

**CONSERVATION OF ANTILLEAN MANATEES  
IN THE DROWNED CAYES AREA OF BELIZE**

A Dissertation

by

CARYN SELF SULLIVAN

Submitted to the Office of Graduate Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2008

Major Subject: Wildlife and Fisheries Sciences

**CONSERVATION OF ANTILLEAN MANATEES  
IN THE DROWNED CAYES AREA OF BELIZE**

A Dissertation

by

CARYN SELF SULLIVAN

Submitted to the Office of Graduate Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Approved by:

Co-Chairs of Committee,	Jane M. Packard William E. Evans
Committee Members,	Wyndylyn M. von Zharen William E. Grant
Head of Department,	Thomas E. Lacher

May 2008

Major Subject: Wildlife and Fisheries Sciences

## ABSTRACT

Conservation of Antillean Manatees in the Drowned Cayes Area of Belize. (May 2008)

Caryn Self Sullivan, B.S., Coastal Carolina University

Co-Chairs of Advisory Committee: Dr. Jane M. Packard  
Dr. William E. Evans

The purpose of this study was to determine how manatees use Swallow Caye, Drowned Cayes, and Gallows Reef, three distinct habitat types within the Belize Barrier Reef lagoon system near Belize City. Data were collected using boat-based point scan methods with the assistance of volunteers. Presence/absence and photo ID methods ensured consistency of data collection despite a changing pool of volunteer researchers. Results confirmed the mangrove and seagrass ecosystem between the Belize Barrier Reef and Belize City as important manatee habitat. Inconsistent with the prevailing "seasonal distribution hypothesis" for manatees in Belize, the probability of encountering manatees at Swallow Caye and in the Drowned Cayes was equal between dry and wet seasons. However, manatees were only observed at Gallows Reef during the wet season. Swallow Caye had the highest probability of encountering manatees, confirming traditional knowledge held by local tour operators, which led to the establishment of Swallow Caye Wildlife Sanctuary in 2002. In contrast to previous studies, my data suggest that at least 44% of the manatee population carry scars from non-lethal boat strikes. The proportion of scarred animals did not vary as a function of habitat type, season, or year. The probability of encountering manatees did not change

between years, despite an exponential increase in cruise ship tourism. Marine Protected Areas (MPAs) and wildlife protection laws indicate that Belize is working to meet obligations under international agreements. However, there is still cause for concern. Manatees do not remain inside designated refuge boundaries; governmental agencies depend on co-management agreements with local non-governmental organizations for enforcement of rules inside MPAs; regulations governing human behavior outside MPAs are lacking; funds for monitoring and evaluation of MPAs are lacking. Manatee conservation strategies should be integrated into a system of riverine, coastal, and marine protected areas supported by additional tactics such as required manatee training for boat captains, slow zones at hot spots outside MPAs, and continued educational outreach. With few modifications and increased enforcement and monitoring, the Belize model for manatee conservation could lead to a shared "triumph on the commons" for the manatees and the user groups that shared their habitat.

## DEDICATION

I dedicate this dissertation to my children, Angie, Patrick, and Sarah, who have been the wind beneath my wings throughout my academic journey--always there to encourage me and lift my spirits, to my grandchildren Matthew, Katherine, and Braeden--born during my journey and from whom I've learned the value of innocent observations, to my sister Barbie--unconditional friend and the stabilizing force in my universe, to Mom and Dad--role models for faith, strength, compassion, and integrity, and finally to Nana and Bigmom--who departed this world during my journey, leaving behind powerful legacies of maternal strength and compassion. I am eternally grateful to you--my family--for your guidance, unconditional love and support. You have sustained me during an extraordinary journey into the world of academia and inter-cultural collaboration.

## ACKNOWLEDGEMENTS

The study of free-ranging marine mammals requires substantial financial and logistical support; therefore I beg your indulgence. First and foremost, I am grateful to the country of Belize for allowing me to conduct research in the Drowned Cayes, Swallow Caye, and Gallows Reef area, a pristine and complex ecosystem within the Belize Barrier Reef Lagoon System. I thank the Forestry and Fisheries Departments, Coastal Zone Management Authority & Institute, and Friends of Swallow Caye for approval of my research design and granting of research permits. I thank the many Belizean scientists and naturalists who listened carefully to my problems and offered valuable advice over the years--especially Nicole Auil, Angeline Valentine, Greg Smith, Kevin Andrewin, Chocolate Heredia, Janet Gibson, Natalie Rosado, Earl Codd, Hector Mai, Marcelo Windsor, George Hanson, Lizandro Quiros, and Rennick Jackson.

For their unwavering enthusiasm, support, and patience, I am grateful to my doctoral committee. My co-chairs, Drs. Jane Packard and Bill Evans, have gone above and beyond all expectations to ensure that I emerged as an experienced and professional scientist. Drs. von Zharen and Grant have always been available, supportive, and provided most valuable alternative perspectives on my activities. There are many other mentors who have helped guide me through this journey. On advice from Tom O'Shea, I took the naturalist's approach and invested thousands of hours watching manatees in their own habitat. I am indebted to Tom, who was the first of many veteran scientists to

generously and graciously give me much needed advice. At the risk of omitting someone, I thank Bob Bonde, Buddy Powell, Leszek Karczmarski, Daryl Domning, Rob Young, John Reynolds, Ellen Hines, Leslee Parr, and Greg Bossart for thier friendship, advice, and moral support.

My dissertation represents only a portion of a comprehensive project started in 1998 with Katie LaCommare, my research partner and friend. I will always remember the first week we met, standing for hours in the hot sun on the bow of Kungo II, stumbling over bench seats to get a better view, and hiding under the tiny canopy to avoid the downpours of rain. As we searched for manatees and felt lost amid a labyrinth of mangroves that would soon become my second home, we talked about how best to study the elusive manatees in Belize as visiting scientists from the USA. We wondered what we could bring to the world of conservation science as women who wanted to change the world just a "lee bit", leaving it a better place for our children and the children of Belize. Sirenian International was born on the bow of Kungo II during that rainy week in November 1998. For almost a decade, Katie and I have worked together, sharing the tragedies and triumphs of novice, but collaborative scientists. Thank you Katie, for your friendship and collaboration, which I hope continues for years to come.

The data presented in the dissertation could not have been collected without the assistance of Gilroy Robinson, our primary boat captain, field assistant and source of local knowledge in Belize. Gilroy's keen interest in the project from both conservation

and scientific perspectives added an unexpected dimension, enabling the valuable exchange of traditional and scientific knowledge. Thank you Gilroy, I will always value your friendship and professionalism. I also thank Dorian Álvarez, Armando 'Pach' Muñoz, Orlando 'Landy' Requena, Jerry Requena, and Mike--local Belizeans who have captained our boats at some point during the project.

For financial and in-kind support, I am grateful to the Earthwatch Institute, National Science Foundation Graduate Fellowship Program, the Hugh Parkey Foundation for Marine Awareness & Education, Spanish Bay Conservation & Research Center, Mario Guerrero and Manta Ray Charters, Jane Packard and the Department of Wildlife & Fisheries Sciences at Texas A&M University, Birgit Winning and the Oceanic Society, Project Aware, Virtual Explorers, Conservation Action Fund (New England Aquarium), and Lerner-Gray Marine Research Fund (American Museum of Natural History). Thank you for your generosity, which was and continues to be essential to maintaining a long-term study of endangered marine megafauna, such as manatees in Belize.

Belize has become my second home thanks to the hospitality of Sidney Turton and Teresa Parkey, former and current owners of Spanish Lookout Caye. I thank you for enabling the unique experience of living sustainably on a pristine mangrove caye. I am also grateful to Teresa, for opening her home in Belize City to me. And for my economical hide-a-ways in Belize and the Cayo District, I thank John and Judy Yaeger



of the Trek Stop, San Jose Succotz, and the Speer family of North Front Street Guest House.

And finally, I thank the students, scientists, and lay volunteers who spent days, weeks, and months assisting me in the field. Many students donated entire seasons to the project in exchange for the field experience; thank you Karen Petkau, Haydée Domínguez, Marie-Lys Bacchus, Rachel Struch, Carly Quisenberry-Dubay, Leigh Bird, Shauna King, Alison Drelich, Emma Cook, Amanda Port, Jason Dean, Brian Casey, Megan Saunders, Liz Johnstone, Pam Quayle, Randie Oaks Lyn, Sarah Bevins, Samantha Waltjen, Tom Strang, Hannah Goorsky, Hoslo Jiwa, Maxine Monsanto, Seleem Chan, Clifton Williams, Daniel Westby, Keren Moaney, Ryan Roland, and Abner Novelo. Visiting scientists and other colleagues have provided both advice and moral support; thank you Leszek Karczmarski, Robert Ford, Ellen Hines, Chris Marshall, Paco Ollervides, Jennifer Pettis, Heidi Petersen, Kecia Kerr, Kate Schafer, and Barbara Bilgre. The Earthwatch, Elderhostel, Oceanic Society, Virtual Explorer and other lay volunteers number in the hundreds, making it impossible to list them all here. Collectively, they have been the driving force behind this project and I am grateful for their generosity of time and money in support of conservation research.

## NOMENCLATURE

BBRLS	Belize Barrier Reef Lagoon System
BBRRS-WHS	Belize Barrier Reef Reserve System-World Heritage Site
CEP	Caribbean Environmental Programme
CZMA&I	Coastal Zone Management Authority & Institute
EW	Earthwatch Institute
FoSC	Friends of Swallow Caye
IUCN	International Union for Conservation of Nature
MIPS	Manatee Individual Photo ID System
MNREI	Ministry of Natural Resources, Environment & Industry
MPA	Marine Protected Area
NGO	Non-Governmental Organization
PACT	Protection Areas Conservation Trust
RSP	Regional Seas Programme
SCWS	Swallow Caye Wildlife Sanctuary
SPAW	Specially Protected Areas and Wildlife Protocol
TASTE	Toledo Association for Sustainable Tourism & Environment
TIDE	Toledo Institute for Development and the Environment
UNEP	United Nations Environmental Programme
WCR	Wider Caribbean Region
WT	Wildlife Trust

## TABLE OF CONTENTS

	Page
ABSTRACT .....	iii
DEDICATION .....	v
ACKNOWLEDGEMENTS .....	vi
NOMENCLATURE.....	x
TABLE OF CONTENTS .....	xi
LIST OF FIGURES.....	xiii
LIST OF TABLES .....	xiv
 CHAPTER	
I INTRODUCTION.....	1
Purpose of the Study .....	1
Endangered Species and Protected Areas .....	3
MPAs and Marine Mammals .....	5
Legal Justification for Conservation of Manatees in Belize .....	5
Problem Statement .....	6
II SEASONAL AND SPATIAL DISTRIBUTION OF MANATEES IN SWALLOW CAYE WILDLIFE SANCTUARY AND ADJACENT AREAS .....	11
Introduction .....	11
Swallow Caye Wildlife Sanctuary .....	14
Background on Manatee Distribution in Belize .....	15
Objectives of This Study .....	20
Methods.....	21
Results .....	35
Discussion .....	44

CHAPTER	Page
III NON-LETHAL BOAT-SCARS: A TOOL FOR EVALUATING SWALLOW CAYE WILDLIFE SANCTUARY .....	53
Introduction .....	53
Objectives of This Study .....	55
Methods .....	56
Results .....	58
Discussion .....	63
IV CONSERVATION OF MANATEES AND THEIR HABITAT IN BELIZE .....	67
Introduction .....	67
Conservation Status of Antillean Manatees in Belize .....	70
Marine Protected Area Policy in Belize .....	72
Swallow Caye Wildlife Sanctuary .....	77
Implications of Research .....	83
V EXECUTIVE SUMMARY .....	89
LITERATURE CITED .....	92
APPENDIX A SCWS STATUTORY INSTRUMENT .....	113
APPENDIX B DATA SHEETS .....	117
APPENDIX C GUIDELINES FOR TOUR OPERATORS .....	123
APPENDIX D SURVEY POINTS .....	126
VITA .....	129

## LIST OF FIGURES

FIGURE		Page
1	Tourism Statistics for Belize 1998-2005.....	8
2	Swallow Caye Wildlife Sanctuary .....	10
3	Study Area: Nested Location Map.....	19
4	Detailed Map of Study Area.....	24
5	Manatee Presence with Respect to SCWS .....	37
6	Manatee Presence by Season: All Areas .....	38
7	Manatee Presence by Season: Swallow Caye .....	39
8	Manatee Presence by Season: Drowned Cayes.....	40
9	Manatee Presence by Season: Gallows Reef.....	41
10	Manatee Presence by Year: Drowned Cayes .....	43
11	Scarred Manatees by Protected Area .....	59
12	Scarred Manatees by Habitat Type .....	60
13	Scarred Manatees by Year.....	61
14	Scarred Manatees by Intensity of Cruise Ship Tourism.....	62
15	Map of Cruise Ship Anchorage and Tour/Tender Routes.....	63
16	Map of Marine Protected Areas in Belize.....	74
17	Minimum Range of Known Manatee with Respect to SCWS .....	85

**LIST OF TABLES**

TABLE		Page
1	Summary of Previous Manatee Aerial Survey Data .....	16
2	Stratified Random Number Table for Scans .....	28
3	Total Scans Conducted within Each Sampling Zone .....	36
4	Examples of Aerial Survey Studies.....	49
5	Aerial Survey Evaluations.....	50
6	Survey Points by Code, Name, and Location.....	126

## CHAPTER I

### INTRODUCTION

#### PURPOSE OF THE STUDY

The overarching objective of this study was to establish a long-term sampling method that would enable valid comparison of data collected across various spatial and temporal dimensions within Swallow Caye Wildlife Sanctuary (SCWS) and adjacent areas in the Drowned Cayes and at nearby Gallows Reef in Belize. The purpose of my dissertation is to report on original research into the distribution of Antillean manatees (*Trichechus manatus manatus*) at Swallow Caye, in the Drowned Cayes, and at Gallows Reef within the broader theoretical context of legal protection for endangered species and their habitats. Not within the scope of this dissertation is an evaluation of the methods used, which will be reported elsewhere.

In this chapter, I briefly introduce the theoretical framework of endangered species and protected areas, the particular case of Marine Protected Areas and marine mammals, and the legal justification for conservation of manatees in Belize. The remainder of this chapter is focused on a site specific problem statement defined by previous research, personal communication with local stakeholders, and my own personal observations over the past 10 years in Belize.

---

This dissertation follows the style of Conservation Biology.

Chapter II addresses the broad conservation question of selecting appropriate spatial and temporal boundaries for an endangered species sanctuary, especially when the target species is highly mobile and difficult to detect. It is based on the results of original research using a boat-based, point scan method to determine: (1) whether manatees are more likely to be encountered inside or outside the boundaries of SCWS, which was established within the study area in 2002; (2) whether manatees are more likely to be encountered in the study area during the wet season; and (3) whether the probability of encountering manatees in the study area has declined over time. Chapter II is written for a broad audience, such as readers of *Conservation Biology* who would be interested in the use of fine scale methods to test hypotheses generated by broad scale distribution and abundance survey data.

Chapter III touches on the broad conservation question of whether species specific protection is needed in areas outside of Marine Protected Areas (MPAs). However, it is written for a more focused audience such as the readers of *Marine Mammal Science*. It is based on results of original research using underwater video methods to determine whether the probability of encountering boat-scarred manatees varied inside and outside Swallow Caye Wildlife Sanctuary. It also addresses the feasibility of building a catalogue of uniquely marked individual manatees to study the population in Belize more closely.



Chapter IV reviews the role of law as a driving force behind conservation of manatees and their habitat in Belize and discusses potential implications of the results presented in Chapter II and Chapter III. It is written for stakeholders in the Wider Caribbean Region, such as the readers of *Journal of International Wildlife Law & Policy*, who are interested in how policy decisions may be in conflict with local law and international agreements.

Chapter V provides an executive summary suitable for use by local stewards of the marine environment, specifically people working within governmental and non-governmental organizations who are interested in influencing policy, such as the readers of the *Belize Audubon Society Newsletter*. Elected officials and other decision makers in Belize are often challenged with finding a balance between conservation of natural resources and the need for increasing economic development within the country. The purpose of the Executive Summary is to present an overview of my results in light of Belize's obligations under International Agreements and National Statutory Instruments, which were reviewed in detail in Chapter IV.

## **ENDANGERED SPECIES AND PROTECTED AREAS**

The conservation and management of an endangered species often includes legislation that creates a “protected area” of habitat. Wildlife parks, reserves, sanctuaries, and refuges have been the cornerstone of conservation efforts for over a century (Noss 1996) and may even prove to be effective strategies for protecting endangered species in suboptimal habitats (Channell & Lomolino 2000). Additionally, the use of endangered

species, especially charismatic megafauna (flagship or umbrella species; see Simberloff 1998, Caro & O'Doherty 1999, and Zacharias & Roff 2001 for definitions), is an effective way to bring public attention to broader conservation issues (Shrader-Frechette & McCoy 1993).

For over a decade, conservation biologists have challenged the effectiveness of using protected areas to conserve endangered species, as well as the effectiveness of using individual species as surrogates for protecting ecosystems (Noss 1990; Lambeck 1997; Simberloff 1998; von Zahren 1999). Many ecologists have argued for a movement towards ecosystem approaches and away from crisis-driven approaches to endangered species conservation (Christensen et al. 1996). Indeed, while conservation strategies may have focused too exclusively on individual species management in the past, preservation of biodiversity is dependent on conservation of individual populations and species (Schwartz 1999). Adopting an approach of ecosystem priority to the exclusion of an endangered species approach may guarantee that the crisis be resolved through extinction. A broad array of conservation strategies should strive to balance the protection of countable objects, such as endangered species, with the protection of natural processes at the ecosystem level. However, it is also important to evaluate such strategies to determine whether they provide an umbrella of protection for all species within an ecosystem, or whether they conflict with other conservation efforts (Simberloff 1998; Zacharias & Roff 2001; Fanshawe et al. 2003; Roberge & Angelstam 2004).

## **MARINE PROTECTED AREAS AND MARINE MAMMALS**

In my literature review, I found that older literature has focused primarily on the design necessary for a "protected area" to be an effective tool for the conservation of terrestrial species and ecosystems (e.g., "how much is enough?", "one large or many small?" see Noss 1996 for a complete review). Within the past decade, however, scientists have begun to expand terrestrial concepts to the marine environment, including literature focused on the use of MPAs for fisheries management (Roberts 1998; Roberts 2000), for conservation of marine mammals (Hooker et al. 1999; Reeves 2000), the use of focal species in establishing MPAs (Zacharias & Roff 2001), and the human dimension that must be considered (Salomon et al. 2001). As with terrestrial systems, MPAs must be legislated to increase compliance and ensure enforcement of rules and regulations (Hooker et al. 1999); and management plans, subject to review and revision, are essential to the evaluation of their effectiveness (Reeves 2000). The optimal protected area for conservation of marine mammals would encompass each population's year-round distribution; but for most species, this is unrealistic due to extremely large habitats and migratory behavior (Reeves 2000).

## **LEGAL JUSTIFICATION FOR CONSERVATION OF MANATEES IN BELIZE**

Academics will undoubtedly continue to debate the effectiveness of conservation strategies for protecting our marine environment. Caribbean governments nonetheless reached an agreement during the Convention for the Protection and Development of the

Marine Environment of the Wider Caribbean Region held in Cartagena de Indias on 24 March 1983 (herein referred to as the Cartagena Convention). The Cartagena Convention established a regional policy of protection for both endangered species and their habitats. Striving to meet these ideals since acceding to the Cartagena Convention and its subsequent Protocol Concerning Specially Protected Areas and Wildlife (SPA Protocol) in 1999, Belize has emerged as a leader within the Wider Caribbean Region (WCR). Although legislation has existed for the protection of wildlife and the environment in Belize since the 1930s (then known as British Honduras), the SPA Protocol has been the driving force behind establishment of MPAs and a focus on conservation of manatees as a species of priority concern (Auil 1998).

## **PROBLEM STATEMENT**

West Indian manatees (*Trichechus manatus*) are one of only four extant species in the Order Sirenia, all of which are listed as threatened or endangered with extinction (IUCN 2007). The species is divided into two subspecies (Hatt 1934; Domning & Hayek 1986), commonly known as Florida (*T. m. latirostris*) and Antillean (*T. manatus manatus*) manatees, both of which are listed as endangered (Deutsch et al. 2007) by the International Union for Conservation of Nature (IUCN). Belize is considered a stronghold for the Antillean subspecies (O'Shea & Salisbury 1991). According to aerial survey data, the cayes east and northeast of Belize City represent one of the most important manatee activity centers in Belize (Auil 1998; Morales-Vela et al. 2000; Auil 2004). Similar to the Everglades and Ten Thousand Islands, where Florida manatees

have been shown to use very specific travel routes between marine and freshwater (Butler et al. 2003; J. P. Reid, personal communication), Antillean manatees using this area have access to abundant marine seagrasses for foraging, quiet secluded areas among the labyrinth of mangrove cayes for resting and raising calves, and close proximity to fresh water in the Belize River system. However, there is also a high rate of manatee mortality near Belize City, possibly a result of the lethal combination of abundant manatees and high human use (Auil 1998, 2004).

Manatees must rise to and break the surface of the water to breath; boats must travel on this same surface of the water. The shared plane at the surface of the water often results in tragic conflict between manatees and humans using boats and other watercraft. Tourism activities make this a high traffic area for watercraft (Auil 2004). Due to high water turbidity near Belize City, it is difficult for boat operators to detect manatees until they have broken the surface to breathe. Because of the shallow, muddy, convoluted sub-surface environment, and the physics of how sound travels in water, it is difficult for manatees to detect and avoid approaching watercraft (personal observations).

An exponential increase (Fig. 1) in cruise ship tourism (Belize Tourism Board 2006) beginning in 2002 (a 584% increase from the previous year) and continuing in 2003 (+ 80%) and 2004 (+ 49%) has resulted in significant increases in small, medium, and large boat traffic as tour and tender boats are used to transport day-passengers to/from the cruise ships (CZMA&I, personal communication; personal observations). Increases in

cruise ship tourism have also led to an increased use of public commons and development of private property (Department of the Environment, personal communication). In addition to direct conflicts due to increasing levels of watercraft activity, indirect impacts from increasing human use and development may have deleterious effects on manatee feeding and resting areas. Unfortunately, we do not have a good understanding of the long-term effects of human disturbance on manatee populations.

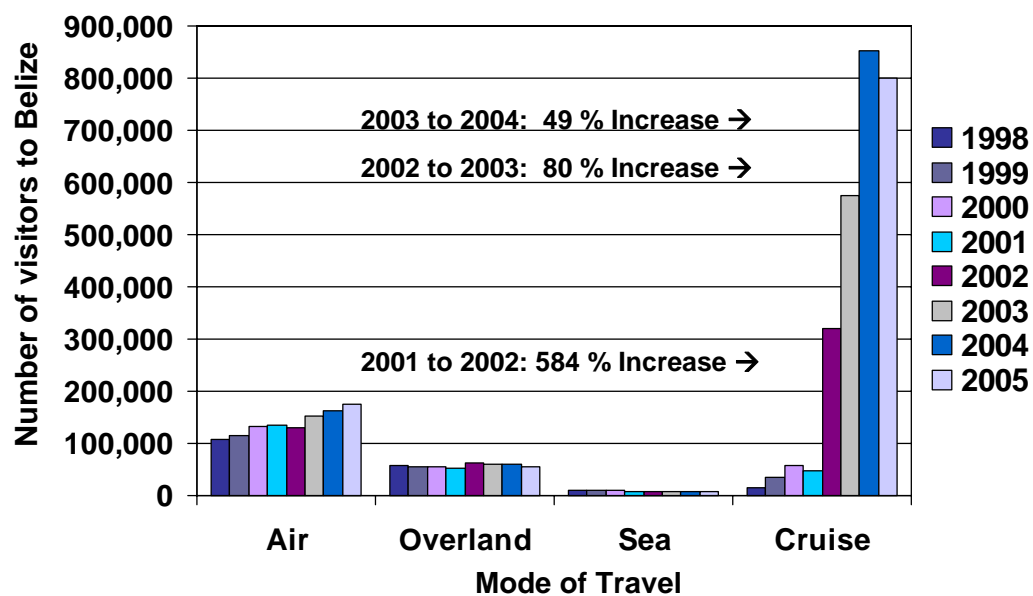


Figure 1. Tourism Statistics for Belize 1998-2005. Note the exponential increase in cruise ship tourism from 2001 to 2004 and leveling off in 2005 (Belize Tourism Board 2006).

With an increase in the number of day-tourists from the cruise ship industry, there followed an increase in water-based tourism such as mangrove and river tours to view wildlife, fishing tours, and tours to small sandy cayes on the reef for picnicking, sun bathing, swimming, snorkeling, and diving (CZMA&I, personal communication). Local stakeholders recognized a negative impact on unregulated public commons such as Geoff's Caye, Sergeant's Caye, and Swallow Caye (personal observations). In an effort to mediate increasing human impacts on the marine commons near Belize City, Coastal Zone Management Authority and Institute (CZMA&I) pushed for legislation to fund rangers at Geoff's Caye and Sergeant's Caye (commonly-used snorkel sites) via a user fee. Local manatee tour operators, spearheaded by Lionel "Chocolate" Heredia and CZMA&I, pushed for a Marine Protected Area centered on Swallow Caye, an area they knew as a hotspot for manatee viewing near Belize City. Lobbying efforts by these local stakeholders resulted in the legislation of Swallow Caye Wildlife Sanctuary (SCWS) on 10 July 2002 by Statutory Instrument No. 102 of 2002 (Appendix A). The 8,970 acre area near Belize City (Fig. 2) includes mangrove islands, seagrass beds, and deeper channels; it was designated specifically for the protection of Antillean manatees in Belize. SCWS is co-managed by the Forestry Department and Friends of Swallow Caye (FoSC).

