Distribution and Conservation of the Antillean Manatee in Hispaniola

by

Haydée María Domínguez Tejo

Marine Science and Conservation
Duke University

Date:_______________________
Approved:

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Andrew J. Read, Supervisor

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Patrick N. Halpin

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Andre Boustany

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John E. Reynolds

Dissertation submitted in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy
in Marine Science and Conservation
in the Graduate School of Duke University

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ABSTRACT

Antillean manatees (*Trichechus manatus manatus*) were heavily hunted in the past throughout the Wider Caribbean Region (WCR), and are currently listed as endangered on the IUCN Red List of Threatened Species. In most WCR countries, including Haiti and the Dominican Republic, remaining manatee populations are believed to be small and declining, but current information is needed on their status, distribution, and local threats to the species.

To assess the past and current distribution and conservation status of the Antillean manatee in Hispaniola, I conducted a systematic review of documentary archives dating from the pre-Columbian era to 2013. I then surveyed more than 670 artisanal fishers from Haiti and the Dominican Republic in 2013-2014 using a standardized questionnaire. Finally, to identify important areas for manatees in the Dominican Republic, I developed a country-wide ensemble model of manatee distribution, and compared modeled hotspots with those identified by fishers.

Manatees were historically abundant in Hispaniola, but were hunted for their meat and became relatively rare by the end of the 19th century. The use of manatee body parts diversified with time to include their oil, skin, and bones. Traditional uses for folk medicine and handcrafts persist today in coastal communities in the Dominican Republic. Most threats to Antillean manatees in Hispaniola are anthropogenic in nature, and most mortality is caused by fisheries. I estimated a minimum island-wide annual

mortality of approximately 20 animals. To understand the impact of this level of mortality, and to provide a baseline for measuring the success of future conservation actions, the Dominican Republic and Haiti should work together to obtain a reliable estimate of the current population size of manatees in Hispaniola.

In Haiti, the survey of fishers showed a wider distribution range of the species than suggested by the documentary archive review: fishers reported recent manatee sightings in seven of nine coastal departments, and three manatee hotspot areas were identified in the north, central, and south coasts. Thus, the contracted manatee distribution range suggested by the documentary archive review likely reflects a lack of research in Haiti. Both the review and the interviews agreed that manatees no longer occupy freshwater habitats in the country. In general, more dedicated manatee studies are needed in Haiti, employing aerial, land, or boat surveys.

In the Dominican Republic, the documentary archive review and the survey of fishers showed that manatees still occur throughout the country, and occasionally occupy freshwater habitats. Monte Cristi province in the north coast, and Barahona province in the south coast, were identified as focal areas. Sighting reports of manatees decreased from Monte Cristi eastwards to the adjacent province in the Dominican Republic, and westwards into Haiti. Along the north coast of Haiti, the number of manatee sighting and capture reports decreased with increasing distance to Monte Cristi province. There was good agreement among the modeled manatee hotspots,

hotspots identified by fishers, and hotspots identified during previous dedicated manatee studies. The concordance of these results suggests that the distribution and patterns of habitat use of manatees in the Dominican Republic have not changed dramatically in over 30 years, and that the remaining manatees exhibit some degree of site fidelity. The ensemble modeling approach used in the present study produced accurate and detailed maps of manatee distribution with minimum data requirements. This modeling strategy is replicable and readily transferable to other countries in the Caribbean or elsewhere with limited data on a species of interest.

The intrinsic value of manatees was stronger for artisanal fishers in the Dominican Republic than in Haiti, and most Dominican fishers showed a positive attitude towards manatee conservation. The Dominican Republic is an upper middle income country with a high Human Development Index. It possesses a legal framework that specifically protects manatees, and has a greater number of marine protected areas, more dedicated manatee studies, and more manatee education and awareness campaigns than Haiti. The constant presence of manatees in specific coastal segments of the Dominican Republic, the perceived decline in the number of manatee captures, and a more conservation-minded public, offer hope for manatee conservation, as non-consumptive uses of manatees become more popular. I recommend a series of conservation actions in the Dominican Republic, including: reducing risks to manatees from harmful fishing gear and watercraft at confirmed manatee hotspots; providing alternative economic alternatives for displaced fishers, and developing responsible ecotourism ventures for manatee watching; improving law enforcement to reduce fisheries-related manatee deaths, stop the illegal trade in manatee body parts, and better protect manatee habitat; and continuing education and awareness campaigns for coastal communities near manatee hotspots.

In contrast, most fishers in Haiti continue to value manatees as a source of food and income, and showed a generally negative attitude towards manatee conservation. Haiti is a low income country with a low Human Development Index. Only a single dedicated manatee study has been conducted in Haiti, and manatees are not officially protected. Positive initiatives for manatees in Haiti include: protected areas declared in 2013 and 2014 that enclose two of the manatee hotspots identified in the present study; and local organizations that are currently working on coastal and marine environmental issues, including research and education on marine mammals. Future conservation efforts for manatees in Haiti should focus on addressing poverty and providing viable economic alternatives for coastal communities. I recommend a community partnership approach for manatee conservation, paired with education and awareness campaigns to inform coastal communities about the conservation situation of manatees in Haiti, and to help change their perceived value. Haiti should also provide legal protection for manatees and their habitat.

DEDICATION

To all the people who have contributed heartfully to manatee conservation in Hispaniola, especially Cheryl and David Belitsky, who inspired me with their pioneering work.

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ACKNOWLEDGEMENTS

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INTRODUCTION

The extant members of the Order Sirenia include the dugong (*Dugong dugon*), the Amazonian manatee (*Trichechus inunguis*), the West African manatee (*Trichechus senegalensis*) and the West Indian manatee (*Trichechus manatus*). The latter is divided into two subspecies: the Florida manatee (*Trichechus manatus latirostris*), found primarily in the southeastern United states; and the Antillean manatee (*Trichechus manatus manatus*), found in Central and South America, and in the Greater Antilles (Lefebvre et al. 2001; Deutsch & Reynolds 2012; Marsh et al. 2011; Self-Sullivan & Mignucci-Giannoni 2012). The two subspecies of the West Indian manatee were described using morphological differences in cranial characters (Domning & Hayek 1986), but genetic studies (García-Rodríguez et al. 1998; Vianna et al. 2006) have challenged this classification, revealing three lineages or biogeographic groups of West Indian manatees: (1) Florida, Bahamas and the Greater Antilles; (2) Central and South America west of the Lesser Antilles; and (3) Northeastern South America east of the Lesser Antilles (Self-Sullivan & Mignucci-Giannoni 2012). Notably, some individuals from Florida have been confirmed in Bahamas (Ferguson & Claridge 2011) and Cuba (Alvarez-Alemán et al. 2010). In the present study, I will refer to the currently accepted taxonomy of the West Indian manatee.

