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Status and Distribution of Manatees in Honduras and the Use of Side-Scan Sonar

by

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A Thesis submitted in partial satisfaction
of the requirements for the degree of
Master of Science in Biology

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Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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All manatee species are listed as endangered or vulnerable. Studying these animals is very challenging because of their reticent behavior and the remote and complex habitats in which they are found. This study dealt with three challenges in manatee conservation: identification of hotspots, manatee detection in turbid and tannin-stained waters, and regional collaboration between countries. Using the West Indian Manatee (*Trichechus manatus*) as the study subject, these three challenges were examined and possible solutions were presented.

The distribution of manatees in Honduras is known from sporadic death reports and informal interviews. Like many other countries in Mesoamerica, Honduras had not been surveyed aerially for manatees for several decades, providing a substantial challenge to those wanting to develop a current recovery plan for the remaining population of manatees. Replicate aerial surveys were flown over the northern coast of Honduras (Rio Aguán to Rio Tinto) to update manatee distribution and identify locations of importance along the coast. These surveys provided critical information about the distribution and relative abundance of manatees in northern Honduras. The results from these surveys were compared to six replicate surveys conducted in 1979-80 to determine change in relative abundance. The average number of manatee sightings was significantly

less than the prior study ($p < 0.001$). Finally, twenty-five manatee death records were compiled from interviews, museum specimens, and unpublished reports from 1970-2006 to determine the main threats to manatees. Most deaths resulted from entanglement in gillnets.

Turbid and tannin-stained waterways are difficult habitats to study and manage aquatic wildlife, particularly when dealing with endangered and solitary animals. The use of side-scan sonar, which produces a picture-like image of the substrate and objects in the water column, was explored to acoustically detect West Indian Manatees in various environmental conditions and habitats. Blind transects (observer looked only at sonar image) were run in both Mexico and Florida to determine sonar detection rate. Good sonar images were produced during most environmental conditions experimented, as long as water movement was minimal, however, they could not be produced by rotating the transducer. Detection rates in Florida were 70% (95% with correction for hidden calves and animals beyond limit of sonar) and 93% in Mexico. This study concludes that side-scan sonar is sensitive enough to accurately detect manatees in the wild, and can be an effective and affordable tool to study and manage them throughout their range.

The First Symposium for the Biology and Conservation of the Antillean manatee (*Trichechus manatus manatus*) in Mesoamerica, was held in Antigua Guatemala, Guatemala, November 1-2, 2006. The primary purpose of this symposium was to update the current knowledge about the status and distribution of Antillean manatee in Mesoamerica. The result of this symposium was the development of a Mesoamerican Manatee Research Workgroup, which aims to unite manatee research and conservation efforts within Mesoamerica.

CHAPTER ONE

INTRODUCTION

1.1 Overview of Manatees

Diversity

Manatees belong to the mammalian order Sirenia (sea cows), which consists of only two families, Trichechidae (manatees) and Dugongidae (dugongs; (Reynolds & Odell 1991), with a total of four extent species: the West Indian manatee (*Trichechus manatus*), the West African manatee (*Trichechus senegalensis*), the Amazonian manatee (*Trichechus inunguis*), and the dugong (*Dugong dugon*; Reynolds and Powell, 2002).

Sirenians date back to the Eocene (~50 Ma) and over 35 species have been described thus far from the fossil record (Domning 1982, Domning 2001). The majority of the species described are from the family Dugongidae, in contrast to the diversity favoring Trichechidae today (Reep & Bonde 2006).

Two subspecies of the West Indian manatee have been described based on cranial measurements, the Florida manatee (*T. m. latirostris*) and the Antillean manatee (*T. m. manatus*; (Domning & Hayek 1986). Recent genetic studies using mtDNA have challenged this view and suggested that there are at least three haplotype clusters for *T. manatus* (Vianna *et al.* 2006, Garcia-Rodriguez *et al.* 1998) and that *T. inunguis* is nested within *T. manatus*, presumably indicating that *T. manatus* is paraphyletic (Vianna *et al.* 2006, Cantanhede *et al.* 2005).

However, analysis of the cyt *b* gene suggests that *T. inunguis* is basal related to *T.*

senegalensis and *T. manatus* (Vianna *et al*. 2006). It also suggests that *T. manatus* and *T. senegalensis* derived from the same marine ancestor (Vianna *et al*. 2006), which agrees with previous conclusions based on analysis of the fossil record (Domning & Hayek 1986). Future work will likely revise our current classification of Trichechidae. For the purpose of this study I will use the accepted subspecies of *T. manatus*.

Distribution

Manatees are found on both sides of the tropical and subtropical Atlantic Ocean (Reynolds & Powell 2002, Lefebvre *et al.* 2001). There is no overlap between the range of the three species, with the exception of both *T. manatus* and *T. inunguis* occurring at the mouth of the Amazon River (Vianna *et al*. 2006, Reynolds & Powell 2002). Both *T. manatus* and *T. senegalensis* live in marine and freshwater environments (Reynolds & Powell 2002), although they seem to prefer rivers and estuaries to marine habitats (Reynolds & Powell 2002, Lefebvre *et al*. 2001). They are two of only a few marine mammals to live extended periods of time in both fresh and marine water.

The Amazonian manatee (*T. inunguis*) is the only species restricted to fresh water. As its common name implies, it occurs in the Amazon River basin and its tributaries in Brazil, Ecuador, Columbia, and Peru (Reynolds & Powell 2002, Cantanhede *et al*. 2005). Their seasonal distribution is largely based on the availability of water. During the dry season, when river and lake waters drop significantly, Amazonian manatees become concentrated in small deep pools (Best 1983). During these periods they will fast, living on their fat reserves (Best 1983).

The West African manatee (*T. senegalensis*) is the only manatee species found in the Old World. Also hinted by its common name, it occurs in West Africa in the coastal area and rivers from Senegal south to Angola (Reynolds & Powell 2002). West African Manatees occur in the rivers and lakes of several interior countries in West Africa including Mali, Burkina Faso, Niger, Chad, and Democratic Republic of the Congo (Reynolds & Powell 2002). The Florida manatee (*T. manatus latirostris*) is primarily restricted to Florida and the coasts of Georgia, however, some venture during the summer to Louisiana, Virginia, and the Carolinas (Reep & Bonde 2006, Lefebvre *et al*. 2001). A single radio tagged animal has migrated as far north as Rhode Island (Reep & Bonde 2006). The Antillean manatee (*T. m. manatus*) occupy the remainder of the West Indian manatee's range (Lefebvre *et al*. 2001). Antillean manatees are found in western Texas, the coast and rivers of Mexico, Belize, Honduras, Guatemala, Nicaragua, Costa Rica, Panama, Venezuela, Columbia, Surinam, French Guyana, and Brazil (Jimenez 2002, Mou Sue *et al.* 1990, Smethurst & Nietschmann 1999, Rathbun *et al.* 1983, Platt *et al.* 2000, O'Shea *et al.* 1988, Morales-Vela *et al.* 2003, Morales-Vela *et al.* 2000, Montoya-Ospina *et al.* 2001, de Thoisy *et al.* 2003, O'Shea & Salisbury 1991). They are also found along the coast of Caribbean islands such as Cuba, Dominican Republic, Haiti, Jamaica, and Puerto Rico; with rare occurrences in the Bahamas (Mignucci-Giannoni *et al.* 2000, Rathbun *et al.* 1984, Powell *et al.* 1981, Odell *et al.* 1978, Erdman 1970, Belitsky & Belitsky 1980)

Figure 1.1 Distribution of manatee species. The distribution of the West Indian manatee, *Trichechus manatus manatus*, is subdivided into the two described subspecies, *T. m. latirostris* and *T. m. manatus*. Distributions are generalized to represent the region in which each species occurs and are not meant to reflect the true distribution, which would be more fragmented and patchy


Florida Manatee
T. m. latirostris
Atlantic Ocean
Antillean Manatee
T. m. manatus
Pacific Ocean
West African Manatee
T. senegalensis
Amazonian Manatee
T. inunguis

As mentioned earlier, the current division into two subspecies has been challenged by the recent genetic analysis of *T. manatus*. The three distinct mtDNA lineages identified within the species correspond to the geographic regions of (a) Florida and the West Indies (b) the Gulf of Mexico and Caribbean mainland coasts and rivers; and (c) the Atlantic coast of South America (Vianna *et al*. 2006, Garcia-Rodriguez *et al*. 1998)

Biology

Understanding the basic biology of manatees is essential to effectively conserve them. However, most of what we know about the biology of manatees comes from studies of *T. m. latirostris* in Florida (Reep & Bonde 2006); thus, comparing aspects to the other species must be done with caution.

Manatees, along with their dugong cousin, are the only aquatic mammals that are exclusively herbivores, feeding on algae, shore grass, and marine plants (Reynolds 1999, Reep & Bonde 2006, Lefebvre *et al*. 2001). Manatees are generalists and have been reported to feed on more than 60 species of vegetation (Best 1981). Their metabolism is one of the lowest among marine mammals, and may explain how they are able to survive on such low-nutrient foods (Irvine 1983).

Manatees are a typical k-selected species (see Pianka 1970): investing in few offspring (almost always one), living long lives, breeding repeatedly during their lives (iteroparity), and taking several years to reach sexual maturity (Reynolds 1999). The only strong relationship appears to be between mother and calf (Hartman 1979). Winter aggregations of *T. m. latirostris* in Florida appear to be for thermoregulation and not social reasons (Reynolds & Odell 1991). No such aggregations have been noted for *T. m.*

manatus, *T. inunguis*, or *T. senegalensis*.

1.2 Conservation Efforts for Manatees

Status of Manatees

There was a fifth recent Sirenian species related to the dugong (in the family Dugongidae) known as Steller's Sea Cow (*Hydrodamalis gigis*), which was found in the Bering Sea (Forsten & Youngman 1982). They were the only known Sirenian to inhabit cold water. Steller's Sea Cows were 8 m long and weighed over 10,000 kg, making them the largest non-cetacean (whale or dolphin) mammal ever. Only 27 years after Mr. Steller first described them (1751) and compared their meat to beef and their fat to butter, they were extinct due to extensive hunting for their meat and hide by sealers (Forsten & Youngman 1982). This example illustrates how rapidly a k-selected species can become over-harvested. Because most of the remaining manatee populations are fragmented and relatively small, they are in jeopardy from not only over-harvesting, but also loss of habitat and genetic variation (Reynolds & Odell 1991).

All three species of manatees are listed as vulnerable by the IUCN (Reynolds 1999). In addition, both *T. inunguis* and *T. manatus* are listed as endangered by the U.S. Endangered Species Act, and *T. senegalensis* as threatened (Reynolds, 1999). In the U.S. manatees are also listed under the Marine Mammal Protection Act (Reep & Bonde 2006).

Current population estimates for *T. m. latirostris* in Florida are between 3200 and 4000 (Reep & Bonde 2006). These estimates are based on synoptic aerial surveys of the whole state. These surveys tend to be highly variable and most manatee scientists caution at using them as exact counts, because of the difficulty in sampling manatees (Reynolds

1999). There are no current estimates for the entire population of *T. m. manatus*; however, several countries have estimated the population of manatees within their borders (Lefebvre *et al*. 2001). Because manatees travel between countries, it is possible that many are being counted twice. Estimates from genetic data for the effective number of females for *T. inunguis* is 400,000 (Cantanhede *et al*. 2005); however, these estimates have been argued to be grossly overestimated and may represent past effective female size without accounting for the recent population decline in many regions of the Amazon (Vianna *et al*. 2006). No current estimates are available for the status of *T. senegalensis* (Reynolds 1999, Reynolds & Powell 2002).

Conservation Efforts

Although manatees are protected in most of the countries in which they occur, proper enforcement of that protection is a problem (Marsh & Lefebvre 1994). Conservation efforts for manatees have primarily focused on the United States. One of the requirements for species listed under the U.S. Endangered Species Act of 1973 is the development of a recovery plan. Manatees in Florida and Puerto Rico are protected by this act and the Florida Manatee Recovery Plan has served as a coordination tool that the various agencies working with the species or habitat can use.

A regional workshop was held in Jamaica in 1994 to coordinate the manatee protection efforts within the Caribbean and draft a management plan for manatees (UNEP 1995). That same year, the First International Manatee and Dugong Research Conference and Sirenian Research Workshop were held in Gainesville, Florida. Over 200 scientists from over 15 countries attended the conference (Marsh & Lefebvre 1994).

These conferences are an important tool for manatee conservation, bringing together the various parties interested in the welfare for the species.

There are various techniques that have been used to study and monitor manatees, such as VHF tracking, aerial surveys, carcass analysis, habitat evaluation, and interviews (Marsh & Lefebvre 1994). Each of these provides different types of information and comes with different challenges. A combination of several is essential to conserve manatees in a specific region. Aerial surveys have been used to determine distribution and to locate important sites for manatees, particularly warm water sites for manatees in Florida (Lefebvre *et al.* 1995, Ackerman 1995). Radio telemetry and satellite telemetry have also been used to study the movements of manatees in Florida, Mexico, Belize and Brazil (Reep & Bonde 2006, Deutsch *et al.* 1998). These studies have greatly advanced our understanding of manatee behavior. Various studies have looked at manatee habitat in association with manatee presence (Spiegelberger & Ganslosser 2005, Olivera-Gomez & Mellink 2005) or to determine if it is suitable for them (Jimenez 2005). Finally, carcass analysis has provided information on diet, contaminants, parasites, genetics, virology, pathology, and anthropomorphic causes of deaths (Rommel *et al.* 2007, Marsh & Lefebvre 1994, Bossart *et al.* 2004, Bossart *et al.* 2002).

Recently, scientist have used genetic tools to determine population diversity and biogeography of the different manatee haplotyes (Vianna *et al*. 2006, Garcia-Rodriguez *et al*. 1998, Cantanhede *et al*. 2005). These studies have shown that manatees in Florida, while relatively numerous, have very low genetic variation and are thus very vulnerable to disease (Vianna *et al*. 2006).

Challenges in Manatee Conservation

There are many challenges in manatee conservation, including: the ever-increasing demand for human use of prime manatee habitat, pollutants from agricultural runoff with unknown consequences, and the lack of proper methodologies to accurately determine populations from aerial surveys (Reynolds 1999, Marsh & Lefebvre 1994, Aipanjiguly *et al.* 2003). Here, I deal with three challenges that particularly apply to the Antillean manatee, but have implications for all Sirenians.

The first major challenge in manatee conservation is identifying “hotspots” or important areas for manatees. Because manatees tend to cluster around suitable habitat, we can protect them by identifying and conserving these areas. Habitat loss has been identified as the “major impediment to species survival and recovery worldwide” (Reynolds 1999). Thus, conservation efforts must focus on the habitat needed by the species. However, to protect these critical areas, they must first be identified.

The second major challenge is the difficulty in observing manatees in the wild, particularly in locations were they have been hunted. Manatees have been reported to become nocturnal in areas of intense hunting (Rathbun *et al*. 1983). In addition to this, with the exception of certain rivers in Florida and coastal areas in Belize and Mexico, manatees reside in habitats that are murky and tannin-stained. This makes it extremely difficult to monitor and study them.