The establishment of Swallow Caye Wildlife Sanctuary during the course of my study provided an opportunity to evaluate how manatees use activity centers within and

adjacent to this MPA near Belize City, Belize. When I first began studying manatees in the Drowned Cayes area, my objective was to provide Coastal Zone Management

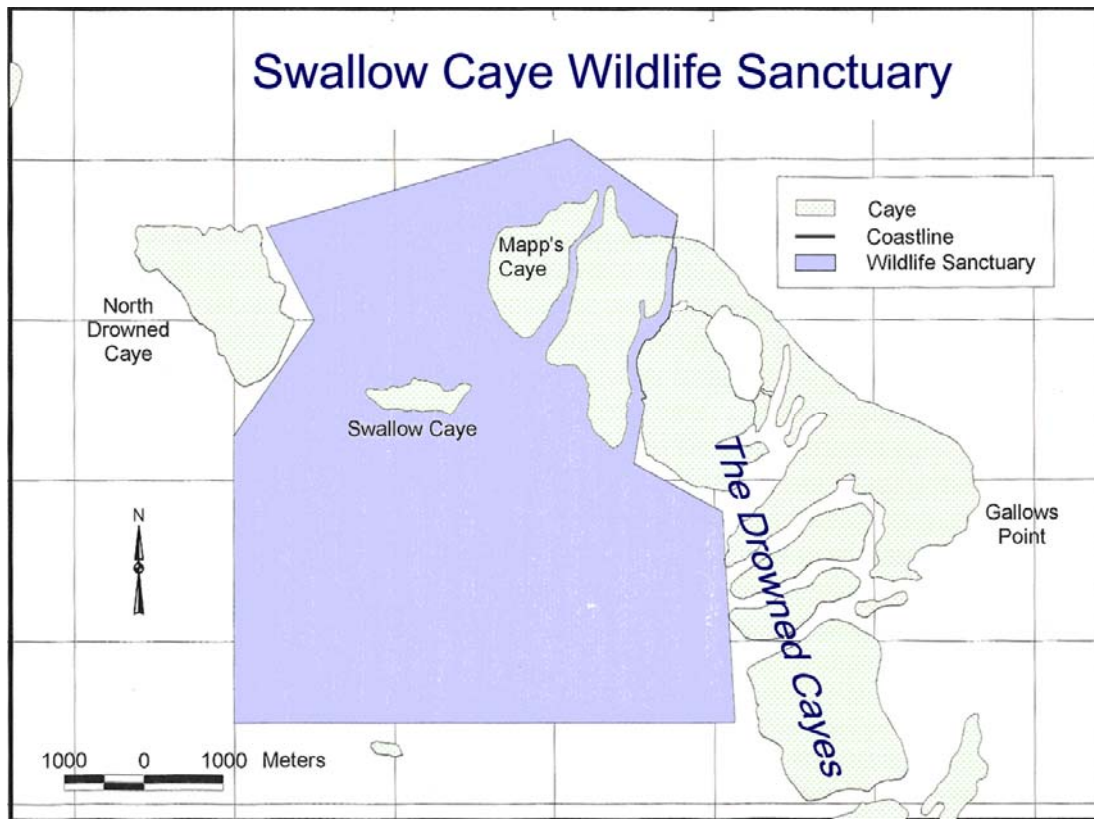


Figure 2. Swallow Caye Wildlife Sanctuary. The sanctuary includes area shown in blue: Swallow Caye, 2 cays in the northern Drowned Cayes, and water. Image modified from proposed sanctuary boundary map provided by Coastal Zone Management Authority and Institute (CZMA&I 2003).

Authority, Conservation Division, and Friends of Swallow Caye with data to support the establishment of the sanctuary. This was accomplished through annual reports to these organizations. The purpose of this dissertation, as described previously, follow Auil's (1998, 2004) recommendations for long-term site specific studies on Antillean manatees in Belize.



## CHAPTER II

### SEASONAL AND SPATIAL DISTRIBUTION OF MANATEES IN SWALLOW

#### CAYE WILDLIFE SANCTUARY AND ADJACENT AREAS

##### INTRODUCTION

The conservation of an endangered species often includes strategies to protect both the targeted species and its habitat (Shrader-Frechette & McCoy 1993). Indeed, protected areas have been a cornerstone of conservation efforts for over a century (Noss 1996). However, selecting appropriate spatial and temporal boundaries for protected areas is often hampered by: (1) theoretical debate over size, shape, and connectivity (McCoy 1983; Noss 1996); (2) theoretical debate over ecosystem vs. species management approaches (Christensen et al 1996; Schwartz 1999); (3) lack of empirical data (Hooker & Gerber 2004); (4) invalid assumptions about distribution of the targeted species (Anderson 2001); and (5) a failure to consider the human dimension, such as economic and social factors, in the planning (van den Belt 2004) and design (Duffus & Dearden 1990; Grumbine 1994; Jacobson & Duff 1998; Pomeroy et al. 2004; Dalton 2005).

A quarter century ago, McCoy (1983) argued that if wildlife sanctuaries are to be effective tools for the conservation of endangered species, sound autecological studies are crucial to the determination of boundaries. In other words, protected areas should be created based on a clear understanding of the particular species life history, ecology, behavior, habitat needs, and its interaction with its environment. However, such

autecological studies are rarely available to the decision makers who establish protected areas (McCoy 1983). In many cases, this type of information must be inferred from other populations. A site specific understanding of the species distribution and habitat use, including identification of essential areas, activity centers, travel corridors, and where these areas overlap with high human use, will improve our ability to protect the local population (Packard & Wetterqvist 1986). However, even in the absence of such studies, recent evaluations have shown that reserves, wildlife sanctuaries, and other protected areas may prove to be effective conservation strategies even when established opportunistically (Roberts 2000) or in suboptimal habitats (Channel & Lomolino 2000).

Optimally, a protected area would encompass the endangered species' year-round distribution; but for most marine mammals, this is unrealistic due to extremely large habitats and migratory behavior (Reeves 2000). Alternatives include: (1) preserves that protect the year-round habitat of one population or sub-population of the species to serve as a source for recruitment outside the protected area (Reeves 2000); (2) a network of spatial and/or temporal sanctuaries that protect key breeding and feeding areas, especially during peak seasons (Reeves 2000); and (3) a system of protected areas created by identifying and protecting essential areas, activity centers, travel corridors, resources for expansion, and the ecosystem that supports the former through a variety of mechanisms (Packard & Wetterqvist 1986; Soulé & Simberloff 1986; Noss 1996; von Zbaren 1998, 1999).

Despite theoretical debate over ecosystem vs. species management approaches (Christensen et al. 1996; Schwartz 1999), the use of charismatic megafauna has long been considered an effective way to bring attention to broader conservation issues (Shrader-Frechette & McCoy 1993). Large ocean megafauna have been used to direct marine conservation efforts (Hooker & Gerber 2004) and the authors have suggested the use of one or more marine predators as a foundation for Marine Protected Area (MPA) design. For example, Hooker et al. (1999) recommended that boundaries for a MPA on the Scotia Shelf (to protect this unique habitat from the deleterious effects of oil and gas exploration) be determined by the distribution of 11 cetacean species (not necessarily endangered species).

Whether an attempt is made to protect an endangered species' year-round habitat or some more or less encompassing alternative, it is necessary to have a reasonable understanding of distribution to determine what areas should be protected and when (McCoy 1983; Soulé & Simberloff 1986; Noss 1996; Channell & Lomolino 2000). Even so, targeted species do not necessarily remain confined to their designated sanctuaries (see Siex & Struhsaker 1999 and Wittemyer 2001 for examples), a phenomenon that is particularly relevant to marine mammal conservation (Reeves 2000).

In reality, cultural, political, and economic factors tend to be the primary criteria for establishment of wildlife refuges and sanctuaries (Soulé & Simberloff 1986; Roberts 2000) with the secondary criteria being whether or not a particular location has optimal

habitat for the targeted species (Soulé & Simberloff 1986; but see Channell & Lomolino 2000). Such is the case for Swallow Caye Wildlife Sanctuary (SCWS), a manatee refuge established near Belize City in 2002.

### **SWALLOW CAYE WILDLIFE SANCTUARY**

By my first visit to in Belize in 1998, Lionel "Chocolate" Heredia, a local manatee tour guide from Caye Caulker, had been lobbying for a Marine Protected Area encompassing Swallow Caye for over a decade (A. Seashore & L. Heredia, personal communication). He had already led a successful campaign to ban commercial swimming with manatees at Swallow Caye (A. Seashore & N. Auil, personal communication). In 1998, Chocolate founded Friends of Swallow Caye (FoSC), a local NGO of manatee tour guides dedicated to conservation of manatees and their "home" at Swallow Caye (A. Seashore & L. Heredia, personal communication). He enlisted the support of his local representative, Patty Arceo, and the Coastal Zone Management Authority and Institute (CZMA&I) for his efforts. Preliminary reports from our research project were provided to Friends of Swallow Caye and CZMA&I in support of these efforts. After some negotiation, the original recommendation by CZMA&I to include the mangrove islands of Swallow Caye and the Drowned Cayes was reduced to Swallow Caye and only the northern 2 mangrove islands in the Drowned Cayes. This decision was made by the Ministry of Natural Resources based on potential conflicts with other stakeholder groups, especially private property owners within the Drowned Cayes range (CZMA&I, personal communication).

## **BACKGROUND ON MANATEE DISTRIBUTION IN BELIZE**

For over a decade, scientists have attempted to determine annual and seasonal changes in the distribution and abundance of Antillean manatees using Belizean waters (Gibson 1995; Auil 1998; Morales-Vela et al. 2000; Auil 2004). Based on variation in country-wide aerial survey data (raw counts) conducted seasonally in 1994-1995 and 1997-2002, the population is thought to be stable, at best, and possibly in decline (Auil 2004).

Variability in country-wide counts has been detected between years, within years by season, and between habitat types, but without clearly defined trends. For the purpose of this chapter, I will focus on previous findings related to sightings within the marine habitat, referred to as "caye" and "coast" habitat by Gibson (1995), "offshore habitat" by Auil (2004), and "cay" and "coast" habitat by Morales-Vela et al. (2000).

Gibson (1995) found significant variance in manatee counts between 3 aerial surveys in 1994 and 1995. While there was a significantly greater proportion and raw count of manatees sighted in caye habitat country-wide during the May 1994 survey (60 manatees; 29% of total) than during the January 1994 survey (27 manatees; 10 % of total), the proportion and raw count remained relatively high during the January 1995 survey (45 manatees; 26 % of total). The variation within 1994 supported a seasonal distribution hypothesis. However, if the hypothesis were true, the January 1995 count resulted in a higher than expected number of manatees sighted in caye habitat. The

author recommended additional systematic aerial surveys to increase sample size and test alternative hypotheses for the variation within and between years (Gibson 1995).

Morales-Vela et al. (2000) analyzed counts from the Gibson (1995) surveys and compared them to counts from earlier surveys done in 1977 (Bengtson & Magor 1979) and 1989 (O'Shea & Salisbury 1991). The count data for the cayes east of Belize City are shown in Table 1. Given the low sample size and long periods of time between aerial surveys, count variability could have resulted from real changes in population size and distribution, short-term and random movements by manatees, variation in observer reliability, variation in survey methods, or by inconsistent detectability biases across spatial and temporal variables such as habitat type and season (Bengtson & Magor 1979; O'Shea & Salisbury 1991; Gibson 1995; Morales-Vela et al. 2000; Morales-Vela et al. 2003; Auil 2004).

Table 1. Summary of Previous Manatee Aerial Survey Data. A subset of data for the cayes east of Belize City; counts were made during broad scale aerial surveys from 1977 to 1995 (Source: Morales-Vela et al. 2000).

<i>Year</i>	<i>Month</i>	<i># Manatees</i>	<i>% of Total Count</i>	<i>Reference</i>
1977	September	12	16.2 %	Bengtson & Magor 1979
1989	May	10	9.8 %	O'Shea & Salisbury 1991
1994	January	30	11.3 %	Gibson 1995
1994	May	60	29.0 %	Gibson 1995
1995	January	31	18.1 %	Gibson 1995

I found some inconsistency in the raw count data presented by Gibson (1995) and Morales-Vela et al. (2000). Without access to the original data set, it was impossible for me to hypothesize further on the source of variation.

Based on these early studies, the Belize Manatee Recovery Plan called for additional aerial surveys and site specific autecological studies to determine probability estimates for detecting manatees and assessing manatee behavior (Auil 1998). The most recent manatee aerial surveys were conducted seasonally, once in the peak dry (March-April) and once in the peak wet season (August-November) in 1997 and again from 1999 to 2002). The results, analyzed using spatial GIS techniques (Auil 2004), led to the hypothesis that there is a higher probability of sighting manatees “inshore” (defined as rivers, estuaries, and coastal lagoons) during the peak dry season and “offshore” (defined as mainland coast and cayes within the Belize Barrier Reef Lagoon) during the peak wet season. Auil (2004) hypothesized that the seasonal variance in distribution was driven by availability of fresh water, a hypothesis that is supported by research in Florida where manatees are thought to be dependent on access to fresh water for osmoregulation (Hartman 1979; but see Hill & Reynolds 1989; Ortiz et al. 1998; Ortiz et al. 1999).

Although aerial surveys in Belize have not focused on potential manatee habitat along the Belize Barrier Reef, the local perception is that manatees are commonly found at breaks along the reef crest during the summer, but not during the winter (Landy Requena & Pach Muñoz, personal communication). A study by Self-Sullivan et al. (2003) tested

this hypothesis at breaks in the reef crest near Basil Jones (Northern Ambergris Caye) and Gallows' Reef (Drowned Cayes). Boat-based point surveys detected a significant difference in the probability of encountering manatees between seasons. At Gallows' Reef, which lies approximately 1 km east of the Drowned Cayes (Fig. 3, right frame), the probability of encountering one or more manatees during the warmer/wet season was 0.44 and during the cooler/transitional-dry season was zero. Similar results were found at Basil Jones Reef where 87% of the animals observed could be individually identified. Fifteen of the 17 individually identifiable manatees at Basil Jones were confirmed to be males, with no females or calves observed at either reef site (Self-Sullivan et al. 2003 and subsequent unpublished data). The findings of this study support the country-wide seasonal distribution based on access to freshwater hypothesis. However, detection of "males only" led the authors to hypothesize that seasonal presence at the reef sites might be explained by reproductive behavior (see Self-Sullivan et al. 2003 for discussion).

Outside the Belize Barrier Reef Lagoon System (BBRLS), manatees are known to use Turneffe Atoll, an isolated 525 km<sup>2</sup> coral reef-mangrove island-seagrass bed ecosystem 50 km east of Belize City (Fig. 3, center frame), during both the wet and the dry season (Gibson 1995; Holguin 2004). Gibson counted 3 manatees at Turneffe in January 1994, and 4 in both May 1994 and January 1995. Although she did not analyze the sighting probability as a function of season, Holguin's data do not indicate any seasonal trend with similar numbers of encounters per time on the water reported in both the wet and



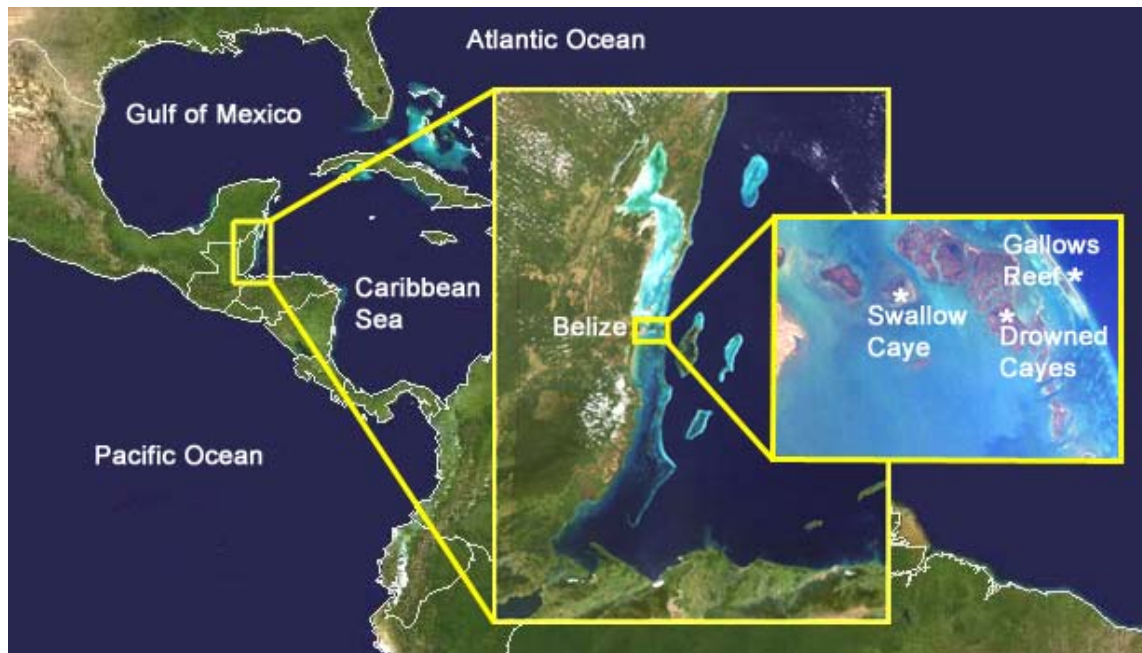


Figure 3. Study Area: Nested Location Map. Study area included Swallow Caye, the Drowned Cayes, and Gallows Reef. Original images courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center (NASA 2001).

dry season. She reported multiple sightings of manatees at Turneffe during two site specific aerial surveys, both done during the dry season. During her investigation, Holguin identified several sources of low salinity water within the Atoll, which may be used by manatees for osmoregulation. In November 2004, a male manatee herein referred to as "Sharkbite" (named for his shark attack scar when he was captured and tagged in May 2004), was tracked via satellite transmitter as he traveled from the Drowned Cayes area to Turneffe Atoll and back within 48 hours, suggesting that changes in distribution between Turneffe and the Drowned Cayes might occur at temporal scales much shorter than seasons (N. Auil & CSS, unpublished data). Until recently, manatees had not been reported at Lighthouse Reef or Glover's Reef, the other two atolls within Belizean waters, but outside the BBR. However, one manatee was

sighted at Glover's Reef during the summer of 2007 (R. Arana, personal communication).

### **OBJECTIVES OF THIS STUDY**

In this chapter, I will evaluate whether SCWS boundaries encompass optimal manatee habitat. I used an inductive approach to compare the probability of encountering manatees inside and outside SCWS. If the area included in SCWS represents optimal habitat for manatees, I would expect the probability of encountering manatees to be greater at points inside the sanctuary.

Additionally, I will test the prevailing hypothesis that manatees use mangrove caye habitat near Belize City (including Swallow Caye, the Drowned Cayes, and Gallows Reef) seasonally (Auil 2004; Self-Sullivan et al. 2003), with higher use during the warmer/rainy season and lower use during the cooler/transitional-dry season. If true, then conservation strategies, including rules and regulations for Swallow Caye Wildlife Sanctuary, could be seasonal in nature, with less prohibitive use during the dry season—which coincides with the peak tourist season. If false, then conservation strategies should be applied consistently through out the year, and may require increased monitoring and enforcement during the peak tourist season when anthropogenic impacts are greater. I used a deductive approach to test the hypothesis that manatees are more likely to use Swallow Caye, the Drowned Cayes, and Gallows Reef (marine habitat previously identified as "caye" or "offshore" habitat) during the warmer/wet season than

during the cooler/transitional-dry season. If true, I would expect to find a significantly higher probability of encountering manatees in the warmer/wet season than in the cooler/transitional-dry season.

Finally, I test alternative hypotheses that the Belize manatee population is either stable or in decline within the Drowned Cayes area. I used a deductive approach, testing whether the probability of encountering manatees in the Drowned Cayes area was stable or declined between 2001 and 2004, as suggested by Auil for marine environments countrywide (2004). If the population using the study area had declined, I would expect the probability of encountering manatees to also have declined from 2001-2004.

Given competition for funding and the pressure for increased economic development in the cayes near Belize City, a clear understanding of these three questions is essential to manatee conservation efforts in Belize. By using a deductive approach, I am following previous recommendations for site specific manatee studies in Belize (Auil 1998, 2004).

## **METHODS**

Manatee presence/absence and count data were recorded during 30-minute sample periods at 54 fixed points within the Drowned Cayes (50 points), at Swallow Caye (2 points), and at Gallows Reef (2 points). Points were categorized as being inside or outside the boundaries of SCWS (established in 2002), as being representative of open or sheltered habitat, and by zone. Our platform for observations was an 8 m fiberglass

boat, equipped with an outboard engine, canopy, and pole for maneuvering to and holding us stationary at each point. Data were recorded on standardized *Manatee Sightings and Scans* data sheets (Appendix B), which included location of the sample point, start/stop time for the scan, time of manatee detection, and other variables not included in the analyses done for this chapter.

Data were collected by teams of observers; the total number of observers on each team generally ranged from 8-14 and included volunteer researchers, interns, visiting scientists, and paid staff. With appropriate training, short-term, non specialist volunteers have demonstrated an ability to collect basic data with the same precision as experienced professionals (Darwall & Dulvy 1996). Volunteers for this project were provided by the Earthwatch Volunteer Model (EVM) with two 3-month field seasons (dry and rainy) per year from 2001-2004. The EVM has been used by scientists in a variety of disciplines for 35 years. The value of using this model has been demonstrated, but with some concern regarding varying abilities among observers (Foster-Smith & Evans 2003). Due to the long-term nature of this project and the high number of volunteer researchers, we have taken great care to ensure consistency in our sampling design. We have sacrificed more complex data collection and analytical methods in favor of a simple standardized sampling design. Our ability to repeatedly sample the same sites over an extended time period has resulted in an increased sample size, enabling valid comparisons across both spatial and temporal variables. I was present during each field season and personally responsible for insuring the precision of collection methods.

## Study Area

This study was conducted in the Drowned Cayes, Swallow Caye, and Gallows Reef area of Belize, Central America, a totally marine environment (Fig. 4). The northern portion of the study area was legislated as Swallow Caye Wildlife Sanctuary in July of 2002, midway through this study (Fig. 2). The Drowned Cayes are a comma-shaped labyrinth of mangrove islands that lie along a NNW-SSE line from approximately 17.53°N, 88.12°W to 17.40°N, 88.05 W. Swallow Caye lies just west of the northern Drowned Cayes and Gallows Reef lies just east of the northern Drowned Cayes. Classified as “offshore” and “caye” habitat type in aerial survey analyses by Auil (2004) and Gibson (1995), the area is located between 5 km east and 10 km southeast of Belize City. Gallows Reef is part of the Belize Barrier Reef (BBR). The Drowned Cayes and Swallow Caye represent habitat typical of mangrove island systems within the BBR lagoon system: a dynamic and convoluted system of mangroves, seagrass beds, and patch reefs, intersected by deep (4-9 m) and shallow (1-3 m) channels locally referred to as *bogues* (Ford 1991).

Some bogues within the Drowned Cayes dead-end in the mangroves, providing quiet protected areas with full or partial mangrove canopy cover and little or no anthropogenic activity. The features of this system provide a unique juxtaposition of manatee

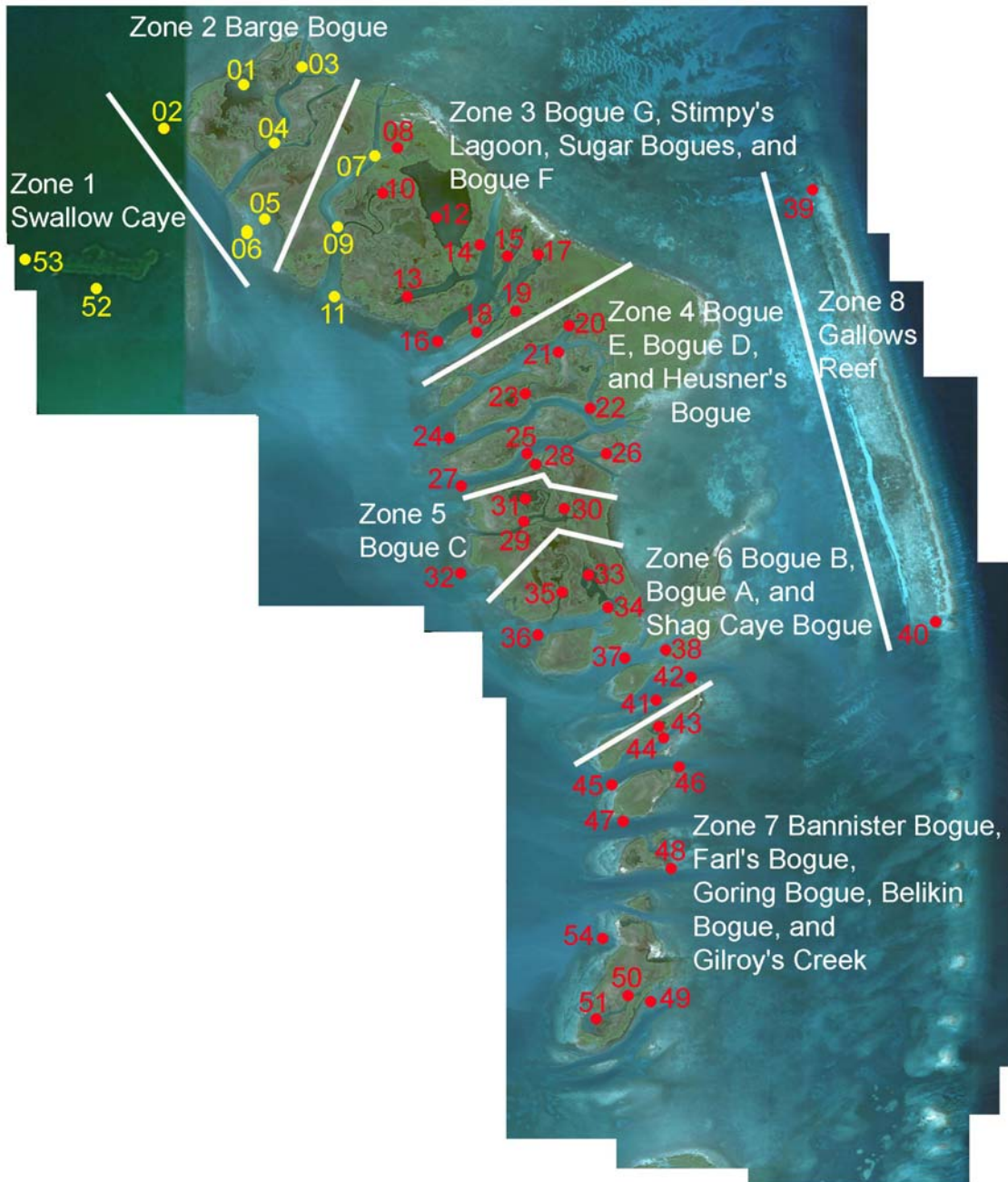


Figure 4. Detailed Map of Study Area. Approximate location of 54 permanent sampling points, divided into zones for random sampling. Points coded in the lighter color (yellow) fall inside the boundary of SCWS. Background image created by Marie-Lys Bacchus with Google Earth Pro.

resources, including extensive seagrass beds for feeding around the perimeter of the Drowned Cayes, Swallow Caye, and west of Gallows Reef; quiet dead-end boggles within in the Drowned Cayes and Swallow Caye for resting, mating, giving birth, and nursing young calves; and deeper boggles for travel between activity centers within the Drowned Cayes area and ingress/egress with adjacent habitat areas such as St. George's Caye, North Drowned Caye, Stake Bank, the Belize River, and Haulover Creek. At two sites within the Drowned Cayes (near points 20 and 46), brackish water has been detected, possibly from groundwater seeps (CSS, unpublished data).