Sirenians are unique, as the only exclusively aquatic herbivorous mammals (UNEP 2010; Hines et al. 2012). Their role as large herbivores in aquatic ecosystems has been studied more in depth for dugongs. Dugongs (and likely most sirenians) affect community structure, productivity, and the chemical composition of their food, as well as community composition of invertebrates, microbial processes, and detritus cycling in seagrass ecosystems (Aragones et al. 2012a; Marsh et al. 2011). However, invertebrates and fish are also eaten by West Indian and West African manatees (Marsh et al. 2011), with the latter species now considered omnivorous (Keith Diagne et al. 2015).

Sirenians hold important cultural and economic value for coastal communities around the world. For some indigenous groups in Australia, both dugongs and sea turtles are considered totemic animals, and they are tightly linked to the economy, nutrition, and well-being of these societies (Delisle 2009; NAILMSA 2009; Marsh et al. 2011). Likewise, West Indian manatees were hunted by aboriginal peoples—and are still captured in many countries today—in the Greater Antilles, and in Central and South America for their meat, but also for their bones and other body parts for curing diseases, and manufacturing ceremonial objects, amulets, and charms (UNEP 2010; Self-Sullivan & Mignucci-Giannoni 2012); some tribes in South America regard manatees as a water spirit or a mythological creature (Self-Sullivan & Mignucci-Giannoni 2012). West Indian manatees have also become an important income source as a tourist attraction. For example, manatees are highly valued by the residents of Citrus County, Florida, who are willing to pay for manatee protection because of the net benefits derived from manatee ecotourism (Solomon et al. 2004).

In the Wider Caribbean Region (WCR), West Indian manatees were heavily hunted in the past (Bertram & Bertram 1973; Durand 1983; McKillop 1985; Lefebvre et al. 2001; UNEP 2010). In the Greater Antilles, except for Puerto Rico, incidental and directed catches have been considered a major source of manatee mortality (Lefebvre et al. 2001; UNEP 2010). In addition to poaching and incidental catches, manatees are also subject to water craft collisions, chemical and noise pollution, other forms of disturbance, habitat degradation and habitat loss, among other threats, because they inhabit freshwater and shallow coastal marine environments that are used heavily by humans (Reynolds & Marshall 2012; Self-Sullivan & Mignucci-Giannoni 2012). The combination of these threats with their slow growth and reproduction makes manatees vulnerable to extinction. Currently, the West Indian manatee is listed as vulnerable on the IUCN Red List of Threatened Species (Deutsch et al. 2008); the Florida and the Antillean subspecies are each listed as endangered (Deutsch 2008; Self-Sullivan & Mignucci-Giannoni 2008).

The updated regional management plan for the West Indian manatee highlighted the need for current information on the status, distribution, and local threats to the Antillean subspecies in most of the WCR countries (UNEP 2010). Thirteen countries were believed to support 100 or fewer individuals, and trends in abundance were categorized as probably declining or unknown in fourteen countries (UNEP 2010;

Self-Sullivan & Mignucci-Giannoni 2012). The Dominican Republic and Haiti were counted among these countries.

One way to address this information need is to mine existing sources of information. Information on Antillean manatees in Hispaniola from archaeological studies and from historical documents has not been fully integrated into previous reviews and conservation plans for the West Indian manatee (Lefebvre et al. 2001; UNEP 2010). Much recent information on the species in the Dominican Republic remains dispersed and mostly unpublished. Available manatee distribution maps for Hispaniola are outdated, and not detailed enough for conservation planning (Belitsky & Belitsky 1980; Rathbun et al. 1985; Lefebvre et al. 1989; Ottenwalder 1995; Pugibet & Vega 2000; Lefebvre et al. 2001). Recent dedicated field studies have been limited to specific areas in the Dominican Republic, and do not allow for a country-wide assessment of the species (Domínguez Tejo 2006, 2007, 2009; Auil Gómez et al. 2011; Reynoso et al. 2011).

To date, no single comprehensive database of manatee records has been developed for Haiti and the Dominican Republic. No study has simultaneously evaluated the status of the species in both countries, and the situation for manatees in Haiti has not been assessed since 1982-1983 (Rathbun et al. 1985). Furthermore, only a single manatee habitat modeling study has been conducted in Hispaniola, limited to one coastal lagoon in the Dominican Republic (Domínguez Tejo & Rivas 2011).

The overall objective of my dissertation is to evaluate the distribution and conservation status of Antillean manatees in Hispaniola. Specifically, I piece together historical, perceptual, and factual knowledge of Antillean manatees, with new information generated through a combination of social and natural science approaches. In Chapter 1, I provide a systematic review of the state of knowledge on Antillean manatees in Hispaniola based on documentary archives expanding from the pre-Columbian era to 2013. I also centralize the information in a database of manatee sighting records compiled from the documentary archives. In Chapter 2, I assess the current status of the species in Hispaniola based on fisher's traditional ecological knowledge. I contrast manatee distribution, mortality, perceived trends in abundance and captures, the cultural value of the species, and the attitude of fishers towards manatee conservation in Haiti and the Dominican Republic. In Chapter 3, I develop a country-wide ensemble model of Antillean manatee distribution for the Dominican Republic, and compare modeled manatee hotspots with those identified by fishers. I conclude with a summary of the legislation protecting manatees and their habitat in Hispaniola, and recommend a series of conservation measures for the species in both countries.

CHAPTER 1: State of knowledge on Antillean manatees in Hispaniola

Introduction

Historical data can provide reference conditions to evaluate the current status of species, and help to set justifiable, achievable, and sustainable conservation and management goals (Pauly 1995; Swetnam et al. 1999). To assess the status of poorly understood marine species of conservation interest, some previous studies have used a combination of naturalists' observations, gray literature, and fishers' anecdotes, to reconstruct past population sizes and trajectories (Sáenz-Arroyo et al. 2005a; Sáenz-Arroyo et al. 2005b).

No formal records of catch data exist for Antillean manatees, *Trichechus manatus manatus*, in Hispaniola. However, manatees were part of the diet of the original inhabitants and the Europeans that settled on the island after Columbus' first voyage to America in 1492. Being considered an extraordinary —and tasty—fish, descriptions of manatees were not uncommon in accounts of the European chroniclers and voyagers of the 15-19th centuries (Durand 1983). In addition, archaeological studies provide valuable insights on aboriginal uses of manatees (e.g., Fewkes 1907; Miller 1916; Krieger 1929; Miller 1929). Only a limited number of these documents have been included in regional reviews (Lefebvre et al. 1989; Lefebvre et al. 2001) and management plans for the West Indian manatee (UNEP 1995, 2010). These documents briefly describe the current status of Antillean manatees in the Dominican Republic and

Haiti, and provide recent but coarse distribution maps. Additional manatee studies have been conducted since these reviews and plans were published, and there is a need to centralize and compare all available information on the species in Hispaniola.