The third major challenge to manatee conservation is the lack of communication, collaboration, and funding, particularly among third world regions such as Central America. Manatees have been recorded to travel up to 77 km in one day in Florida (Deutsch *et al.* 2003). Over the course of a year, adult manatees have been recorded to travel an average of 278 km with a range of 11-831 km (Deutsch *et al*. 2003). Recently, a manatee tagged in Mexico traveled all the way to southern Belize (Morales-Vera, per. comm.), confirming the long-suspected idea that manatees travel from country to country. Because of this, recovery plans and research cannot solely focus on small sub-regions, but rather, must include neighboring countries and regions.

1.3 Addressing Challenges of West Indian Manatee Conservation

This study focuses on addressing the three major challenges facing manatee conservation that were previously mentioned. Chapter 2 explores the use of replicate aerial surveys to determine the status and distribution of manatees on the northern coast of Honduras. Honduras was selected because the last aerial surveys were conducted in 1979-80 and the northern coast is rapidly being developed. Honduras serves as an example of the importance of aerial surveys in identifying key areas for manatee conservation in the ever-shrinking coastal habitats of Mesoamerica.

Chapter 3 presents the use of side-scan sonar as a surveying technique to detect and study West Indian Manatees in the wild. This study represents the first and only study to successfully identify manatees with side-scan sonar. Study sites in Honduras, Mexico, and Florida were selected to represent the variability in habitat of the species. The application of this technique is relevant to all manatee species and also to dugongs in areas where they are difficult to see due to coastal sedimentation.

Chapter 4 summarizes the results of the First Symposium of the Biology and Conservation of Manatees in Mesoamerica, which was organized to bring together the various groups working with Antillean manatees in Mesoamerica (Mexico, Belize, Guatemala, Honduras, Nicaragua, Costa Rica, and Panama). This symposium was the first time that scientists from the various countries came together to collaborate on plans and needs for manatee conservation in Mesoamerica as a whole. Finally, chapter 5 presents a general summary of the major points in each chapter and presents recommendations for future research in the area.

CHAPTER TWO

STATUS AND DISTRIBUTION OF THE ANTILLEAN MANATEE (*TRICHECHUS MANATUS MANATUS*) ON THE NORTHERN COAST OF HONDURAS

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Abstract

The current status and distribution of the Antillean manatee, *Trichechus manatus manatus*, is poorly known in various countries, such as Honduras, where the last published surveys for manatees were conducted in 1979-80. The northern coast of Honduras is the most vulnerable to habitat loss due to rapid development. Six replicate aerial surveys were conducted in March and April of 2006 on the northern coast of Honduras (Rio Aguán to Rio Tinto). Eighteen manatee sightings were recorded, with an average of 1.23 sightings per survey hour. Manatee sightings were mainly clustered in CySWR (11) and along Rio Chapagua and Rio Aguán (5), which were identified as important areas for manatees on the northern coast. The average manatee sightings per survey hour in the coastal area, rivers, and lagoons between the town of El Porvenir and Zambuco, was significantly less than during six surveys of this area in 1979-80. Twenty-five manatee death records were compiled from interviews, museum specimens and unpublished reports from 1970-2006. Most deaths resulted from entanglement in gillnets. Based on the maximum count sighted in each section of the northern coast we roughly estimate that there are 10-25 manatees between Rio Aguán and Rio Tinto.

2.1 Introduction

All manatee species are classified as vulnerable by The World Conservation Union (IUCN, 2006). The Antillean manatee (*Trichechus manatus manatus*), a subspecies of the West Indian manatee, ranges from southwestern Texas to northeastern South America, including the Greater Antilles (Reynolds & Powell 2002). However, most studies of Antillean manatees have been done in Mexico (Olivera-Gomez &

Mellink 2005, Olivera-Gomez & Mellink 2002, Morales-Vela *et al*. 2003) and Belize (Platt *et al*. 2000, Morales-Vela *et al*. 2000), with Belize being its last stronghold (Reynolds & Powell 2002, O'Shea & Salisbury 1991).

Historical manatee abundance and distribution in Honduras are unknown (Lefebvre *et al*. 2001), but archeological evidence suggests that manatee meat provided a substantial portion of the pre-historic diet of Mayas on the Bay Islands (Strong 1935) and on the mainland (Mckillop 1985). Manatee meat also was apparently an important source of food for the early Spanish explorers and settlers. English pirates in the mid-1600s were known to recruit the local Miskito Indians as manatee hunters aboard their ships. One account documents that two skilled hunters could kill a pair of manatees per day for a week at a time (Mckillop 1985). These early accounts suggest that manatees were abundant and had a wide distribution in Honduras.

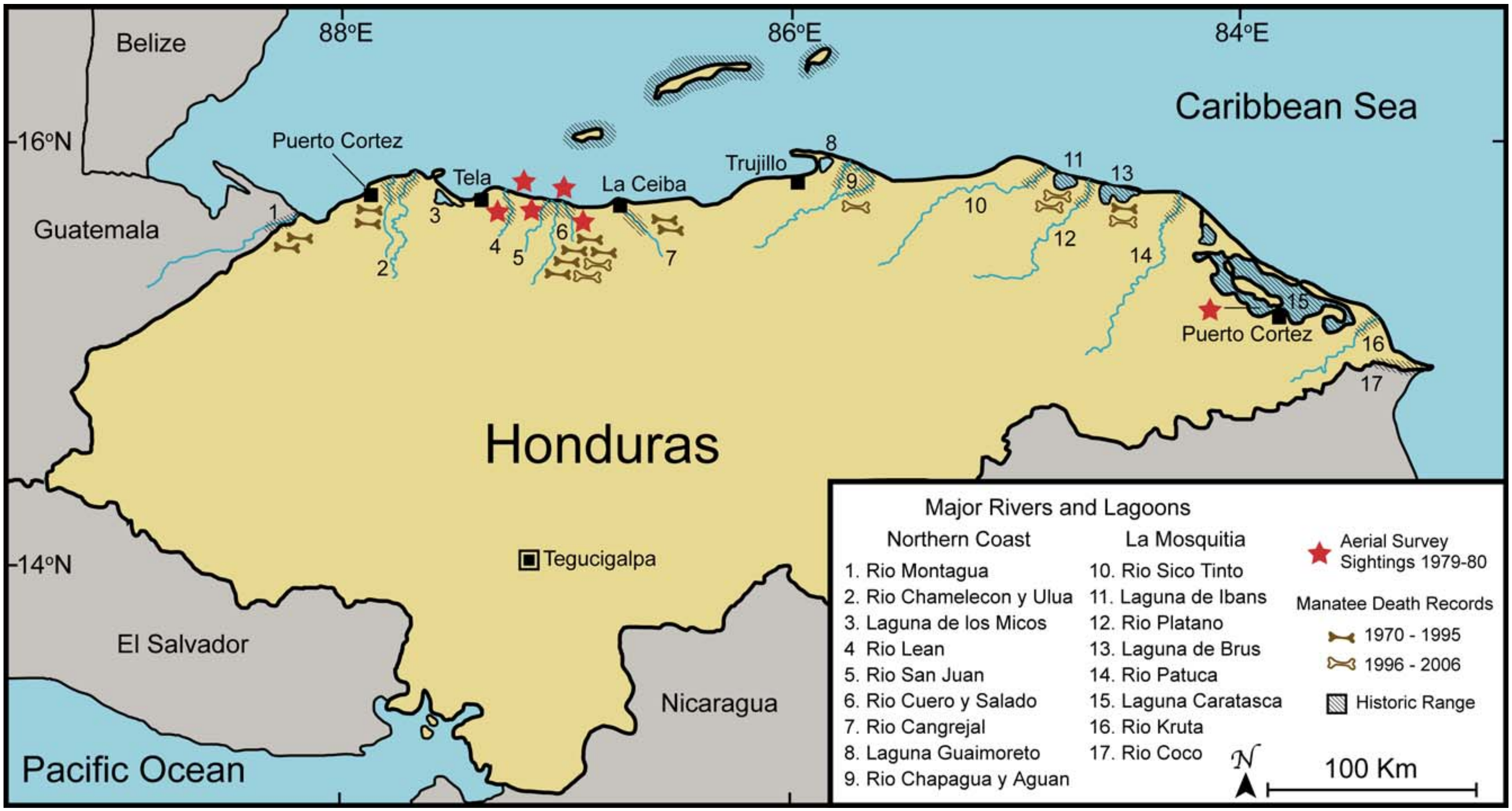
More recently, only two published papers document the status of manatees in Honduras; both are based on field surveys from the late 1970's (Rathbun *et al*. 1983, Klein 1979). Based largely on these observations, and unpublished interviews, estimates for the entire manatee population in Honduras vary from 100 to 150 animals (Cerrato 1996, Cruz 1996).

The only aerial manatee survey of the entire Atlantic coast of Honduras initially recorded 11 manatee sightings (Rathbun *et al*. 1983). The coast, rivers and lagoons between the towns of El Porvenir and Zambuco (west of La Ceiba and east of Tela) were subsequently flown five additional times, resulting in a total of 40 sightings for this small section of the north coast (Rathbun *et al*. 1983). Four manatees were sighted between Rio Montagua (on the border with Guatemala) and Tela during single aerial surveys in 2000 and again in 2005 (Auil 2000, Quintana-Rizzo 2005). Based on these data, several key areas in Honduras were identified as important for manatees, including the rivers and lagoons of La Mosquitia, the rivers east of Trujillo (Rio Aguán and Rio Chapagua), and the rivers and lagoons west of La Ceiba (Rio Cuero and Rio Salado; see Figure 2.1).

Whereas the remote northeastern coast of Honduras, known as La Mosquitia, remains relatively undeveloped with a sparse human population, the northern section of this coast, from the Rio Aguán to the Guatemalan border, has experienced a dramatic increase in human population and development in the last 20 years (Pineda Portillo 1997). The rivers east of Trujillo, and the rivers and lagoons west of La Ceiba, both previously identified as important to manatees, are in this region (Figure 2.1) and are the most vulnerable to habitat alteration and, thus, reduced suitability for manatees.

The objectives of this study were to: 1) determine the current distribution and minimum number of manatees on the northern coast of Honduras, 2) compare past and current relative abundance of manatees between the towns of El Porvenir and Zambuco (west of La Ceiba and east of Tela), and 3) compile information on manatee mortality and historical presence for Honduras.

Figure 2.1 Map of historical distribution, death records, and previous aerial survey sightings of Antillean manatees in Honduras. Historic range was determined by previous sightings, reports and historic interview data. The northern coast is represented by rivers and lagoons between Rio Montagua and Rio Aguán (east of Trujillo), and La Mosquitia is represented by rivers and lagoons between Rio Sico Tinto and Rio Coco (on the boarder with Nicaragua). Previous aerial survey sightings are represented by the open star symbol. Offshore sightings appear in the ocean and inland sightings appear next to the corresponding river or lagoon. Records of manatee deaths corresponding to Table 2.1 are divided into records from 1970-1995 (closed bone symbol) and from 1996-2006 (open bone symbol).


Belize
88°E
86°E
84°E
Caribbean Sea
16°N
14°N
Puerto Cortez
Tela
La Ceiba
Trujillo
Guatemala
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Puerto Cortez
Honduras
Tegucigalpa
El Salvador
Nicaragua
Pacific Ocean
Major Rivers and Lagoons
Northern Coast
1. Rio Montagua
2. Rio Chamelecon y Ulua
3. Laguna de los Micos
4 Rio Lean
5. Rio San Juan
6. Rio Cuero y Salado
7. Rio Cangrejal
8. Laguna Guaimoreto
9. Rio Chapagua y Aguan
La Mosquitia
10. Rio Sico Tinto
11. Laguna de Ibans
12. Rio Platano
13. Laguna de Brus
14. Rio Patuca
15. Laguna Caratasca
16. Rio Kruta
17. Rio Coco
Aerial Survey Sightings 1979-80
Manatee Death Records
1970 - 1995
1996 - 2006
Historic Range
N
100 Km

2.2 Material and Methods

Study Area

We refer to the area between Rio Motagua (on the boarder with Guatemala) and Rio Aguán (east of Trujillo) as the northern coast, and the area between Rio Aguán and Rio Coco (on the border with Nicaragua) as La Mosquitia (Figure 2.1). Five major river basins on the northern coast empty into the Atlantic: 1) Rio Montagua, 2) Rio Ulúa and Rio Chalamecon, 3) Rio San Juan, Rio Cuero and Rio Salado, 4) Rio Cangrejal, and 5) Rio Aguán and Rio Chapagua (Figure 2.1). The coastal area between these rivers is characterized by steep mountain ranges that often reach the shore. The expansive lagoon and wetland system of the northeastern coast, known as La Mosquitia, contains no mountain ranges. The major rivers in La Mosquitia are: 1) Rio Sico Tinto, 2) Rio Plátano, 3) Rio Patuca, 4) Rio Kruta, and 6) Rio Coco. The major lagoons in La Mosquitia are: 1) Laguna Brus, 2) Laguna Ibans, and 3) Laguna Caratasca, the latter comprising at least 20 smaller lagoons (Figure 2.1).

Current distribution and minimum population estimate on the northern coast

Six replicated aerial surveys were conducted on the northern coast between Rio Aguán and Rio Tinto (Figure 2.2), but the first three surveys failed to include Rio Aguán (we mistakenly identified Rio Chapagua as Rio Aguán during these surveys). Rio Tinto was selected as the western limit because a contemporary study (Quintana-Rizzo 2005) of manatee distribution of the Gulf of Honduras included the area from Rio Tinto to Rio Montagua (on the border with Guatemala).

Aerial surveys were conducted during the dry season, March and early April, because water conditions were clearer and most favorable for viewing manatees, and a more valid comparison could be made with previous surveys (Rathbun *et al*. 1983). Flights were conducted in a Cessna 206 at a mean elevation of 212 m and a mean airspeed of 148 km/hr (*cf*. Ackerman 1995, Lefebvre *et al*. 1995). Each survey was flown parallel to the coast from east to west, 500 m offshore because manatees preferentially use estuaries, rivers and lagoons (Reynolds & Odell 1991), tend to avoid deep waters, and stay within 1 km of the coastline (Olivera-Gomez & Mellink 2002). River mouths and lagoons were covered more intensely than the coast (variable effort recount; Lefebvre & Kochman 1991) by circling and we also intensively circled sites where manatees were sighted to determine numbers. Flight paths were recorded with an onboard GPS. Wind direction, wind speed, sea state (Beaufort scale), and cloud cover were recorded on data sheets at the start of each survey, as all of these can influence visibility during surveys.

Three observers were located on the right side of the aircraft with the door removed for better visibility; the front person navigated and recorded data and the other two spotted. The same individuals participated on all surveys. Manatee sightings, boats, and the presence of gillnets were recorded on data sheets and maps.

To estimate the minimum number of animals in the population for the northern coast of Honduras, we used the maximum count of manatees seen during a single flight in a river or lagoon. Assuming that manatees can travel between nearby rivers but not further than 70 km per day (Deutsch *et al*. 2003), we grouped proximal rivers and lagoons within this distance to estimate minimum number of manatees. The river and lagoon groups consisted of: 1) the rivers and lagoon east of Trujillo (Rio Aguán, Rio Chapagua, and Laguna Guaimoreto), 2) the rivers west of La Ceiba (Rio Salado, Rio Cuero, and Laguna Boca Cerrada), and 3) the river and lagoon west of Tela (Laguna de los Micos and Rio Tinto).

