. in press; Buckland et al. 2001; Gibbs 2000; Gibbs et al. 1998; Scheiner & Gurevitch 2001; Thompson 2004). Local knowledge can be utilized in pilot studies to locate high use areas in a short period of time – e.g. 1 year (Self-Sullivan and LaCommare, personal observation). Utilizing locals and local knowledge in research programs also has the effect of improving success in corollary conservation programs - e.g. poaching reduction programs (Aragones et al. in press; Kendall 2009).

In addition to being a practical and repeatable way to examine population trends, boat surveys can be used to assess spatial distribution (LaCommare et al. 2008) and habitat use (LaCommare et al. 2008 Self-Sullivan 2007, also see chapter 3 and 4).

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Table 6.1. Results from the GLM relating number of manatees to variables that may influence detection probability ( $n = 216$ ). Dependent variable is number of manatees. Independent variables are number of volunteers, total number of observers, precipitation, cloud cover, sea state, swell height and behavior.

Variables in the Model <i>n = 216</i>	Wald Chi-square	df	Significance
<b>Dependent variable</b>			
Number of manatees			
<b>Independent variables</b>			
<u>Observer variables</u>			
Number of volunteers	0.114	1	NS
Total number of observers	0.468	1	NS
<u>Sighting condition variables</u>			
Precipitation (subcategories: dry/light rain/heavy rain)*	0.806	2	NS
Cloud cover (subcategories: clear/partly cloudy/overcast)*	0.226	2	NS
Sea state (subcategories: Beaufort scale – 0/1/2/3)*	0.442	3	NS
Swell Height	0.113	1	NS
<u>Manatee Behavior</u>	0.108	1	NS
Behavior**	3.631	7	NS
(subcategories: disturbed/feeding/milling/other/rest/social/travel/)			
Subcategory: social behavior	3.082	1	0.079

\*No significant subcategories \*\* No other subcategories significant

Table 6.2. Simulation results: Percentage of declines detected (in bold italics) for five different sampling regimens and three different levels of decline, assuming a perfectly consistent relationship between population index and actual abundance (1000 runs for each simulation). Scan duration indicates whether the negative binomial distribution parameters were generated from 20 or 30-minute scans. Number of points indicates the number of points used to create the array of manatee sightings for the simulation models (parentheses indicates which points were used to generate the negative binomial distribution parameters). Number of two-week survey periods indicates the number of survey periods used in the simulation. We ran our simulation for three potential declines in the number of manatees after 15 years: 10%, 25% and 50%. These declines are equivalent to a 0.7%, 1.7% and 3.6% decrease in the number of manatees sighted per scan per year.

Sampling Regime					
Scan Interval	20-minute scan	30-minute scan			
Num. of two-week survey periods	6	6	6	8	8
Num. of points (Points used to generate negative binomial distribution parameters.)	28 points (from all points)	21 points (from all points)	28 (from points with >30 % sighting probability)	28 (from points with >30 % sighting probability)	21 (from points with >30 % sighting probability)
Results					
<b>10%</b>	10	8	11	16	14
<b>25%</b>	51	34	57	71	60
<b>50%</b>	100	99	100	100	100