In this chapter, I summarize the state of knowledge on Antillean manatees in Hispaniola. Specifically, I: (1) review documentary archives with findings from the Pre-Columbian era to 2013; (2) compare previous dedicated manatee studies; (3) present a new database of manatee sighting records that can be queried and mapped by different qualitative attributes; (4) compare historical and recent manatee distribution, abundance and mortality estimates, population trend, hunting methods and uses; and (5) list identified threats to manatees and their habitat. I used a systematic approach, including: rare book collections; published and unpublished literature written in English, French, or Spanish; documents not widely distributed and difficult to access (e.g., bulletins from national museums, national archaeology magazine articles, technical reports of local institutes); and personal communications with local experts in the Dominican Republic and Haiti.

Documentary archive search

This review is based on written, tabulated, mapped or photographic records of manatees in Hispaniola. I used a variety of strategies to search these documentary archives, classifying them into three time periods: Pre-Columbian era; 1492 to 1900; and 1900 to 2013.

The Pre-Columbian era included archaeological studies in Hispaniola (conducted in the 20th or the 21st century) in which manatee bones or bone objects were found, derived from aboriginal cultures present before the arrival of Columbus. I consulted a detailed account of archeological explorations in the Antilles by Veloz Maggiolo (1972), to find those conducted in Hispaniola. I complemented this initial list with previous archeological work in Hispaniola cited by Krieger (1931), Rainey (1941), and Lefebvre et al. (2001). For the most recent archaeological studies, I searched volumes 1 to 5 (dating from 1971 to 1972) of the Revista Dominicana de Arqueología y Antropología (Dominican Magazine of Archaeology and Anthropology), and numbers 1 to 41 (dating from 1972 to 2007) of the Boletín del Museo del Hombre Dominicano (Bulletin of the Museum of the Dominican Man).

The time period from 1492 to 1900 included the works of chroniclers, voyagers, missionaries, and settlers, during the conquest, colonization, and independence of the West Indies. I examined works by the authors cited in Peña Linares (1981) and Durand (1983), who mentioned manatees in Hispaniola during that time period. I complemented this initial list with the works cited by Krieger (1930a, 1931), Veloz Maggiolo (1972), Cassá (1974), and Lefevbre et al. (2001).

I searched for these historical documentary archives in Duke University Libraries, David M. Rubenstein Rare Book and Manuscript Library, the library of Museo del Hombre Dominicano (the Museum of the Dominican Man), and the following digital libraries: Internet Archive (https://archive.org/), Hathi Trust Digital Library (https://www.hathitrust.org/) and Gallica (http://gallica.bnf.fr/).

The most recent time period included any documentary archive from 1900 to 2013 mentioning manatees in Hispaniola. I searched for published and unpublished documents from dedicated and non-dedicated manatee studies. I consulted the sources cited by Lefevbre et al. (2001), and the regional management plans for the West Indian manatee (UNEP 1995, 2010). I visited the libraries of Centro de Investigaciones de Biología Marina (CIBIMA), Fundación Dominicana de Estudios Marinos Inc. (FUNDEMAR), Acuario Nacional, and The Nature Conservancy in the Dominican Republic, and collected: (a) the most recent dedicated manatee studies; (b) manatee sighting and stranding records kept by the Red Dominicana de Varamientos (RDV) and the Centro de Rescate y de Rehabilitación de Especies Acuáticas (CERREA); (c) documents from other projects that included coastal surveys where manatees were sighted. For unpublished accounts of manatees, I consulted with local experts such as Jose A. Ottenwalder (a former manatee researcher in the Dominican Republic and Haiti), marine biologists from the above mentioned institutes, and staff from the Ministerio de Medio Ambiente y Recursos Naturales. I also collected manatee sighting sheets from 2006 to 2013 from Dominican commercial pilots, divers, and biologists who volunteered to contribute to my research with opportunistic sightings. For the most updated information from Haiti, I consulted with Jean Wiener, director of Fondation pour la

Protection de la Biodiversite Marine (FoProBiM) (http://www.foprobim.org/), and Jaime Aquino, director of the Haiti Ocean Project (http://www.haitioceanproject.net/).

For documentary archives available in digital format, I used Spanish, French or English variations of the words manatee, seacow, cow, bones, ivory, Hispaniola, Santo Domingo, and Haiti, to search automatically for relevant information. Otherwise, I read the documents in full, to select only those referring explicitly to manatees in Hispaniola. I extracted qualitative or quantitative estimates of manatee abundance and mortality, indications of population trend, descriptions of hunting methods and uses, and listings of threats to the species and its habitat. For dedicated manatee studies, I also extracted information on the survey methods, effort, and geographic extent of the study.

Database creation and record mapping

I created a database in Excel to include all manatee sighting records from Hispaniola in the three time periods described above. Each row represents a sighting record, and each column is an attribute of the sighting. Examples of attributes include timing, location, and characteristics such as number of animals observed, type of record (e.g., capture, stranding, boat strike, archaeological find), source (e.g., dedicated manatee study, interview, documentary archive), among others. The novelty of the database is that each record is scored based on a time, location, evidence, and overall reliability scale as described in Table 1.

Table 1: Time, location, evidence, and overall reliability score descriptions for manatee sighting records in Hispaniola.

Score	Time reliability Description
0	An estimated time frame not obtained from the observer
5	A date stated by an interviewee occurring more than one year before the interview
10	A date stated by an interviewee occurring within a year of the interview
15	Dates formally documented by observers
Score	**Location reliability** **Description**
0	An estimated location from historical records (<1900), or sightings that could not be placed into a single coastal segment (see Figure 1)
5	A stated place name
10	Hard copy maps
15	Digital maps
20	Geographic coordinates
Score	**Evidence reliability** **Description**
0	Historical records (<1900) and an unknown number of observers
5	Recent records (>1900) with at least one observer
10	Recent records and an observer knowledgeable about manatees, or surveying for manatees
15	Recent records and two or more knowledgeable observers
20	Recent records with physical evidence such as images or bones
Score	**Overall reliability** **Description**
5-55	Time reliability + Location reliability + Evidence reliability

To avoid duplicates, I only made a single database entry for carved manatee bone objects and manatee sightings that were present in multiple documentary archives. To map sightings lacking geographic coordinates, in ArcGIS 10.3.1 I used the coastline of Hispaniola and located the place name of the town or the coastal feature mentioned in the documentary archive. I then created coordinates representing approximately the center of the town or feature at approximately 500 m from the coastline. Archaeological finds and manatee strandings were mapped on land. To map sightings from hard copy maps, I geo-referenced the maps to obtain sighting coordinates. All maps were projected in WGS84 UTM Zone 19 N.

Description of documentary archives reviewed

Approximately one-third (32%) of the 152 documentary archives I reviewed were historical documents from before the 1900s, consisting mainly of books and journal articles (Table 2). The historical photographic records in Table 2 are from carved manatee bones from a pre-Columbian archaeological site, and unworked bones from a 1720-1723 ship wreck collected during ongoing research by the Anglo Danish Maritime Archaeological Team (ADMAT 2015) in Monte Cristi province, on the northwest coast of the Dominican Republic. I photographed the objects during field work, but results from their study have not yet been published.