During a study on the St. Johns River, Florida, the proportion of total manatees sighted during aerial surveys in the turbid waters ranged from 0.33 to 0.57 and averaged 0.47 (Packard *et al.* 1985). If we use this range as a rough guide, we can develop an estimate of the manatee population in Honduras.

Change of relative abundance between El Porvenir and Zambuco (northern coast)

To compare our data with those conducted in 1979-80, survey durations and manatees per survey hour were limited to the coastal region between the town of El Porvenir and Zambuco (Figure 2.2). We used an independent sample t-test to compare average manatee sightings per hour between the two studies (1970-80 and 2006). We divided the survey route between the towns of El Porvenir and Zambuco into four sub-regions (Rio Salado, Rio Cuero, Laguna Boca Cerrada, and the coastal area of Zambuco; Figure 2B), each containing a major river or lagoon, to compare differences in manatee sightings between years. We ran independent sample t-tests to compare the average manatee sightings per survey for each sub-region between study years. For tests of the four subsections, Bonferroni adjustments were applied (alpha = 0.05/4 tests) to control for type II error.

Manatee mortality and historical presence of manatees in Honduras

To determine the historical presence of manatees along the entire coast of Honduras, we compiled manatee mortality records from reports, abstracts, and other unpublished documents. We also carried out our own informal interviews of local fishermen in Brus Lagoon, Ibans Lagoon and Rio Plátano in June 2005 and in Rio Montagua, Rio Ulúa, Laguna Boca Cerrada, Rio Cuero, Rio Salado, Rio Aguán, and Roatan (Bay Islands) in March 2005.

2.3 Results

Current distribution and minimum population estimate on the northern coast

Aerial surveys were conducted on March 29, 30, 31 and April 2, 3, and 4, 2006, with each survey conducted between 8:00 am and 2:00 pm. Cloud cover during the surveys varied from 0% to 100% and averaged 50%. Sea state on the Beaufort scale was 1, except for March 29 when it was 3. Flying conditions were favorable and followed the pattern of calm or no wind in the morning and light winds up to 8 kn in the early afternoon.

We totaled 14.36 flight hours surveying for manatees and recorded 18 manatee sightings during the six surveys (Table 2.1). The average (± *SD*) survey duration was 2.39 ± 0.22 hours and we averaged 1.23 ± 0.21 manatee sightings per survey hour (Table 2.1). Manatees were sighted in Rio Aguán, Rio Chapagua, Laguna Guaimoreto, Rio Salado, Rio Cuero, and Laguna Boca Cerrada (Figure 2.2). No manatees were seen west of Laguna Boca Cerrada (Figure 2.2B).

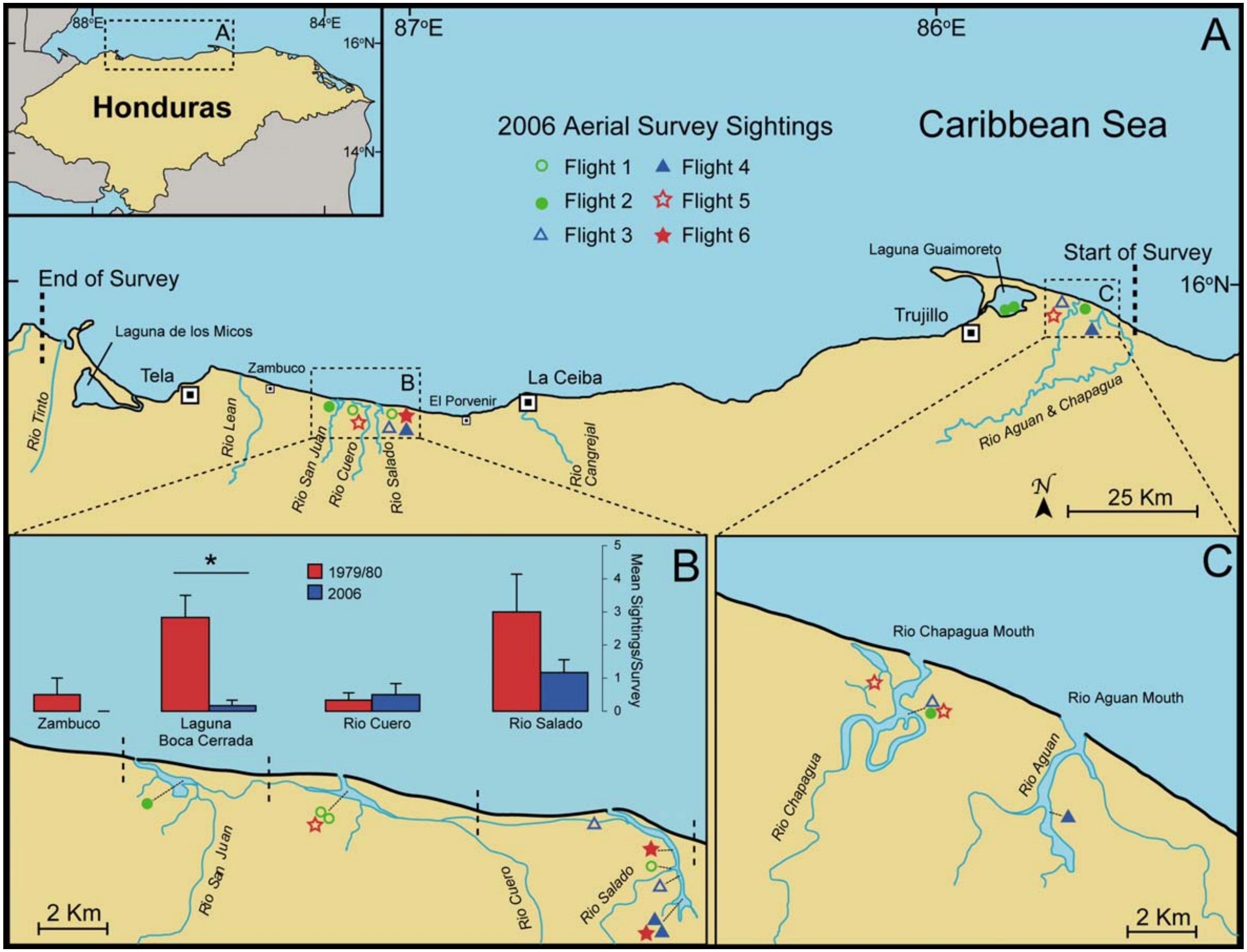
The maximum number of manatees sighted during a single survey in the rivers east of Trujillo (Rio Aguán and Rio Chapagua) was two and west of La Ceiba (Rio Salado, Rio Cuero, and Laguna Boca Cerrada) was three (Table 2.1).

Table 2.1 Summary of results from aerial manatee surveys of major rivers and lagoons on the northern coast of Honduras in 2006.

Flight Date	Survey Duration (hours)	Rio Aguán	Rio Chapagua	Laguna Guaimoreto	Rio Cangrejal	Rio Salado	Rio Cuero	Laguna Boca Cerrada	Rio Lean	Laguna de los Micos	Rio Tinto	Total Sightings/ Survey	Manatees/ Survey Hour
March 29	2.66	NS[a]	0	0	0	1	2	0	0	0	NS	3	1.1
March 30	2.66	NS	1	2	0	0	0	1	0	0	0	4	1.5
March 31	2.38	NS	1	0	0	2	0	0	0	0	0	3	1.3
April 2	2.25	1	0	0	0	2	0	0	0	NS	0	3	1.3
April 3	2.25	0	2	0	0	0	1	0	0	NS	0	3	1.3
April 4	2.16	0	0	0	0	2	0	0	0	NS	0	2	0.9
Total	14.36	1	4	2	0	7	3	1	0	0	0	18	
Mean	2.39	0.33	0.67	0.33	0	1.17	0.50	0.17	0	0	0	3.0	1.23

[a] NS = Area not surveyed.

Figure 2.2 Distribution of manatee sightings on the northern coast of Honduras from aerial surveys in 2006. A) Enlarged survey area of the northern coast of Honduras. Six surveys were conducted from east to west, starting at Rio Aguán and ending at Rio Tinto. Locations of manatee sightings are symbolized by flight number. For the sake of simplicity, symbols in the dashed boxes represent the location and not the exact number of sightings. Major coastal cities are represented by the large squares. The area between El Porvenir and Zambuco (small squares) was used for direct comparison of sightings with the 1979-80 surveys. B) Enlarged area of the Rio San Juan, Rio Cuero and Rio Salado detailing distribution of manatee sightings. Each symbol represents a unique manatee. Identical (same flight) symbols that touch slightly represent manatees that were seen together. Dashed lines represent the barrier between the four sub-regions (Rio Salado, Rio Cuero, Laguna Boca Cerrada, and Zambuco) of the area of comparison. The graph indicates the average number of manatee sightings between the six surveys conducted in both 1979-80 and 2006 by sub-region. Error bars represent standard error and the asterisk indicates significance. C) Enlarged area of the Rio Chapagua and Rio Aguán detailing distribution of manatee sightings.



A
88°E
84°E
16°N
14°N
Honduras
87°E
86°E
Caribbean Sea
2006 Aerial Survey Sightings
Flight 1
Flight 2
Flight 3
Flight 4
Flight 5
Flight 6
End of Survey
Start of Survey
Laguna de los Micos
Laguna Guaimoreto
Trujillo
Tela
Zambuco
La Ceiba
El Porvenir
Rio Tinto
Rio Lean
Rio San Juan
Rio Cuero
Rio Salado
Rio Cangrejal
Rio Aguan & Chapagua
25 Km
B
C
1979/80
2006
Mean Sightings/Survey
0
1
2
3
4
5
*
Zambuco
Laguna Boca Cerrada
Rio Cuero
Rio Salado
2 Km
Rio San Juan
Rio Cuero
Rio Salado
Rio Chapagua Mouth
Rio Aguan Mouth
Rio Chapagua
Rio Aguan
2 Km

Change of relative abundance between El Porvenir and Zambuco (northern coast)

We recorded 11 manatee sightings (all adults) between the towns of El Porvenir and Zambuco (Figure 2.2B), and all were within rivers and lagoons (Figure 2.3A). We surveyed this area a total of 3.28 hours, averaging 32.8 ± 5.7 min per survey (Table 2.2). We averaged 3.3 ± 0.4 (± SE) manatee sightings per survey hour for this region, which was significantly less than the average (13.3 ± 2.4) sighted in 1979-80 ($t(10) = 5.03$, $p < 0.001$; Figure 2.3B). Comparing across sub-regions (Figure 2.2B), mean manatee sightings per survey were higher in 1979-80 than in 2006 in three of four sub-regions, but the only statistically significant difference ($t(10) = 3.95$, $p = 0.003$) was for Laguna Boca Cerrada (Table 2.3; Figure 2.2B; all other p values = 0.318-0.862).

Manatee mortality and historical presence of manatees in Honduras

Historical data documented the presence of manatees in most major rivers and lagoons along the coast of Honduras, with the exception of Laguna de los Micos and Laguna Guaimoreto (Figure 2.1). We found twenty-five cases of mortality (Table 2.4); about half (13) were from the northern coast of Honduras during 1970-95 (Figure 2.1). Deaths since 1995 were clustered in Rio Cuero and Rio Salado (2) of the northern coast, and in Laguna Brus and Laguna Ibans (3) of the La Mosquitia region, with a single record also from Rio Aguán (Figure 2.1).

Table 2.2 Comparison and summary of results from aerial manatee surveys between El Porvenir to Zambuco on the northern coast of Honduras in 1979-80 and 2006.

Year	No. of Flights	Duration/ Survey [b]	Speed [b] (km/hr)	Altitude [b]	No. of Observers	Time of Year	Total Sightings
1979/1980[a]	6	30.1 min.	120-160	150-300m	2-3	March, May	40
2006	6	32.8 min.	148	212m	3	March, April	11

[a] Data from unpublished trip report, 1979, G. Rathbun and J. Powell, National Fish and Wildlife Laboratory, 13p. and Rathbun *et al*. 1983.
[b] Mean value.

Table 2.3 Descriptive statistics for the number of manatee sightings per survey for each sub-region in 2006 and 1979/80.

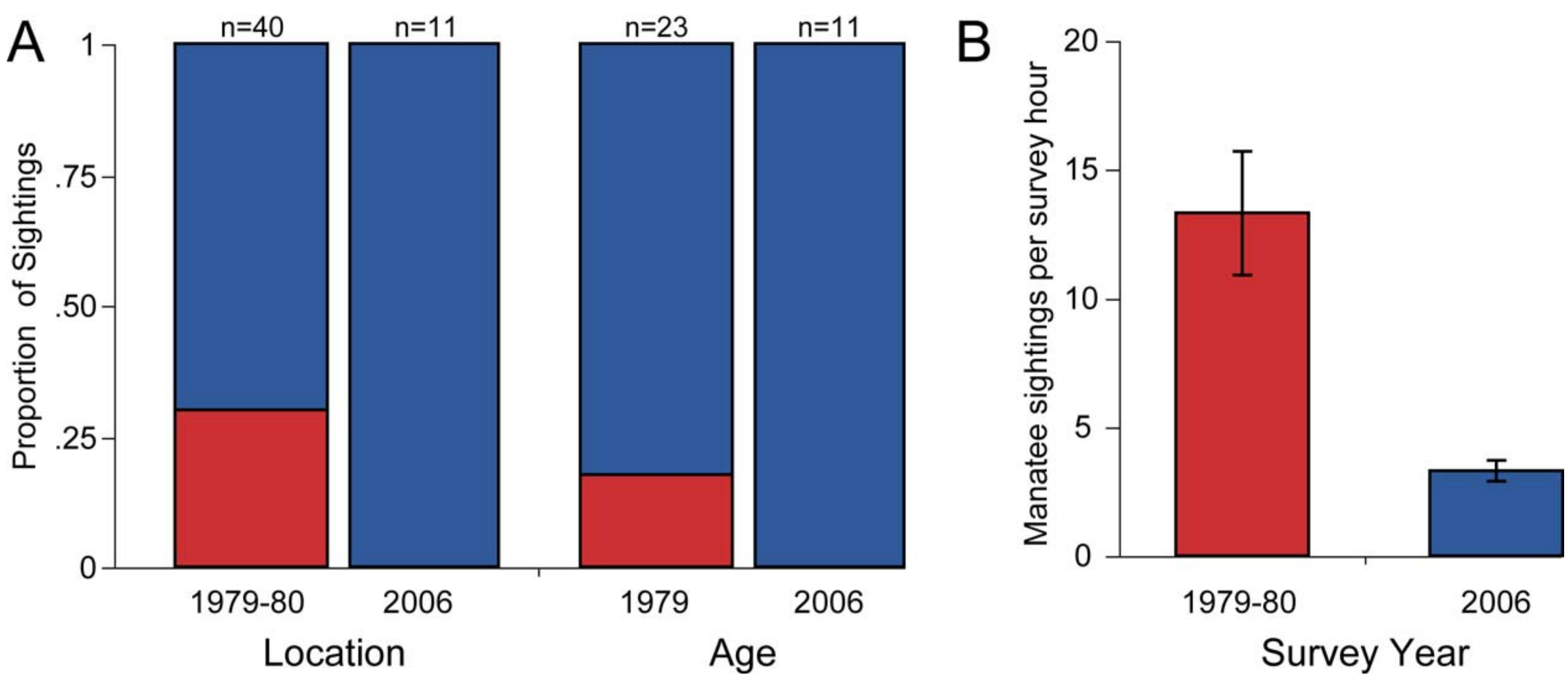
		1979-80		2006	
	N	Mean	SE	Mean	SE
Rio Salado	6	3.00	1.15	1.17	0.40
Rio Cuero	6	0.33	0.21	0.50	0.34
L. Boca Cerrada	6	2.83	0.65	0.17	0.17
Zambuco	6	0.50	0.50	0.00	0.00

Table 2.4 Summary of 25 death records of Antillean manatee in Honduras [a].