### **Sampling Design**

Presence/absence data were used to determine the probability of encountering one or more manatees as a function of area, season, and year. Presence/absence methods have proven to be reliable in monitoring changes in area of occupancy and changes in population size with large sample sizes (Joseph et al. 2006). Prior to the collection of data for analysis in this chapter, preliminary observations were made using boat based surveys along established routes within the Swallow Caye, Drowned Cayes, and Gallows Reef area modeled after methods used for surveying dolphins (Kerr et al. 2005). We found this method to be unreliable in detecting manatees due to the extended period of time manatees remained submerged between breaths. After several hundred manatee observations from 1998-2000 (CSS & K. LaCommare, unpublished data), it became obvious that a moving survey boat could easily pass a submerged manatee undetected. After consultation with my research partner, we established a point scan sampling design

(LaCommare et al. 2008) modified from methods used in the ornithology literature (Reynolds et al. 1980; Farnsworth et al. 2002). The advantage of this method is that it enabled us to repeatedly and randomly sample specific sites within a large area, detecting manatees when they surfaced to breathe.

In bird studies, detection using this method is based on hearing birds sing; however the probability of birds singing is not necessarily equal on either a daily or seasonal basis. Critiques of the method include a failure to consider the potential differences in the detection probability of singing birds among points as a function of time of day and season of the year. Fortunately for our study, manatees must surface to breathe regardless of location, time of day, season, or year. Breathing manatees can be detected both visually and audibly; using two senses increased our odds of detecting a manatee, given a manatee was present.

Fifty sample points were located within the Drowned Cayes, 2 points at Swallow Caye, and 2 points at Gallows Reef (Fig. 4). Sample points included two broad habitat types



(open and sheltered) in areas perceived as having both high and low probabilities of encountering manatees (CSS, unpublished data). From 2001 to 2004, the two points at Swallow Caye and two points at Gallows Point were sampled systematically. The two points at Swallow Caye were sampled once during each two-week Earthwatch Team; the two points at Gallows Reef were sampled twice during each Earthwatch Team. The 50 points within the Drowned Cayes were sampled randomly, with replacement, using a stratified random number table created in Excel (Table 2). The random number table was generated once for each of 28 Earthwatch teams. Starting with the top row on the table and the first field day for each team, the first zone within the Drowned Cayes and first point within that zone to be sampled were determined. To conserve fuel and collect data in the most efficient manner, subsequent points for the field day were selected using the nearest neighbor criterion. In hindsight, I would recommend using random sampling without replacement in the future, as this should result in a more even distribution of sample size across the 50 points located within the Drowned Cayes.

Table 2. Stratified Random Number Table for Scans.

<i>Sample Date</i>	<i>Zone #</i>	<i>Zone 2</i>	<i>Zone 3</i>	<i>Zone 4</i>	<i>Zone 5</i>	<i>Zone 6</i>	<i>Zone 7</i>
	First sample to be taken at point in the column corresponding to the Zone #. For example, in row one, zone is 5 and 1st point is # 30.						
	5	3	8	26	30	42	48
	5	5	10	27	31	33	47
	2	2	11	20	32	35	50
	7	1	15	26	32	36	46
	3	4	9	25	29	36	51
	5	6	7	26	30	43	49
	2	1	13	26	29	38	47
	5	4	14	22	29	39	50
	4	1	10	22	31	37	50
	5	4	19	26	32	38	47
	2	6	16	26	29	43	45
	6	2	11	22	30	44	49
	7	3	8	23	32	41	46
	5	1	10	27	30	42	47

For example, using the random number table example above (Table 2), our team would have started sampling on field day one at point # 30 in zone five. Using the nearest neighbor criterion, we would have then moved to points 31, 29, and 32 (see Fig. 4). If time allowed, we would then have moved to the nearest point south (towards our base camp on Spanish Lookout Caye) and continued doing scans as time allowed. Because the distribution study was part of a larger study, the number of points sampled each day varied depending on other activities and ranged from zero to six, with an average of three scans per day.

## **Detectability**

Consideration of detectability during wildlife surveys is essential to valid interpretation of results (Anderson 2001; Pollock et al. 2006). Preliminary observations from 1998-2000 enabled the design of a sampling method based on a good understanding of manatee behavior within the study site. Using the methods outlined below, I am confident that the presence of manatees was detected, given one or more manatee were present, within the area defined as a sample point, however, I make no assumptions as to the presence or absence of manatees outside the area defined as the sample point. Because we cannot assume equal distribution of manatees within the available habitat, I did not attempt to calculate abundance for the study area.

A point scan began as we approached within 100 m of the sample point. At that 100 m distance, the boat engine was turned off and we maneuvered to the fixed point with a 7 m wooden pole, commonly used by fishermen and tours guides in Belize to approach sites with limited disturbance to wildlife. During each sample period, the boat was tied in position using the pole, and an area with radius  $\leq 300$  m around the survey boat was scanned for 30-minutes to determine whether manatee were present. During the first sampling season, we conducted 20-minute scans and started measuring environmental variables at the end of each scan, for a total time at each point of  $\geq 40$  minutes. We occasionally detected a manatee immediately upon starting to measure environmental variables. Analysis of this phenomenon determined that we detected manatee presence 85% of the time within the first 20 minutes of each scan (K. LaCommare & CSS,

unpublished data). After the first season, we changed our protocol to conduct 30-minute scans, continuing to begin measuring environmental variables after 20 minutes. Data from the first field season were updated to include manatee detected during a full 30-minute sample.

If present, the total number of manatees detected and the time of detection were recorded. These data were used to calculate the frequency of encountering manatees (i.e., total manatees/total scans). The “point” was not a true point in the mathematical sense, since it consisted of a circle around our research boat with radius  $\leq 300\text{m}$ . In the case of points in narrow or dead-end boggles, the point was bounded by the presence of mangroves and was often irregular in shape with a radius of less than 300m. The sampling circle was divided into quadrants. I personally scanned the area from 90 degrees port to the bow to 90 degrees starboard and back; my primary field assistant scanned the area from 90 degrees starboard to the stern to 90 degrees port and back; one seasonal field assistant (intern) scanned from the stern to 90 degrees port to the bow and back; a second seasonal field assistant (intern) scanned from the bow to 90 degrees starboard to the stern and back. Observers were trained to scan their assigned area continuously, with no staring and no conversation during the 30-minute scan period. Using this method, each quadrant was overlapped by at least two primary observers. Primary observers were backed up by EW Volunteers who scanned a dedicated quadrant for a minimum of one PI or field assistant, one intern, and one EW volunteer covering each area with overlap between areas. Since manatees in the Drowned Cayes area of

Belize surface to breath every 2-12 minutes (CSS, unpublished data), this protocol provided several opportunities to detect manatees, if present, during each 30-minute scan period.

### **Data Consistency**

As mentioned earlier, short-term, non-specialist, volunteer researchers have been used to assist in data collection on conservation projects for many years (Darwall & Dulvy 1996; Foster-Smith & Evans 2003). To ensure consistency across field seasons and years, my research partner, Katie LaCommare, and I were both in the field together every day during the first season (2001 dry). At the request of our first host, Mr. Sidney Turton, we trained and used four field assistants, one for each Earthwatch Team during that season. When not working with us on the project, these assistants were employed as tour guides and fishermen by Mr. Turton. At the end of this first season, we were able to modify our methods to use one primary field assistant, Gilroy Robinson; we felt like this would increase consistency in our field methods when Ms. LaCommare and I could not both be in the field. Mr. Robinson was recruited based on his traditional knowledge of the study site, his objective and questioning mind, and his passion for conservation and learning more about the scientific nature of the project. During the last EW Team of the first field season (2001 dry) and the first EW Team of the second field season (2001 rainy) LaCommare, Robinson, and I worked in the field together every day (20 days). We established and defined the specific scan protocols described above to be followed consistently over the course of this study. Both during and since that time, Gilroy

Robinson, and/or I have personally been present during each sampling period. Mr. Robinson was added as a co-PI to our research permit and attended the 2001 Earthwatch PI Conference for additional training. Within each 3-month field season, one or more interns were personally trained by me prior to the first EW Team of the season. These interns worked with the team providing increased consistency and oversight of EW Volunteers within the field season.

### **Categorization of Points**

The 54 sample points were lumped into zones to enable a stratified random sample design (Table 2). Zones were created based on the connectivity between points. Zones 1 (Swallow Caye) and 8 (Gallows Reef) were sampled systematically; Zones 2-7 (the Drowned Cayes) were sampled randomly. We do not assume any physical barriers preventing movement by manatees between zones; rather they were identified based on the assumption that within each zone, manatees could easily travel between points without leaving the sheltered habitat provided by the labyrinth of mangrove islands, seagrass beds, and small boggles connecting the points. The lines in figure 4 indicate the zones; the openness of the zones indicates that manatees could also travel between zones.

Each of the 54 points was categorized as being inside or outside the boundaries of SCWS established in 2002. Points 1-7, 9, 11, 52, and 53 fell inside the sanctuary boundaries. Additionally, each point within the Drowned Cayes area was categorized as

representative of two broad habitat types: OPEN or SHELTER. Points categorized as OPEN were located in wider, deeper bogues within the Drowned Cayes or outside the perimeter of the Drowned Cayes near deeper bogues; points categorized as SHELTER were located in narrow, shallower bogues, dead-end bogues, or in quiet coves, lagoons, and bays away from deeper bogues.

Tidal state was recorded for the start time of each 30-minute scan based on predicted tides for Belize City, and subjectively confirmed in the field. If the scan began within 60 minutes of the predicted high tide, the sample was classified as High; if the scan began within 60 minutes of the predicted low tide, it was classified as Low; if the scan began between the predicted high tide plus 61 minutes and the predicted low tide minus 61 minutes, it was classified as Ebb; if the scan began between low tide plus 61 minutes and high tide minus 61 minutes, it was classified as Flood. Predicted tidal data were provided by the Belize Meteorological Service (daily radio reports) and the X-Tide Program (Flater 1998).

### **Environmental Data**

The weather in Belize varies with latitude and season; seasons are defined by rainfall and temperature (Beletsky 1999). Air temperature in Belize City averages 23°C during the dry season (December - May/June) and 31°C during the wet season (May/June - November). Annual rainfall varies greatly with latitude, ranging from an average of 130 cm per year in the north to 450 cm per year in the south. The average annual

rainfall for Belize City is 200 cm, with about 16 rainy days per month during September or October, but only 4-5 rainy days per month during March or April. The hurricane season is June - November. It is important to note that the dry and rainy seasons in the Belize City area are not as well defined as elsewhere in Belize or in the tropics in general, so I analyzed actual water temperature and precipitation for the study period. For the purposes of analysis, data collected from January to April were categorized as the cooler/transitional-dry season; data collected from June to September were categorized as the warmer/wet season.

**Rainfall Data:** 2001-2004 daily precipitation data were provided by Belize Meteorological Service for Philip W. Goldson International Airport (PGIA). PGIA is located in Ladyville, near the Belize River, which was the primary source of river runoff affecting the Drowned Cayes area. Raw data were converted to a 10-previous-days cumulative rainfall datum for each sample date.

**Sea-surface Temperature:** To measure the sea-surface temperature for the study area, we collected a one pint sample of water at the sea surface from Baldwin Bogue twice per day--as we departed and returned to our base camp on Spanish Lookout Caye. Baldwin Bogue is a wide, deep, fast flowing bogue adjacent to Spanish Lookout Caye; it is the location within our study area that best reflects the general conditions between Belize City and the Barrier Reef. With the boat facing into the wind, a 0.5 L sample bottle was held at the surface and slowly decanted to reduce the potential for mixing surface water with subsurface water. Temperature was measured using a Taylor pocket digital thermometer. Accuracy of readings could not be confirmed as field conditions did not



allow for calibration of the thermometer. However, a standard method was employed to ensure precision of readings for comparison between days. Immediately upon retrieving the sample, the thermometer was placed into the sample bottle and held in place and out of the direct sunlight until the reading stabilized, about 2 minutes. The reading was then confirmed by at least two observers. Measurements were recorded on the daily Trip Summary datasheet (Appendix B).

### **Statistical Analyses**

In keeping with our KIS methods, manatee presence/absence data were analyzed by temporal and spatial categories using the Likelihood-Ratio Chi-Squared Statistic,  $G^2$  (Agresti 1990). The Kruskal-Wallis H statistic was used to analyze variation in rainfall and sea surface temperature data by season (Quinn & Keough 2003). All statistical analyses were performed using SPSS Version 14.0 (George & Mallery 2007).

### **RESULTS**

Over a period of 260 field days distributed between two seasons across four years (2001-2004), 729 30-minute scan samples were completed at 54 permanently fixed scan points. Forty-four samples were collected at two points near Swallow Caye (Zone 1); 605 samples were collected at 50 points within the Drowned Cayes (Zones 2-6); and 80 samples were collected at two points near Gallows' Reef (Zone 8). Manatees were significantly more likely to be encountered at Swallow Caye, than anywhere else in the study area (Table 3).

Table 3. Total Scans Conducted within Each Sampling Zone. Number of points, total number of samples, and the probability of detecting manatee in each of 8 Zones. Zone 1 (Swallow Caye) and Zone 8 (Gallows' Reef) were sampled systematically, Zones 2 through 7 (Drowned Cayes) were sampled randomly.

<i>Area</i>	<i>Swallow Caye</i>	<i>Drowned Cayes</i>						<i>Gallows' Reef</i>
Zone	1	2	3	4	5	6	7	8
# Points	2	6	13	9	4	8	9	2
# Samples	44	77	177	89	65	100	104	80
Probability	0.82	0.32	0.39	0.34	0.37	0.44	0.32	0.14

### **Distribution Inside and Outside SCWS**

The probability of encountering a manatee inside the boundaries established for SCWS in 2002 was significantly higher than the probability of encountering a manatee outside SCWS (Log-Likelihood Ratio  $G^2=11.792$ ,  $p=0.001$ ). From 2001 to 2004, 569 scans were conducted at points outside SCWS with a probability of encountering manatees of 0.34; 160 scans were conducted at points inside SCWS with a probability of encountering manatees of 0.49 (Fig. 5).

### **Distribution by Habitat and Tidal State**

The probability of manatee presence did not vary significantly by habitat type within the Drowned Cayes (Log-Likelihood Ratio  $G^2=0.808$ ,  $p=0.369$ ). During 253 scans in OPEN habitat, manatees were present 88 times (35%); during 352 scans in SHELTER habitat, manatees were present 135 times (37%). However, a trend was detected with respect to tidal state. Manatees more likely to be present at points within the Drowned Cayes

during low tide, than during flood, high, or ebb tides (Log-Likelihood Ratio  $G^2=6.974$ ,  $p=0.073$ ).

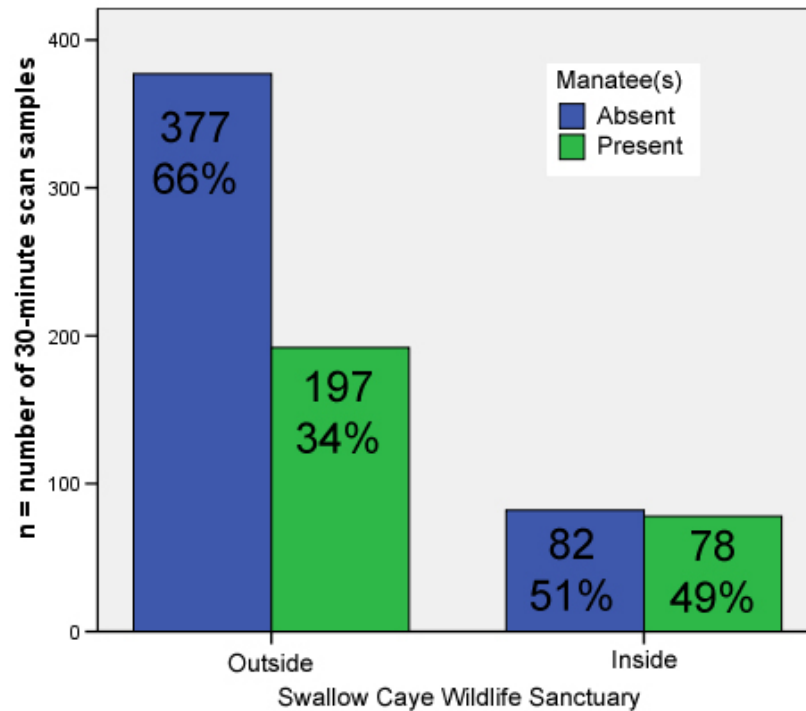


Figure 5. Manatee Presence with Respect to SCWS. Numbers in bars represent the number of scans and percentage of total for location (outside/inside SCWS) where manatees were absent (blue) and present (green).

### Seasonal Distribution

The overall probability of encountering manatee during a 30-minute scan sample at any point was 0.37 with no significant difference between seasons (Log-Likelihood Ratio  $G^2=0.446$ ,  $p=0.504$ ). During 333 dry-season scans, manatees were detected 119 times

for a probability of 0.36; during 396 wet-season scans, manatees were detected 151 times for a probability of 0.38 (Fig. 6).

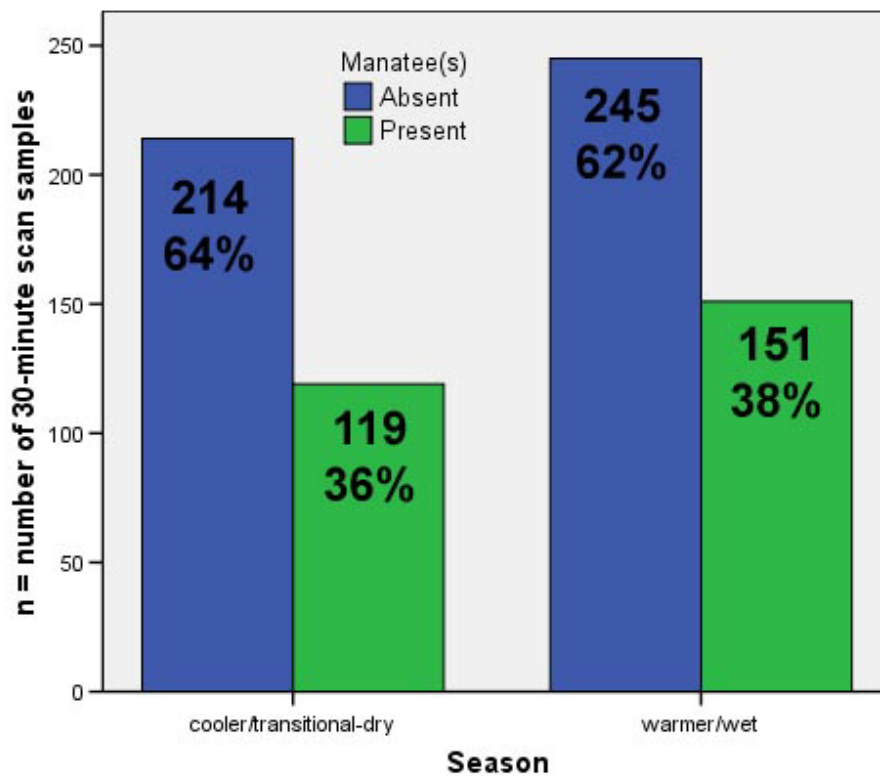


Figure 6. Manatee Presence by Season: All Areas. Numbers in bars represent the number of scans and percentage of total for season where manatees were absent (blue) and present (green).

The four points at Swallow Caye and Gallows Reef represented distinctive areas outside the Drowned Cayes mangrove labyrinth and were sampled systematically rather than randomly to ensure an ample sample size for each area. Due to these differences in location, connectivity, and sampling regime, I also analyzed the three areas

independently. The overall probability of encountering manatee at Swallow Caye (2 points) was 0.82 (n=44 scan samples), significantly higher than the overall probability for any other zone. During 18 dry-season scans, manatees were detected 16 times for a probability of 0.89; during 26 wet-season scans, manatees were detected 20 times for a probability of 0.77 (Fig. 7). There was no significant difference in the probability of encountering manatee between seasons at Swallow Caye (Log-Likelihood Ratio  $G^2=1.076$ ,  $p=0.300$ ).

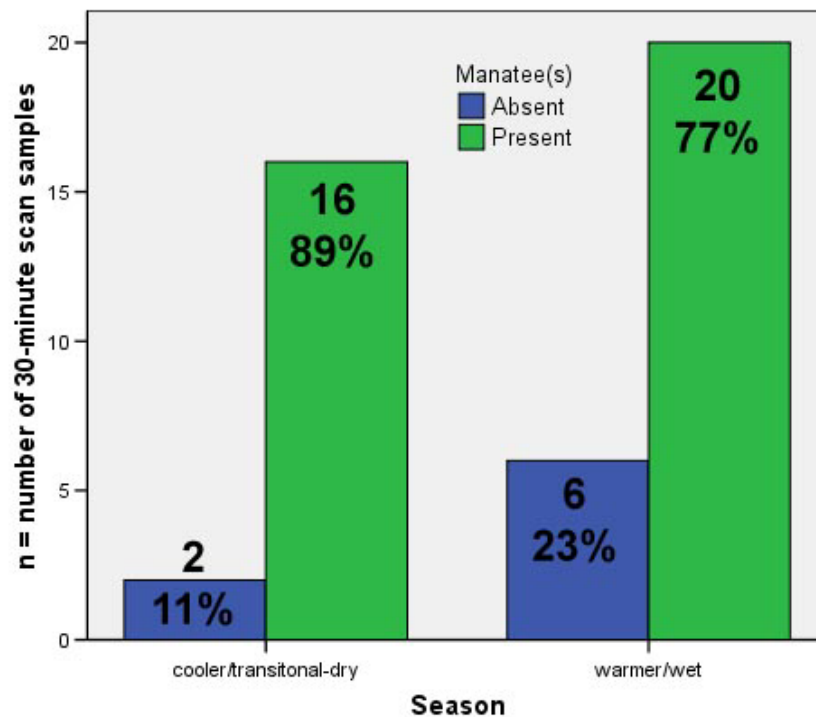


Figure 7. Manatee Presence by Season: Swallow Caye. Numbers in bars represent the number of scans and percentage of total for season where manatees were absent (blue) and present (green).

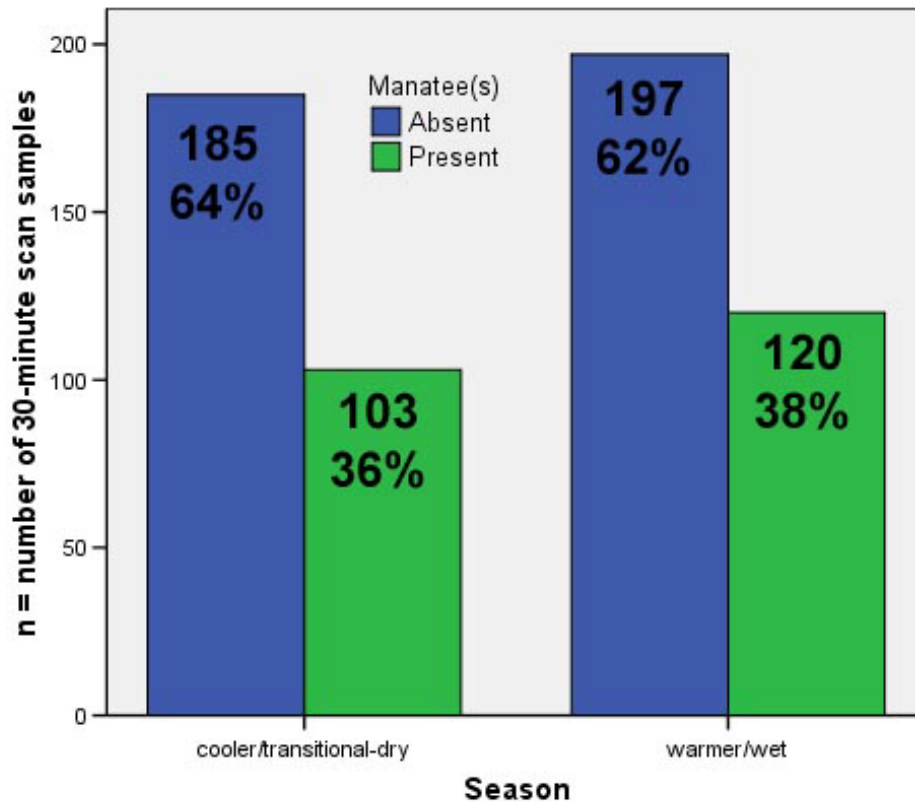


Figure 8. Manatee Presence by Season: Drowned Cayes. Numbers in bars represent the number of scans and percentage of total for season where manatees were absent (blue) and present (green).

**Drowned Cayes:** The overall probability of encountering manatee within the Drowned Cayes mangrove labyrinth (50 points) was 0.37 (n=605 scan samples). During 288 dry-season scans, manatee were detected 103 times for a probability of 0.36; during 317 wet-season scans, manatee were detected 120 times for a probability of 0.38 (Fig. 8). There was no significant difference in the probability of encountering manatee between seasons in the Drowned Cayes (Log-Likelihood Ratio  $G^2=0.284$ ,  $p=0.594$ ). The probability of detecting manatee was similar among all 6 zones within the Drowned Cayes (Table 3).

**Gallows Reef:** The overall probability of encountering manatee at Gallows' Reef (2 points) was 0.11 (n=80 scan samples). During 27 dry-season scans, manatees were detected 0 times for a probability of 0.00; during 53 wet-season scans, manatees were detected 11 times for a probability of 0.21. There was a highly significant difference between seasons (Log-Likelihood Ratio  $G^2=9.931$ ,  $p=0.002$ ) with no manatees observed during the cooler/transitional-dry season (Fig. 9).