More recent documents from 1900 onwards represented 68% of the total, but most of these were personal communications (e.g., telegraphs, letters, and electronic mails reporting manatee sightings), technical reports of limited distribution, and photographs or videos.

Table 2: Type and quantity of documentary archives reviewed from different time periods. If a cell is empty, there are no documents in that category.

Document type	Pre-Columbian era	1492-1900	1900-2013	Total
Book	10	18	4	32
Book chapter			4	4
Journal article	16	2	9	27
Newsletter article			2	2
Newspaper article			3	3
Photograph / video	1	1	13	15
Scientific poster / abstract			5	5
Technical report			25	25
Unpublished personal communication			33	33
Unpublished report / raw data			6	6
Total	**27**	**21**	**104**	**152**

Most (72%) of the 116 documentary archives that provided manatee sighting records were from the recent period (Table 3). However, 33 of the 48 historical documents reviewed provided enough information to create manatee sighting records in the database. The remaining documents only provided general information on aspects discussed below.

Table 3: Time period and number of documentary archives providing only general information about manatees in Hispaniola versus manatee sighting records, n (%).

Time Period	General information	Manatee sighting records
Pre-Columbian era	6 (17)	21 (18)
1492-1900	9 (25)	12 (10)
1900-2013	21 (58)	83 (72)
Total	**36**	**116**

Comparison of dedicated manatee studies

I identified 13 dedicated manatee studies in Hispaniola (i.e., studies that actively collected data through interviews, or field observations during land, boat, or aerial surveys). One was conducted in Haiti from 1982 to 1983 (Rathbun et al. 1985), and the remainder were from the Dominican Republic from 1975 to 2011. In this section, I describe their general spatial coverage and study effort. I discuss more detailed results in other sections below.

To represent the spatial coverage of studies in the Dominican Republic, I used predefined 30 km coastal segments (Belitsky & Belitsky 1978) (Figure 1**Error! Reference source not found.**), and counted the number of studies in each segment. On average, each segment has been covered by only 4 studies, and the coverage has been uneven, with some segments overrepresented (segments 5, 14, and 28), and others underrepresented (segments 25-27, 36-37, and 48) (Figure 2).

Dedicated manatee studies in Hispaniola have been discontinuous in time, and have lacked uniformity in spatial coverage, survey methods, and survey effort (Table 4). In general, studies conducted between 1975 and 2000 covered more coastal segments, but except for Belitsky and Belitsky (1978), the field surveys consisted of short site visits of only a few consecutive days. Manatee sightings in these studies were recorded with place names or in hard copy maps. Studies conducted from 2006 onwards covered fewer coastal segments, but at least half of them included field surveys with multiple site visits to the same areas in different months (Domínguez Tejo 2007; Auil Gómez et al. 2011; Reynoso et al. 2011), and sightings were recorded with geographic coordinates.

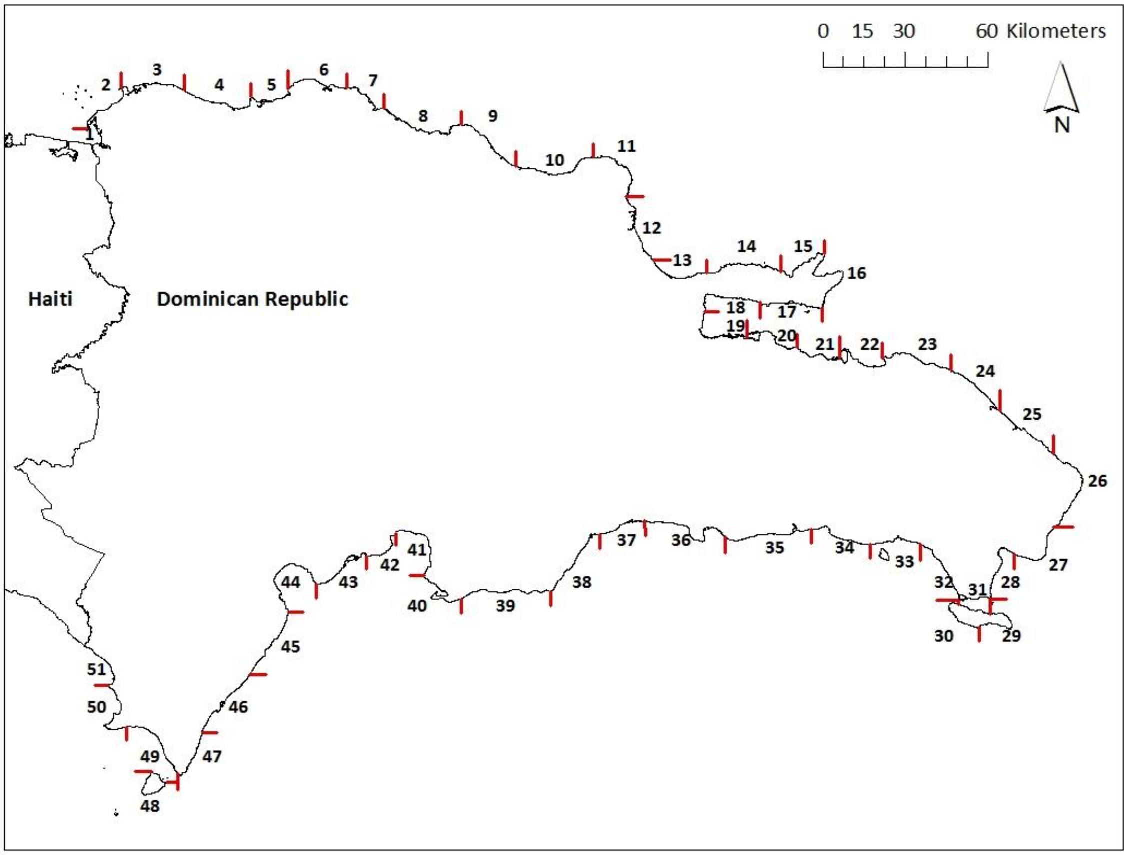


Figure 1: Coastal segments of approximately 30 km in the Dominican Republic, following Belitsky and Belitsky (1978).

Most studies have relied on interviews and land or boat surveys; few aerial surveys have been completed (Table 4). The study by Belitsky and Belitsky (1978, 1980), remains the most complete to date for the Dominican Republic, with country-wide interviews in 1976 and 1977, and country-wide surveys: 6 aerial surveys in different months in 1977, as well as land and boat surveys. Their study provided more manatee sightings to the database than the two previous studies (Campbell & Irvine 1975; Crombie 1975). The study by Rathbun et al. (1985) remains the most complete to date for Haiti, with a 12.5 h country-wide aerial survey in 1982, and interviews with coastal residents in 1982 and 1983. However, their study provided very few manatee sightings.