Date	Specific Location[b]	No. of Manatees	Cause of Death	Age	Sex	Association with other manatees	Source[c]
1970-80?	2. Rio Ulúa	1	U death	A	U	Alone	MS
1974	13. Laguna Brus	1	Drowning	C	U	Alone	MS
1976	7. Rio Cangrejal	1	Hunted	A	U	Alone	PS
1977	7. Rio Cangrejal	1	Hunted	A	U	Alone	PS
1978	6. Rio Salado	2	U deaths	A (2)	U (2)	Group of 4	PS
1979	6. Rio Salado	1	U death	A	U	Pair	PS
1980	6. Rio Salado	1	Drowning	A	U	Alone	MS
1983	1. Rio Montagua	6	Drowning	A (5), C	U (6)	Group of 6	CS
1984	2. Rio Monje	1	Drowning	A	U	Group of 11	MS
1989	1. Laguna Jaloa	2	Hunted	A, C	F, U	Pregnant	CS
1990	6. Rio Salado	1	Drowning	A	U	Alone	CS
1992	6. Rio Salado	1	U death	C	U	Alone	CS
1996	9. Rio Aguán	1	Drowning	A	U	Alone	CS
2000	6. Rio Salado	1	Drowning	A	U	Alone	MS, CS
2000	13. Laguna Brus	1	Drowning	A	U	Alone	MS
2004	11. Laguna Ibans	1	Hunted	A	F	Alone	MS, CS
2005	6. Rio Salado	1	U death	C	M	Alone	MS, CS
2005	11. Laguna Ibans	1	U death	A	M	Alone	CS

[a] Drowning, death by gillnet or other form of entanglement, accidental or intentional; Hunted, killed with harpoon, axe or gun; U, Unknown; A, Adult (>200cm); C, Calf (<200cm); M, male; F, Female
[b] Number corresponds to classification in Figure 1 of the nearest major river.
[c] MS, Museum specimen, either in Natural History Museum, San Pedro Sula; or National University of Honduras Natural History Museum, Tegucigalpa; PS, Previous study, Rathbun *et al*. 1983 or Klein 1979; CS, current study, from our interviews and unpublished reports.

Figure 2.3 Summary of manatee sightings within the area of comparison, from El Porvenir to Zambuco, in 1979-80 and 2006. A) Proportion of inland (blue) /offshore (red) and adult (blue) /calf (red) manatee sightings in 1979-80 and 2006. Manatees sighted in rivers and lagoons were considered inland and manatees sighting in coastal waters were considered offshore. Calves were characterized as half the size of adults and closely associated with another manatee (presumably the mother). Only the sightings (23) from 1979 were used for age proportion, because data on calves were not recorded in the 1980 surveys. B) Average manatee sightings per survey hour in 1979-80 and 2006.


A
Proportion of Sightings
1
.75
.50
.25
0
n=40
n=11
n=23
n=11
1979-80
2006
1979
2006
Location
Age
B
Manatee sightings per survey hour
20
15
10
5
0
1979-80
2006
Survey Year

2.4 Discussion

Current distribution and minimum population estimate on the northern coast

Although aerial surveys provide the best means of obtaining manatee distribution and relative abundance (Lefebvre *et al*. 1995, Ackerman 1995), there are several inherent biases (Marsh & Sinclair 1989, Lefebvre *et al*. 1995), including visibility bias and perception bias. Independent observers can reduce perception bias, but because the rate of manatee encounters was low, the observers in our surveys were not independent and were in constant communication during the flights.

There are two types of visibility biases: perception bias (the animal is at the surface and can be seen, but the observer did not perceive it), and availability bias (when the animal is not at the surface and the water is not clear or the animal is too deep to be seen (Lefebvre *et al.* 1995). In addition, absence bias occurs when the animal is not in the survey area and is just outside of the visible range (Lefebvre *et al*. 1995). One way to correct for visibility bias and absence bias is to compare counts of radio-tagged manatees sighted during surveys with the known number in the area (Packard *et al*. 1985). Estimating our visibility bias would be very difficult because of the different aquatic environments on the northern coast of Honduras, which include clear coastal waters, semi- clear shallow rivers, tannin-stained rivers and lagoons, and turbid rivers and coastal areas. We circled several times over river mouths and lagoons to reduce visibility bias (Lefebvre & Kochman 1991).

Another way to reduce the effect of visibility bias (both perception and availability bias) and absence bias is to conduct replicate surveys. Our surveys support the conclusion that replicate surveys are necessary to determine distribution (Olivera-

Gomez & Mellink 2002). The distribution of our sightings varied greatly between surveys, even though the total number seen remained relatively constant (Table 2.1; Figure 2.2B). The effect of visibility bias may be magnified when surveying locations of low manatee densities, as the likelihood of seeing an animal is greater when they are in a group. This may explain why no manatees were seen by Rathbun *et al*. (1983) in Rio Aguán and Rio Chapagua during their single survey of the area.

The overall distribution of manatee sightings on the northern coast of Honduras did not differ from the distribution documented in 1979-80. Most (11 of 18) of our sightings occurred in the Cuero y Salado Wildlife Refuge (CySWR), which includes Rio Cuero, Rio Salado, and Laguna Boca Cerrada, although a substantial number were clustered in both Rio Aguán and Rio Chapagua (5 of 18), which represent the second-most important area for the remaining manatees of the northern coast of Honduras.

We observed two manatees during one of the surveys of Laguna Guaimoreto. This represents the first report of manatees in this lagoon. The pair may have been traveling, because they were only sighted on one of the six surveys.

The minimum manatee population in Rio Aguán and Rio Chapagua, and Rio Cuero, Rio Salado, and Laguna Boca Cerrada is two and three, respectively. Because all of our sightings were in rivers and lagoons, similar habitats that Packard *et al*. (1985) worked in to develop their correction factors to reduce visibility bias, we used their correction factor on our data. However, unlike the St. Johns River, not all of our rivers and lagoons had turbid water; most were tannin-stained, which tend to have clear but dark water. If at best our detection ratio was 0.50, and at worst it was 0.20, then the potential population estimates are: 6-15 in CySWR, 4-10 for Rio Aguán and Rio Chapagua, and 10-25 for the northern coast from Rio Tinto to Rio Aguán.

Even with the most liberal estimates, the population of manatees on the northern coast is very low. Our surveys averaged 1.23 manatees per survey hour for the northern coast and 3.3 manatees per survey hour between El Porvenir and Zambuco, while a recent study of the Gulf of Honduras (Monkey River, Belize to Tela, Honduras) found 13.35 manatees per survey hour for all of Guatemala and 80.19 manatees per survey hour for southern Belize during a single survey (Quintana-Rizzo 2005). Surveys in southern Mexico (Chetumal Bay) averaged 16.48 manatees per survey hour (Olivera-Gomez & Mellink 2002). Nicaragua also appears to have a larger manatee population where 40 are estimated to be killed annually (Jimenez 2002).

Change of relative abundance between El Porvenir and Zambuco (northern coast)

While single aerial surveys cannot be statistically compared to other single surveys between years, because of unknown variance (Lefebvre *et al*. 1995), the averages of replicated aerial surveys can be statistically compared between years (Miller *et al.* 1998). Our survey area, time of year, speed, and plane type were comparable to that in 1979-80 (Table 2.2). Our survey altitude was slightly higher than in the previous study due to new safety regulations. While this might slightly bias against us, our number of observers (always 3) and slightly longer average survey duration (32.8 ± 5.7 min versus 30.1 min) provided an increased probability of sighting manatees.

All manatee sightings between El Porvenir and Zambuco were adults within the rivers and lagoons, whereas calves (17%) and offshore animals (30%) were relatively common during the 1979-80 survey (Figure 2.3A). This does not mean calves are not present, one calf was found dead in early January 2005, in Rio Salado (Table 2.4), but rather that they are very low in number. The absence of offshore sightings during the 2006 surveys are puzzling, but may simply reflect low densities of animals and thus lesser likelihood of spotting an animal traveling offshore from river to river.

Rio Cuero and Rio Salado along with Laguna Boca Cerrada were designated as a manatee protected area (CySWR) in 1987. Manatees in Florida have been reported to preferentially use protected areas, thus resulting in total counts slowly increasing from year to year (Provancha & Provancha 1988). Based on this observation, we expected to locate more manatees using CySWR during our surveys compared to those conducted in 1979-80, when the area was not protected. However, in spite of protection, manatee sightings have decreased – probably because manatee deaths have been continually reported from this region (Figure 2.3; Table 2.4).

Manatee mortality and historical presence of manatees in Honduras

The northern coast of Honduras had the most death records (Table 2.4), which may result from a bias due to the higher likelihood of manatee deaths being reported in this region. However, the geographic distribution of manatee deaths on the northern coast seems to have decreased. Although the majority of the manatee death records concur with the survey sightings in Rio Cuero, Rio Salado and Laguna Boca Cerrada, there have been no recent manatee sightings in Rio Cangrejal or Rio Lean (Rathbun *et al*. 1983; Figure 2.1).

Even though we did not conduct aerial surveys of the region between Rio Montagua (on the border with Guatemala) and Rio Tinto (west of Tela), manatees occur there based on our interviews, mortality records (Table 2.4), and recent aerial survey sightings in 2000 and 2005 (Auil 2000, Quintana-Rizzo 2005). However, those eight sightings were all offshore, suggesting that the manatees were traveling between rivers and lagoons.

Manatees formerly occurred in the Bay Islands (Strong 1935), but they have not been reported there since the 1970s (Rathbun *et al*. 1983, Davidson 1974), which is consistent with our findings from interviews.

Most of La Mosquitia is designated as a protected area, but our interviews indicate that manatees are still opportunistically taken for local consumption; proper enforcement is difficult due to the large area. Due to its low human population density (INE 2001) and extensive untouched habitat, this area could have the greatest density of manatees within Honduras. This area should be extensively surveyed for manatees to determine important areas within La Mosquitia.

To our knowledge, no manatee mortality has resulted from boat collisions and no manatees have been reported with propeller scars in Honduras. However, the use of gillnets is widespread in Honduras and has resulted in manatee entanglements and deaths (8 of 25 carcasses; Table 2.4). Fishermen interviewed on the northern coast and in La Mosquitia indicate that manatees are still occasionally killed by gillnets, such as a single adult in both Rio Salado and Laguna de Brus in 2000 (Table 2.4). A young 150 cm-long calf was found dead in Rio Salado in 2005; local people indicated that it died by entanglement in fishing gear. However, no external marks were found on the animal and there were no gillnets found nearby when it was discovered. We speculate that it was orphaned and starved to death, based on extreme dental wear. In Florida, young manatees prematurely separated from their mothers reportedly wear down their teeth by consuming large quantities of sand and dirt (Bossart, per. comm.).

2.5 Conclusions and Recommendations

Eighteen manatee sightings were recorded on the northern coast of Honduras during six replicate surveys between Rio Aguán to Rio Tinto. Sightings clustered around 1) Rio Salado, Rio Cuero, and Laguna Boca Cerrada (11 of 18), and 2) Rio Chapagua, and Rio Aguán (5 of 18). Two animals were sighted in Laguna Guaimoreto. We estimate that the minimum manatee population size of the entire northern coast of Honduras is 10-25 animals. Of those we estimate 6-15 are found in CySWR and 4-10 are found in Rio Aguán and Rio Chapagua. The number of manatees between the town of El Porvenir and Zambuco has decreased significantly since 1979-80. Within this area only Laguna Boca Cerrada showed a significant decrease in manatee sightings. Of the available manatee death records in Honduras, 8 of 25 died from entanglement in gillnets. Gillnets may be the biggest threat on the northern coast while in La Mosquitia manatees are still hunted opportunistically.

We recommend that: 1) due to the high mortality of manatees by gillnets, existing laws prohibiting the use of gillnets in protected areas (such as CySWR) should be more strongly enforced. In addition, the practice of extending gillnets across the whole river mouth should be prohibited along the whole coast, 2) a local conservation effort should accompany the gillnet restrictions by providing education about the harmful effects they have on manatees, 3) CySWR and Rio Aguán and Rio Chapagua should be surveyed regularly to monitor changes in relative abundance and distribution, and 4) La Mosquitia should be surveyed intensively to determine the distribution and relative abundance of manatees within this undisturbed area.

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CHAPTER THREE

THE USE OF SIDE-SCAN SONAR TO DETECT WEST INDIAN MANATEE (*TRICHECHUS MANATUS*) IN TURBID AND TANNIN-STAINED WATERWAYS

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Abstract

Turbid and tannin-stained waterways are difficult habitats to study and manage aquatic wildlife, particularly when dealing with endangered and solitary animals. We explored the use of side-scan sonar, which produces a picture-like image of the substrate and objects in the water column, to acoustically detect West Indian manatees (*Trichechus manatus manatus*) in various environmental conditions and habitats. Blind transects (observer only looked at sonar) were run in both Mexico and Florida to determine sonar detection rate. Good sonar images were produced during most environmental conditions examined, as long as ambient water movement was minimal. Attempts to produce clear images by rotating the transducer 360 degrees were not successful. Manatees were successfully detected by side-scan sonar in Honduras, Mexico, and Florida. The best acoustic images of manatees were produced when the animals were stationary and parallel to the boat (perpendicular to the sonar beam). Detection rates in Florida were 70% (95% with correction for hidden calves and animals beyond limit of sonar) and 93% in Mexico. This study concludes that side-scan sonar is sensitive enough to accurately detect manatees in the wild, and can be an effective and affordable tool to study and manage them throughout their range.

3.1 Introduction

Estuaries, lagoons and turbid rivers have long been complicated study locations for aquatic fauna due to the difficulty of observing them in the murky waters. This is especially true of solitary animals like manatees (*Trichechus* spp.), which use these waterways throughout most of their range (Reynolds & Powell 2002). This difficulty is also influenced by the cryptic nature of the species. Manatees tend to be very shy in areas where they have been hunted and may even become nocturnal (Rathbun *et al.* 1983). Because of this, accurate counts for them in most of their range are nearly impossible from aerial surveys and traditional boat surveys.

Active acoustic detection, such as sonar (horizontal beams) and echo sounders (vertical beams), have been used as tools to study fish densities (Gerlotto *et al.* 2000) and some swimming behavior (Rose *et al.* 2005, De Robertis *et al.* 2003). The target strength of several aquatic animals has been measured, including krill (Clay & Horne 1994), a species of dolphin (Au 1996), and recently the Florida Manatee, *T. m. latirostris*, (Jaffe *et al.* 2007). Au (1996) found that most acoustic energy was reflected in the location of the dolphin's lungs and that target strength was largely dependent on the orientation of the dolphin. Manatees have elongated lungs that are positioned dorsally (Rommel & Reynolds 2000), ideally providing an excellent acoustic target.