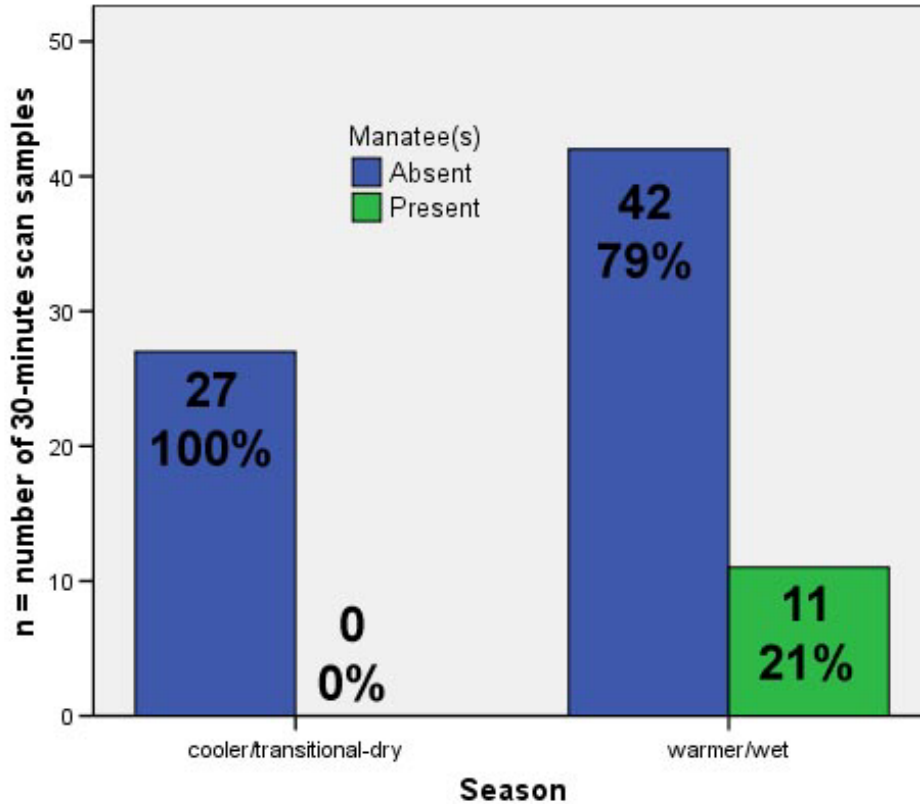


Figure 9. Manatee Presence by Season: Gallows Reef. Numbers in bars represent the number of scans and percentage of total for season where manatees were absent (blue) and present (green).

**Rainfall**

The 10-previous-day cumulative rainfall varied from 0.00 cm to 25.80 cm, with a mean of 3.9 cm and standard deviation of 4.17 cm (n=260). There was a significant difference in 10-previous-day cumulative rainfall between seasons (Kruskal-Wallis H=24.652, p=.000, n=260). The mean 10-previous-day rainfall was 2.6 cm (SD=2.7) for the cooler/transitional-dry season (n=118) and 4.9 cm (SD=4.8) for the rainy season (n=142).

**Sea-Surface Temperature**

The daily sea-surface temperature varied from 25.0°C to 31.6°C, with a mean of 28.6°C and standard deviation of 1.7°C. There was a significant difference in daily sea-surface temperature between seasons (Kruskal-Wallis H=173.313, p=0.000, n=236). The mean sea surface temperature was 27.0°C (SD=0.9) for the cooler/transitional dry season (n=109) and 30.0°C (SD=0.7) for the rainy season (n=127).

**Daily Probability of Encountering Manatees**

The daily probability of encountering manatees during a point scan varied from 0.0 to 1.0, with no animals observed during any scan on 75 days (29%) and one or more animals observed during at least one scan on 185 days (71%). There was no significant difference in the daily probability (Kruskal-Wallis H=0.527, p=0.468, n=260) of encountering manatees between seasons.



### Yearly Probability of Encountering Manatees

The points within the Drowned Cayes were scanned 199 times in 2001, 150 times in 2002, 144 times in 2003, and 112 times in 2004. Despite a slightly reduced effort over time, the probability of encountering manatees remained remarkably consistent (Fig. 10).

The probability of encountering manatees did not differ by year within the Drowned Cayes (Log-Likelihood Ratio  $G^2=1.917$ ,  $p=0.590$ ).

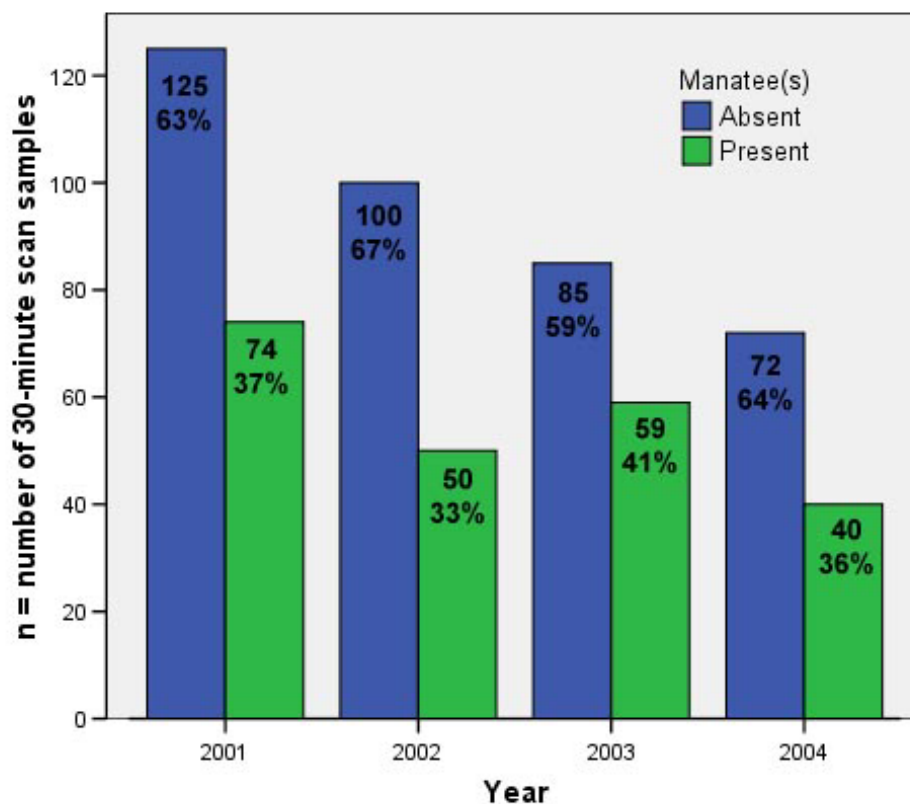


Figure 10.. Manatee Presence by Year: Drowned Cayes. Numbers in bars represent the number of scans and percentage of total for year where manatees were absent (blue) and present (green).

## **DISCUSSION**

From my personal observations over the past decade in Belize, Swallow Caye Wildlife Sanctuary appears to have been established based on significant local knowledge (Chocolate Heredia and other manatee tour operators), opportunism (stakeholder concerns over increasing impacts from the cruise ship industry), scientific data (broad scale aerial surveys by Gibson (1995) and Auil (1998) and preliminary reports by CSS and LaCommare), and a bit of compromise (negotiated between CZMA&I and the Ministry of the Environment), just as Roberts (2000) described for most MPAs. If you evaluate optimal habitat by how much it is used, the boundaries for SCWS appear to encompass the most important habitat for manatees within the area investigated.

Manatees were present during 82% of the point samples conducted at Swallow Caye (Zone 1, points 52 and 53), a finding in support of local knowledge. The probability of encountering manatees in the remainder of SCWS (Zone 2 and part of Zone 3, points 1-7, 9, and 11, manatees present during 36% of the point scans) was similar to the probability within the overall Drowned Cayes range (Zones 2-7, manatees present in 32-40% of the samples).

Data collected during this study indicate that manatees use Swallow Caye and the Drowned Cayes equally during both the cooler/transitional-dry season and the warmer/rainy season. Within the Drowned Cayes labyrinth of mangrove islands and at Swallow Caye, the probability of encountering manatees was consistent across seasons, years, and habitat types. These data contradict the prevailing hypothesis (Auil 2004) that

manatees use the marine habitat seasonally, with lower use in the cooler/transitional-dry season and higher use in the warmer/wet season. However, data from the 2 points at Gallows Reef support the prevailing hypothesis that manatees use the BBR habitat seasonally, with no presence detected during the cooler/transitional-dry season (Self-Sullivan et al. 2003). It is important to note that this study only reflects the situation in the Drowned Cayes, Swallow Caye, and Gallows Reef for 2001-2004.

When looking at the data set as a whole, the Drowned Cayes data over-shadowed the probability of encounter patterns unique to Swallow Caye and Gallows Reef. This artifact was obviously due to the large size of the Drowned Cayes area and greater number of points within the Drowned Cayes. However, the phenomenon reflects the importance of small scale, site specific studies for Antillean manatees in Belize. Broad scale country-wide aerial surveys have been successful in predicting high use areas for further study, but they failed to detect unique distribution and probability of encounter patterns on smaller spatial scales, such as those found for Swallow Caye, the Drowned Cayes, and Gallows Reef.

Post-hoc analysis detected a variance in probability of encountering manatees among the three areas investigated. Swallow Caye, the focal point for Swallow Caye Wildlife Sanctuary, has long been considered a manatee hotspot by local tour operators. With manatees present during 82% of the scans at Swallow Caye (points 52 and 53), this study confirms the validity of traditional knowledge and reinforces the need for special

protection of Swallow Caye. With manatees present during 37% of the scans within the Drowned Cayes, and relatively consistent probabilities among zones, seasons, years, and habitat types, consideration should be given to expanding the boundaries of Swallow Caye Wildlife Sanctuary to include the entire Drowned Cayes.

The lower probability of encountering manatees at Gallows Reef is partly explained by the seasonal variation. However, I am not as confident in our ability to detect manatees at these two points due to the broader area available to manatees, the higher ambient wave and wind noise, and the higher wave energy at the reef sites. On many occasions during the warmer/wet season, manatees were detected at these sites during a post-scan snorkel on the reef. It was not feasible to determine whether these manatees arrived at the site before, during, or after the 30-minute sample. In support of the seasonal distribution hypothesis, manatees were never detected during post-scan snorkel events during the cooler/transitional-dry season. However, I have received anecdotal reports from tour operators (snorkel and dive guides) of manatees sighted at Gallows Reef, Sergeants Caye, and Goff's Caye in the months of April (dry season) and November (wet/transitional season). The gender of manatees observed during post-scan snorkel events was determined for approximately 75% of the sightings. Consistent with previous reports (Self-Sullivan et al. 2003), 100% of sexed animals were adult or independent juvenile males, with no females or calves observed.

If rainfall or temperature had a significant effect on manatee presence within the study area, I would have expected to see abnormally high rainfall and sea-surface temperatures during the cooler/transitional-dry seasons covered by this study to account for the consistent presence of manatee across seasons and years. However, the rainfall and temperature data were significantly different between seasons, as expected for Belize City. There were no abnormally wet dry-seasons and no abnormally dry wet-seasons during this study.

In recent years research techniques focused on detecting trends in wildlife populations have shifted from fine scale, labor intensive, site-specific studies to broad scale attempts to monitor entire populations (Pollock et al. 2002). Broad scale methods often use convenience sampling methods and/or some index (e.g., Index of Relative Abundance or IRA) to estimate trends in distribution, abundance, habitat use, and population size of many wildlife species (Anderson 2001; Pollock et al. 2002). However, assuming that an index is closely related to true distribution and abundance of a species across spatial (e.g., habitat types) and temporal (e.g., seasons) variables is flawed in many species due

to variance in habitat use and detection probabilities, among other factors (Anderson 2001; Pollock et al. 2002). Aerial surveys have been widely used to estimate wildlife population distribution and abundance since the 1940s (Pollock et al. 2002).

Specifically, aerial survey counts have been used as an index for determining distribution and relative abundance of sirenians since the 1970s (Table 4). As a result, considerable research has also been devoted to developing sampling and analytical techniques that can be used to convert raw counts of manatees and dugongs into useful population data. Table 5 lists some of the more comprehensive evaluations of aerial survey methods for sirenians and the recommendation from each I considered in developing methods for this research project.

Aerial surveys are useful in determining minimum population size and where manatees are likely to be encountered for finer scale studies, but are unreliable in determining actual population size or trends in relative abundance over time, unless site-specific visibility bias correction factors are applied to the raw data (Packard et al. 1985;

Table 4. Examples of Aerial Survey Studies. This table is not intended to be totally inclusive, but to list examples of studies that used aerial survey counts to estimate distribution and abundance of sirenians.

<i>Species</i>	<i>Location</i>	<i>Reference</i>
<i>T. m. latirostris</i>	Southeastern USA: NC, SC, GA, FL	Irvine & Campbell 1978
<i>T. m. latirostris</i>	Florida: Indian & Banana Rivers	Leatherwood 1979
<i>T. m. manatus</i>	Belize	Bengtson & Magor 1979
<i>D. dugong</i>	Papua New Guinea: Manus Province	Hudson 1981
<i>T. m. manatus</i>	Panama	Mou Sue et al. 1990
<i>T. m. manatus</i>	Belize	O'Shea & Salisbury 1991
<i>T. m. latirostris</i>	Florida: power plants	Reynolds & Wilcox 1994
<i>D. dugong</i>	Australia: Shark Bay, Western Australia	Marsh et al. 1994
<i>T. m. latirostris</i>	Florida: winter aggregation sites	Garrott et al. 1994
<i>D. dugong</i>	Australia: Shark Bay, Western Australia	Anderson 1994
<i>T. m. manatus</i>	Costa Rica	Reynolds et al. 1995
<i>D. dugong</i>	Palau	Marsh et al. 1995
<i>D. dugong</i>	East Indonesia	de Iongh et al. 1995
<i>D. dugong</i>	Western Australia	Preen et al. 1997
<i>D. dugong</i>	Torres Straight AU & Papua New Guinea	Marsh et al. 1997
<i>T. m. manatus</i>	Belize & Chetumal Bay, Mexico	Morales-Vela et al. 2000
<i>T. m. latirostris</i>	Florida: Tampa Bay	Wright et al. 2002
<i>T. m. manatus</i>	Mexico: Yucatan Peninsula	Morales-Vela et al. 2003
<i>D. dugong</i>	Australia: Moreton Bay, Queensland	Lanyon 2003
<i>D. dugong</i>	Arabian Gulf	Preen 2004
<i>D. dugong</i>	Western Australia	Gales et al. 2004
<i>T. m. manatus</i>	Mexico: Chetumal Bay	Olivera-Gomez & Mellink 2005
<i>D. dugong</i>	Australia: Torres Straight	Marsh et al. 2004
<i>D. dugong</i>	Australia: Queensland	Marsh et al. 2005
<i>D. dugong</i>	Thailand: Andaman Coast	Hines et al. 2005
<i>D. dugong</i>	Australia: Queensland	Lanyon et al. 2005
<i>T. m. latirostris</i>	Florida: major overwintering sites	Laist & Reynolds 2005
<i>D. dugong</i>	Australia: Shark Bay, Western Australia	Holley et al. 2006

Table 5. Aerial Survey Evaluations. This table is not intended to be totally inclusive in either studies or recommendations from any referenced study. Each of the publications listed includes discussion and recommendations too comprehensive to summarize here.

<i>Species</i>	<i>Recommendation</i>	<i>Reference</i>
<i>T. m. latirostris</i>	Single-survey counts should not be used as an index of abundance unless visibility bias is measured or variability otherwise assessed.	Packard et al. 1985
<i>T. m. latirostris</i>	Density index and total counts are less suitable than sight-resight index technique for detecting annual trends in abundance.	Packard et al. 1986
<i>D. dugong</i>	Aerial surveys designed to obtain population estimates or indices of abundance should be designed to cover areas large enough to accommodate known and potential movements of the population.	Marsh & Sinclair 1989
<i>T. m. latirostris</i>	In areas with no well defined aggregation point, a stratified random sample design should be developed taking into account environmental variables.	Lefebvre & Kochman 1991
<i>T. m. latirostris</i>	Avoid temptation to improve survey methods; data must be collected in a consistent manner if temporal changes in counts are to attributed to population changes.	Garrott et al. 1994
<i>T. m. latirostris</i>	Hierarchical modeling and Bayesian analysis allows the incorporation of biological data, and data from other sampling methods with aerial survey data to improve predictive ability of models.	Craig et al. 1997; Craig & Reynolds 2004
<i>T. m. latirostris</i>	Transect surveys are most appropriate in large homogeneous areas; manatees commonly inhabit areas with high turbidity that are obscured by vegetation.	Miller et al. 1998
<i>T. m. latirostris</i>	Variable-shape filters are more ecologically relevant for studying manatees than fixed shape filters.	Flamm et al. 2001
<i>D. dugong</i>	It is possible to reduce variation in detectability by using standardized protocols and defining acceptable survey conditions.	Pollock et al. 2006



Lefebvre & Kochman 1991; Garrott et al. 1994; Miller et al. 1998; Pollock et al. 2006).

While significant sampling and analytical advances have been made with respect to aerial surveys of dugongs (*Dugong dugon*) in recent years (Pollock et al. 2006), broad application to manatee (*Trichechus* spp.) aerial surveys may not be practical due to the variety of coastal environments they inhabit.

Based on the results of this study, I conclude that long-term, site specific, boat-based point scan surveys using standardized methods are more reliable than aerial survey counts in determining spatial and temporal distribution of manatees in the Drowned Cayes, Swallow Caye, and Gallows Reef area of Belize. Due to very different methods, sample periods, and sample sizes, it is not possible to compare results between this and previous studies. Replicate counts and other methods have been useful in determining site-specific visibility bias for manatees in Florida (Packard et al. 1985; Packard et al. 1996; Lefebvre & Kochman 1991), but the time and cost required to conduct these for each site may override the benefits of aerial surveys over other fine scale site-specific methods, such as boat surveys. Because low detection probabilities exist in many coastal habitat types (e.g., turbid and/or deep water, dense canopy cover), aerial surveys probably fail to detect manatees in some areas (e.g., animals resting or feeding on the seafloor or beneath overhanging mangroves and other vegetation).

Currently, the use of raw aerial survey counts to develop hypotheses with respect to population size and/or trends in relative abundance of endangered West Indian manatees,

*Trichechus manatus*, continues in the Wider Caribbean Region (e.g., Mou Sue et al. 1990; Morales-Vela et al. 2000; Morales-Vela et al. 2003; Auil 2004; Olivera-Gómez & Mellink 2005). Surveys are expensive, whether conducted by aircraft, boats, or from land. The need to "get it right" cannot be over emphasized (Anderson 2001). The Earthwatch Volunteer Model provides a unique funding opportunity for labor intensive studies such as boat and land based surveys, but is not suitable for aerial surveys. With the growing increase in eco-tourism and community conservation on a global scale, funding and man-power are available from several sources similar to Earthwatch. I suggest that old-fashioned, labor intensive, site-specific methods provide a less costly and more easily funded alternative to aerial surveys. The method enables the larger sample sizes necessary to draw conclusions about distribution of manatees within a marine environment. If aerial surveys continue to be conducted in the Drowned Cayes area, I recommend they be conducted in collaboration with the Drowned Cayes project to enable simultaneous boat-based and aerial survey counts. Collaboration would enable the development of site-specific visibility bias correction factors for the Drowned Cayes, Swallow Caye, and Gallows Reef, which could be applied to future aerial surveys for the area.

**CHAPTER III**  
**NON-LETHAL BOAT SCARS: A TOOL FOR EVALUATING SWALLOW**  
**CAYE WILDLIFE SANCTUARY**

**INTRODUCTION**

In establishing a protected area, it is important to remember that the targeted species may not necessarily remain confined to its designated refuge (see Siex & Struhsaker 1999 and Wittemyer 2001 for examples). The use of natural markings and scars to study the ecology, behavior, life history, social grouping, and population structure of mammals has been well established in the literature (Whitehead 2001; Evans & Yablokov 2004; Karczmarski et al. 2005). For some marine mammals, natural marks (e.g., tail flukes of the humpback whale, *Megaptera novaeangliae*) and scars (e.g., dorsal fin of the bottlenose dolphin, *Tursiops truncatus*) are not only unique, but also location specific, making a good photo of only one body part necessary to identify an individual. Unfortunately, this is not the case for West Indian manatees (*Trichechus manatus*), which lack a dorsal fin and rarely have any variability in coloration.

In Florida, where watercraft collision is a primary cause of manatee injury and death, most manatees (*T. m. latirostris*) bear one or more unique scar patterns, the result of non-lethal collisions with boats (Hartman 1979; Beck et al. 1982; Beck & Reid 1995). These scar patterns have been used to identify individual Florida manatees since the late 1950s (Moore 1956; Hartman 1979), leading to the development of an automated

Manatee Individual Photo ID System, commonly referred to as MIPS (Beck & Reid 1995). Because scars may be found anywhere on a manatee, MIPS requires photos of the tail, dorsum, and both lateral aspects of each individual to qualify for inclusion in the MIPS catalog. Individuals with unique marks, but incomplete photographic records are categorized as Distinct Unknowns (DUs) and only assigned an individual ID number after all required aspects are photographed, reducing the possibility of multiple ID numbers for the same animal (Cathy Beck, personal communication).

Although previous studies detected no scarring from boats in Belize (O'Shea & Salisbury 1991), watercraft collision has more recently been identified as a leading cause of manatee mortality in Belize, with an increasing trend in boat-related mortality from 1996 to 2003 (Auil & Valentine 2003, 2006). With an exponential increase in cruise ship tourism (Fig. 2) since 2001, and corresponding increases in tender and tour boat activity, the local perception is that more manatees are being injured or killed by boats each year, especially near Belize City. One previous study used boat scarring to identify individual manatees in at Basil Jones in northern Belize (Self-Sullivan et al. 2003). However, no data are available regarding the number of non-lethal boat collisions with manatees in Belize or the proportion of boat-scarred animals in the population. In this chapter, I investigate the probability of encountering a boat-scarred manatee and the potential of using non-lethal boat scars to evaluate the effectiveness of Swallow Caye Wildlife Sanctuary and develop a MIPS-like catalog for manatees near Belize City.

## **OBJECTIVES OF THIS STUDY**

Due to the difficulty of photographing all aspects (tail, dorsal, and both lateral views) of any individual manatee in Belize, actual development of a MIPS catalog for Belize is beyond the scope of this dissertation. The objectives of this chapter are to examine the effects of space and time on the likelihood of ‘capturing’ a boat-scarred manatee in the Swallow Caye, Drowned Cayes, and Gallows Reef study area using underwater video techniques. I will (1) determine the probability of observing a boat-scarred manatee given a manatee was captured on video; (2) determine whether boat-scarred manatees were more likely to be observed inside or outside the boundaries of Swallow Caye Wildlife Sanctuary (SCWS); and (3) determine if there was an increase in the likelihood of observing a boat-scarred manatee over time.

If the likelihood of observing a boat-scarred manatee is high, then techniques used to study the Florida manatee population may be useful in the Swallow Caye, Drowned Cayes, and Gallows Reef area of Belize. If the area designated as SCWS provided a preferred refuge for manatees previously struck by a boat then I would expect to see a higher likelihood of encountering boat-scarred manatees within the boundaries established for SCWS. Alternatively, if Swallow Caye, Gallows Reef, and the entire Drowned Cayes area provided a refuge for manatees previously struck by a boat, then I would expect to encounter boat scarred manatees equally distributed within the study area. If there has been an increase in non-lethal boat strikes since the exponential

growth in cruise ship tourism, then I would expect to see an increase in the likelihood of observing a scarred manatee after 2001.

## **METHODS**

In Florida, during the winter months, manatees aggregate at warm water effluents and rest at the surface to thermoregulate using solar radiation. This behavior enables researchers to capture images of individual manatees from a fixed or floating platform without entering the water. In the Swallow Caye, Drowned Cayes, and Gallows Reef area of Belize, manatees neither aggregate in large groups, nor do they rest at the surface, making it more difficult to capture images of individuals from surface. As an alternative, I used a digital video camera and underwater housing to capture images of manatees opportunistically encountered in the study area from 1999 to 2005. For a detailed description of the study area, see Chapter II.

### **Definitions**

I define boat-scar as any visible markings representative of fresh, recent, healing, or healed wounds (Beck et al. 1982) most likely resulting from a watercraft collision. Lacerations due to propellers and skegs leave distinctive scars, which are easily detected prior to re-pigmentation of the skin. In this chapter, the word ‘scar’ refers to a boat-scar as distinct from other types of scars or natural markings that may be found on manatees; and the word ‘capture’ refers to video captures as distinct from physical captures of manatees. Re-pigmented scars and scars on animals encrusted with sediment, algae,

and/or barnacles, are difficult to detect using underwater video techniques. As a result, I have most likely underestimated the probability of capturing a scarred manatee.

However, I assumed that the probability of capturing a manatee using underwater video techniques was not affected by whether or not the animal was scarred; and detecting a scar, given a scar is present, is equal across all categories used for analysis in this chapter.

Whenever a manatee was encountered, whether opportunistically or during a point scan as described in Chapter II, I evaluated whether conditions were optimum for capturing its image based on behavior of the animal, water clarity, and time available to devote to the capture. If all three of these conditions were optimal for a successful video capture, I entered the water with mask, snorkel, fins, and camera, and maneuvered cautiously towards the animal. The capture event continued until one of 3 events occurred: (1) I had recorded images of the animal's tail, trunk (dorsal and both lateral views), and face, and determined its sex; (2) the animal moved away from the area; or (3) conditions became less than optimal for recording (e.g., low visibility due to angle of sun or disturbance of substrate, low battery, or tape end).

### **Data Reduction and Analysis**

Only data from video captures were used in the analysis. Videos were reviewed using a Toshiba Satellite M35X-S349 computer with

15-inch screen and Adobe Premiere 6.0 software, which enabled slow-motion and frame-by-frame playback. Suspected re-captures of previously videoed individuals were rare (unpublished data). For the purpose of this analysis, each capture was recorded as an event without regard to individual identity of the manatee. In the case of replicate captures of the same animal on the same day only one capture was included as an event ( $n=1$ ). Log-likelihood ratio tests ( $G^2$ ) were used to determine whether the probability of capturing a scarred manatee differed from what was expected by chance (Agresti 1990).

## **RESULTS**

Scars were detected in 103 of the 233 events analyzed resulting in the overall probability of capturing a scarred manatee, given a manatee was captured on video, of 0.44 (Fig. 11). Probability in this context is defined as a simple probability (i.e., percentage) of scarred animals captured during all events (Bakeman & Gottman 1986). The probability of capturing a scarred manatee inside SCWS (probability =0.44,  $n=43$  events, 19 scarred) was equal to the probability of capturing a scarred manatee outside SCWS (probability=0.44,  $n=190$  events, 84 scarred).