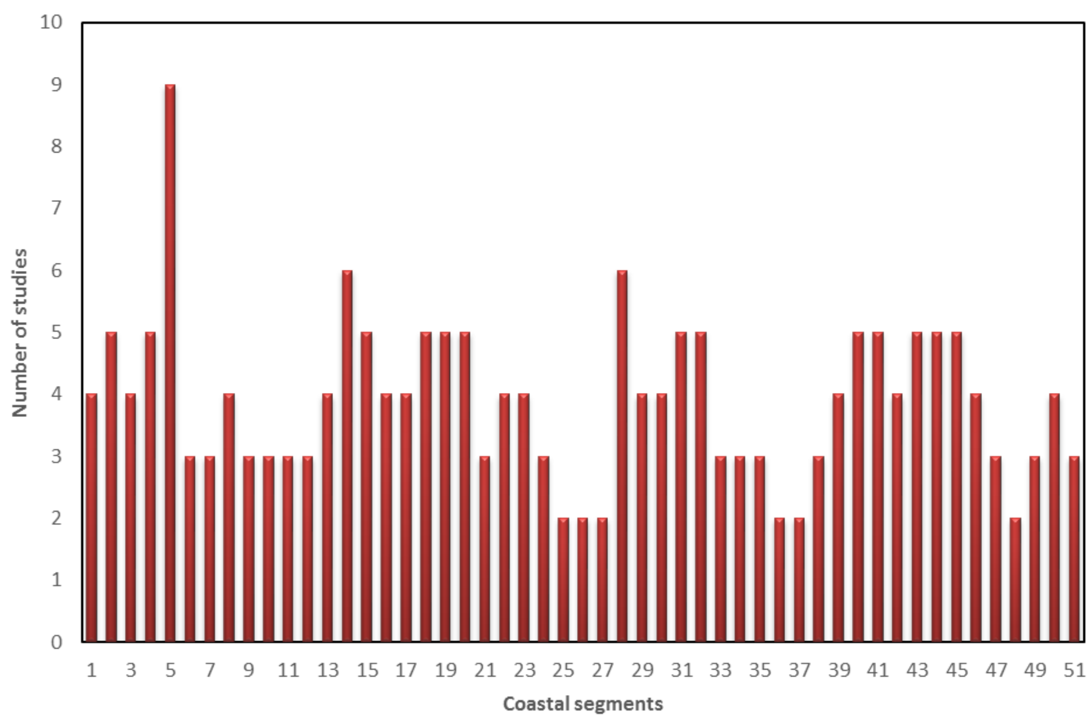


Figure 2: Number of dedicated manatee studies conducted in each coastal segment in the Dominican Republic.

Table 4: Comparison of dedicated manatee studies in Hispaniola. nr indicates that the value was not reported. [a] indicates the number of coastal segments of the Dominican Republic covered by the study from a maximum of 51. [b] indicates the number of days spent conducting land, boat, or aerial surveys. [c] indicates the approximate number of hours of survey effort. [d] indicates the number of manatee sightings that were included in the database. [e] results are pooled because the references belong to the same study. If a cell is empty, the column attribute does not apply to the study.

References	Coastal segments covered [a]	Interviews	Field work days [b]	Effort (h)[c]		Sighting records [d]	
				Land/ Boat	Aerial	From interviews	From field work
Campbell and Irvine (1975)	29	nr	12	nr	nr	5	1
Crombie (1975)	6	nr	5	nr	nr	1	0
Belitsky and Belitsky (1978)	51	48	43	149	63	33	70
Rathbun et al. (1985)		nr	nr		13	3	4
Ottenwalder (1995) & Ottenwalder and León (1999) [e]	49	418	5		nr	159	nr
Pugibet and Vega (2000)	26	50				39	
Lancho et al. (2006)	1	6	2	10		3	7
Domínguez Tejo (2006)	9	23	15	87		37	26
Domínguez Tejo (2007)	2	138	34	240		173	77
Domínguez Tejo (2009)	3	17	10	38		27	26
Domínguez Tejo (2010)	1		2	3			3
Auil Gómez et al. (2011)	10	63	22	65	5	nr	13
Reynoso et al. (2011)	12		10		36		25

In 1994, the NGO Prospectiva Ambiental Dominicana (PAD), started a comprehensive manatee study in the Dominican Republic. Over 400 country-wide interviews were completed between 1994 and 1996 (providing over 150 manatee sightings to the database), but these results remain unpublished and available only in a report by Ottenwalder and León (1999). The aerial surveys planned for 1995 were not completed due to a tragic accident, and only some general information was published by Ottenwalder (1995). In Table 4 these two documentary archives were pooled together because they arose from the same research project.

Several of the following manatee studies included interviews, land, and boat surveys during short site visits to Caño Estero Hondo, a coastal lagoon in the northwest of the Dominican Republic (Domínguez Tejo 2006; Lancho et al. 2006; Domínguez Tejo 2009, 2010), and other areas around the country like Monte Cristi, Bahía de Samaná, the north coast of Samaná peninsula, Boca de Yuma, and Barahona (Domínguez Tejo 2006, 2009). In 2007, I completed a detailed study of Caño Estero Hondo (Domínguez Tejo 2007), with over 130 interviews, multiple site visits during the year, and 240 h of effort, the highest to date (Table 4). However, this study covered only two coastal segments.

Partial results of the two most recent studies in the Dominican Republic are available in scientific abstracts. They include interviews, boat, and aerial surveys in Bahía de Samaná, and the north coast of Samaná peninsula (Auil Gómez et al. 2011), and aerial surveys in the southwest coast of the country (Reynoso et al. 2011). In both cases, aerial surveys yielded relatively few manatee sightings (Table 4).

Description of database records

Of 889 manatee sighting records in the database, pre-Columbian records accounted for 3%, the period from 1492 to 1900 accounted for only 1%, and the most recent period accounted for the vast majority (96%). This temporal distribution of the records was expected, because fewer documentary archives from the second time period contributed manatee sightings (see Table 3). Writers of that period provided valuable information about manatees, as discussed in following sections, but they were not conducting systematic surveys for manatees, and rarely noted exact times and locations of sightings. Pre-Columbian records, on the other hand, were often recorded by scientists systematically exploring archaeological sites, and reporting manatee bones or bone objects—many of which were ceremonial and richly carved. In the most recent period, a large proportion (92%) were from three decades: the 2000s (when most of the dedicated manatee studies were conducted) contributed 51%; the 1990s with 27%; and the 1970s with 14% (Figure 3**Error! Reference source not found.**).

In general, database records scored high in time reliability, but low in location and evidence reliability, because most sightings lacked geographic coordinates and were generated opportunistically (i.e., by observers not surveying for manatees) (Table 5). Nevertheless, 42% of the records scored 30 or higher in overall reliability, and could be considered of high quality. Most importantly, these reliability attributes allow users to filter the records as needed. As an example of the versatility of the database, Figure 4 illustrates records of different time periods and overall reliability scores.