Dickerson *et al.* (1996) summarize previous attempts in the early 1980s by NASA and others to develop sonar equipment that could detect manatees. Most of the work was done on captive animals with minimal success. Some of the major problems encountered during field experiments were scatter, sonar shadowing, and reduced sonar resolution (Dickerson *et al.* 1996). The report also presents their attempt at detecting manatees with newer sonar equipment. They experimented with 10 different sonar units with the aim of creating a manatee detection system in order to prevent manatee deaths in canal locks. However, they concluded that while it was possible to detect manatees, the acoustic response was not consistent and at times no acoustic reflection was detected (Dickerson *et al.* 1996).

Recently Jaffe *et al.* (2007) measured the acoustic reflectivity of the Florida Manatee by experimenting with a detection frequency of 171 kHz on both live captive animals and analyzing animal tissue in order to predict reflectivity. They reported that while the majority of the reflections from live animals were between -32 dB and -35 dB, a substantial portion were below -48 dB, which was their detection threshold due to ambient noise. In addition, they observed that many times the animals would not give an acoustic response even though it was in front of the beam. However the previous hypothesis that manatee skin acted as an acoustic sink was ruled out based on the tissue analysis (Jaffe *et al.* 2007). They concluded that the animal skin may act as a specular reflector at the frequency detected, reflecting the acoustic signal in an unobservable angle, and therefore not being a reliable frequency for detection (Jaffe *et al.* 2007). This may explain why previous efforts of detecting manatees in the wild with sonar have been relatively unsuccessful (Dickerson *et al*. 1996).

All these previous attempts to detect manatees have used stationary sonar and echo sounder systems (Dickerson *et al*. 1996, Jaffe *et al*. 2007). While some scanning systems have been tested (rotating 360 degrees), they work under the same idea of detecting a change in the constant background. Our goal is to develop a technique that can successfully survey and monitor manatees in locations where they are difficult to see through the water. In addition our goal is to cover a large area without the animal having to “cross” the beam. To accomplish this, we used side-scan (or lateral scanning) sonar that produces an image of the acoustic signal as it moves in a linear direction. Side-scan sonar has traditionally been used to observe sea-floor structure, including underwater objects (Dura *et al.* 2004). The advantage with side-scan sonar is that under optimal conditions it creates a picture-like image of the bottom including objects on the surface and water column (Kenny *et al.* 2003). As far as we are aware, this is the first time that linear scanning sonar is tested on manatees.

The objectives of this study were three fold: 1) test side-scan sonar in a variety of manatee habitats and environmental conditions to determine its usefulness in studying manatees in the wild, 2) use side-scan sonar to correctly detect manatees in different water conditions, and 3) estimate the detection rate of the side scan sonar.

3.2 Material and Methods

Study sites

Side-scan sonar was tested in three locations (Figure 3.1), each representing a different manatee habitat throughout the species range. In Honduras, side-scan sonar was tested in Cuero y Salado Wildlife Refuge (CySWR), which is located on the northern coast (15º 46´ 30˝ N, 87º 3´ 25˝ S) and has been identified as an important area for manatees in Honduras (Gonzalez-Socoloske *et al*. 2006). CySWR consists of a series of rivers, canals, and lagoons, several of which have access to the Caribbean Sea. Water visibility is very low, due to turbidity, from both sedimentation and from tannins.

In Florida, side-scan sonar was tested in Crystal River (28º 53´ 20˝ N, 82º 35´ 35˝ S), which has long been identified as an important wintering site for manatees due to the naturally occurring warm water discharges (Kochman *et al.* 1985, Langtimm *et al.* 1998). The number of manatees that use Crystal River during the cold winter months has grown from the 63 initially identified in the 1960s (Hartman 1979), to more than 400 that use it today (Reep & Bonde 2006). As its name implies, Crystal River has clear water, which provides an opportune location to confirm manatee detection from sonar. In addition, Crystal River is shallow (1-5 m) and thus mimics the environments that we are targeting.

Finally, in Mexico, side-scan was tested in Laguna de las Ilusiones (18º 0´ 0˝ N, 92º 55´ 59˝ S) in Villahermosa, Tabasco. We selected this landlocked lagoon because of the known population of manatees (~ 9) and the dark shallow waters (Olivera-Gomez, unpublished data). This environment provided an ideal habitat to have wild manatees behaving like they would. We could also determine where the manatees were by following the bubbles that they released from the bottom substrate while "walking" with their flippers. Like Crystal River this lagoon is also very shallow (1-3 m).

Equipment and Interpretation of Side-Scan Images

We used a Humminbird® 987c SI (subsequently replaced by 997c model) fishing system, which is powered by a 12 V battery and has a draw of 5 amps. This quarto-beam system is equipped with two narrow lateral sonar beams (side-scan), 262 kHz and 455 kHz, and two echo sounder beams (vertical), 200 kHz and 50 kHz (Figure 3.2A). Only one sonar beam can operate at a time, although both the sonar and echo sounder beams can operate simultaneously. This provides a continuous depth reading during side-imaging. This system is also equipped with a built-in GPS receiver for accurate location and time. In addition, the transducer is equipped with a thermometer for water temperature.

Figure 3.1 Locations of side-scan sonar study sites.

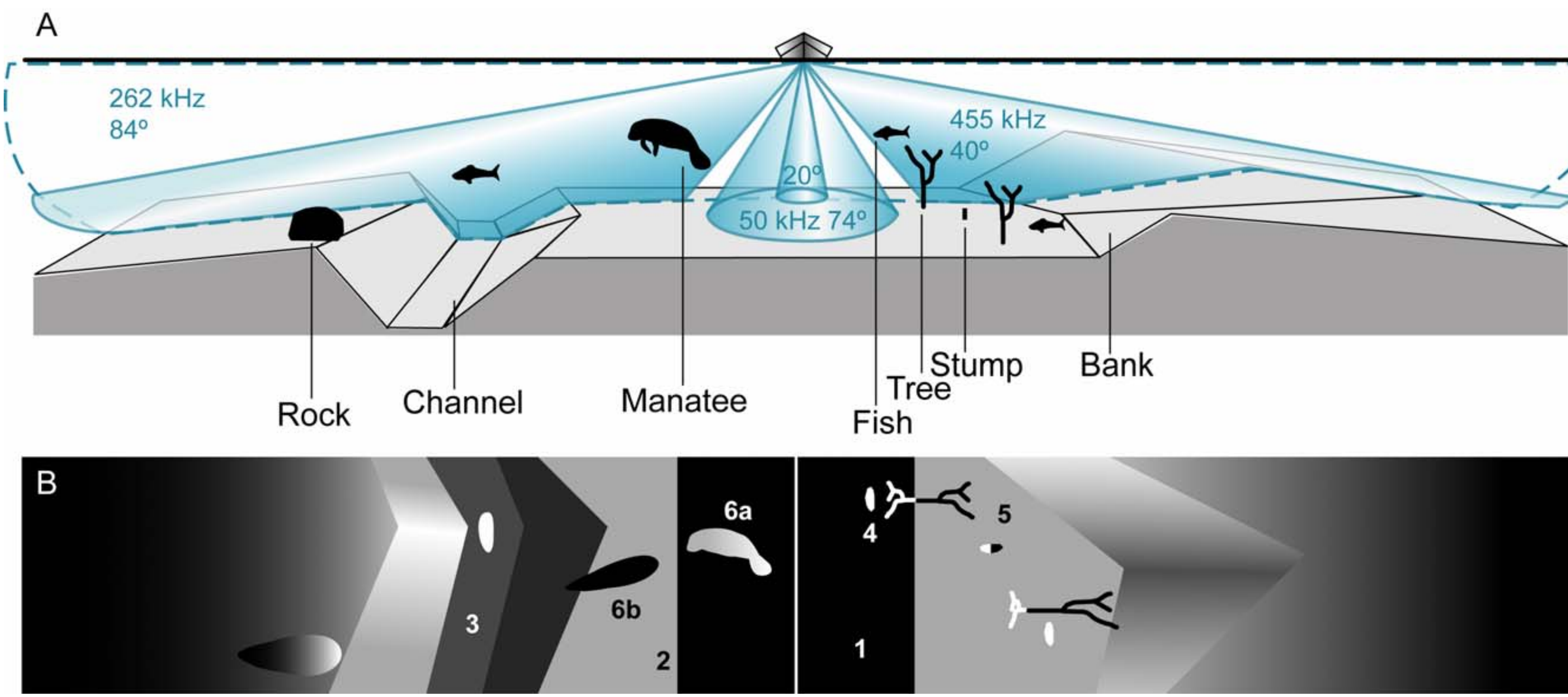

UNITED STATES
Atlantic Ocean
Crystal River
MEXICO
Laguna de las Ilusiones
Cuero y Salado Wildlife Refuge
HONDURAS
Pacific Ocean

Side-scan sonar images are displayed on a 17.8 cm (new model is 20.3 cm) screen and were captured by using screen capture software designed by the manufacturer as a promotional tool (standard in new model). Screenshots were saved in bmp format on a SD memory card.

Side-scan sonar transducers are usually towed in a “fish” behind the boat but in this case it was attached to the boat. Since we were working in relatively shallow waters (max depth of 10 m) it did not matter that it was attached to the rear of the boat. Because the transducer was at the surface of the water, we also had a more accurate depth reading.

Screenshots produced by the unit consist of a left and right side, each corresponding to the acoustic response of the right and left side beam. The water column appears as a black (or blue if color setting is on) area from the central line to the substrate bottom (Figure 3.2B). Objects in the water appear white and cast a black shadow on the bottom. Denser objects will appear brighter than less dense objects, thus rocks and coral will give a stronger response than sand and clay bottoms. Similarly, fish should appear much brighter than manatees due to the differences in the skin density. Bottom topography will be evident from the shadows and acoustic response gradient (Figure 3.2B). Shadows, created by objects blocking the acoustic beam, are used to determine shape and form of objects and can be more telling than the actual acoustic reflection from the object (Figure 3.2B).

Figure 3.2 Humminbird® 987c side-scan sonar beams and interpretation of acoustic image. A) The unit is equipped with two narrow lateral (side) beams of 262 kHz (84° coverage angle indicated by dashed line) and 455 kHz (40° coverage angle indicated by solid line) and two echo sounder beams of 200 kHz (20° coverage angle indicated by center cone) and 50 kHz (74° coverage angle indicated by outer cone). B) The acoustic signal is displayed in a conveyer belt fashion with the latest response as the top horizontal line. As the boat moves in a linear direction new sonar lines are added. The components of the acoustic image consist of the water column (1), which appears as a dark area between the midline and the bottom return (2). Channels (3) appear darker because of the lack of an acoustic response. Objects, such as fish (4) in the water column appear bright white. Objects on or near the bottom produce a shadow (5) because of the blocked signal. Shadows are more indicative of the exact shape of the object than the actual acoustic response. A manatee in the water column (6c) would presumably produce a response not as bright as a fish, but would have a large shadow (6b) associated with it, from the area of the sonar beam blocked by the body of the manatee.


A
262 kHz
84°
455 kHz
40°
20°
50 kHz 74°
Rock
Channel
Manatee
Fish
Tree
Stump
Bank
B
6a
6b
4
5
3
2
1

Field Experiments

A) Use of sonar in various environmental conditions and manatee habitats

We tested side-scan sonar in various environmental conditions (during rain, wind, full sun, and cloud cover), various water surface conditions (calm, flowing, and choppy), time of day (night and day), water clarity (clear, turbid, and tannin-stained), and methodological conditions (linear and rotational) to determine its usefulness as a survey tool in the field. All field sites were used for these experiments (Table 3.1). Sonar images were ranked from 1-3 (poor to good) based on the clarity of the acoustic response.

B) Detecting manatees accurately

To determine if manatees were being detected accurately, we experimented in Crystal River, Florida, where we could clearly see the animals as we passed them with the sonar. We also tested the unit in Laguna de las Ilusiones, Mexico, where we could determine the presence of manatees by the trail of bubbles they released. Sonar images were also captured of a crocodile in Laguna de las Ilusiones, Mexico, for comparison of its acoustic response with that of manatees.

C) Determining detection rate

To determine the manatee detection rate of the side-scan sonar we conducted blind transects in both Florida and Mexico. Blind transects consisted of the boat driver locating manatees and slowly (3-6 km/h) passing next to them, while the “blind” observer located them only by looking at the sonar image. Verbal confirmation was given when a manatee was detected by the sonar observer by indicating on which side of the boat it was and the approximate distance from the boat. The body orientation and whether manatees were accompanied by calves were recorded in Florida by the boat driver. The driver would then note if the detection was correct or not without informing the observer. Communication was resumed at the end of the blind transect. We did not conduct transects in Honduras because of the low density of manatees and because it is very difficult to confirm their presence.

Results

A) Use of sonar in various environmental conditions and manatee habitats

Good sonar images were produced under any conditions where the water was not moving (Table 3.2). Attempts to produce good sonar images by rotating the transducer were unsuccessful (Table 3.2). Optimal conditions for the best image clarity were produced when traveling in a straight line at speeds of 2.5 to 7.0 km/h. The lateral range of the sonar that produced the best results was between 10-15 m, although manatees could still be distinguished at 18 m. Optimal beam frequency, sonar sensitivity, chart speed, and noise filter depended on the water and environmental conditions.

B) Detecting manatees accurately

Visual confirmation of manatee detection by the side-scan sonar was attained in Florida and Mexico (Figure 3.3). Manatees were also presumably detected in Honduras, although visual confirmation was not attained. Manatees were successful detected in both the water column and on the bottom substrate (Figure 3.3). Under optimal conditions, direction of travel and orientation of animals could be detected (Figure 3.3 A and C). The strongest acoustic response from manatees was from the dorsal area, where the elongated lungs are located. Relative size of the animal could be determined by the known range of the sonar beam in the image produced and by the known depth of the water column. In addition, calves could be identified when next to their mothers by the smaller size and the continual proximity after multiple passes (Figure 3.3 E, F and J).

Presence or absence of the sonar unit had no influence on the behavior of the surrounding manatees. On several occasions when the boat motor was off, manatees would swim right up to the active sonar transducer.

Finally, a single 2 m crocodile, *Cocodrylus moreletti*, was detected by side-scan sonar in Mexico, after repeated visual confirmation (Figure 3.3 L).

C) Determining detection rate

Fourteen blind transects were conducted in Crystal River, in which 60 manatees were passed laterally (Table 3.3). Of those, 42 (70%) were detected correctly by the blind observer using side-scan sonar. The side on which the manatees were located was always the left side because the sonar image screen was modified to only include the left side. This was done because of distortion produced by the outboard motor located to the right of the transducer. The approximate distance of the animal from the boat was also correctly detected by the blind observer.

Table 3.1 Summary of experiments with side-scan sonar and study locations.