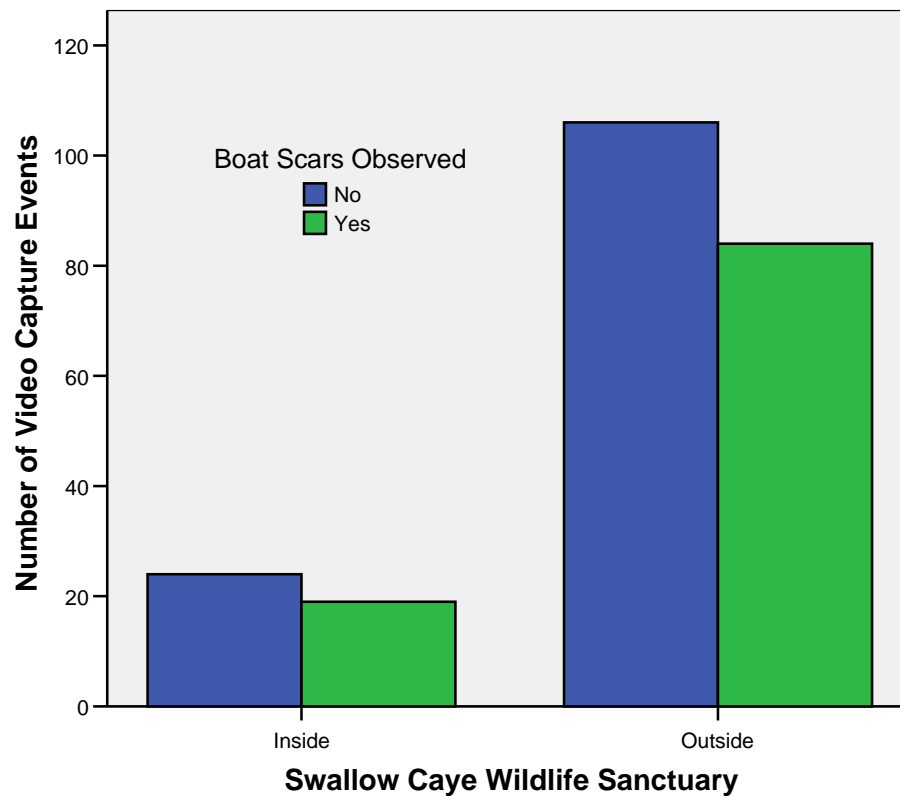


Figure 11. Scarred Manatees by Protected Area. The probability of observing a boat-scarred manatee inside Swallow Caye Wildlife Sanctuary (0.44) was equal to the probability of observing a boat-scarred manatee outside Swallow Caye Wildlife Sanctuary (Log-Likelihood Ratio  $G^2 = 0.00$ ,  $p = 0.998$ ).

Following my original hypothesis that manatees previously struck by a boat might seek refuge in protected areas more often other manatees, I coded the habitat type for each video capture event as SHELTER (N=123), OPEN (N=58), or REEF (N=52), without respect to whether or not the event occurred within the boundaries of SCWS. Events coded as SHELTER occurred in bights, coves, lagoons, and dead-end boggles protected by the mangrove islands (Swallow Caye and Drowned Cayes) with relatively shallow depths (< 3 meters). Events coded as OPEN occurred in open-ended boggles, which cut

through the mangrove islands, and in areas outside the islands with relatively greater depths (> 3 meters). Events coded as REEF occurred east of the Drowned Cayes and within 100 m of Gallows Reef in water ranging in depth from 3 to 5 meters. The probability of observing a scarred manatee did not differ significantly among habitat types (Fig. 12).

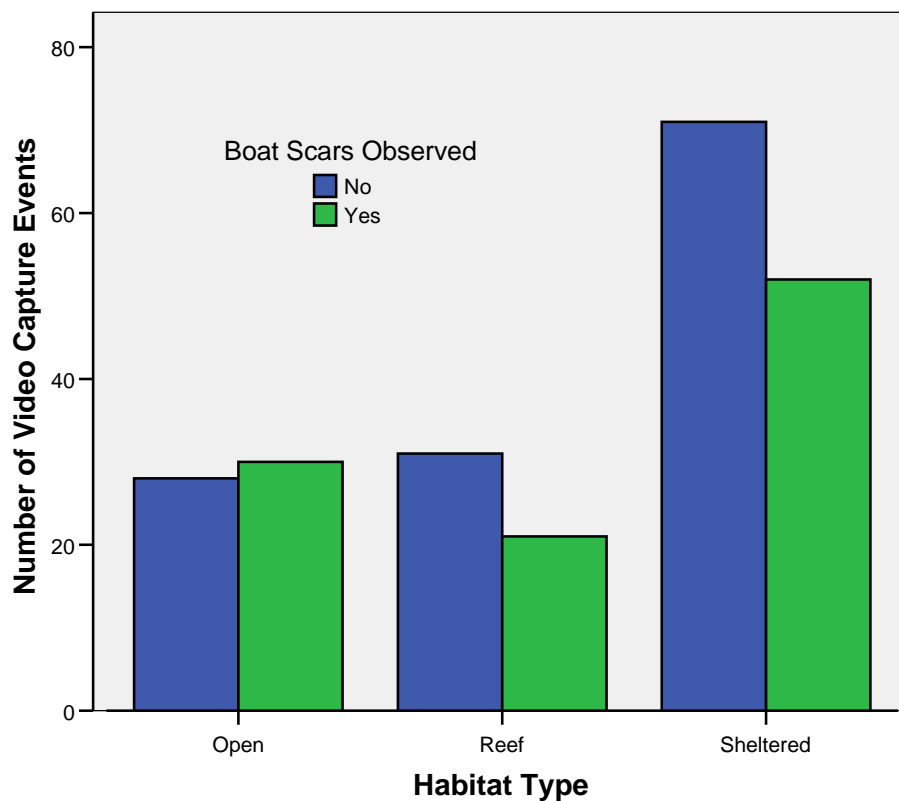


Figure 12. Scarred Manatees by Habitat Type. The probability of observing a scarred manatee did not differ by habitat type ( $G^2 = 1.815$ ,  $p = 0.404$ ).

To determine if the likelihood of capturing a scarred manatee changed with time, I examined the capture events by year. Log-likelihood analysis indicated that the probability of capturing a scarred manatee was variable across years, but with no trend towards an increase over time (Fig. 13).

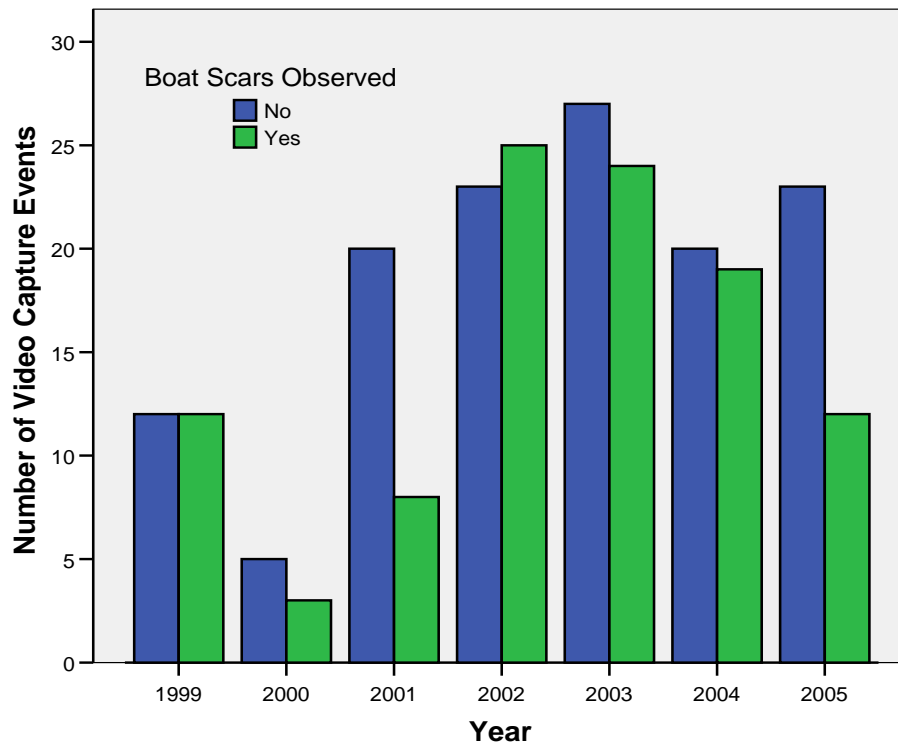


Figure 13. Scarred Manatees by Year. Distribution of opportunistic capture events by year split by unscarred (blue bars) and scarred (green bars) manatees. The exponential increase in cruise ship activity occurred between the 2001 and 2002 field seasons. Although there appeared to be an increase in the likelihood of capturing a scarred manatee between 2001 and 2002, analysis of the data over an extended number of years indicated that this is neither significant nor a trend within the Drowned Cayes study area ( $G^2 = 6.48$ ).

Preliminary analysis had indicated an increasing trend in the likelihood of capturing a scarred manatee from 1999-2002. However, additional data collected during 2003-2005, contradicted the trend (Fig. 13). To verify no significant increase in the probability of observing a scarred manatee with the increase in cruise ship activity, I collapsed annual data into before and after the exponential growth categories. Years 1999-2001 had low cruise ship activity; years 2002-2005 had high cruise ship activity, with an exponential increase each year beginning in 2002 (Fig. 14).

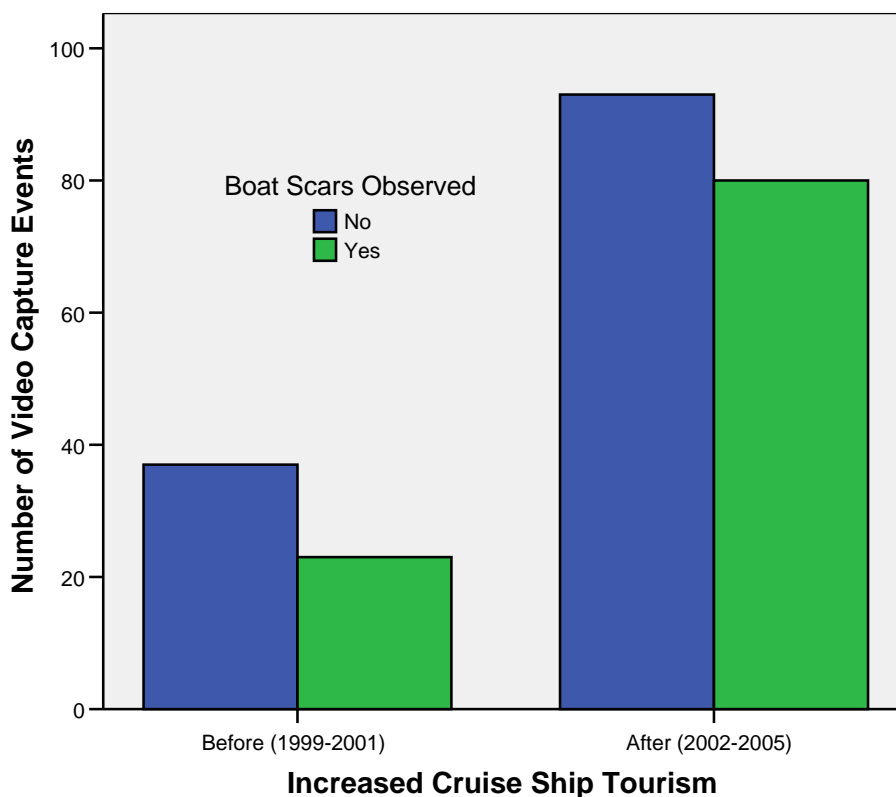


Figure 14. Scarred Manatees by Intensity of Cruise Ship Tourism. Probability of observing a scarred manatee before and after the exponential increase in cruise ship tourism, which began in 2002. The data indicate no significant change in the probability of observing a scarred manatee between low and high cruise ship activity ( $G^2 = 1.139$ ,  $p = 0.286$ ).

## DISCUSSION

I was surprised to see no significant change in the likelihood of capturing a scarred manatee over time. Cruise ship tourism, as defined as the number of passengers leaving the cruise ship during a one-day Port of Call in Belize City, increased by 564% between 2001 and 2002 (Fig. 2). This exponential increase continued in 2003 (+80%), 2004 (+48%). Cruise ships anchor offshore between Belize City and the Drowned Cayes study area for an 8-10 hour Port of Call. Up to 12,000 passengers per day disembark the cruise ship via tender and tour boats for water and land based activities, which has dramatically increased the boat traffic in the Belize City area over the course of this study (Fig. 15).



Figure 15. Map of Cruise Ship Anchorage and Tender/Tour Routes. Up to 12,000 passengers per day disembark from the cruise ships via tender and tour boat for destinations both inland and offshore; primary travel routes are designated by red arrows. Original image courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center (NASA 2001).

The lack of relationship between the likelihood of capturing a scarred manatee and increased cruise ship activity is surprising. This finding is in conflict with the increasing boat-related mortality, and contradicts both local perception and preliminary analysis. However, the impact on manatees using Swallow Caye, the Drowned Cayes, and Gallows Reef appear to be negligible. On only one occasion was a manatee captured with a fresh (pink) boat scar. In all other events the scarring appeared to be healing (white) or healed (gray) (Beck et al. 1982). I have been unable to find any published studies on the healing and re-pigmentation of wounds in manatees, but the rate of healing and re-pigmentation would most likely vary depending on multiple factors such as the original depth of the wound and extent of tissue damage, the general condition of the animal and environmental factors such as water temperature (G. Bossart, personal communication). An analysis of propeller wounds on living and dead Florida manatees suggested that larger watercraft are responsible for most boat related mortality and that manatees probably survive strikes by boats with smaller propellers (Beck et al. 1982), such as those used by many tour operators near Belize City.

To evaluate the effectiveness of a Marine Protected Area as a conservation strategy for an endangered species, it is important to know to what extent the population using the MPA is open or closed. If the population is relatively closed, then it can be assumed that the MPA provides some protection beyond other conservation strategies because it is protecting an entire population, which may serve as a source for recruitment outside the

MPA. Indeed this is just such the argument for MPAs used to protect and enhance commercial fisheries species. However, if the population using the area is relative open and individuals do not tend to stay within the MPA, then how do we know whether it is providing additional protection? If the endangered species is a focal species, meant to serve as the flagship, umbrella, indicator, or keynote for conservation of biodiversity within the protected area, then, what if its numbers continue to decline due to factors outside the MPA? How do we interpret the effectiveness of the MPA on the conservation of either the endangered species or biodiversity in such a case?

Analysis of manatee boat scars indicated that the probability of capturing a scarred manatee in SCWS and nearby habitat was relatively high (0.44), enabling the possibility of long-term photographic capture-recapture methods to further analyze the population of manatees using SCWS and adjacent study area. Preliminary capture-recapture analysis of the events have indicated a low number of recaptures (CSS, unpublished data), which is indicative of an open population. This hypothesis is supported by data collected in collaboration with other manatee researchers in Belize. For example, one male manatee, captured southeast of SCWS during the May 2004 Wildlife Trust Capture Event, spent most of his time west and north of SCWS during the seven months immediately post-capture (Auil & CSS, unpublished data). This same animal also made at least one trip outside the Belize Barrier Reef Lagoon System, traveling east to Turneffe Atoll and back, during the tracking period. Another male manatee, originally

identified at Basil Jones cut (northern Ambergris Caye) in 1994-95, was resighted at Gallows' Reef in 1999 (Self-Sullivan et al. 2003).

The ability of researchers in Florida to identify individual manatees by non-lethal boat-scarring has enabled significant population oriented research resulting in a better understanding of the Florida subspecies (Langtimm et al. 1998; Koelsch 2001; Kendall et al. 2003; Langtimm & Beck 2003; Kendall et al. 2004; Langtimm et al. 2004). The most recent IUCN Red List assessment of the Antillean manatees (*T. m. manatus*) suggested human activities, such as habitat degradation, poaching, incidental take, watercraft collision, and human disturbance, are an increasing threat to survival of the sub-species in the Wider Caribbean Region (Deutsch et al. 2007). In 14 of the 21 countries assessed, "Protected Area" was reported as an important conservation strategy for protecting manatees and their habitat. In many countries, "Watercraft Collision" was reported as a growing threat to the local manatee population. Given that 44% of the animals captured on video tape during this preliminary study bear unique scars from boats, I propose that a MIPS Database for Belize should be developed and made available to manatee researchers and other stakeholders in the Wider Caribbean Region. Similar to the ECOCEAN database for whale sharks, the system should provide protection for intellectual property rights and collaboration among scientists (Arzoumanian et al. 2005).



## CHAPTER IV

### CONSERVATION OF MANATEES AND THEIR HABITAT IN BELIZE

#### INTRODUCTION

The conservation and management of an endangered species often includes legislation that creates a “protected area” of habitat. However, there is much debate in the literature regarding the effectiveness of this strategy (see Chapter I for a review). One primary concern is that targeted species such as manatees do not necessarily remain confined to their designated refuge (e.g., "Sharkbite," the manatee described in Chapter II page 20; also see Siex & Struhsaker 1999 and Wittemyer 2001 for other examples). Additionally, it is important to remember that the ecological integrity of a marine protected area is dependent on the supporting ecosystem (Harborne et al. 2006). For marine mammals, a protected area should encompass the targeted population’s year-round distribution (Reeves 2000). However, for most marine mammal species, this is unrealistic due to large habitat ranges and migratory behaviors. Alternative strategies include: (1) large marine preserves that protect the year-round habitat of one population of the species to serve as a source for recruitment outside the protected area (Reeves 2000); (2) a network of spatial or temporal sanctuaries that protect key breeding and feeding areas (Reeves 2000); and (3) a system, designed to conserve both the species and its habitat. A system should protect essential areas, activity centers, travel corridors, resources for expansion, and the supporting ecosystem, through a variety of mechanisms (Packard & Wetterqvist 1986; Soulé and Simberloff 1986; Noss 1996; von Zahren 1998, 1999).

Ecologists have argued for a movement toward ecosystem approaches for conservation of biodiversity and away from crisis-driven approaches for conservation of individual species (Christensen et al. 1996). Indeed, conservation strategies for the protection of endangered species may have focused too exclusively on individual species management in the past (Schwartz 1999). In the case of marine predators, this approach has been shown to be in conflict with other conservation efforts such as fisheries management (Fanshawe et al. 2003). However, adopting an approach of ecosystem priority to the exclusion of an endangered species approach may guarantee that the crisis be resolved through extinction (Schwartz 1999). Schwartz argues that a broad array of conservation strategies should strive to balance the protection of countable objects, such as endangered species, with the protection of natural processes at the ecosystem level. Preservation of biodiversity is dependent on conservation of individual species and the genetic diversity within each species, as well as conservation of the ecosystem in which the species evolved. In order to implement a conservation strategy for endangered species, it is necessary to have a reasonable autecological understanding of the target species. In other words, a study of the biology of the particular species and its interaction with the environment as a whole is essential to conservation efforts (McCoy 1983).

Although few MPAs have been established exclusively for the conservation of marine mammals (Reeves 2000), charismatic marine predators have been used to direct marine

conservation efforts by attracting political attention to the need for protected areas (Hooker & Gerber 2004). Two factors are often missing when using this approach to design of MPAs: (1) consideration of the protected species ecology and life history (Hooker & Gerber 2004); and (2) adequate involvement of the public in planning of the MPAs (Dalton 2005; van den Belt 2004). Over a decade ago, Grumbine analyzed the evolving concept of ecosystem management and concluded that, "Ecosystem management is not just about science nor is it simply an extension of tradition resource management; it offers a fundamental reframing of how humans may work with nature" (Grumbine 1994, page 27). Since then, many MPA boundaries have been defined through a "complex mix of aesthetics, opportunism, a little science, and a large helping of compromise" (Roberts 2000). The debate has matured over the past half decade at least from the marine perspective, from one of protected species versus protected ecosystems, to more specific discussions of how to incorporate both in an effort to conserve marine biodiversity (for examples, see Fanshawe et al. 2003; Kritzer 2004; Jacobson & Duff 1998; Dalton 2005). Although academics continue to debate the effectiveness of conservation strategies for protecting endangered species and ecosystems, international agreements among governments such as the Cartagena Convention (Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region, Cartagena de Indias, 24 March 1983) encourage the conservation of both species and their habitats.

In this chapter my objectives are to: (1) review the conservation status of manatees in Belize; (2) review the driving forces behind marine conservation efforts in Belize; (3) focus specifically on Swallow Caye Wildlife Sanctuary as a model for the conservation of manatees in Belize; and (4) discuss the implications of scientific research on existing conservation strategies for the Belize City area.

### **CONSERVATION STATUS OF ANTILLEAN MANATEES IN BELIZE**

The Belizean population of manatees may be essential (O'Shea & Salisbury 1991) to the survival of the entire genetic clade, one of only three within the species *Trichechus manatus* (Garcia-Rodriguez et al. 1998; Vianna et al. 2006). Although the species is sparsely distributed from the northern coast of South America throughout Central America and into North America, Belize is thought to provide habitat to the densest population of the subspecies, *T. m. manatus*, within the Wider Caribbean Region (Deutsch et al. 2007).

Historical, geographic, and cultural reasons for the high density of manatees in Belize include a coastline that was difficult to access by early explorers due to the barrier reef, high quality of manatee habitat within the barrier reef lagoon system, high levels of public awareness, and low levels of hunting (O'Shea & Salisbury 1991). The geography of the Belize's 280 km coastline precluded historic exploitation and today provides large areas of pristine manatee habitat including coastal lagoons, estuaries and mangrove swamps, slow flowing rivers, and the Belize Barrier Reef and Turneffe Atoll lagoon

systems. Additionally, the Belize Barrier Reef lagoon system is contiguous with Chetumal Bay, Mexico, and the Gulf of Honduras; both areas are also known to be important manatee habitat (Morales-Vela et al. 2000; Auil 1998). Belize has a very low human population, averaging 12 people per square kilometer (less than 280,000 people spread over 22,965 square kilometers of mainland and cayes), which has kept human impacts on the environment relatively low until recently (Chapter I).

Currently classified as an endangered species in Belize, manatees have been legally protected since the 1930s. Although statistically valid population numbers are not available, the Belize National Manatee Working Group estimated at least 1000 manatees used habitats within Belizean waters in 2005 (N. Auil, personal communication).

Current threats include incidental catch, watercraft collisions, habitat degradation and loss, human disturbance, illegal hunting, and pollution (Deutsch et al. 2007). Current conservation strategies include species protection, habitat protection, a national recovery and management plan, a stranding network and rehabilitation program, national and localized surveys and scientific studies, and educational outreach programs.

From 1998 until 2007, I personally observed and participated in educational outreach activities conducted by local and international organizations such as Coastal Zone Management Institute, Green Reef, Hugh Parkey's Foundation for Marine Awareness and Education, Wildlife Conservation Society, Belize Audubon Society, Belize Zoo, Friends of Nature, Friends of Swallow Caye, Toledo Institute for Development and the

Economy (TIDE), and Wildlife Trust, among others. Although no studies have been conducted to evaluate the effectiveness of these outreach activities, it is my perception that the current level of public awareness among residents is high.

### **MARINE PROTECTED AREA POLICY IN BELIZE**

Belize has taken significant action to meet its obligations under international environmental protection agreements. Formerly under British rule, Belize gained independence in 1981, the same year that the Governments of the Wider Caribbean Region (WCR) adopted the Action Plan of the Caribbean Environmental Programme (CEP). CEP addresses problems affecting the coastal and marine environment of the WCR (Vanzella-Khouri 1998) and is one of the Regional Seas Programmes (RSP) of the United Nations Environmental Programme (UNEP 2006). The Cartagena Convention and subsequent Protocol Concerning Specially Protected Areas and Wildlife (SPAW) have been cited as the most successful international agreements to come out of UNEP/CEP (Sheehy 2004). Article 10 of the Cartagena Convention specifically obligates Belize and other Contracting Parties to protect endangered species habitat and to establish protected areas. The SPAW Protocol expounds this obligation and has been cited as the driving force behind the use of protected area and protected species conservation strategies in the WCR (Freestone 1991) and Belize (Auil 1998; CZMA&I 2003; Auil 2004; MNREI 2005).

Since acceding to the Cartagena Convention in 1999, Belize has emerged as a leader within the Wider Caribbean Region. Over the past decade or so, Belize has implemented several types of MPAs, including Marine Reserves, National Parks, Natural Monuments, Wildlife Sanctuaries, and World Heritage Sites; these MPAs now serve as cornerstones for the National Integrated Coastal Zone Strategy. Currently, there are 26 coastal and marine protected areas (Fig. 16) including 7 that make up the Belize Barrier Reef Reserve System World Heritage Site (Auil 2004). Coastal Zone Management Authority and Institute (CZMA&I), a quasi-governmental organization, has played a vital leadership role in coordinating and integrating species protection and ecosystem protection during this period. Among other accomplishments, this institution developed a National Manatee Recovery Plan (1998) and a National Integrated Coastal Zone Management Strategy (CZMA&I 2003). On November 30th, 2005, the Belize National Protected Areas System Plan (NPASP-the end product of 2 years of work by the Protected Areas Task Force) was published; this plan includes references to marine, estuarine, riverine, and terrestrial protected areas.