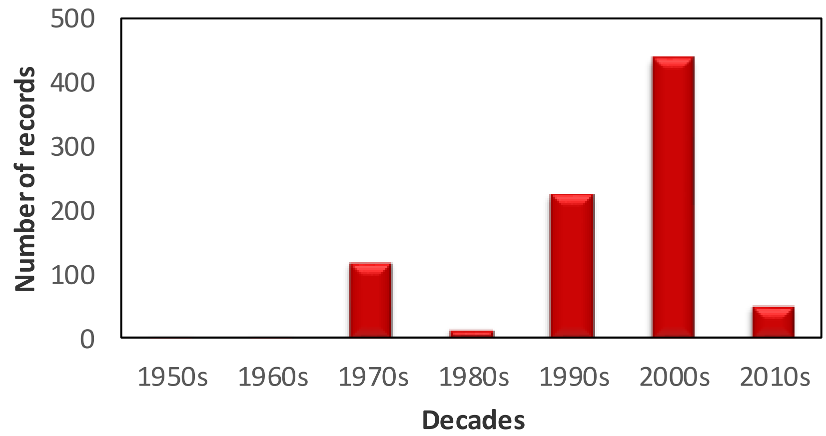


Figure 3: Number of recent manatee sighting records in the database by decade.

Table 5: Time, location, evidence, and overall reliability score of manatee sighting records, n (%). If a cell is empty, there is no record for that category.

Score	Time	Location	Evidence	Overall
0	38 (4)	5 (1)	9 (1)	
5	186 (21)	597 (67)	468 (53)	9 (1)
10	292 (33)	124 (14)	67 (8)	1 (0)
15	373 (42)	23 (3)	219 (25)	160 (18)
20		140 (16)	126 (14)	285 (32)
25				56 (6)
30				70 (8)
35				12 (1)
40				135 (15)
45				21 (2)
50				98 (11)
55				42 (5)
Total	**889**	**889**	**889**	**889**

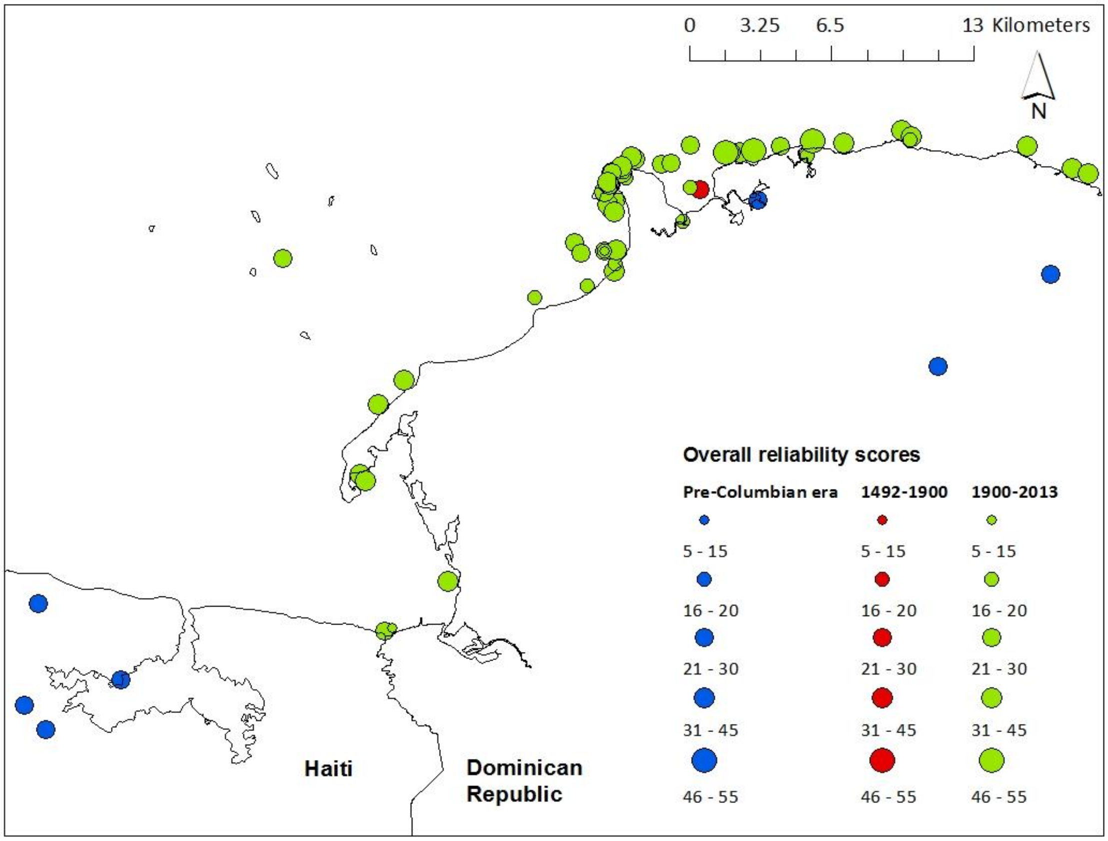


Figure 4: Manatee sighting records of different time periods and overall reliability scores from the northern coast of Hispaniola.

Manatee distribution in Haiti

Of 889 database records, only 22 (2%) were located in Haiti. Records from before the 1900s suggest that manatees were historically more widely distributed, and that they occupied some freshwater habitats (Figure 5).

Four pre-Columbian records were derived from archaeological explorations in 1934 and 1935 by Rainey (1941), and Rouse (1941), around Fort-Liberté (Figure 5). They found bone picks possibly used for agricultural work, a rib bone possibly used as an anvil, and manatee bone fragments.