Location	Country	Date	Detection Experiment	Detection Rate Tested	Conditions Tested*
Crystal River, Florida	USA	1/29/06 & 1/31/06	Yes	Yes	(E, WC)
Laguna de Las Ilusiones	Mexico	3/22/06 - 3/23/06	Yes	Yes	(E, WC)
Cuero y Salado Wildlife Refuge	Honduras	6/21/05 - 6/27/05	No	No	(E, WS, TD, WC, SM)

*E = Environmental; WS = Water Surface; TD = Time of Day; WC = Water Clarity; SM = Scanning Methodology

Table 3.2 Summary of results from experiments with side-scan sonar under various conditions.

	Environmental				Water Surface			Time of Day		Water Clarity			Scanning Method	
	Rain	Wind	Full Sun	Cloud Cover	Calm	Flowing	Choppy	Night	Day	Clear	Turbid	Tannin-stained	Linear	Rotational
Quality of Image*	2	1	3	3	3	2	1	3	3	3	2	3	3	1

* 1 = Poor/Unreadable, 2 = Intermediate, 3 = Good

Figure 3.3 Representative side-scan sonar screenshots of manatees. **A)** Crystal River, water depth 2.13 m, boat speed 3.5 km/h, left side of side-scan sonar with a range of 12.2 m, 262 kHz. Screenshot of a single adult manatee oriented parallel to the boat, swimming near the bottom of the river in the opposite direction. Note the gap between the acoustic response and the shadow indicating that the animal was not in contact with the bottom substrate. The dark area on the far left represents the shore (thus no acoustic response).
B) Crystal River, water depth 1.83 m, boat speed 6.1 km/h, left side of side-scan sonar with a range of 12.2 m, 262 kHz. Screenshot of four adult manatees resting at a distance of 6-9 m from the boat. Note the different shapes of the shadows caused from the different orientations of the animals. All shadows are connected to the acoustic response from the animal indicating that they were in contact or very close to the bottom substrate. **C)** Crystal River, water depth 3.04 m, boat speed 6.4 km/h, left side of side-scan sonar with a range of 12.2 m, 262 kHz. Screenshot of a single adult manatee oriented parallel to the boat swimming downwards head first. Note the strongest acoustic response is located on the dorsal area of the body (representing the location of the lungs). The shadow created by the manatee is on the far left indicating this animal was higher in the water column. The acoustic response is located completely in the area of the water column because this animal was directly below the boat and the side beams hit it before the substrate bottom.
D) Crystal River, water depth 2.44 m, boat speed 6.3 km/h, left side of side-scan sonar with a range of 12.2 m, 262 kHz. Screenshot of a single adult male. The orientation of the animal is perpendicular to the boat. While the shadow produced is very evident the actual acoustic response of the animal is all but absent.

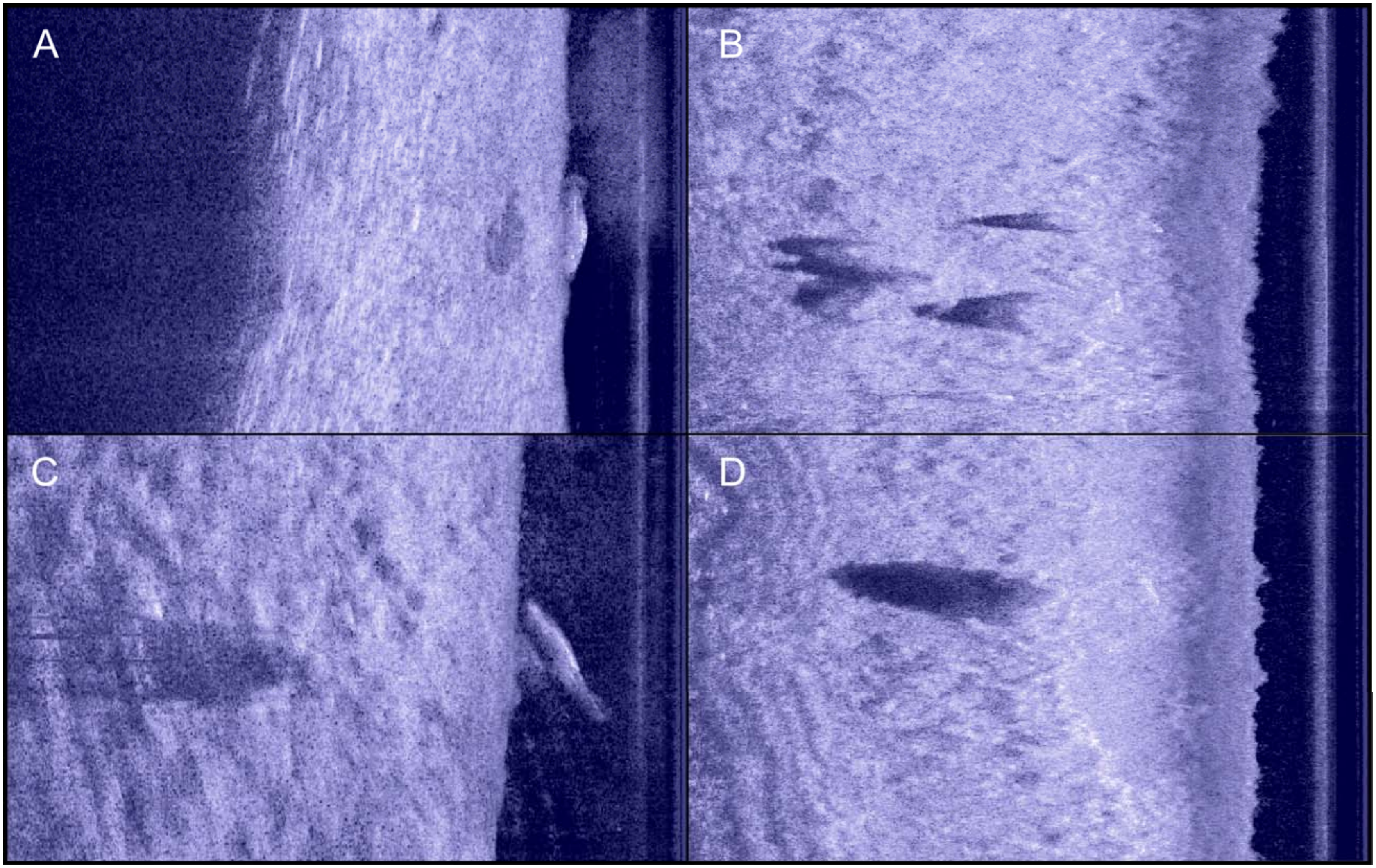

A
B
C
D

Figure 3.3 (continued). **E)** Laguna de las Ilusiones, water depth 5 ft, boat speed 3.5 km/h, side-scan sonar range of 12.2 m, 262 kHz. Screenshot of two adult manatees and a calf. Note the strong response from the dorsal area of all three animals. Based on the sonar image, the bottom substrate is very smooth and has very few holes. The water was very calm producing a very clear image. **F)** Laguna de las Ilusiones, water depth 1.5 m, boat speed 3.5 km/h, side-scan sonar range of 12.2 m, 262 kHz. Screenshot of single adult on right side and an adult and calf on left side. **G)** Laguna de las Ilusiones, water depth 1.5 m, boat speed 4.8 km/h, side-scan sonar range of 12.2 m, 262 kHz. Screenshot of single adult manatee on right side of boat. Note the sediment stirred by the swimming action of the animal. **H)** Laguna de las Ilusiones, water depth 2.1 m, boat speed 7.4 km/h, side-scan sonar range of 6.1 m, 262 kHz. Screenshot of three manatees (one calf) resting in a depressed area on the bottom substrate.

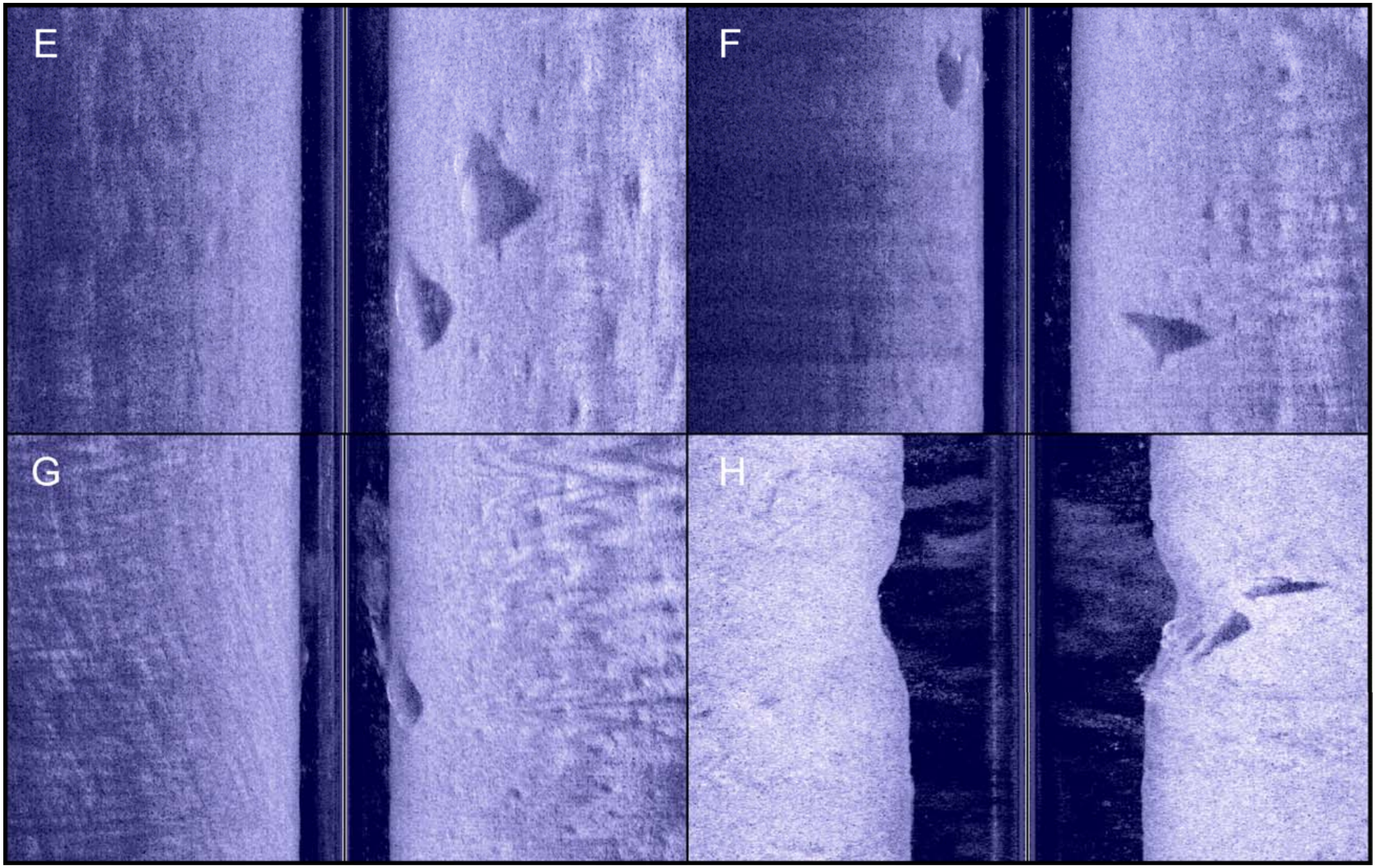

E
F
G
H

Figure 3.3 (continued). **I)** Laguna de las Ilusiones, water depth 4.9 m, boat speed 5.2 km/h, side-scan sonar range of 10.7 m, 262 kHz. Screenshot of two adult manatees, one on each side of the boat. Note the sediment stirred by the manatee on the left side. **J)** Laguna de las Ilusiones, water depth 2.1 m, boat speed 6.8 km/h, side-scan sonar range of 12.2 m, 262 kHz. Screenshot of two adult manatees and a calf on left side of boat. **K)** Crystal River, water depth 2.7 m, boat speed 4.3 km/h, left side of side-scan sonar with a range of 12.2 m, 262 kHz. Screenshot of a mother and calf under a bridge. Both cement columns of the bridge produce strong acoustic responses and never ending shadows because they stick out of the water and the sonar beam never travels over them. **L)** Laguna de las Ilusiones, water depth 1.7 m, boat speed 4.8 km/h, side-scan sonar range of 12.2 m, 262 kHz. Screenshot of a crocodile, *Cocodrylus moreletii*, with its body parallel to the boat.

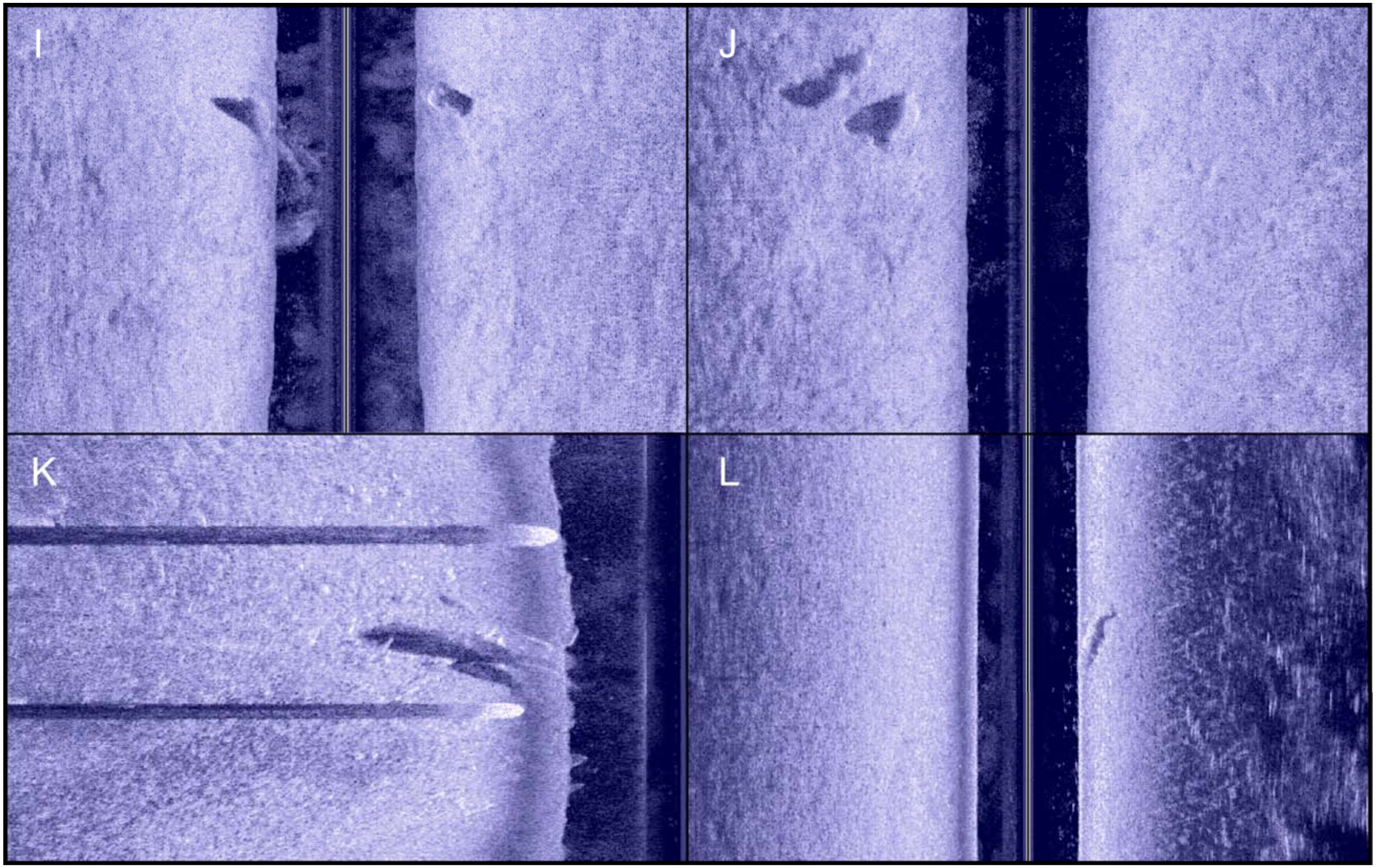

I
J
K
L

Table 3.3 Results for 14 blind transects in Crystal River, Florida.