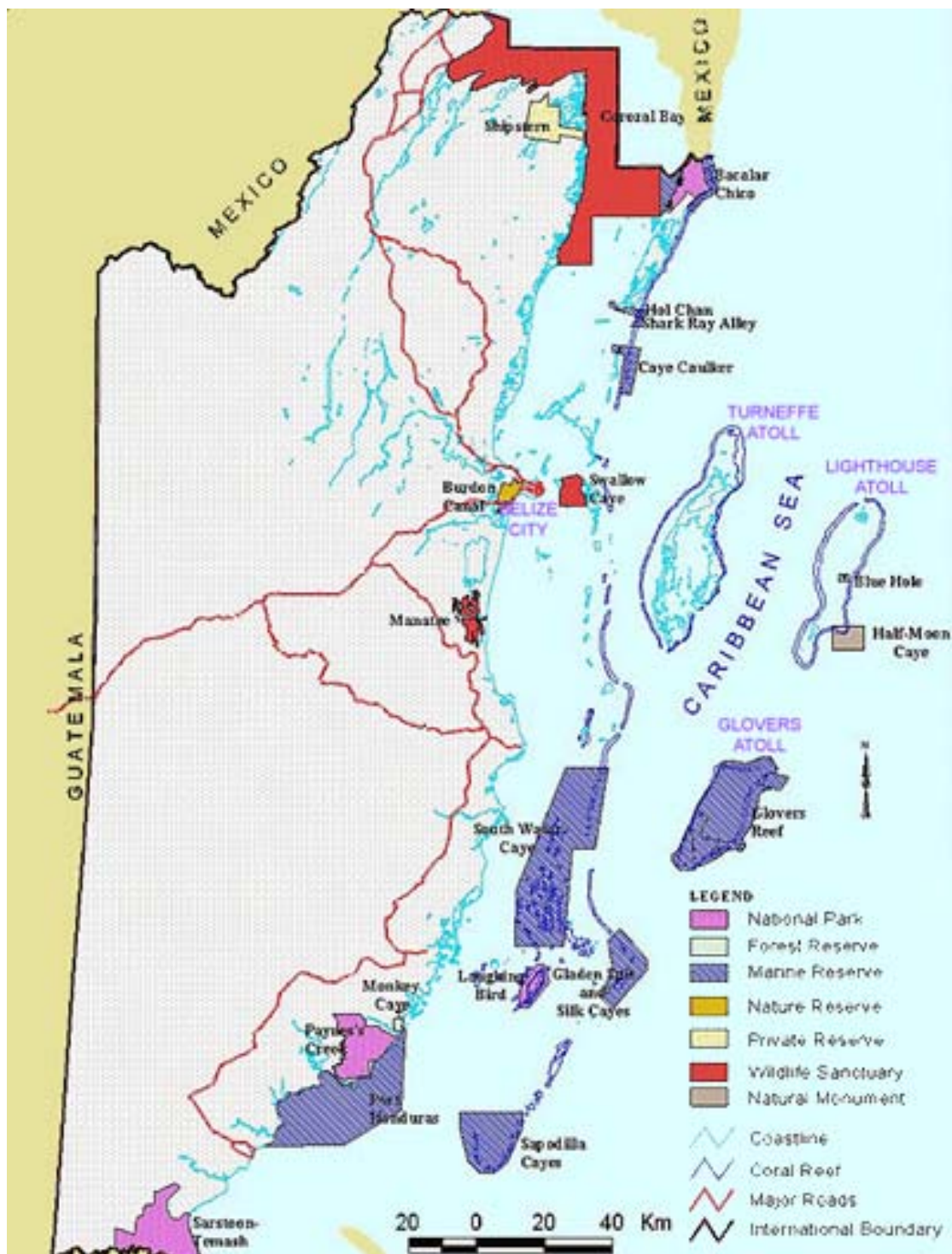


Figure 16. Map of Marine Protected Areas in Belize. Marine Protected Areas in Belize as of July 2002 included National Parks, Marine Reserves, Nature Reserves, Private Reserves, Wildlife Sanctuaries, and Natural Monuments. Modified from map provided by Coastal Zone Management Institute (CZMA&I 2003).



Policy, specific to West Indian manatee conservation, is in place at the national level (Auil 1998) and well aligned with policy at the regional level (CEP/UNEP 1995). The National Manatee Recovery Plan is a product of the Memorandum of Understanding between the Regional Co-ordination Unit of the Caribbean Environment Programme (CEP/RCU) and the Belize Fisheries Department (Auil 1998). The Forest Department, Conservation Division, is responsible for enforcing rules and regulations related to this endangered species in Belize. A National Manatee Working Group, organized by CZMA&I, makes recommendations to the Conservation Division regarding rules and regulations, protected areas, and issuance of research permits.

However, there is still cause for concern. As noted, manatees are considered to be an endangered species in Belize. Implementation of legal regimes and policy are limited by the lack of resources (N. Auil, J. Gibson & M. Windsor, personal communication), and an exponential growth in tourism and related development activities (Chapter I). Like many countries in the Wider Caribbean Region striving to meet their obligations set forth in international agreements, the governmental agencies charged with managing protected species and protected areas in Belize are relatively small and understaffed (Sheehy 2004, personal observations). In Belize, a solution to the problem of limited resources is being sought through a variety of mechanisms including a Protected Areas Conservation Trust (PACT) and co-management agreements in which the enforcement agencies (Forestry Department and Fisheries Department) work with non-governmental organizations (NGOs) to manage protected areas. PACT is well funded by a

conservation tax levied on every traveler who leaves Belize. PACT does not engage directly in conservation activities but awards grants to governmental agencies and NGOs based on proposals to implement conservation of protected areas policy. At the grassroots level, dedicated people are actively involved in conservation issues as employees of local and international NGOs such as The Nature Conservancy, Wildlife Trust, Wildlife Conservation Society, World Wildlife Fund, Friends of Nature, Toledo Institute for Development and the Environment (TIDE), Toledo Association for Sustainable Tourism & Environment (TASTE), and Friends of Swallow Caye, among others.

Throughout the Caribbean, co-management agreements between governmental agencies and NGOs are emerging as a solution to the lack of governmental resources and many have been implemented for MPAs in Belize with varying success (Pomeroy et al. 2004). The oldest examples of co-managed MPAs in Belize include those managed by the Belize Audubon Society (e.g., Half Moon Caye Natural Monument), Wildlife Conservation Society (e.g., Glovers Reef Marine Reserve), and Friends of Nature (e.g., Sapodilla Cayes Marine Reserve). Successful co-management of MPAs requires consideration of stakeholder livelihoods and natural resources; both must be conserved to ensure long-term success of the MPA. Reviews of co-management agreements in Belize have focused on MPAs designated to protect coral reefs and provide for sustainable fisheries (e.g., Pomeroy et al. 2004), evaluation of terrestrial Wildlife Sanctuaries co-managed by a large, Belizean NGO (Leikam et al. 2004), and a critique

of the social inequities associated with community conservation (e.g., Belsky 1999). However, general concepts of co-management can be applied to MPAs designated for marine mammal protection with sustainable tourism as the primary stakeholder livelihood. For example, in the case of Swallow Caye Wildlife Sanctuary (SCWS), a co-management agreement has been established between the Belize Forestry Department and Friends of Swallow Caye, a not-for-profit organization of manatee tour operators and other interested stakeholders. In fact, it was actually the tour guide user group that lobbied for protected area legislation at this site (Chapter II).

### **SWALLOW CAYE WILDLIFE SANCTUARY**

Swallow Caye Wildlife Sanctuary (SCWS) was established specifically for protection of the Antillean manatee. However, this designation also provided protection for almost 9,000 acres of mangrove islands and seagrass beds that are listed in Annex I of the SPAW Protocol (Freestone 1991). SCWS is an example of how local knowledge, opportunism, scientific data, and compromise came together in Belize to establish an MPA (Roberts 2000, Chapter II). The story of Swallow Caye could be defined as a "triumph on the commons", and serve as a model exception to the *Tragedy of the Commons* described by Hardin (1968, 1998). In his essays, Hardin argued for "mutual coercion, mutually agreed upon" (1968, page 1247) and described how legislative and administrative law were able to prevent various tragedies on public commons. However, the driving forces behind SCWS came not from governmental agencies, scientists, or NGOs, but from the resource user group: manatee tour operators. The emergent model

predates Sorice's 2003 recommendation for Florida manatee conservation in which he argues for a movement away from agency driven "regulations" and towards "best practices" to be developed by the user groups, themselves.

In Belize, fishermen-turned-manatee tour guides identified Swallow Caye, a small mangrove island surrounded by shallow seagrass beds near Belize City, as a 'hot spot' for manatees. This site quickly became the primary site for swim-with-manatee tours. By 1992, harassment of manatees by uncontrolled guests on this public commons had led to fewer and fewer manatee sightings and a corresponding loss of income to tour guides (Auil 1998). In response, Lionel "Chocolate" Heredia, a manatee tour operator from Caye Caulker, lead other manatee tour guides in lobbying efforts that resulted in the Forest Department Conservation Division prohibiting commercial swim-with-manatee tours at the Swallow Caye site. Between 1992 and 1998, Heredia and others worked closely with CZMA&I and the Forestry Department to develop a set of "best practices" for manatee tour operators (Appendix C) and a voluntary "manatee tour guide" specialty course, which is taught through the Belize Tourism Board's licensing program.

In 1999, Heredia founded Friends of Swallow Caye, rallied tour guides and other stakeholder groups, lobbied local representatives, the Ministry of Natural Resources, and CZMA&I in an effort to establish Swallow Caye Wildlife Sanctuary specifically for the protection of manatees. The legislation of Swallow Caye and 8,970 acres around it as a

Wildlife Sanctuary was finally passed on 10 July 2002 (Appendix A). With tears in his eyes, the 73 year old Heredia accepted his personal copy of the statutory instrument at a special signing ceremony held at the Coastal Zone Management Authority and Institute in Belize City.

Now that the MPA is established, with tour operators being the primary stakeholder group charged with enforcement and monitoring, local and international scientists and agencies are left with the question of whether it will prove to be a successful strategy for protecting manatees in Belize. In a report to the U.S. Marine Mammal Commission, Reeves (2000) concluded that the value of MPAs was dependent on increased benefits beyond other forms of marine mammal protection. To be effective in the United States (US), Reeves argued that a Marine Protected Area must provide additional protection that is not already provided by the Marine Mammal Act and the Endangered Species Act. Using the example of Florida manatees and Crystal River National Wildlife Refuge, the report suggested that a MPA might actually be detrimental to marine mammal conservation efforts if establishment of the MPA resulted in increased tourism. To support this statement, Reeves cited an evaluation of the Crystal River National Wildlife Refuge (Shackley 1992), which concluded that increased tourism ultimately poses a greater threat to the Southern Florida manatee population than the benefits derived from the related opportunities for educational outreach. In her report, Shackley warned that:

The final nail in the manatee's coffin has probably been provided by the large numbers of tourists now coming to visit them, increasing their levels of environmental stress and decreasing reproductive rates. Anyone who wants to ensure the survival of the species would be well advised to avoid visiting them. (Shackley 1992, p. 264)

In contrast to Reeves (2000) and Shackley (1992), Sorice et al. (2003, 2006) offer a solution to the Florida manatee "use-preservation" paradox remarkably similar to the situation in SCWS. They argue that despite the increased impact of swim-with-the-manatee programs, ongoing conflict between stakeholders, an array of definitions for harassment, and the inability of the U.S. Fish and Wildlife Service (USFWS) to adequately control tourism activities, the Crystal River manatee population has thrived with one of the highest survival rates in Florida and a significant increase in manatee use of the protected area.

Based on the Duffus and Dearden model (1990), which identifies both the wildlife species and the wildlife user as two primary components of non-consumptive wildlife management, Sorice et al. (2003) recommended an alternative approach to the current enforcement model used at Crystal River Wildlife Refuge. This alternative would create a non-governmental organization of tour operators to establish "best practices" that reflect the shared goal of diverse stakeholder groups to protect manatees. This recommendation is precisely the situation that began evolving in 1992 at Swallow Caye

Wildlife Sanctuary in Belize and provides an example of how agencies and NGOs in the US could learn from models developed outside the US.

To exemplify, in 2005, Friends of Swallow Caye built a ranger station just southeast of Swallow Caye (near the 'a' in Caye in Figure 3). To ensure compliance with rules and regulations laid out in the co-management agreement, the ranger moves about within the sanctuary by small boat. During a conversation with the ranger on duty in 2006, he told me that the co-management agreement authorizes Friends of Swallow Caye to: (1) protect manatees from harassment by tour operators and others; (2) collect entrance fees from anyone entering the Sanctuary; and (3) have final approval over any research conducted within the Sanctuary. Entrance fees are retained by Friends of Swallow Caye to employ the ranger and cover boat and fuel expenses. This strategy embodies the recommendation of Sorice et al. (2003): a non-governmental organization of tour operators implemented a system to ensure "best practices", peer-enforced rules that reflect the shared goal of diverse stakeholder groups to protect manatees.

At first glance, the evolution of this situation at Swallow Caye appears antithetical to the *Tragedy of the Commons* (Hardin 1968, 1998). However, closer examination finds that the Swallow Caye commons have not been left "unmanaged." Rather, effective management developed through individual leadership and stakeholder peer pressure over a decade or more. The result of these efforts could indeed be called "triumph on the commons" if it ensured a sustainable manatee tourism industry within SCWS and

reduced the deleterious impact of tourism on manatees and their habitat within the Belize Barrier Reef lagoon system. However, SCWS represents only a small portion of the habitat used by manatees in Belize. Based on what we know about manatee movements in the United States (Deutsch et al. 2003), we cannot expect individual manatees to remain within the boundaries of the protected area (Chapter II). Perhaps more importantly, the integrity of SCWS, like any other marine protected area, is dependent on the supporting ecosystem (Harborne et al. 2006). The increased demands for development and tourism activities near Belize City are threats to manatee habitat within the sanctuary and the supporting ecosystem.

*Triumph* implies an end to the struggle; and the struggle continues within the Belize Barrier Reef lagoon system due to the dependence by Belize on increasing tourism revenues to improve its economic status. Based on previous studies (Pomeroy et al. 2004), the long-term success of the Friends of Swallow Caye co-management regime will require ongoing, active communication between governmental agencies and the NGO, sustainability of stakeholder livelihoods, implementation of conservation goals, and effective monitoring. As noted previously, the sanctuary encompasses only a fraction of the activity centers known to be used by manatees in the vicinity of Belize City. At present, rules and regulations for boat travel within and adjacent to SCWS have not been established beyond the primary viewing area at Swallow Caye. A scientifically based, hypothesis driven monitoring system has not been established. Friends of Swallow Caye, unlike Belize Audubon Society, Wildlife Conservation Society, and



Friends of Nature, do not yet have the continued funding needed to employ professionals trained in science and management to evaluate the effectiveness of this conservation strategy in meeting the goals laid out in the Belize Manatee Recovery Plan.

### **IMPLICATIONS OF RESEARCH**

The primary purpose of this study was to provide site specific information regarding the population of manatees using the Drowned Cayes area in Belize. Scientifically based information is necessary for the major stakeholders to make wise decisions that will balance conservation of natural resources with economic development. As a scientist and friend of Belize, I am obligated to convey my professional opinion with respect to the implication of my findings on current policy to those people and agencies that have enabled me to conduct research in this unique country since 1998.

Long term goals of the Belize Manatee Recovery Plan (Auil 1998) included evaluation of the manatee habitat in the cayes near Belize City. Auil recommended site specific studies to determine which areas near Belize City should be classified as essential, and which areas should be classified as activity centers and travel corridors. Perhaps the most difficult challenge is determining which areas, if any, should be classified as essential to continued survival of the Antillean manatee population. Packard and Wetterqvist (1986) defined essential areas as those resources without which manatees could not survive in the short term, such as warm water effluents in Northern Florida that are essential to the over-wintering manatee population. If these effluents were

eliminated, a significant portion of the population would die within days from cold stress. However, ambient water temperatures in the Drowned Cayes area always exceed (CSS, unpublished data) the minimum suitable water temperature for manatees of 20° C (Irvin 1983), which eliminates warm water effluents as a factor in defining essential habitat in Belize.

Reduction of the manatee population may be slower and more subtle in tropical areas such as Belize. It could be that travel corridors connecting activity centers, such as those surrounding North Drowned Caye, Swallow Caye, and the Drowned Cayes, with fresh water resources in the Belize River are the most important areas necessary for survival of the manatee population. Perhaps the feeding areas, those massive seagrass beds surrounding the cayes and coastline near Belize City, are the most important for continued survival of the population. Alternatively, the pristine nature of the water, free from pollution associated with aquaculture, could be essential to survival. In any case, it is important to understand manatee behavior in establishing effective conservation strategies.

Antillean manatees near Belize City are not confined to one small area such as SCWS. For example, one animal (nicknamed "Sharkbite") was captured and outfitted with a satellite tag in the Drowned Cayes area during the spring of 2004 in collaboration with Wildlife Trust in 2004 (Auil & CSS, unpublished data). During the year, he used the area around North Drowned Caye extensively, but he also used other areas: the Northern

part of the Drowned Cayes; areas west of St. George's Caye; areas north and south of Swallow Caye; Hen & Chicken Cayes; Rider's Bluff, Hick's Cayes; and areas near the mouth to the Belize River and Haulover Creek; and areas between Swallow Caye and Stake Bank. He even traveled to Turneffe Atoll and back once during the tracking period, a total distance of over 40 km (Fig. 17).

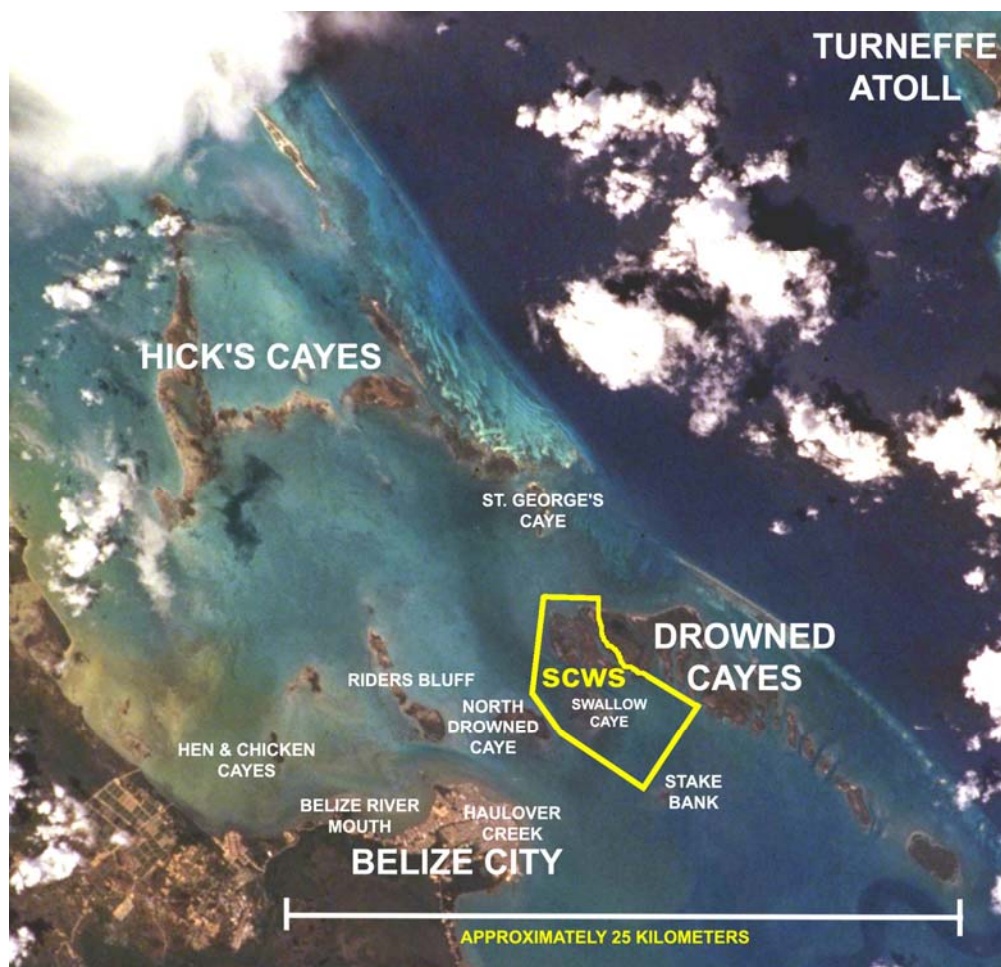


Figure 17. Minimum Range of Known Manatee with Respect to SCWS. In 2004 "Sharkbite" was tracked near activities centers in the Drowned Cayes, Stake Bank, Haulover Creek, Belize River Mouth, Hen & Chicken Cayes, Riders Bluff, North Drowned Caye, Hick's Cayes, St. George's Caye, and Turneffe Atoll (Auil & CSS, unpublished data). Approximate boundaries of Swallow Caye Wildlife Sanctuary are shown in yellow. Dark blue water between the BBR and Turneffe exceeds depths of 1000 km. Original image courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center (NASA 2001).

This one set of data, along with what we know about manatee behavior and habitat use in Florida, supports the concept that these animals need a large habitat area and safe travel corridors connecting one activity center with another. The Belizean population of manatees may be essential to the survival of the entire genetic clade, one of 3 within the species *Trichechus manatus* found sparsely distributed from the northern coast of South America throughout Central America, the Caribbean, to the southern coasts of North America (Deutsch et al. 2007; Vianna et al. 2006). Indeed, Belize may be the last stronghold for this important and endangered marine mammal within the Wider Caribbean Region (O'Shea & Salisbury 1991).

Ultimately, it is up to Belizeans to choose how to deal with the delicate balance between development and conservation of natural resources. Concerns center on the current rate of development among the cayes near Belize City. If it continues in the manner we have seen for Stake Bank and two other cayes within the Drowned Cayes over the past 3-4 years, then I that the manatee population will decline due to loss of feeding areas, resting areas, and nursery areas. Three cayes in the area have been totally cleared, leading to sedimentation and smothering of seagrass beds around these mangrove islands. If the cayes near Belize City (Fig. 17) continue to be developed, the increased human activity will become major stressors impacting current resting areas and nursery areas.

The concern is not over any one particular development proposal. Instead, it is the cumulative impact of continued deleterious development that allows for the cutting of

most, if not all, mangroves from any given mangrove island between the Belize Barrier Reef and the mainland. The destruction of mangroves and the dredging and filling of whole islands have a negative impact not only to the adjacent seagrass beds, but to the entire coastal marine ecosystem (Harborne et al. 2006). As a good example of the type of problem observed, an island just north of Heusner's "Yellow Fish Camp" between Bogue A and Shag Caye Bogue in the Drowned Cayes, was completely filled with spoil dredged from adjacent seagrass beds during the summer of 2006. The dredging and filling started before our field season began in May and continued after it ended in September. During that time, virtually every mangrove on the island was destroyed, water clarity was reduced to less than 1m (CSS & K. LaCommare, unpublished data), and the seagrass beds around the cayes were smothered with sediment (CSS & K. LaCommare, unpublished data).

Based on my interactions with the Forestry and Fisheries Departments, I am confident that decision makers intend to adhere to the provisions of the Cartagena Convention and SPAW Protocol, to which Belize acceded in 1999. In doing so, the manatee population in Belize would be best protected by moving from a simple network of MPAs to a system of riverine, coastal, and marine conservation strategies. This system should identify and include essential areas, activity centers, travel corridors, resources for expansion, and the supporting ecosystem through a variety of mechanisms (Packard & Wetterqvist 1986), including species protection, habitat protection, comprehensive planning for development, and long-term monitoring of both the manatee population and

its habitat. Development of even small cayes should follow processes and guidelines established by the Department of the Environment; otherwise, the rich habitat necessary for survival of the manatee and associated elements of the marine ecosystem in the vicinity of Belize City will soon be destroyed.

## **CHAPTER V**

### **EXECUTIVE SUMMARY**

In Belize, existing Marine Protected Areas (MPAs) and wildlife protection laws indicate a national policy of meeting obligations under international agreements affecting the Antillean manatee population. At the grassroots levels, there are highly motivated stakeholder groups and a handful of local and visiting scientists with specialized knowledge dedicated to both conservation of natural resources and sustainable economic development. Unlike the situation in Crystal River, Florida, where a three point polarization exists among governmental agencies, user-tour operators, and advocacy groups (Sorice 2003, 2006), Belizean stakeholders appear less polarized and more motivated to work together. Governmental agencies depend on co-management agreements with the NGOs, the latter consisting of both user-groups and advocates. This model could well lead to a shared "triumph on the commons" for the manatees, the user groups, and their shared habitat in Belize.

However, the manatee population in Belize would be best protected by moving from a simple network of MPAs, to a system of riverine, coastal, and marine protected areas supported by a variety of additional conservation strategies. The protected areas should encompass essential areas, activity centers, travel corridors, resources for expansion, and the supporting ecosystem (Packard & Wetterqvist 1986). In addition to habitat protection via existing protected areas, conservation strategies should include existing

species protection, expanded protected areas, a comprehensive plan for future development, long-term monitoring of both the manatee population and its habitat, and continued evaluation of such strategies. In summary, there are seven major points resulting from this research project, which are important for consideration by decision makers responsible for conservation of manatees and their habitat near Belize City:

1. The mangrove and seagrass ecosystem between the Belize Barrier Reef and Belize City is an extremely important habitat for Antillean manatees, which consistently use the area in both the dry and wet seasons.
2. Manatees are more likely to be encountered at Swallow Caye than in other areas of the Drowned Cayes, confirming the establishment of Swallow Caye Wildlife Sanctuary as an important area for protection.
3. At least 44% of the manatees using this area have been injured by non-lethal boat strikes, leaving these animals with unique scar patterns. However, the proportion of injured animals does not appear to have increased with the increase in cruise ship tourism from 2001 to 2004, suggesting that Swallow Caye and the Drowned Cayes provide a refuge for manatees.
4. This relatively high proportion of uniquely scarred animals provides the opportunity for establishment of a Photo/Video Database for Belize and neighboring countries.
5. Manatee use of Swallow Caye and the Drowned Cayes has not diminished with the increase in cruise ship tourism, suggesting that the current level of tourism,



given appropriate behavior by tour guides and enforcement of rules and regulations by Friends of Swallow Caye, is sustainable with respect to the manatee population using the Drowned Cayes area of Belize.

6. The fixed point (Appendix D) sampling method used in this study was statistically sound. Continuation of this method could provide site-specific monitoring data to be used in evaluation of Swallow Caye Wildlife Sanctuary and other conservation strategies in the Belize City area. This method could also be expanded to include additional sites in Belize, using a similar ecotourism and community conservation model.
7. If current development of cayes near Belize City continues unabated, I predict that the related habitat destruction and increased human activity will have a deleterious impact on the mangrove, seagrass, and coral reef habitat, resulting in a reduction in the local manatee population.

## LITERATURE CITED

- Agresti, A. 1990. Categorical data analysis. John Wiley and Sons, New York.
- Anderson, D. R. 2001. The need to get the basics right in wildlife field studies. *Wildlife Society Bulletin* **29**:1294-1297.
- Anderson, P. K. 1994. Dugong distribution, the seagrass *Halophila spinulosa*, and thermal environment in winter in deep waters of Eastern Shark Bay, Western Australia. *Wildlife Research* **21**:381-388.
- Arzoumanian, Z., J. Holmberg and B. Norman. 2005. An astronomical pattern-matching algorithm for computer-aided identification of whale sharks *Rhincodon typus*. *Journal of Applied Ecology* **42**:999-1011.
- Auil, N. E. 1998. Belize manatee recovery plan. UNDP/GEF Coastal Zone Management Project, Belize (BZE/92/G31). UNEP Caribbean Environmental Programme, Kingston, Jamaica.
- Auil, N. E. 2004. Abundance and distribution trends of the West Indian manatee in the coastal zone of Belize: implications for conservation. M.S. thesis. Department of Wildlife and Fisheries Sciences. Texas A&M University, College Station.
- Auil, N. E. and A. Valentine. 2003. Manatee stranding report 1996-2003. Coastal Zone Management Institute. Belize City, Belize.