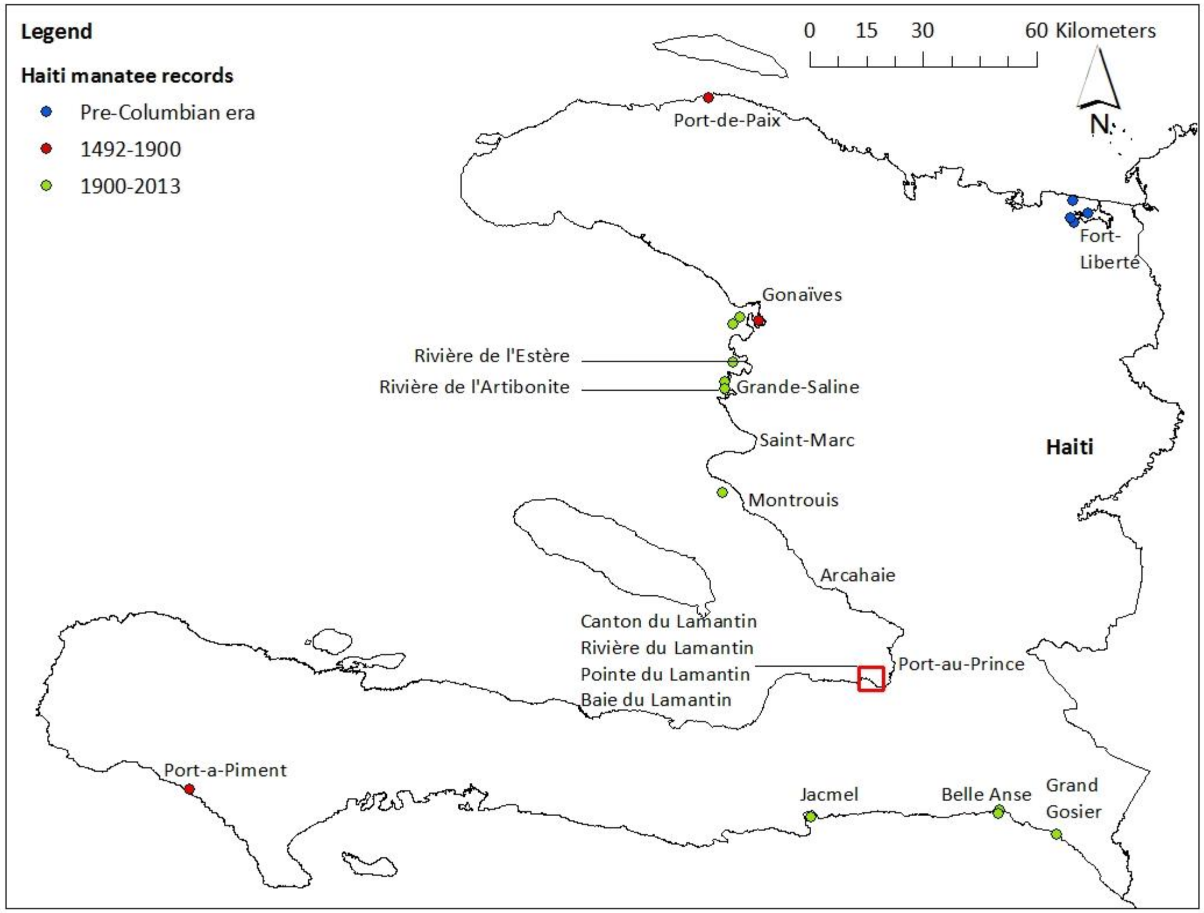


Figure 5: Manatee sighting records of different time periods in Haiti. The map shows the approximate location of the mouths of two historically important rivers for manatees: Rivière de l'Estère and Rivière de l'Artibonite. A former manatee river, point, bay, and administrative division were located within the enclosed area near Port-au-Prince.

Five records came from the period from 1492 to 1900. According to de Charlevoix (1731), manatees were more common in Etang des Gonaïves (the lake of Gonaïves) than in any other place in Hispaniola (Figure 5). Moreau de Saint-Méry (1798), mentioned both Port-de-Paix in the north, and Port-a-Piment in the south, as places where manatees were frequently fished—some weighing more than a thousand pounds. Interestingly, the author also mentioned a Rivière du Lamantin, Pointe du Lamantin, Baie du Lamantin, and Canton du Lamantin (a manatee river, point, bay, and administrative division), all located near present-day Port-au-Prince. Today, a manatee lighthouse (Phare Lamentin), and two manatee streets (Lamentin 52, and Lamatin 54), remain in that area. Descourtilz (1809), mentioned that manatees were sometimes found in Rivière de l'Artibonite, but more particularly in Rivière de l'Estère. Figure 5 shows the approximate location of the mouths of these two rivers. However, the author's descriptions imply that manatees were commonly hunted inside the rivers; therefore, they occupied freshwater habitats.

Thirteen recent records from 1900 to 2013 were located in two areas: from Gonaïves to Montrouis, and from Jacmel to Grand Gosier (Figure 5). Most records date back to 1982 or 1983 (Rathbun et al. 1985), but both areas have sightings from 2007 or later. The latest record in the database was a manatee killed just north of Grande-Saline in 2013 (J. Wiener, personal communication). Manatees may no longer occupy rivers in Haiti because they have become non-navigable. However, dedicated manatee studies are needed to confirm extirpated habitat in general.

Manatee distribution in the Dominican Republic

Of 889 database records, 867 (98%) were located in the Dominican Republic. The distribution of the earliest records suggest that manatees historically occupied some freshwater habitats; but unlike in Haiti, both historical and recent records were widely distributed around the country (Figure 6 and Figure 7).

Twenty four records were pre-Columbian (Figure 7). One photographic record of worked manatee ribs came from an archaeological site by Laguna de la Piedra, in Monte Cristi province, collected by ADMAT staff (Figure 8). The remaining records came from published books or journal articles about archaeological studies. Objects typically found were manatee teeth and unworked bones, bone utensils (e.g., picks, adzes, hoes, and pestles), amulets or idols, or objects used by the aborigines during religious rituals.

Manatee bones or carved bone objects were found in the following provinces in the Dominican Republic: Azua (Veloz Maggiolo 1976); Distrito Nacional (Herrera Fritot & Youmans 1946; Veloz Maggiolo 1972; Cassá 1974; García Arévalo & Chanlatte Baik 1976; Veloz Maggiolo 1976; Scott 1985; Veloz Maggiolo 1993); La Altagracia (Cassá 1974; García Arévalo & Chanlatte Baik 1976; Hall 1978; Morbán Laucer 1988; Veloz Maggiolo 1993); Monte Cristi (Miller 1929; Krieger 1930a, b, 1931); Puerto Plata (VanderVeen 2005); San Pedro de Macorís (Miller 1916; de Booy 1919; Veloz Maggiolo 1976; García Arévalo 1983; Scott 1985); and Samaná (Krieger 1929; Miller 1929; Krieger 1930a, 1931).