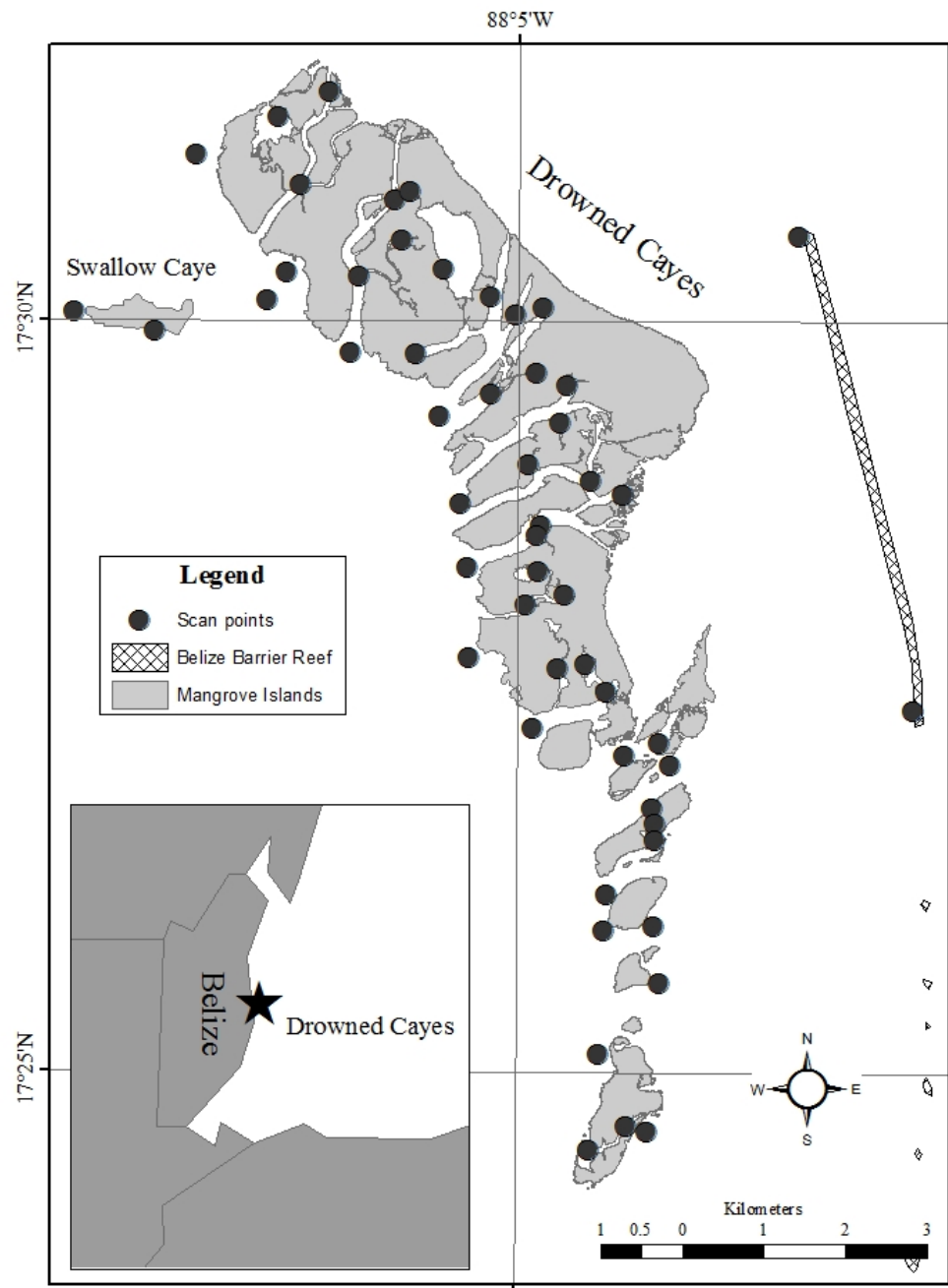


Figure 6.1. Map of the Drowned Cayes area and scan points

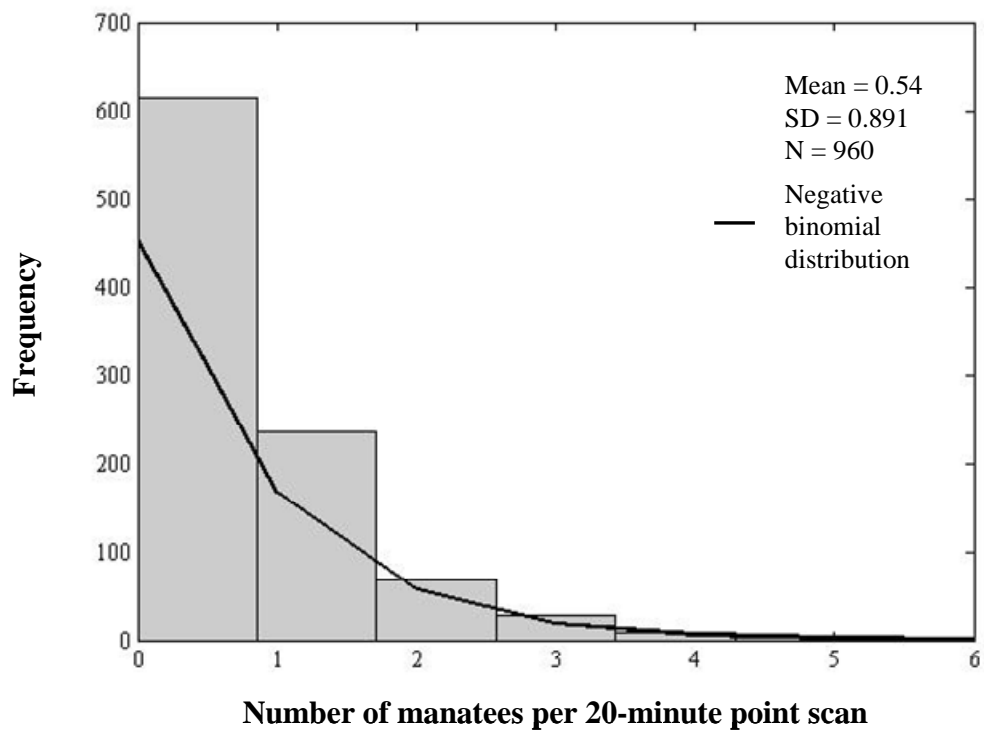


Figure 6.2. Histogram of number of manatees counted per 20-minute point scan (mean = 0.54, SD = 0.891, n = 960) with negative binomial distribution (solid line).