- Auil, N. E., and A. Valentine. 2006. Manatee strandings along the coastal zone of Belize 1996-2003. Extended Abstract *in* National Marine Science Symposium Programme, 18-20 January 2006, Belize City, Belize.
- Bakeman, R., and J. M. Gottman. 1986. Observing interaction: an introduction to sequential analysis. Cambridge University Press, Cambridge, United Kingdom.
- Beck, C. A., R. K. Bonde, and G. B. Rathbun. 1982. Analyses of propeller wounds on manatees in Florida. *Journal of Wildlife Management* **46**:531-535.
- Beck, C. A., and J. P. Reid. 1995. An automated photo-identification catalog for studies of the life history of the Florida manatee. Pages 120-134 in T. J. O'Shea, B. B. Ackerman and H. F. Percival, editors. Population biology of the Florida manatee. Information and Technology Report 1. U. S. Department of the Interior, National Biological Service, Washington, D.C.
- Beletsky, L. 1999. Belize and Northern Guatemala: The ecotravellers' wildlife guide. Academic Press, New York.
- Belize. 2000. Wildlife Protection Act Chapter 220, Revised Edition 2000, The Substantive Laws of Belize, Printed by the Government Printer, No. 1 Power Lane, Belmopan, by the authority of the Government of Belize. Available from <http://www.belize-law.org/lawadmin/index2.html> (accessed January 2004).
- Belize Tourism Board. 2006. Cruise arrivals by month 1998 - 2005. Available from <http://www.belize-tourism.org> (accessed December 2006).

- Belsky, J. M. 1999. Misrepresenting communities: the politics of community-based rural ecotourism in Gales Point Manatee, Belize. *Rural Sociology* **64**:641-666.
- Bengtson, J. L., and D. Magor. 1979. A survey of manatees in Belize. *Journal of Mammalogy* **60**:230-232.
- Butler, S. M., J. P. Reid and B. M. Stith. 2003. Detailed movements and habitat use patterns of radio tagged manatees in the western Everglades. Poster presentation at the 15th Biennial Conference on the Biology of Marine Mammals, 15-19 December 2003, Greensboro, North Carolina. Available from <http://cars.er.usgs.gov/posters/index.html#manatee> (accessed March 2008).
- Caro, T. M., and G. O'Doherty. 1999. On the use of surrogate species in conservation biology. *Conservation Biology* **13**:805-814.
- CEP/UNEP (Caribbean Environmental Programme/United National Environmental Programme). 1995. Regional management plan for the West Indian manatee, *Trichechus manatus*. CEP Technical Report No. 35. UNEP Caribbean Environment Programme, Kingston.
- Channell, R., and M. V. Lomolino. 2000. Dynamic biogeography and conservation of endangered species. *Nature* **403**:84-86.
- Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. D'Antonio, et al. 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. *Ecological Applications* **6**:665-691.

- Craig, B. A., M. A. Newton, R. A. Garrott, J. E. Reynolds III, J. R. Wilcox. 1997. Analysis of aerial survey data on Florida manatee using Markov Chain Monte Carlo. *Biometrics* **53**:524-541.
- Craig, B. A., and J. E. Reynolds III. 2004. Determination of manatee population trends along the Atlantic coast of Florida using a Bayesian approach with temperature-adjusted aerial survey data. *Marine Mammal Science* **20**:386-400.
- CZMA&I (Coastal Zone Management Authority and Institute). 2003. National integrated coastal zone management strategy for Belize. CZMA&I, Belize City, Belize.
- Dalton, T. M. 2005. Beyond biogeography: a framework for involving the public in planning of U.S. marine protected areas. *Conservation Biology* **19**:1392-1401.
- Darwall, W. R. T., and N. K. Dulvy. 1996. An evaluation of the suitability of non-specialist volunteer researchers for coral and reef fish surveys. Mafia Island, Tanzania – a case study. *Biological Conservation* **78**:223-231.
- de Iongh, H. H., B. Wenno, B. Bierhuizen, and B. van Orden. 1995. Aerial survey of the dugong (*Dugong dugon* Müller, 1776) in coastal waters of the Lease Islands, East Indonesia. *Marine and Freshwater Research* **46**:759-61.
- Deutsch, C. J., J. P. Reid, R. K. Bonde, D. E. Easton, H. I. Kochman, et al. 2003. Seasonal movements, migratory behavior, and site fidelity of West Indian

manatees along the Atlantic coast of the United States. *Wildlife Monographs* No. 151. Supplement to the *Journal of Wildlife Management* 67 January 2003.

Deutsch, C.J., C. Self-Sullivan, and A. Mignucci-Giannoni. 2007. *Trichechus manatus*. In *The World Conservation Union (IUCN), editors. 2007 IUCN red list of threatened species*. Available from [www.iucnredlist.org](http://www.iucnredlist.org) (accessed March 2008).

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

Duffus, D. A., and P. Dearden. 1990. Nonconsumptive wildlife-oriented recreation: A conceptual framework. *Biological Conservation* **53**:213-231.

Evans, W. E., and A. V. Yablokov. 2004. *Noninvasive study of mammalian populations*. PENSOFT Publishers, Moscow.

Fanshawe, S., G. R. Vanblaricom, and A. A. Shelly. 2003. Restored top carnivores as detriments to the performance of marine protected areas intended for fishery sustainability: a case study with red abalones and sea otters. *Conservation Biology* **17**:273-283.

Farnsworth, G. L., K. H. Pollock, J. D. Nichols, T. R. Simons, J. E. Hines, et al. 2002. A removal model for estimating detection probabilities from point-count surveys. *The Auk* **119**:414-425.

- Flamm, R. O., L. I. Ward, and B. L. Weigle. 2001. Applying a variable-shape spatial filter to map relative abundance of manatees (*Trichechus manatus latirostris*). *Landscape Ecology* **16**:279-288.
- Flater, D. 1998. XTide software. Available from <http://www.flaterco.com/xtide/index.html> (accessed March 2006).
- Ford, R. E. 1991. Toponymic generics, environment and culture history in pre-independence Belize. *Names* **39**:1-25.
- Foster-Smith, J., and S. M. Evans. 2003. The value of marine ecological data collected by volunteers. *Biological Conservation* **113**:199-213.
- Freestone, D. 1991. Laws of the sea – protection of marine species and ecosystems in the wider Caribbean, the Protocol on Specially Protected Areas and Wildlife. *Marine Pollution Bulletin* **22**:579-581.
- Gales, N., R. D. McCauley, J. Lanyon, and D. Holley. 2004. Change in abundance of dugongs in Shark Bay, Ningaloo and Exmouth Gulf, Western Australia: evidence for large-scale migration. *Wildlife Research* **31**:283-290.
- Garcia-Rodriguez, A. I., B. W. Bowen, D. Domning, A. A. Mignucci-Giannoni, M. Marmontel, et al. 1998. Phylogeography of the West Indian manatee (*Trichechus manatus*): how many populations and how many taxa? *Molecular Ecology* **7**:1137-1149.

- Garrott, R. A., B. B. Ackerman, J. R. Cary, D. M. Heisey, J. E. Reynolds III, et al. 1994. Trends in counts of Florida manatees at winter aggregation sites. *Journal of Wildlife Management* **58**:642-654.
- George, D., and P. Mallery. 2007. *SPSS for Windows step by step: a simple guide and reference 14.0 update*. 7<sup>th</sup> Edition. Pearson, Boston.
- Gibson, J. 1995. *Managing manatees in Belize*. M. S. thesis. Department of Marine Sciences and Coastal Management. University of Newcastle upon Tyne, Newcastle, United Kingdom.
- Grumbine, R. E. 1994. What is ecosystem management? *Conservation Biology* **8**:27-38.
- Harborne, A. R., P. J. Mumby, F. Micheli, C. T. Perry, C. P. Dahlgren, et al. 2006. The functional value of Caribbean coral reef, seagrass, and mangrove habitats to ecosystem processes. *Advances in Marine Biology* **50**:57-190.
- Hardin, G. 1968. The tragedy of the commons. *Science* **162**:1243-1248.
- Hardin, G. 1998. Extensions of “the tragedy of the commons.” *Science* **280**:682-683.
- Hartman, D. S. 1979. Ecology and behavior of the manatee (*Trichechus manatus*) in Florida. Special Publication 5, American Society of Mammalogists, Lawrence, Kansas.



- Hatt, R. 1934. A manatee collected by the American Museum Congo Expedition, with observations on the recent manatees. *Bulletin of the American Museum of Natural History* **66**:533-566.
- Hill, D. A., and J. E. Reynolds III. 1989. Gross and microscopic anatomy of the kidney for the West Indian manatee, *Trichechus manatus* (Mammalia:Sirenia). *Acta Anatomica* **135**:53-56.
- Hines, E. M., K. Adulyanukosol, and D. A. Duffus. 2005. Dugong (*Dugong dugon*) abundance along the Andaman Coast of Thailand. *Marine Mammal Science* **21**:536-549.
- Holguin, S. B. P. 2004. Contextual conservation: Antillean manatees (*Trichechus manatus manatus*) of Turneffe Atoll, Belize. M. A. thesis. Geography: Resource Management and Environmental Planning, San Francisco State University, San Francisco.
- Holley, D. K., I. R. Lawler, and N. J. Gales. 2006. Summer survey of dugong distribution and abundance in Shark Bay reveals additional key habitat area. *Wildlife Research* **33**:243-250.
- Hooker, S. K., and L. R. Gerber. 2004. Marine reserves as a tool for ecosystem-based management: the potential importance of megafauna. *BioScience* **54**:27-39.

- Hooker, S. K., H. Whitehead, and S. Gowans. 1999. Marine protected area design and the spatial and temporal distribution of cetaceans in a submarine canyon. *Conservation Biology* **13**:592-602.
- Hudson, B. E. T. 1981. Interview and aerial survey data in relation to resource-management of the dugong in Manus Province, Papua New-Guinea. *Bulletin of Marine Science* **31**:662-671.
- Irvin, A. B., 1983. Manatee metabolism and its influence on manatee distribution in Florida. *Biological Conservation* **25**:315-334.
- Irvin, A. B., and H. W. Campbell. 1978. Aerial census of West Indian manatee, *Trichechus manatus*, in the Southeastern United States. *Journal of Mammalogy* **59**:613-617.
- IUCN (International Union for the Conservation of Nature). 2007. 2007 IUCN red list of threatened species. Available from [www.iucnredlist.org](http://www.iucnredlist.org) (accessed March 2008).
- Jacobson, S. K., and M. D. Duff. 1998. Training *Idiot Savants*: the lack of human dimension in conservation biology. *Conservation Biology* **12**:263-267.
- Joseph, L. N., S. A. Field, C. Wilcox, and H. P. Possingham. 2006. Presence-absence versus abundance data for monitoring threatened species. *Conservation Biology* **20**:1679-1687.

- Karczmarski, L., B. Würsig, G. Gailey, K. W. Larson, and C. Vanderlip. 2005. Spinner dolphins in a remote Hawaiian atoll: social grouping and population structure. *Behavioral Ecology* **16**:675-685.
- Kendall, W. L., J. E. Hines, and J. D. Nichols. 2003. Adjusting multistate capture-recapture models for misclassification bias: manatee breeding proportions. *Ecology* **84**:1058-1006.
- Kendall, W. L., C. A. Langtimm, C. A. Beck, and M. C. Runge. 2004. Capture-recapture analysis for estimating manatee reproductive rates. *Marine Mammal Science* **20**:424-437.
- Kerr, K. A., R. H. Defran, and G. S. Campbell. 2005. Bottlenose dolphins (*Tursiops truncatus*) in the Drowned Cayes, Belize: group size, site fidelity and abundance. *Caribbean Journal of Science* **41**:172-177.
- Koelsch, J. K. 2001. Reproduction in female manatees observed in Sarasota Bay, Florida. *Marine Mammal Science* **17**:331-342.
- Kritzer, J. P. 2004. Effects of noncompliance and the success of alternative designs of marine protected-area networks for conservation and fisheries management. *Conservation Biology* **18**:1021-1031.
- LaCommare, K. S., C. Self-Sullivan, and S. Braugh. 2008. Distribution and habitat use of Antillean Manatees (*Trichechus manatus manatus*) in the Drowned Cayes area of Belize, Central America. *Aquatic Mammals* **34**: in press.

- Laist, D. W., and J. E. Reynolds III. 2005. Influence of power plants and other warm-water refuges on Florida manatees. *Marine Mammal Science* **21**:739-764.
- Lambeck, R. J. 1997. Focal species: a multi-species umbrella for nature conservation. *Conservation Biology* **11**:849-856.
- Langtimm, C. A., and C. A. Beck. 2003. Lower survival probabilities for adult Florida manatees in years with intense coastal storms. *Ecological Applications* **13**:257-268.
- Langtimm, C. A., C. A. Beck, H. H. Edwards, K. J. Fick-Child, B. B. Ackerman, et al. 2004. Survival estimates for Florida manatees from photo-identification of individuals. *Marine Mammal Science* **20**:438-463.
- Langtimm, C. A., T. J. O'Shea, R. Pradel, and C. A. Beck. 1998. Estimates of annual survival probabilities for adult Florida manatees (*Trichechus manatus manatus*). *Ecology* **79**:981-997.
- Lanyon, J. M. 2003. Distribution and abundance of dugongs in Moreton Bay, Queensland, Australia. *Wildlife Research* **30**:397-409.
- Lanyon, J. M., T. Johns, and H. L. Sneath. 2005. Year-round presence of dugongs in Pumicestone Passage, south-east Queensland, examined in relation to water temperature and seagrass distribution. *Wildlife Research* **32**:361-368.

- Leatherwood, S. 1979. Aerial survey of the bottlenosed dolphin, *Tursiops truncatus*, and the West Indian manatee, *Trichechus manatus*, in the Indian and Banana Rivers, Florida. *Fishery Bulletin of the Fish and Wildlife Service* **77**:47-59.
- Lefebvre, L. W., and H. I. Kochman. 1991. An evaluation of aerial survey replicate count methodology to determine trends in manatee abundance. *Wildlife Society Bulletin* **19**:298-309.
- Leikam, G., S. Otis, T. Raymond, N. Sielken, and T. Sweeney. Evaluation of the Belizean Audubon Society co-management project at Crooked Tree Wildlife Sanctuary and Cockscomb Basin Wildlife Sanctuary, Belize. M. S. professional paper. School of Natural Resources and Environment, University of Michigan, Ann Arbor.
- Marsh, H., G. De'ath, N. Gribble, and B. Lane. 2005. Historical marine population estimates: triggers or targets for conservation? The dugong case study. *Ecological Applications* **15**:481-492.
- Marsh, H., A. N. M. Harris, and I. R. Lawler. 1997. The sustainability of the indigenous dugong fishery in Torres Strait, Australia/Papua New Guinea. *Conservation Biology* **11**:1375-1386.
- Marsh, H., I. R. Lawler, D. Kwan, S. Delean, K. Pollock, et al. 2004. Aerial surveys and the potential biological removal technique indicate that the Torres Strait dugong fishery is unsustainable. *Animal Conservation* **7**:435-443.

Marsh, H., R. I. T. Prince, W. K. Saalfeld, and R. Shepher. 1994. The distribution and abundance of the dugong in Shark Bay, Western Australia. *Wildlife Research* **21**:149-161.

Marsh, H., G. B. Rathbun, T. J. O'Shea, and A. R. Preen. 1995. Can dugongs survive in Palau? *Biological Conservation* **72**:85-89.

Marsh, H., and D. F. Sinclair. 1989. An experimental evaluation of dugong and sea turtle aerial survey techniques. *Australian Wildlife Research* **16**:639-650.

McCoy, E. D. 1983. The application of island-biogeographic theory to patches of habitat: how much land is enough? *Biological Conservation* **25**:53-61.

Miller, K. E., B. B. Ackerman, L. W. Lefebvre, and K. B. Clifton. 1998. An evaluation of strip-transect aerial survey methods for monitoring manatee populations in Florida. *Wildlife Society Bulletin* **26**:561-570.

MNREI (Ministry of Natural Resources, Environment and Industry). 2005. The Belize national protected areas system plan. J. Meerman and J. R. Wilson, editors. Ministry of Natural Resources, Environment and Industry, Belmopan, Belize.

Moore, J. C. 1956. Observations of manatees in aggregations. *American Museum Novitates* **1811**:1-24

- Morales-Vela, B., D. Olivera-Gomez, J. E. Reynolds, III, and G. B. Rathbun. 2000. Distribution and habitat use by manatees (*Trichechus manatus manatus*) in Belize and Chetumal Bay, Mexico. *Biological Conservation* **95**: 67-75.
- Morales-Vela, B., J. A. Padilla-Saldivar, and A. A. Mignucci-Giannoni. 2003. Status of the manatee (*Trichechus manatus*) along the northern and western coasts of the Yucatán Peninsula, México. *Caribbean Journal of Science* **39**:42-49.
- Mou Sue, L. L., and D. H. Chen. 1990. Distribution and status of manatees (*Trichechus manatus*) in Panama. *Marine Mammal Science* **6**:234-241.
- NASA (National Aeronautical and Space Administration). 2001. The gateway to astronaut photography of earth. Science and Analysis Laboratory, NASA-Johnson Space Center. Available from <http://eol.jsc.nasa.gov/> (accessed March 2008).
- Noss, R. F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology* **4**:355-364.
- Noss, R. F. 1996. Protected areas: how much is enough? Pages 91-120 in R. G. Wright and J. Lemons, editors. *National parks and protected areas: their role in environmental protection*. Blackwell Science, Cambridge, United Kingdom.
- Olivera-Gómez, L. D., and E. Mellink. 2005. Distribution of the Antillean manatee (*Trichechus manatus manatus*) as a function of habitat characteristics, in Bahía de Chetumal, Mexico. *Biological Conservation* **121**:127-133.

- Ortiz, R. M., G. A. J. Worthy, D. S. MacKenzie. 1998. Osmoregulation in wild and captive West Indian manatees (*Trichechus manatus*). *Physiological Zoology* **71**:449-457.
- Ortiz, R. M., G. A. J. Worthy, and F. M. Byers. 1999. Estimation of water turnover rates of captive West Indian manatees (*Trichechus manatus*) held in fresh and salt water. *The Journal of Experimental Biology* **202**:33-38.
- O'Shea, T. J., B. B. Ackerman and H. F. Percival. 1995. Population biology of the Florida manatee. National Biological Service, Information and Technology Report 1. U. S. Department of the Interior, National Biological Service, Washington, D.C.
- O'Shea, T. J. and C. A. Salisbury. 1991. Belize - a last stronghold for manatees in the Caribbean. *Oryx* **25**:156-164.
- Packard, J. M., D. B. Siniff, and J. A. Cornell. 1986. Use of replicate counts to improve indices of trends in manatee abundance. *Wildlife Society Bulletin* **14**:265-275.
- Packard, J. M., R. C. Summers, and L. B. Barnes. 1985. Variation of visibility bias during aerial surveys of manatees. *Journal of Wildlife Management* **49**:347-351.
- Packard, J. M. & Wetterqvist, O. F. 1986. Evaluation of manatee habitat systems on the northwestern Florida coast. *Coastal Zone Management Journal* **14**:279-310



- Peterson, M. N., R. R. Lopez, P. A. Frank, B. A. Porter, and N. J. Silvy. 2004. Key deer fawn response to urbanization: is sustainable development possible? *Wildlife Society Bulletin* **32**:493-499.
- Pollock, K. H., H. D. Marsh, I. R. Lawler, and M. W. Alldredge. 2006. Estimating animal abundance in heterogeneous environments: an application to aerial surveys for dugongs. *Journal of Wildlife Management* **70**:255-262.
- Pollock, K. H., J. D. Nichols, T. R. Simons, G. L. Farnsworth, L. L. Bailey, et al. 2002. Large scale wildlife monitoring studies: statistical methods for design and analysis. *Environmetrics* **13**:105-119.
- Pomeroy, R. S., P. McConney, and R. Mahon. 2004. Comparative analysis of coastal resource co-management in the Caribbean. *Ocean & Coastal Management* **47**:429-447.
- Preen, A. 2004. Distribution, abundance and conservation status of dugongs and dolphins in the southern and western Arabian Gulf. *Biological Conservation* **118**:205-218.
- Preen, A. R., H. Marsh, I. R. Lawler, R. I. T. Prince, and R. Shepherd. 1997. Distribution and abundance of dugongs, turtles, dolphins and other megafauna in Shark Bay, Ningaloo Reef and Exmouth Gulf, Western Australia. *Wildlife Research* **24**:185-208.

- Quinn, G. P., and M. J. Keough. 2003. Experimental design and data analysis for biologists. Cambridge University Press, Cambridge, United Kingdom.
- Reeves, R.R. 2000. The value of sanctuaries, parks, and reserves (protected areas) as tools for conserving marine mammals. Final report to the Marine Mammal Commission, contract number T74465385. Marine Mammal Commission, Bethesda.
- Reynolds III, J.E. 1999. Efforts to conserve the manatee. Pages 267-295 in J. R. Twiss and R. R. Reeves, editors. Conservation and management of marine mammals. Smithsonian Press, Washington D.C.
- Reynolds III, J. E., W. A. Szelistowski, and M. A. León. 1995. Status and conservation of manatees *Trichechus manatus manatus* in Costa Rica. *Biological Conservation* **71**:193-196.
- Reynolds, J. E., and J. R. Wilcox. 1994. Observations of Florida manatees (*Trichechus manatus latirostris*) around selected power plants in winter. *Marine Mammal Science* **10**:163-177.
- Reynolds, R. T., J. M. Scott, and R. A. Nussbaum. 1980. A variable circular-plot method for estimating bird numbers. *Condor* **82**:309-313.
- Roberge, J-M., and P. Angelstam. 2004. Usefulness of the umbrella species concept as a conservation tool. *Conservation Biology* **18**:76-85.

- Roberts, C. M. 1998. Sources, sinks, and the design of marine reserve networks. *Fisheries* **23**:16-19.
- Roberts, C. M. 2000. Selecting marine reserve locations: optimality versus opportunism. *Bulletin of Marine Science* **66**:581-592.
- Salomon, A. K., J. L. Ruesink, B. X. Semmens, and R. T. Paine. 2001. Incorporating human and ecological communities in marine conservation: an alternative to Zacharias and Roff. *Conservation Biology* **15**:1452-1455.
- Schwartz, M. W. 1999. Choosing the appropriate scale of reserves for conservation. *Annual Review Ecological Systems* **30**:83-108.
- Self-Sullivan, C., G. W. Smith, J. M. Packard, and K. S. LaCommare. 2003. Seasonal occurrence of male Antillean manatees (*Trichechus manatus manatus*) on the Belize Barrier Reef. *Aquatic Mammals* **29**:342-354.
- Shackley, M. 1992. Manatees and tourism in southern Florida: opportunity or threat? *Journal of Environmental Management* **34**:257-265.
- Sheehy, B. 2004. International marine environmental law: a case study in the Wider Caribbean Region. *Georgetown International Environmental Law Review* **16**:441-472.
- Shrader-Frechette, K. S., and E. D. McCoy. 1993. *Method in ecology: strategies for conservation*. Cambridge University Press, Cambridge, United Kingdom.

- Siex, K. S., and T. T. Struhsaker. 1999. Colobus monkeys and coconuts: a study of perceived human-wildlife conflicts. *Journal of Applied Ecology* **36**:1009-1020.
- Simberloff, D. 1998. Flagships, umbrellas, and keystones: is single-species management passé in the landscape era? *Biological Conservation* **83**:247-257.
- Sorice, M. G., C. S. Shafer, and D. Scott. 2003. Managing endangered species within the use/preservation paradox: understanding and defining harassment of the West Indian manatee (*Trichechus manatus*). *Coastal Management* **31**:319-338.
- Sorice, M. G., C. Scott Shafer, and R. B. Ditton. 2006. Managing endangered species within the use-preservation paradox: the Florida manatee (*Trichechus manatus latirostris*) as a tourism attraction. *Environmental Management* **37**:69-83.
- Soulé, M. E., and D. Simberloff. 1986. What do genetics and ecology tell us about the design of nature reserves? *Biological Conservation* **35**:19-40.
- UNEP (United Nations Environmental Programme). 2006. United National Environmental Programme Cartagena Convention and its Protocols. Available from <http://www.cep.unep.org/cartagena-convention> (accessed February 2006).
- van den Belt, M. 2004. Mediated modeling: A systems dynamics approach to environmental consensus building. Island Press, Washington, D.C.

- Vanzella-Khoury, A. 1998. Implementation of the Protocol Concerning Specially Protected Areas and Wildlife (SPA) in the Wider Caribbean Region. *The University of Miami Inter-American Law Review* **30**:53-83.
- Vianna, J. A., R. K. Bonde, S. Caballero, J. P. Giraldo, R. P. Lima, et al. 2006. Phylogeography, phylogeny and hybridization in trichechid sirenians: implications for manatee conservation. *Molecular Ecology* **15**:433-447.
- von Zharen, W. M. 1998. Ocean ecosystem stewardship. *William and Mary Environmental Law and Policy Review* **22**:1-107.
- von Zharen, W. M. 1999. An ecopolicy perspective to sustaining living marine species. *Ocean Development and International Law* **30**:1-41.
- Whitehead, H. 2001. Analysis of animal movement using opportunistic individual identifications: application to sperm whales. *Ecology* **82**:1417-1432.
- Wittemyer, G. 2001. The elephant population of Samburu and Buffalo Springs National Reserves, Kenya. *African Journal of Ecology* **39**:357-365.
- Wright, I. E., J. E. Reynolds III, B. B. Ackerman, L. I. Ward, B. L. Weigle, et al. 2002. Trends in manatee (*Trichechus manatus latirostris*) counts and habitat use in Tampa Bay, 1987-1994: implications for conservation. *Marine Mammal Science* **18**:259-274.

Zacharias, M. A., and J. C. Roff. 2001. Use of focal species in marine conservation and management: a review and critique. *Aquatic Conservation: Marine and Freshwater Ecosystems* **11**:59-76.

**APPENDIX A**  
**SCWS STATUTORY INSTRUMENT**

**BELIZE:**

**STATUTORY INSTRUMENT**

**No. 102 of 2002**

*ORDER made by the Minister of Natural Resources, the Environment and Industry in exercise of the powers conferred upon him by section 3 (1) of the National Parks System Act, Chapter 215 of the Substantive Laws of Belize, Revised Edition 2000, and all other powers thereunto him enabling.*

*(Gazetted 7th September, 2002.)*

1. This Order may be cited as the

Short title.

**NATIONAL PARKS SYSTEM  
(SWALLOW CAYE WILDLIFE SANCTUARY)  
ORDER, 2002.**

2. The area of land specified in the Schedule to this Order is hereby declared to be a Wildlife Sanctuary.

Declaration of Wildlife Sanctuary Schedule.