Transect #	# of manatees	Side	Distance from Boat (m)	Animal Orientation	# Detected
1	1	L	6	↓	0
1	1	L	1	↓	1
1	1	L	2	↓	1
1	1	L	7	↓	0
1	1	L	3	↓	1
1	2	L	3	↓	2
1	3	L	3	↓	3
2	1	L	3	↑	1
3	1	L	2	↓	1
3	2	L	1	↓↓*	1
4	3	L	2.5	↙, ↙↙*	3
4	1	L	1	↓	0
4	3	L	3.5	↙	3
5	1	L	7	↓	1
5	1	L	7	↓	1
5	1	L	3.5	↓	1
5	1	L	3	←	1
5	2	L	3	↙↙*	1
5	1	L	3	↓	0
5	1	L	3	↓	1
5	2	L	3	↙↙*	2
6	1	L	3	↑	1
6	3	L	3	↑↑*	2
6	2	L	1	↑↑*	1
7	2	L	4	↙↙*	1
7	1	L	4	↓	1
7	3	L	10	↓	0
7	1	L	10	↓	0
7	4	L	10	↙	0
7	1	L	3	↑	1
8	1	L	3	↓	1
9	1	L	0	↑	1
10	1	L	3	↓	1
10	1	L	3	↑	2
11	0	N/A	N/A	N/A	0
12	1	L	3	↓	1
13	2	L	3	↑	2
14	2	L	3	↑↑*	0
14	1	L	3	↓	1
14	1	L	3	↓	1

*The smaller arrow indicates a calf with its mother.
**The number in the parenthesis indicates the corrected value of manatees. Corrected value is equal to total number - # calves hidden by mothers – animals further than 10m.

Table 3.4 Results for 29 blind transects in Laguna de las Ilusiones, Villahermosa, Mexico.

Transect #	# of manatee(s)	Side	Distance from Boat (m)	# Detected
1	1	L	1.5	1
2	1	L	.5	1
3	2	R	Not Recorded	0
4	1	R	Not Recorded	0
5	1	R	3	1
6	3	R	2	3
7	1	L	3	1
8	1	R	2	1
9	1	R	2	1
10	1	R	3	1
11	2	R	1	2
12	1	L	.5	1
13	1	L	1	1
14	1	R	1	1
15	1	R	6	1
16	2	L	1.5	2
17	3	R	1	3
18	3	R	.5	3
19	3	R and L	.5	3
20	1?	R	Not Recorded	2
21	2	L	5	2
22	1	R	1	1
23	1	R	0	1
24	1?	R	10	1
25	1	L	0	1
26	2	L	.5	2
27	1	L	1.5	1
28	1	R	0	1
29	1	R	10	0

Twenty-nine blind transects were conducted in Laguna de las Ilusiones (Table 3.4). Both the right and left sonar beams were used. Twenty-seven manatees were passed on the right side and 15 on the left, making a total of 42 animals passed. Of these, the blind observer correctly detected, described the distance from the boat, and on which side the animal was on 24 (89%) of the animals on the right and 15 (100%) on the left, for a total of 39 (93%) animals (Table 3.4).

3.4 Discussion

A) Use of sonar in various environmental conditions and manatee habitats

The side-scan sonar unit (Humminbird® 987c) produced picture-like images of the bottom substrate and objects in the water column from the acoustic response of the sonar beams. The best images were produced in calm waters (with no waves or currents), traveling in a linear direction at 2.5-7.0 km/h. Water clarity, time of day, and environmental conditions not influencing water movement had no effect on the sonar images produced. Images produced in the clear Florida waters were at times not as clear as those produced in turbid and tannin-stained waters of Honduras and Mexico (See Figure 3.3A-K). This may be explained by lack of a strong current in the clam lagoons of Mexico. Flowing water caused sediment to stir up and clouded the image. In the same respect, wind caused the water surface to become choppy, which in turn distorted the sonar image. In addition, it was very difficult to go in a straight line in Crystal River because of the boat traffic and also the narrowness and windiness of the river.

B) Detecting manatees accurately

Manatees were accurately detected in both Florida and Mexico. There was no noticeable response to the sonar by manatees as was expected since all frequencies used are well above the hearing range of 6-20 kHz (Gerstein *et al.* 1999). The strongest response correlated with the area of the lungs, in accordance to results from experiments on dolphins (Au 1996). Manatees appear to give a much weaker acoustic response than that recorded for dolphins (Au 1996, Jaffe et al. 2007). The reason for this is unclear but it may be due to the differences in the skin density (Kipps *et al.* 2002).

The orientation of the animal greatly influenced the acoustic response, as noted by Au (1996) with dolphins. Manatees that were parallel to the boat (perpendicular to the sonar beam) gave the best acoustic response (Figure 3.3). When animals were perpendicular to the boat (parallel to the beam) the acoustic response was not as evident or at times missing altogether, however a shadow was always produced (see Figure 3.3 D). This lack of acoustic response was also noted by previous attempts to detect manatees with sonar (Dickerson et al. 1996, Jaffe et al. 2007). The presence of the characteristic shadow produced by the manatee blocking the sonar beam presents an advantage over other acoustic attempts.

It is possible that manatees in clear water behave differently to boats than in turbid water. In Florida, manatees have been documented to respond to approaching boats in an apparent flight response (Nowacek *et al.* 2004), which can include swimming to deeper water. In shallow water or near the shore they orient themselves towards deeper water (Nowacek *et al*. 2004). We noted in Crystal River that if manatees where in the center of the channel as we approached, they would either swim deeper (Figure 3.3 C) or orient themselves and begin swimming towards the shore (Figure 3.3 B and K). While in Mexico, even at a distance of less than 1 m, manatees would rather sink to the bottom and remain in the orientation they were at. This difference in behavior had an effect in the clarity and distinguishability of the image produced.

The orientation and position in the water of the animal and the respective acoustic image produced is summarized in Figure 3.4, based on actual screenshots and personal observation of the animal as it passed by the sonar beam in Florida. This model is idealistic and assumes calm water and traveling in a straight line. It also assumes that the water is relatively clear of sediment and the animal is relatively sedentary.

The acoustic response produced by the crocodile was very different than the ones produced by manatees (Figure 3.3 L). While manatees produce round shadows with soft edges, the crocodile produced a very small shadow with a crisp, well-defined edge surrounding its body. This difference in the shadow shape and definition can be attributed to the higher density of the crocodile skin and the flattened shape of the crocodile's body. In addition, following the edge of the shadow, two sets of appendages and a tail can be seen on the sonar image of the crocodile (Figure 3.3 L).

C) Determining detection rate

Due to the heavy volume of manatees in Crystal River, a separate observer was used to note manatee orientations and numbers as they were passed. With this information we were able to adjust the total number of animals passed by removing the number of calves shadowed by their mothers (8; parallel to them and the boat as the sonar beam passes them), and animals at or further than the range limit of 10 m (8). The adjusted total (representing the total number of animals visible to the sonar) goes down to 44, given a new detection rate of 95%.

Experience in understanding the sonar response influences manatee detection. In Florida the same observer was used in all blind transects. In Mexico, driver and observer alternated positions. The density of manatees was much lower in Laguna de las Ilusiones and manatees stood out clearly from the sandy bottom substrate. In addition, water surface in Mexico as very clam. These two differences may explain the higher detection rate in Mexico.

D) Implications for conservation

The application of this technology for the study and management of this species is evident. Having a system that can detect manatees reliably in turbid and tannin-stained waters provides scientists and conservationist with a very valuable tool. Locations could be surveyed during the day and night for manatees to determine habitat use. This technique could be used in combination with visual observation to determine presence of animals and the number of individuals in a sight event.

A methodology could be developed to used sonar transects to estimate manatee abundance in the same way that aerial surveys and land transects are done. In addition, this tool could also be very useful in detecting manatees in attempts to capture them for telemetry studies.

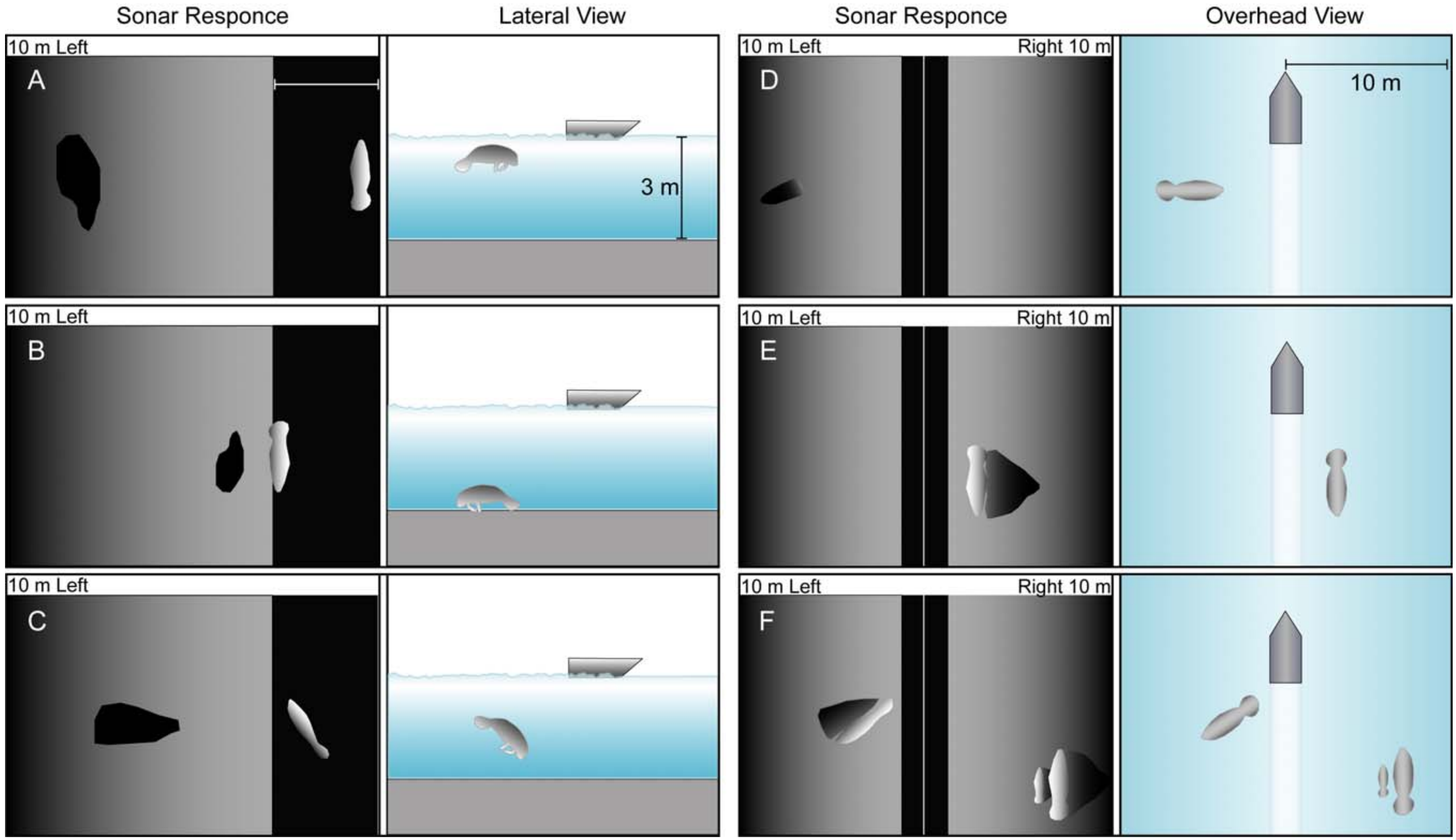
Finally this tool could be used to study manatee habitat in ways that were not possible before. With this tool, scientists can detect depth and contour of river and lagoon bottoms. It can also determine the bottom surface texture (rocks, logs, sand, vegetation, etc.), which can be an important variable for manatee use.

3.5 Conclusion

This study successfully used linear side-scan sonar to detect manatees in the wild. This represents the first study to do so. Manatees were detected in clear, turbid, and tannin-stained waters. Detection rates varied between 70-95%. Advantages of using this unit are that it: 1) is affordable ($2000), compared to other side-scan sonar's ranging from $10-$100K, 2) works at any time of the day or night (not dependant on light), during most environmental conditions, in shallow waterways, and at a frequency above both the hearing of manatees and dolphins, 3) provides additional data simultaneously, such as GPS location, water surface temperature, water depth, speed of boat, time of day, and date, and 4) it provides information about the topology of the bottom substrate.

We recommend that side-scan sonar be tested on other large aquatic vertebrate fauna (i.e. sea turtles, crocodiles, dolphins, sturgeons, dugongs), to determine its usefulness in detecting them. We also recommend the development of a survey methodology using the unit to determine population estimates in a specific area covered.

Figure 3.4. Model of acoustic images of manatees produced by side-scan sonar. A) If a manatee is detected on the top of the water column and is located close or immediately under the boat the acoustic response will be in the dark area (representing the water column) near the white middle line. The corresponding shadow will be on the far side. B) If the manatee is at the bottom of the water column then it will appear completely or partially in the dark area with the shadow closely associated separated by a small gap. C) If the manatee is located in between and the body orientation is vertical or in an angle the acoustic response will reflect that and the shadow will appear at an in-between distance. D) If the manatee is perpendicular to the boat the acoustic response will be minimal or absent and the shadow will have a horizontal shape. E) If the manatee is located parallel to the boat the shadow will be on the opposite side and will have a triangle shape reflecting the general shape of the manatee as it slims at the ends. F) Finally, if a mother and calf are present and parallel to the boat they will only both be visible if the calf is in front of the mother in relation to the boat. Animals that are at an angle relative to the boat with have a slanted shadow. Relative distances from the boat can be observed in the acoustic response.


Sonar Responce
Lateral View
Sonar Responce
Overhead View
10 m Left
A
3 m
10 m Left
Right 10 m
D
10 m
10 m Left
B
10 m Left
Right 10 m
E
10 m Left
C
10 m Left
Right 10 m
F

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CHAPTER FOUR

FIRST SYMPOSIUM FOR THE BIOLOGY AND CONSERVATION OF THE ANTILLEAN MANATEE (*TRICHECHUS MANATUS MANATUS*) IN MESOAMERICA

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Mesoamericana, (*in press*), 2007 [a]
[a] Translated from Spanish

The manatee is a charismatic species that serves as a flagship for the conservation of the aquatic fauna in the Mesoamerican region. It is also considered an important species because the efforts to protect it simultaneously protect many other species of fauna and flora that inhabit the same ecosystem as the manatee. However, in Mesoamerica, many of the research and conservation efforts are isolated and of short duration, even though the majority of the challenges are similar throughout the whole region.