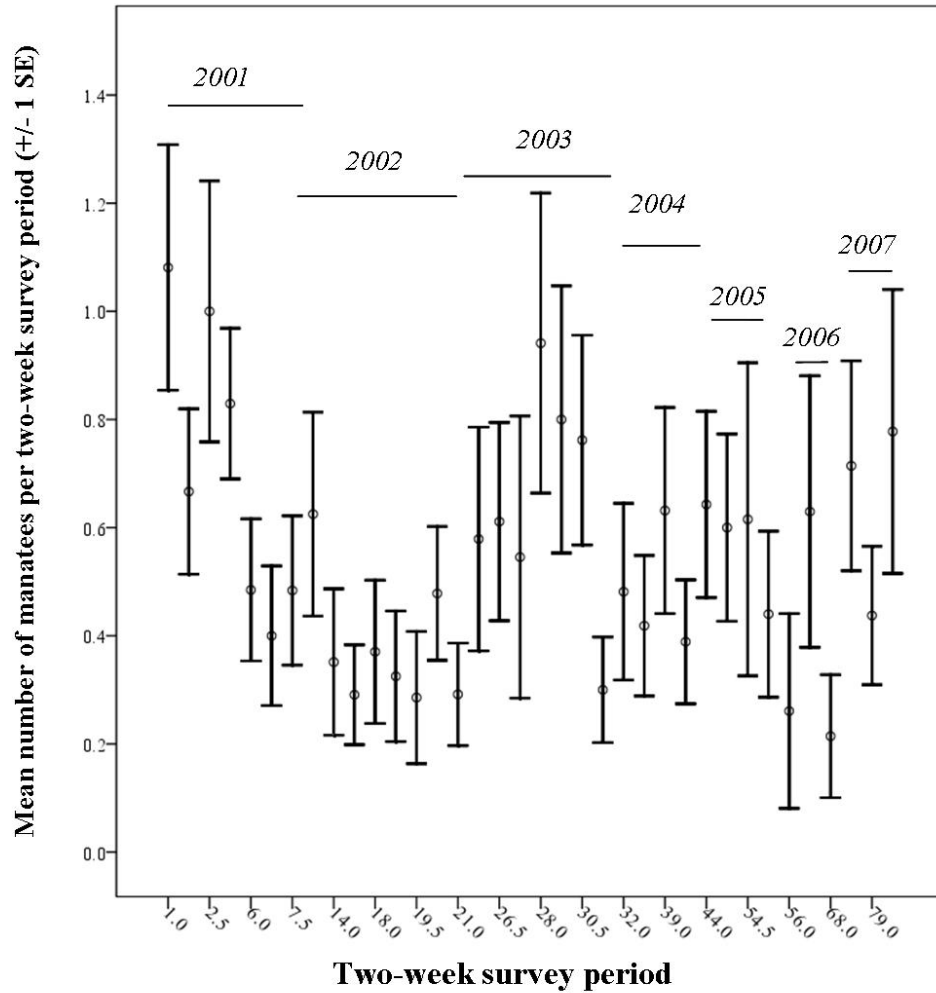


Figure 6.3. Mean number of manatees sighted per 20-minute scan did not change from 2001-2007 in the Drowned Cayes area of Belize (Likelihood Ratio Chi-Square = 1.56,  $df = 1$ ,  $p = 0.212$ ,  $B = -0.003$ ,  $n = 960$ ). Error bars:  $\pm 1$  SE