3. A map of the said area may be seen at the Office of the Chief Forest Officer, Ministry of Natural Resources, the Environment and Industry, Belmopan.

Map of Wildlife Sanctuary; where to be seen.

**MADE** by the Minister of Natural Resources, the Environment and Industry this 10th day of July, 2002.

**(JOHN BRICEÑO)**

*Minister of Natural Resources*



SCHEDULESWALLOW CAYE WILDLIFE SANCTUARY

**ALL THAT** piece or parcel of land and water east of Belize City in the Belize District including Swallow Caye and Mapps Cay, comprising of approximately **8,970.13 acres** and hereinafter described as follows:-

Commencing at a point having the scaled UTM co-ordinates of 1937 150 North and 378 400 East;

Thence east north east on a bearing of 73.7 degree for an approximate distance of 3970 meters to a point having the scaled UTM co-ordinates of 1938 250 North and 382 200 East;

Thence east south east on a bearing of 124.9 degree for an approximate distance of 1,642 meters to a point having the scaled UTM co-ordinates of 1937 300 North and 383 550 East;

Thence south-south west along the southern side of channel on a bearing of 189.9 degrees for an approximate distance of 3,161 meters to a point having the scaled UTM co-ordinates of 1934 200 North and 383 000 East;

Thence south east on a bearing of 117.8 degrees for an approximate distance of 1,243 meters to a point having the scaled UTM co-ordinates of 1933 600 North and 384 100 East;

Thence south-south east on a bearing of 176.6 degree for an approximate distance of 2,611 meters to a point having the scaled UTM co-ordinates of 1931 000 North and 384 250 East;

Thence west on a bearing of 270 degree for an approximate distance of 6,252 meters to a point having the scaled UTM co-ordinates of 1931 000 North and 378 000 East;

Thence directly north on a bearing of 0 degree for an approximate distance of 3,540 meters to a point having the scaled UTM co-ordinates of 1934 550 North and 378 000 East;

*[No. 102]*

*National Parks System*

*3*

---

Thence north east on a bearing of 34.9 degree for an approximate distance of 1,762 meters to a point having the scaled UTM co-ordinates of 1936 000 North and 379 000 East;

Thence north-north west on a bearing of 332.5 degree for an approximate distance of 1,310 meters back to the point of commencement.

*Printed in Belize by the Government Printer*

**APPENDIX B**  
**DATA SHEETS**

**TRIP SUMMARY SHEET (page 1)**

Day of the Week: \_\_\_\_\_

Trip ID: \_\_\_\_\_  
(yy-julianday-onedigittrip#)Date: \_\_\_\_\_  
(dd-mon-yy)Julian Day: \_\_\_\_\_  
(001-365)EW Team #: \_\_\_\_\_  
(yy-one digit team#)

# EW Vols: \_\_\_\_\_

Total Obs: \_\_\_\_\_

EW Team Members (first and last name): \_\_\_\_\_

Researcher(s): \_\_\_\_\_  
(first name)Intern(s): \_\_\_\_\_  
(firstname and initials)Field Asst.: \_\_\_\_\_  
(firstname and initials)

Effort Data Taken by: \_\_\_\_\_

Sighting/Scan Data Taken by: \_\_\_\_\_

Trip Summary Data Taken by: \_\_\_\_\_

Behavioral Data Taken by: \_\_\_\_\_

Seagrass Data Taken by: \_\_\_\_\_

Locations (scan locations): \_\_\_\_\_

Total # of Scans: \_\_\_\_\_ Total # of Sightings (opp/scan): \_\_\_\_\_ Total # Manatees: \_\_\_\_\_

**GENERAL WEATHER CONDITIONS**

DEPART DOCK:	WEATHER CHECK I:	WEATHER CHECK II:
RETURN DOCK:	Time:	Time:
*TIDES IN ORDER:	Wind Speed: mph	Wind Speed: mph
High:	Wind Direction:	Wind Direction:
Low:	Sea State:	Sea State:
High:	Swell Height: ft	Swell Height: ft
Low:	Cloud Cover:	Cloud Cover:
High:	Water Temp: °C	Water Temp: °C
Low:	Air Temp: °C	Air Temp: °C
Rainfall Overnight:	Salinity: PPT	Salinity: PPT
Rainfall Today:	Barometer: HPa	Barometer: HPa
Cruise Ships (#): _____		
Comments: _____		

\* If a high or low falls pre/post today's date, put in parentheses in order of occurrence.

**Please Complete Trip Log on reverse side and additional pages!**

CSS/KSL	<b>Trip Summary Sheet</b>	Page	Of
---------	---------------------------	------	----

MANATEE SIGHTINGS AND SCANS Page 1 of \_\_\_\_\_ ID # \_\_\_\_\_

(yy-julianday-sight#scan#)

**Sighting Number** \_\_\_\_\_ **Sight Start (24 hr)** \_\_\_\_\_ **Sight Stop** \_\_\_\_\_**Point Scan Number** \_\_\_\_\_ **Scan Start (24 hr)** \_\_\_\_\_ **Scan Stop** \_\_\_\_\_**Sighting Type (circle one):** Opportunistic or Scan**Waypoint (Garmin):** \_\_\_\_\_ **Accuracy:** \_\_\_\_\_**Location:** \_\_\_\_\_ **Loc. Code (see list for proper code):** \_\_\_\_\_

MUST Enter for both sightings and scans

ONLY Enter code if this is a scan (whether there is a sighting or not).

# Of Other Boats in area during scan: \_\_\_\_\_ **Distance (closest point)** (1) \_\_\_\_\_ (2) \_\_\_\_\_ (3) \_\_\_\_\_**Comments (size, type, speed)** (1) \_\_\_\_\_ (2) \_\_\_\_\_ (3) \_\_\_\_\_**Manatee Sighted By** \_\_\_\_\_ **Confirmed By** \_\_\_\_\_

Enter one of the following: Researcher, Field Assistant, Intern, Volunteer, Team, Not confirmed

**\*Total # Of Manatees** \_\_\_\_\_ **No. Calves** \_\_\_\_\_ **Calf Size** NEW, YOY, OTHER \_\_\_\_\_1<sup>ST</sup> 20 minutes of SCAN: Minimum: \_\_\_\_\_

Maximum: \_\_\_\_\_

Best Estimate: \_\_\_\_\_

\*TOTAL # DURING SIGHTING

Total 30 minutes of SCAN: Minimum: \_\_\_\_\_

Maximum: \_\_\_\_\_

Best Estimate: \_\_\_\_\_

**Initial Distance to 1<sup>st</sup> Manatee at 1<sup>st</sup> Sighting (m):** \_\_\_\_\_ **Time:** \_\_\_\_\_ **Initial Movement of 1<sup>st</sup> Manatee:** \_\_\_\_\_Aw from boat ◆ Towards boat ◆ Milling ◆ No change ◆ Undetermined

(CIRCLE Distance Detection Method: DIRECT INDIRECT ESTIMATE) (CIRCLE initial movement in relationship to observation boat)

**Habitat Type:** (Circle habitat where the manatee is, NOT the scan pt.) UNDETERMINED Resting hole-yes or no or unkInBogue/OutBogue/Reef | Chann/ChannEdge/DeadEndBogue/Lagoon/Grassflat/UNK | Mud/Grass/Sand/Coral/UNK | Turtle/Shoal/Manatee/None/UNK**DISTURBED?** YES OR NO**Predominate Behavioral State (circle one):**Feeding ◆ Resting ◆ Socializing ◆ Traveling ◆ Milling ◆ Undetermined ◆ Other (describe): \_\_\_\_\_**Initial Distance to 2<sup>nd</sup> Manatee at 1<sup>st</sup> Sighting (m):** \_\_\_\_\_ **Time:** \_\_\_\_\_ **Initial Movement of 2<sup>nd</sup> Manatee:** \_\_\_\_\_Aw from boat ◆ Towards boat ◆ Milling ◆ No change ◆ Undetermined

(CIRCLE Distance Detection Method: DIRECT INDIRECT ESTIMATE) (CIRCLE initial movement in relationship to observation boat)

**Habitat Type:** (Circle habitat where the manatee is, NOT the scan pt.) UNDETERMINED Resting hole-yes or no or unkInBogue/OutBogue/Reef | Chann/ChannEdge/DeadEndBogue/Lagoon/Grassflat/UNK | Mud/Grass/Sand/Coral/UNK | Turtle/Shoal/Manatee/None/UNK**DISTURBED?** YES OR NO**Predominate Behavioral State (circle one):**Feeding ◆ Resting ◆ Socializing ◆ Traveling ◆ Milling ◆ Undetermined ◆ Other (describe): \_\_\_\_\_**Initial Distance to Center of Manatee Group at 1<sup>st</sup> Sighting (m):** \_\_\_\_\_

U/W Video Attempt : yes no; if yes, was it successful? \_\_\_\_\_

Seagrass Sample/Habitat Sample/No

Sample

**SIGHTING/SCAN CONDITIONS**

Glare	Glare Direction	Cloud cover	Precipitation	Sea State	Swell Height	Tide State*
Yes		clear	Dry			High (+/- 60m)
No		scattered	Light rain			Low (+/- 60m)
		partly	Heavy rain			Flood Ebb
		mostly				
		overcast				

\* If Scan Start Time falls within 60 min of High or Low Tide, then circle High or Low; if not and Scan Start Time falls b/t High and Low, circle Ebb; if not and Scan Start Time falls b/t Low and High, circle Flood.

**DATE:** \_\_\_\_\_ **Sighting/Scan Data Taken By?** \_\_\_\_\_

(dd-mon-yy)

**Trip ID:** \_\_\_\_\_ **SIGHTINGS AND SCANS** **Data Set** \_\_\_\_\_ **of** \_\_\_\_\_

(yy-julianday-one digit trip#)

MANATEE SIGHTINGS AND SCANS Page 2 of \_\_\_\_ ID # \_\_\_\_\_  
(yy-julianday-sight#scan#)

**Site Map:** On this page you will sketch the characteristics of the scan point in relationship to the Boat. Map Perspective: illustrator is standing on the driver's seat and facing north when looking towards the top of this page. Sketch the above water characteristics and draw a vector (distance & direction) to each landmark and to each manatee sighted. Label each manatee vector with time, distance, & direction.

N

W



E

S

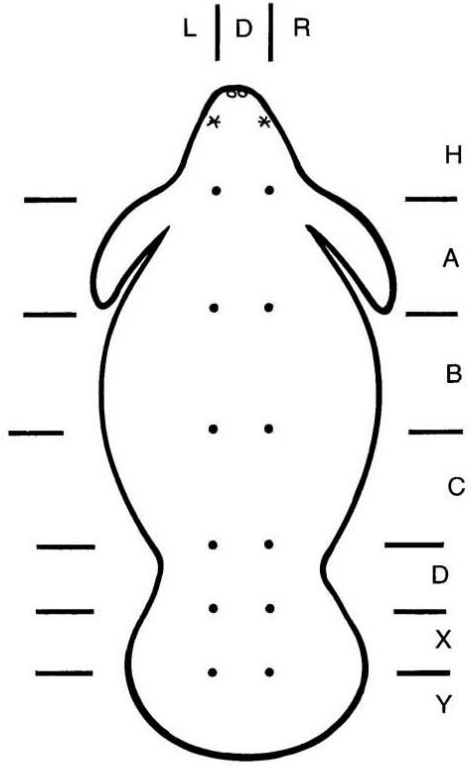
MANATEE SIGHTINGS AND SCANS Page 3 of \_\_\_\_ ID # \_\_\_\_\_  
 (yy-julianday-sight#scan#)

Comments: \_\_\_\_\_

CatalogID # \_\_\_\_\_ Marked / Un-Marked / Undetermined Sex: M / F / U Prop Scars? Yes / No  
 RESIGHT? \_\_\_\_\_ Tape Start \_\_\_\_\_ Stop \_\_\_\_\_ Animal \_\_\_\_\_ of \_\_\_\_\_ captured on tape

Enter Feature Codes\*2 (see below)  
 for each unique marking seen on animal

-----  
 -----  
 -----  
 -----  
 -----  
 -----  
 -----  
 -----



**Barnacles:** Yes / No / Undetermined  
 Number? \_\_\_\_\_ Size? \_\_\_\_\_

**Remoras:** Yes / No / Undetermined  
 Number? \_\_\_\_\_

**Algae:** Yes / No / Undetermined  
 Color/Coverage? \_\_\_\_\_

**Medial Notch:** Yes / No / Undetermined  
 Comments? \_\_\_\_\_

**Behavioral State:** Rest / Feed / Travel / Social / Mill  
 Play / Other / Undetermined  
**Initial Reaction to diver:** Approach / Retreat / No Change / Touch / Other  
**Secondary Reaction to diver:** Approach / Retreat / No Change / Touch / Other

\*2 Identifying Feature Codes to use in blanks above, use one line for each unique marking:

Type	Region	Position	Number	Size	Color	Shape
S - scar	D - dorsal	F - flipper	1 - single	L - large	G - gray	B - blotch
M - mutilation	L - left	H - head 2 - 2 or 3		M - medium	W - white	L - line(s)
D - deformity	R - right	A - ant. trunk	4 - 4 or more	S - small		
F - freeze brand	V - ventral	B - mid. trunk				
N - medial notch		C - post. trunk				
K - trunk plain		D - peduncle				
L - tail plain		X - ant. tail				
P - skin pigmentation		Y - post. tail				

MANATEE SIGHTINGS AND SCANS Page 4 of \_\_\_\_ ID # \_\_\_\_\_  
(yy-julianday-sight#scan#)

Initial Distance to 3<sup>rd</sup> Manatee at 1<sup>st</sup> Sighting ((m): \_\_\_\_\_ Time: \_\_\_\_\_ Initial Movement of 3<sup>rd</sup> Manatee:  
Aw from boat ◆ Towards boat ◆ Milling ◆ No change ◆ Undetermined  
(CIRCLE Distance Detection Method: DIRECT INDIRECT ESTIMATE) (CIRCLE initial movement in relationship to observation boat)

Habitat Type: (Circle habitat where the manatee is, NOT the scan pt. ) UNDETERMINED Resting hole-yes or no or unk  
InBogue/OutBogue/Reef | Chann/ChannEdge/DeadEndBogue/Lagoon/Grassflat/UNK | Mud/Grass/Sand/Coral/UNK | Turtle/Shoal/Manatee/None/UNK

DISTURBED? YES OR NO Predominate Behavioral State (circle one):  
Feeding ◆ Resting ◆ Socializing ◆ Traveling ◆ Milling ◆ Undetermined ◆ Other (describe):

Initial Distance to 4<sup>th</sup> Manatee at 1<sup>st</sup> Sighting ((m): \_\_\_\_\_ Time: \_\_\_\_\_ Initial Movement of 4<sup>th</sup> Manatee:  
Aw from boat ◆ Towards boat ◆ Milling ◆ No change ◆ Undetermined  
(CIRCLE Distance Detection Method: DIRECT INDIRECT ESTIMATE) (CIRCLE initial movement in relationship to observation boat)

Habitat Type: (Circle habitat where the manatee is, NOT the scan pt. ) UNDETERMINED Resting hole-yes or no or unk  
InBogue/OutBogue/Reef | Chann/ChannEdge/DeadEndBogue/Lagoon/Grassflat/UNK | Mud/Grass/Sand/Coral/UNK | Turtle/Shoal/Manatee/None/UNK

DISTURBED? YES OR NO Predominate Behavioral State (circle one):  
Feeding ◆ Resting ◆ Socializing ◆ Traveling ◆ Milling ◆ Undetermined ◆ Other (describe):

Sighting Comments (con't):  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_



**APPENDIX C**  
**GUIDELINES FOR TOUR OPERATORS**

## Manatee Facts

Belize has the largest population of the West Indian manatee *Trichechus manatus manatus* in the world. Still small, Belize's manatee population is probably less than 700 country wide. It is an endangered species and is protected by law. Manatees bring revenue for the tourist sector, they provide an ecological balance, and they help to diversify Belize's animal life!

*Help to increase the manatee population in Belize by abiding by the suggested guidelines. Be especially careful in the following areas:*

- ☞ **BELIZE CITY COAST and CAYS:**  
Swallow Cay, St. Georges Cay, Moho Cay, Port-O-Stuck, Drowned Cays, Hicks Cay, Bluefield Range, Rider Cay, Turneffe Atoll.
- ☞ **SOUTHERN AND NORTHERN LAGOON**
- ☞ **PLACENTIA LAGOON**
- ☞ **CHETUMAL BAY**
- ☞ **PORT HONDURAS AREA**
- ☞ **INDIAN HILL LAGOON**
- ☞ **RIVERS:** Deep River, The Belize River, Monkey River, Rio Hondo, Mullins River.

## Please Help Save the Manatee!

For more information, or to report manatee deaths or injury, please contact:

Manatee Researcher\*  
Coastal Zone Management Authority and Institute  
Princess Margaret Drive  
P.O. Box 1884  
Belize City, Belize  
Phone: 501-223-0719/5739/2616  
Toll Free: 0-800-MANATEE  
email: [czmbze@btl.net](mailto:czmbze@btl.net)

Belize Audubon Society  
12 Fort Street  
Belize City, Belize  
Phone:

Forest Department  
Belmopan, Belize  
Phone: 501-822-3629

Fisheries Department  
Princess Margaret Drive  
Belize City, Belize  
Phone: 501-224-4552/223-2623  
Email: [species@btl.net](mailto:species@btl.net)



# MANATEES IN BELIZE

## Guidelines for Tour Operations



**DO YOUR PART TO PROTECT BELIZE'S  
HERITAGE, ENVIRONMENT, AND FUTURE!**

# ONLY YOU CAN HELP SAVE THE MANATEE

## TOURIST ORIENTATION:

- ☞ *Familiarize tourists with proper behavior for viewing manatees:*
- ☞ **NO** loud noises as it frightens manatees.
- ☞ **NO** touching or feeding the manatees, this can alter their natural behavior.
- ☞ **NO** approaching females with calves.

## BOAT APPROACH:

- ☞ Slow to idle speed 1/2 mile to 100 yards from manatee site to prevent hitting or scaring away the manatees.
- ☞ Once within 75 to 100 feet from the site, turn engine off and drift or pole to site.
- ☞ When in position, use pole to hold boat.

## NUMBER OF BOATS AT A SITE:

- This will be different at each site, but guides should not use an area if many boats and tourists are already there.*
- ☞ **NO** more than 2 boats at a site. Very large areas can possibly accommodate 3-4 boats (without swimmers).
- ☞ Boats should cooperate and share a site.

## SWIMMING:

- ☞ **NO** swimming in "Manatee Hole" at Swallow Cay and at Gales Point.
- ☞ Swim only at deep, clear holes.
- ☞ Enter the water only if manatees seem undisturbed and stay in area.
- ☞ Enter water quietly and stay on surface of water with a guide [do not dive].
- ☞ No chasing nor attempting to corner or isolate a manatee.
- ☞ Small groups at a time in the water (about 5 persons).
- ☞ Minimize time in the water (no more than 15 minutes).

## TIME AT A SITE:

- ☞ If a boat is waiting, the boat using the site should only stay 20 minutes more, or share the site if big enough.  
*Accommodate one another.*

## DEPARTURE OF BOATS:

- ☞ Leave site by drifting or poling away 75-100 ft. before starting engine.
- ☞ Leave boat at idle speed, do not rev motor.
- ☞ *Please don't throw trash where manatee splash!!!*

# PROTECTION BY LAW

The West Indian Manatee is protected in Belize under the **Wildlife Protection Act, No. 4 of 1981**. Jurisdiction is under the Forest Department, Ministry of Natural Resources.

Under this act, no person shall hunt, meaning "to kill, molest by any method and includes attempting to kill, take or molest by any method" any manatee.

Anyone who hunts a manatee will be fined \$500.00 on a first offence, and \$1000.00 and/or imprisonment for 6 months for previously convicted wildlife offenders.

**CALL THE COASTAL ZONE MANAGEMENT AUTHORITY AND INSTITUTE TO REPORT MANATEE INJURIES, DEATHS, OR BIRTHS**

**0-800-MANATEE**

**APPENDIX D**  
**SURVEY POINTS**

Table 6. Survey Points by Code, Name, and Location.

<b>Code</b>	<b>Location</b>	<b>Latitude</b>	<b>Longitude</b>
01 MaLa	Mapp Caye Lagoon Resting Hole	17.5226	-88.1113
02 ScN	Ship's Channel North	17.5188	-88.1206
03 BbHo	Barge Bogue Pach's Hole	17.5254	-88.1053
04 BbCh	Barge Bogue Channel	17.5151	-88.1086
05 LHoS	Landy's Hole South	17.5053	-88.1091
06 ScS	Ship's Channel South	17.5038	-88.1128
07 G2Mo	Bogue G Arm 2 Mouth	17.5135	-88.0978
08 G2En	Bogue G Arm 2 End	17.5143	-88.0961
09 G1Mo	Bogue G Arm 1 Mouth	17.5049	-88.1019
10 G1En	Bogue G Arm 1 End	17.5090	-88.0968
11 GMo	Bogue G Mouth	17.4966	-88.1027
12 StLa	Stimpy's Lagoon Resting Hole	17.5063	-88.0917
13 Su3	Sugar Bogue Arm 3 End	17.4964	-88.0952
14 Su2	Sugar Bogue Arm 2	17.5027	-88.0867
15 Su1	Sugar Bogue Arm 1	17.5008	-88.0837
16 SuMo	Sugar Bogue Mouth	17.4895	-88.0924
17 F2En	Bogue F Main (Arm 2) End	17.5015	-88.0805
18 FCh	Bogue F Channel	17.4903	-88.0875
19 F1En	Bogue F South (Arm 1) End	17.4943	-88.0812
20 ESp	Bogue E Spoonbill Cove	17.4934	-88.0769
21 ECo	Bogue E Cove on South Side	17.4889	-88.0784
22 EDJ	Bogue E and D Junction	17.4831	-88.0746
23 DYCo	Bogue D Yamaha's Cove	17.4842	-88.0820
24 DMo	Bogue D Mouth	17.4793	-88.0899
25 HuCh	Huesner Bogue Channel	17.4778	-88.0803
26 HuCo	Huesner Bogue Jane's Cove	17.4809	-88.0713
27 HuMo	Huesner Bogue Mouth	17.4724	-88.0887
28 HuLi	Little Heusner Bogue	17.4762	-88.0813
29 CCh	Bogue C Channel	17.4620	-88.0754
30 CCo	Bogue C Cove at End	17.4697	-88.0779
31 CLa	Bogue C Big Lagoon	17.4723	-88.0810
32 MuGr	Mullet Bay Grassbed	17.4627	-88.0890
33 HeCo	Heraclitus Cove	17.4620	-88.0754
34 HeMo	Heraclitus Mouth (in Bogue B)	17.4590	-88.0729
35 BLa	Bogue B Lagoon Arm 1	17.4620	-88.0788
36 BMo	Bogue B Mouth	17.4204	-88.0701
37 AMi	Bogue A Middle	17.4527	-88.0673
38 AGr	Bogue A Grassbed	17.4525	-88.0674
39 NGA	North Gallows	17.5095	-88.0510
40 SGA	South Gallows	17.4569	-88.0376

Table 6. Continued

<b>Code</b>	<b>Location</b>	<b>Latitude</b>	<b>Longitude</b>
41 ShW	Shag Caye Bogue West	17.4460	-88.0677
42 ShE	Shag Caye Bogue East	17.4491	-88.0648
43 BaCo	Bannister Bogue Jerry's Cove	17.4444	-88.0673
44 BaE	Bannister Bogue East	17.4426	-88.0674
45 BaW	Bannister Bogue West	17.4365	-88.0728
46 FaE	Farl's Bogue East	17.4331	-88.0675
47 FaW	Farl's Bogue West	17.4325	-88.0732
48 GoE	Goring Bogue East Side	17.4267	-88.0668
49 GiGr	Gilroy's Grassbed East Side	17.4102	-88.0680
50 GiCr	Gilroy's Creek	17.4109	-88.0705
51 GiLa	Gilroy's Lagoon	17.4081	-88.0749
52 SwS	Swallow Caye South	17.4989	-88.1254
53 SwW	Swallow Caye West	17.5010	-88.1347
54 SLCW	Spanish Lookout Caye West	17.4176	-88.0728

## VITA

- Name: Caryn Self Sullivan
- Address: 200 Stonewall Drive, Fredericksburg, VA 22401-2110
- Email: caryn@sirenian.org
- Education: B.S. Marine Science, Coastal Carolina University, 1997  
Ph.D. Wildlife & Fisheries Sciences, Texas A&M University, 2008
- Professional Experience:
- President and Co-founder, Sirenian International, Inc.
  - Principal Investigator and Advisor, Earthwatch Institute
  - Advisor, Hugh Parkey Foundation for Marine Awareness and Education
  - Member, Belize National Manatee Working Group
  - Member, IUCN Species Survival Commission Sirenia Specialist Group
- Publications:
- LaCommare, K. S., C. Self-Sullivan, and S. Brault. 2008. Distribution and habitat use of Antillean manatees (*Trichechus manatus manatus*) in the Drowned Cays area of Belize, Central America. *Aquatic Mammals* 34: in press.
- Deutsch, C., C. Self-Sullivan, and A. A. Mignucci-Giannoni. 2007. ICUN Red List Assessment of the Conservation Status of West Indian Manatees in Central and South America and the Caribbean. IUCN, Gland, Switzerland. Available from <http://www.iucnredlist.org>.
- Self-Sullivan, C., Smith, G. W., Packard, J. M., and LaCommare, K. S. 2003. Seasonal occurrence of male Antillean manatees (*Trichechus manatus manatus*) on the Belize Barrier Reef. *Aquatic Mammals* 29(3):342-354.
- Williams, Jr., E. H., Mignucci-Giannoni, A. A., Bunkley-Williams, L., Bonde, R. K., Self-Sullivan, C., Preen, A., and Cockcroft, V. G. 2003. Echeneid-sirenian associations, with information on sharksucker diet. *Journal of Fish Biology* 63:1176-1183.
- Fellowships and Awards:
- 2003 Earthwatch Young Scientist Award
  - 1998-2001 NSF Graduate Fellowship
  - 1997 Outstanding Marine Science Graduating Senior
  - 1997 President's Academic Excellence Nominee
  - 1996 Exchange student to Deakin University, Australia
  - 1995 NSF-REU Fellowship
- Grants:
- Earthwatch Institute, 2001-2006, \$180,000
  - Conservation Action Fund, New England Aquarium, 2001, \$5000
  - Lerner-Grey Fund for Marine Research, AMNH, 2000, \$2000
  - Project Aware, 2004, \$1000