When several researchers and managers had the opportunity to meet in forums such as the annual convention of the Mesoamerican Society for Biology and Conservation, the idea came up of organizing a symposium that would bring together specialists and other people interested in the manatees of the Mesoamerican region.

This is how, during the X Annual Congress of the Mesoamerican Society for Biology and Conservation the First Symposium for the Biology and Conservation of the Antillean Manatee (*Trichechus manatus manatus*) in Mesoamerica was held in Antigua Guatemala, Guatemala, on the 1st and 2nd of November, 2006.

The organizers of the symposium were Daniel Gonzalez-Socoloske (Loma Linda University, Loma Linda, California, USA), Dr. Leon David Olivera-Gomez (Universidad Juarez Autonoma de Tabasco, Villahermosa, Tabasco, Mexico), and Dr. Ester Quintana-Rizzo (Mote Marine Laboratory, Florida, USA).

The symposium was primarily sponsored by Sirenian International, with additional money provided by a grant to Dr. Robert E. Ford (Loma Linda University, California, USA) from ESSE21 (http://esse21.usra.edu/ESSE21/).

The primary purpose of this symposium was to update the current knowledge about the status and distribution of Antillean Manatee in Mesoamerica (Mexico, Guatemala, Belize, Honduras, Nicaragua, Costa Rica, and Panama). Representatives from each country were invited to give twenty-minute presentations on the current status and distribution of manatees within their country.

The second purpose of the meeting was to provide a time and place for those working with manatees in Mesoamerica to present results from their current work, to meet and begin to collaborate in larger, region-wide projects such as fine scale DNA collection and coordinated aerial surveys.

Finally, the symposium provided a location where new students and scientists in the Sirenian field could interact with more experienced scientists and learn from their experiences.

A total of 14 individuals participated in the symposium representing every Mesoamerican country and Venezuela (see Appendix I for program and abstract titles). Participates were given a CD containing various documents including: the symposium program, a list of participants with their contact information, and the manatee necropsy manual both in English and Spanish. Participants were recognized with a certificate of participation. The number of attendants fluctuated from 50 to 30 depending on the day and the presentation.

After the presentations, a roundtable was held to discuss collaboration between countries. The primary outcome of the roundtable was the formation of the "Mesoamerican Manatee Research Workgroup". Representatives from each country were selected to be in the workgroup (Table 4.1). The purpose of the workgroup is to coordinate region-wide efforts for the study and conservation of manatees in Mesoamerica.

One of the first proposed projects for the workgroup was to coordinate a finer scale

DNA study for manatees in the Mesoamerican region. At the moment a lab is being selected to do the analyses once the sample are collected. Because both Mote Marine Laboratory and the USGS Sirenian Project Laboratory have been working in the region, collaboration between the two might be asked for.

Table 4.1 Current members of the Mesoamerican Manatee Research Workgroup.

Name	**Country**	**Email**
Benjamin Morales-Vela	Mexico	benjamin@ecosur-qroo.mx
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Adda G. Manzanilla-Fuentes	Venezuela	aeseijas@yahoo.com

CHAPTER FIVE

CONCLUSIONS

This thesis aims to increase our understanding of manatees, particularly in Mesoamerica, by addressing some of the major challenges that scientists and wildlife managers face in promoting conservation of this charismatic species.

The use of replicate aerial surveys to determine relative abundance and distribution is now seen as an improvement over single aerial surveys. Most countries, south of Belize that have manatees, have not been recently surveyed, and thus, lack data on current manatee distribution. This challenge limits all other efforts to conserve and manage the species. This was the case with Honduras, having had its last survey for manatees in 1980.

Current surveys in Honduras found that the overall distribution on the northern coast had not changed, but the relative abundance between study years had. CySWR was again identified as the most important area for manatees on the northern coast of Honduras; however, there was a significant decrease in the number of manatee sightings per aerial survey hour compared to 1980.

Gill nets are the greatest cause of mortality based on twenty-five death records that exist for the whole country, however secondary reasons like contamination and habitat loss are hard to quantify. While this study lays the foundation for future work in Honduras, more work is needed to survey the eastern end of the country to determine the status of the species in the whole country.

Side-scan sonar was shown to be an effective tool to detect manatees in turbid and tannin-stained waterways. The side-scan sonar had a manatee detectably rate of 70% and 93% in Florida and Mexico, respectively. A model for the acoustic response of manatees in different orientations and distances from the boat was developed.

This revolutionary tool provides scientists the ability to scan for manatees at night and in locations where the water is too dark to make visual confirmation. This study is the first to successfully detect manatees with side-scan sonar in the wild.

Future work is needed to develop a transect technique to determine relative abundance. In addition, this tool could assist groups attempting to capture manatees for telemetry studies in locations where they are virtually impossible to see.

Finally, the first Mesoamerican research collaboration meeting specifically for manatees was organized. This marked a starting point for scientists working in the region to begin collaborating and sharing their challenges and successes. Manatees are known to be able to travel long distances that in many cases cross geo-political boundaries. This first meeting established a regional research workgroup, with representatives from each country, which will serve as a coordination tool for future projects.

One example of the ramifications of such a meeting was a tri-country (Panama, Costa Rica, and Nicaragua) workshop held in Costa Rica in April of 2007. The aim of that workshop was to develop a management plan for manatees in those three countries. Members of the regional research workgroup were involved in the meeting and several special guests that participated in the Mesoamerican meeting were invited as experts.
It is this kind of collaboration and communication between countries, NGO's, and protected areas that will in the end help determine the fate of these elusive and

mysterious creatures.

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APPENDIX I

PRIMER SIMPOSIO PARA LA BIOLOGÍA Y CONSERVACIÓN DEL MANATÍ ANTILLANO EN MESOAMERICA

Programa del Primer Simposio para la Biología y Conservación del Manatí Antillano en Mesoamerica

1 de Noviembre 2006

Hora	Presentación	Autores
8:40-9:00	EL 1ER SIMPOSIO PARA LA BIOLOGÍA Y CONCERVACION DEL MANATÍ ANTILLANO (*TRICHECHUS MANATUS MANATUS*) EN MESOAMERICA	Daniel González-Socoloske, León D. Olivera-Gómez, y Ester Quintana-Rizzo
	Presentaciones Invitadas "El Estado Actual del Manatí en Mesoamerica"	
9:00-9:20	ESTADO DEL MANATÍ ANTILLANO (*TRICHECHUS MANATUS MANATUS*) EN BELICE	Nicole E. Auil
9:20-9:40	ESTADO ACTUAL DEL MANATÍ ANTILLANO (*TRICHECHUS MANATUS MANATUS*) EN COSTA RICA	Carlos Espinoza e Ignacio Jiménez
9:40-10:00	ESTADO ACTUAL DEL MANATÍ ANTILLANO (*TRICHECHUS MANATUS MANATUS*) EN NICARAGUA	Carlos Espinoza e Ignacio Jiménez
10:00-10:20	**REFRIGERIO**	
10:20-10:40	ESTADO ACTUAL DEL MANATÍ ANTILLANO (*TRICHECHUS MANATUS MANATUS*) EN GUATEMALA	Ester Quintana-Rizzo
10:40-11:00	ESTADO ACTUAL DEL MANATÍ ANTILLANO (*TRICHECHUS MANATUS MANATUS*) EN HONDURAS	Daniel González-Socoloske, Cynthia Taylor, Saul Flores, Gustavo A. Cruz, y Robert E. Ford
11:00-11:20	ESTADO DEL MANATÍ (*TRICHECHUS MANATUS*) EN HUMEDALES DEL SUR DEL GOLFO DE MÉXICO	León D. Olivera-Gómez
11:20-11:40	ESTADO DEL MANATÍ (*TRICHECHUS MANATUS*) EN LA COSTA CARIBE DE MÉXICO	Benjamín Morales

11:40-12:00	ESTADO ACTUAL DEL MANATÍ ANTILLANO (*TRICHECHUS MANATUS MANATUS*) EN PANAMA	Lenin Requelme
	Estudios Regionales "La Biología y Conservación del Manatí en Mesoamerica"	
12:00-12:20	LA CONSERVACION DEL MANATÍ (*TRICHECHUS MANATUS*) COMO OBJETO FOCAL DE MANEJO DEL PARQUE NACIONAL TORTUGUERO, COSTA RICA	Allan Valverde Blanco
12:20-14:00	**ALMUERZO**	
14:00-14:20	MONITOREO CIENTIFICO PARA LA CONSERVACION DEL MANATÍ Y SU HABITAT	H. García de la Vega y O. Hugo Machuca
14:20-14:40	DETERMINACIÓN DE LA PRESENCIA DE *TRICHECHUS MANATUS* EN CUATRO ZONAS DE LA PARTE NORTE DE LA COSTA DEL GOLFO DE MÉXICO (TAMIAHUA, TUXPAN, TECOLUTLA Y CASITAS-NAUTLA).	A. García Jiménez, A. Serrano, y C. González-Gandara
14:40-15:00	CEBADO DE MANATÍES (*TRICHECHUS MANATUS*) COMO EXPERIENCIA PARA LA CAPTURA DE LA ESPECIE EN EL PARQUE NACIONAL TORTUGUERO, LIMÓN, COSTA RICA.	Alexander Gomez-Lopez
15:00-15:20	USOS CULTURALES Y MANEJO DEL MANATÍ ANTILLANO (*TRICHECHUS MANATUS MANATUS*), EN EL SISTEMA LAGUNAR DE ALVARADO, VERACRUZ, MÉXICO	Claudia Rodríguez-Ibáñez y Enrique Protilla Ochoa
15:20-15:40	CARACTERIZACIÓN DE PUNTOS DE DESCANSO Y SU USO DIURNO Y NOCTURNO POR EL MANATÍ ANTILLANO (*TRICHECHUS MANATUS MANATUS*) EN LOS DROWNED CAYES, BELICE	Marie-Lys C. Bacchus, Stephan G. Dunbar, y Caryn Self-Sullivan
15:40-16:00	CONSIDERACIONES SOBRE LA SITUACIÓN DEL MANATÍ ANTILLANO *(TRICHECHUS MANATUS MANATUS)* EN CUBA	José Antonio Santos-Mariño
16:00-16:20	ANÁLISIS DE LA VIABILIDAD DE LA POBLACIÓN Y DEL HÁBITAT DEL MANATÍ (*TRICHERUS MANATUS*) EN LA COSTA DEL CARIBE COSTARRICENSE	Yolanda Matamoros

Expositor es el primer autor, caso contrario señalado por un *.

2 de Noviembre 2006

Hora	Presentación	Autores
8:40-9:00	INTRODUCCIÓN Y ANUNCIOS	Comité Organizador
	Estudios Regionales "La Biología y Conservación del Manatí en Mesoamerica"	
9:00-9:20	TELEMETRÍA Y TÉCNICAS ACÚSTICAS PARA EL MONITOREO DE MANATÍES EN AMBIENTES FLUVIOLAGUNARES EN EL SURESTE DE MÉXICO	León D. Olivera-Gómez, Darwin Jiménez-Domínguez, Suad Jorge-Vargas, y Daniel González-Socoloske
9:20-9:40	CAUSAS DE MORTALIDAD DE MANATÍES EN LA ZONA NORTE DEL LAGO DE MARACAIBO, ALGUNAS EVIDENCIAS Y SOLUCIONES	Adda Manzanilla-Fuentes y Andrés Eloy Seijas
9:40-10:00	EVALUACIÓN DEL EFECTO DEL PÚBLICO SOBRE EL COMPORTAMIENTO Y LOS NIVELES DE CORTISOL EN EL MANATÍ ANTILLANO (*TRICHECHUS MANATUS MANATUS*) EN CAUTIVERIO	Claudia Villanueva-Garcia, M. Romano-Pardo, y R. Valdéz-Pérez
10:00-10:20	**REFRIGERIO**	
	Estudios de Aplicación Universal "Herramientas para estudiar el Manatí"	
10:20-10:40	AMENAZAS DE CONTAMINATES ORGANICOS PARA LOS MANATIES (*TRICHECHUS MANATUS*) Y OTROS MAMIFEROS MARINOS DE MESOAMERICA	Dana L. Wetzel, John E. Reynolds III, y Benjamin Morales*
10:40-11:00	METODOS DE MUESTREO PARA EXTRAER Y DESARROLLAR MARCADORES PARA ADN SATELITE EN EL MANATI DE LA FLORIDA, *TRICHECHUS MANATUS LATIROSTRIS*	Susan Carney, Ester Quintana-Rizzo*, Ellen Bolen, Micheal Tringali, y John E. Reynolds III
11:00-11:20	EL USO DEL SONAR LATERAL (SIDE-SCAN) PARA DETECTAR Y ESTUDIAR EL MANATÍ (*TRICHECHUS MANATUS*) EN CUERPOS DE AGUA TURBIA Y ESTUARIOS	Daniel González-Socoloske, Robert E. Ford, León D. Olivera-Gómez, y Robert K. Bonde
11:20-11:40	CICATRICES NO LETALES DE EMBARCACIONES EN MANATIES DE BELICE COMO HERAMIENTAS PARA LA EVALUACION DE UN AREA MARINA PROTEGIDA	Caryn Self-Sullivan
11:40-12:20	NECROPSIAS DE MANATÍES: UNA HERRAMIENTA IMPORTANTE PARA CIENTÍFICOS Y MANEJADORES	Gregory D. Bossart
12:20-14:00	**ALMUERZO**	

Mesa Redonda “Planificación de futuros estudios del Manatí en Mesoamerica”		
14:00-16:00	CONSEJOS DE MANEJOS POR PAIS Y PLANIFICACIÓN	Abierto a participantes
16:00-16:20	ENTREGA DE CERTIFICADOS DE PARTICIPACION Y RECONOCIMIENTOS	Comité Organizador

Expositor es el primer autor, caso contrario señalado por un *.

Presentaciones de Póster

Titulo	**Autores**
PROGRAMA DE MANTENIMIENTO EN CUATIVERIO DE LOS MANATIES DEL ACUARIO DE VERACRUZ, MÉXICO	Fabián Fco. Vanoye Lara
ESTADO ACTUAL DE LA POBLACIÓN DE MANATÍ EN LA BAHÍA EL TABLAZO, LAGO DE MARACAIBO ESTADO ZULIA, VENEZUELA	Adda Manzanilla-Fuentes y Andrés Eloy Seijas
HELMINTOS GASTROINTESTINALES DEL MANATÍ ANTILLANO (*TRICHECHUS MANATUS MANATUS)* DEL ESTADO DE TABASCO, MÉXICO	Arturo Hernández-Olascoaga y León D. Olivera-Gómez

Antigua, Guatemala, 1-2 de Noviembre 2006
X Congreso de la Sociedad Mesoamericana para la Biología y la Conservación
http://resweb.llu.edu/rford/courses/ESSC5xx/SMBC_manatee_symposium_es.html