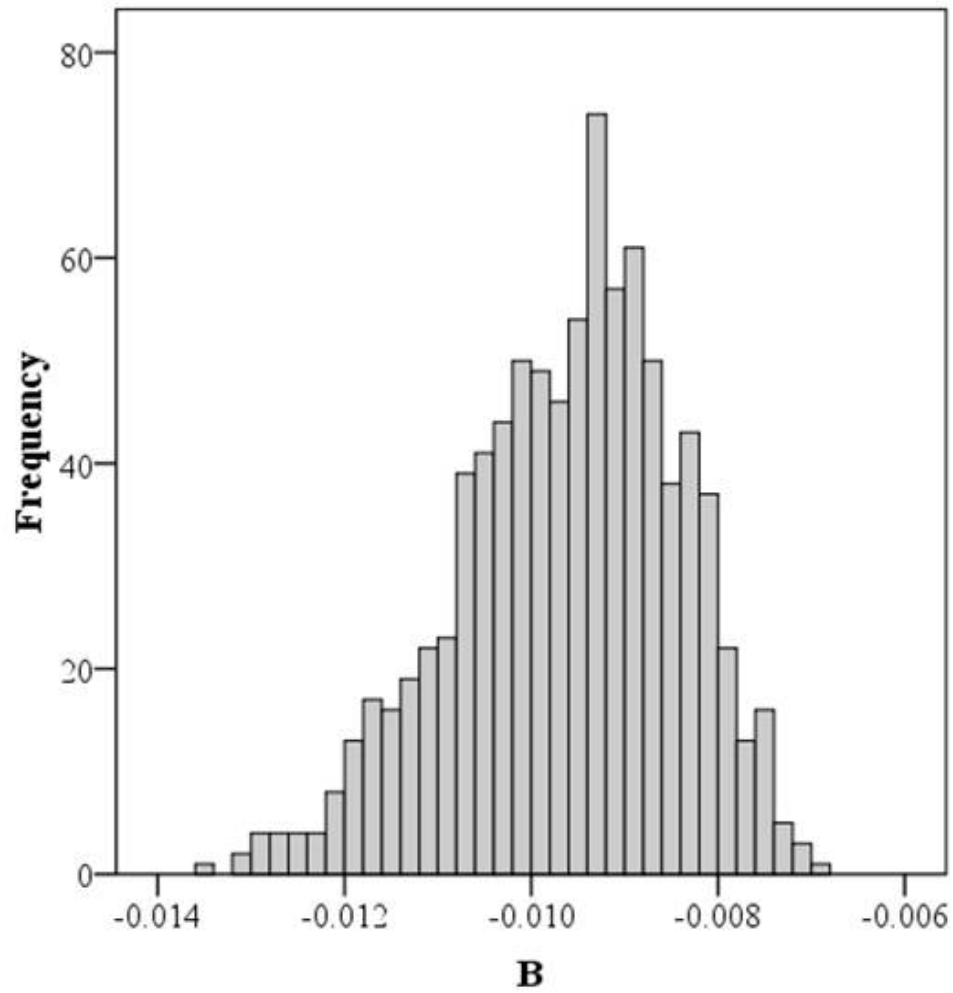


Figure 6.4. Histogram of B values for 25% decline in the number of manatees over 15 years - 30-minute scan, 28 points, points had a >30% probability of sighting a manatee and 8 two-week survey periods.

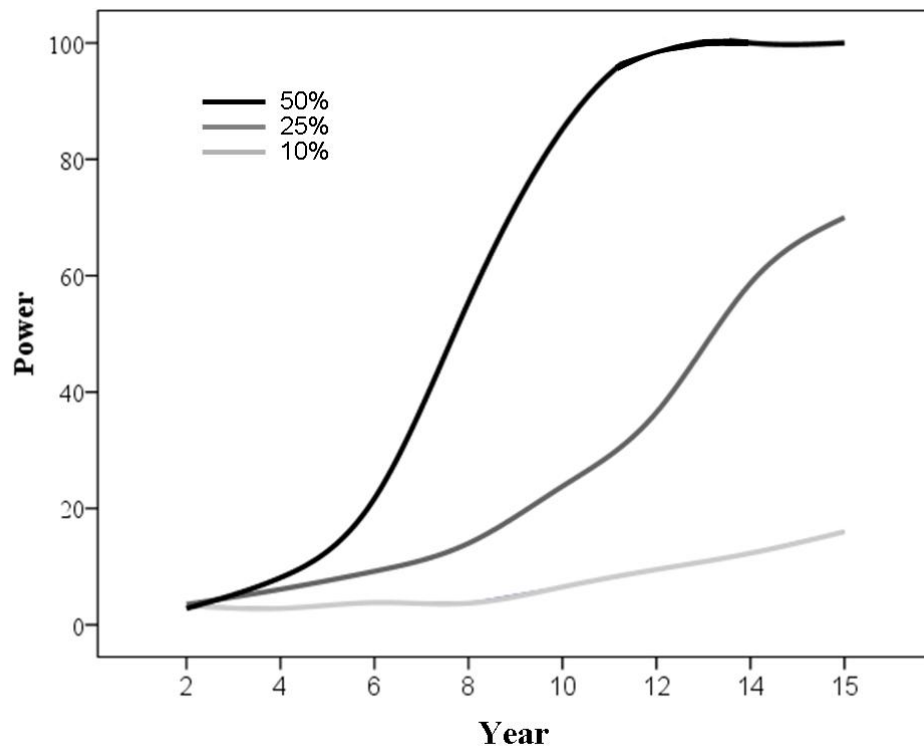


Figure 6.5. Power to detect 10, 25, and 50% declines in the number of manatees over 15 years - 30-minute scan, 28 points, points had a >30% probability of sighting a manatee and 8 two-week survey periods.

## CHAPTER 7

### CONCLUSION

Manatees in the Drowned Cayes area are integral to the conservation of Antillean manatees in Belize, the region and maybe even the subspecies. This dissertation advances our knowledge about their habitat use, selection, disturbance and status. It contributes a monitoring protocol to the international sirenian community for use in developing nations where fiduciary constraints on conservation programming are severe and it highlights needs for management and future research.

In the Drowned Cayes area manatees utilize all habitat types to meet a variety of their physiological and behavioral requirements. Manatees utilize the entire Drowned Cayes island chain, but some locations are clear manatee high use areas. Some habitat types, like seagrass beds and resting holes are clearly important components to the overall seascape. Resting holes and seagrass beds that are adjacent to each other are a particularly important habitat configuration as it provides resting places adjacent to forage resources – a previously un-emphasized habitat requirement. Manatees selectively forage on *Halodule wrightii*. Manatee habitat use seems to be resilient to mangrove removal, but seagrass may not be, which ultimately could be detrimental to manatees. Finally, number of manatees sighted per scan over the duration of this study does not appear to have changed, but our method would not be able to detect a slight decline in

abundance. Because the number of manatees in Belize and neighboring countries is small (Quintana-Rizzo & Reynolds 2008) even a slight decline should trigger conservation actions.

Species behavior, habitat and severely limited fiscal resources hamper the ability to conduct robust estimating procedures on Antillean manatees and other sirenians in developing nations (Aragones et al. in press; Aragones et al. 1997; Dawson et al. 2008; Dick & Hines in prep). Our survey protocol – point-based scan sampling from a small boat platform - is a relatively inexpensive, effective and repeatable method for monitoring sirenian population trends.

Tourism is a rapidly developing industry within Belize (BTB 2010). The Drowned Cayes which lie off the coast from Belize City, adjacent to the Belize Barrier Reef, are situated in the pathway of boats traversing from the city to outlying tourist destinations and are highly suited for resort development. By identifying high use areas, important habitat types, foraging resources and resting areas, this research provides information that wildlife managers can use to promote watercraft guidelines and guide development decisions. This research also highlights the need to continue manatee and establish seagrass monitoring programs. Seagrass monitoring should be conducted both before and after proposed development projects.

Like most scientific research, this dissertation is just one link in a larger puzzle. While it advances our knowledge of manatees in the Drowned Cayes and of the Antillean manatee subspecies, it also accentuates areas of needed research. The Drowned Cayes and surrounding seagrass beds are heavily utilized by foraging manatees. Yet, our understanding of manatee nutritional ecology and the impact of manatees on seagrass

ecosystem processes is paltry. More research should be done on the linkages between manatees and seagrass ecosystem dynamics. In addition, the validity of using our survey protocol to detect trends in manatee abundance is predicated on the assumption that our population index is linearly related to population abundance. Validation studies should be conducted to evaluate this.



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