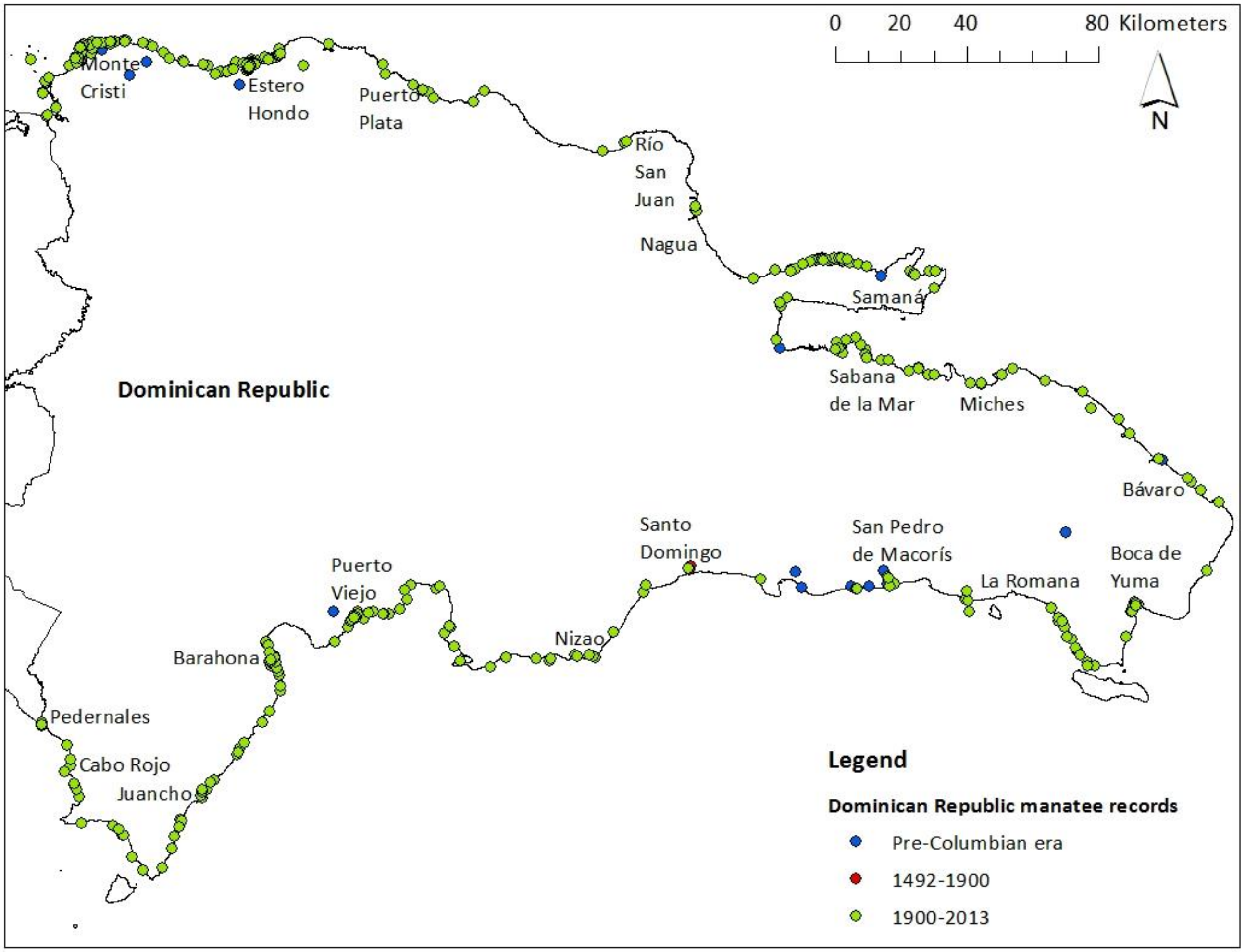


Figure 6: Manatee sighting records of different time periods in the Dominican Republic.

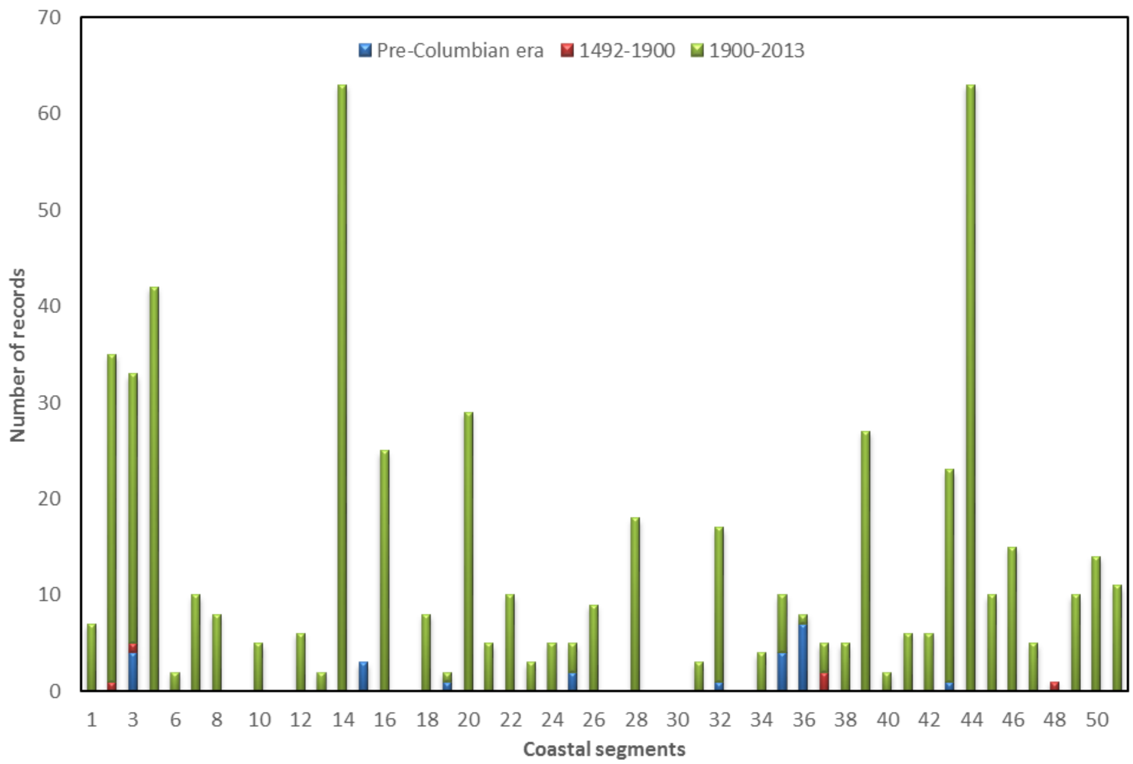


Figure 7: Number of manatee sighting records in each coastal segment of the Dominican Republic. Due to the large number of records (n=281), coastal segment 5 was omitted.

Figure 8: Manatee bones collected during ongoing archaeological studies in Monte Cristi, Dominican Republic. Left panel: Worked bones from an archaeological site at Laguna de la Piedra. Right panel: Unworked rib fragment rescued from a 1720-1723 ship wreck at Ensenada La Granja.

Five database records came from 1492 to 1900 (Figure 7). The first is from Columbus' log during his first voyage to America, when he sighted three "sirens" in January 1493 near Río Yaque del Norte, in the northwest coast of the Dominican Republic (de Herrera y Tordesillas 1726; de Charlevoix 1731; Fernandez de Navarrete 1858; Hazard 1873; de las Casas 1875; Baughman 1946; Husar 1977). Columbus had already seen manatee skulls in Cuba in October 1492 (Royero 1995) but mistook them for cows. In his general history of the West Indies, first published in 1535, Fernández de Oviedo y Valdés mentioned that manatees grazed on the banks of Río Ozama (the river that bisects Santo Domingo city), where many large manatees were harpooned from boats and canoes (Fernández de Oviedo y Valdés 1992). The missionary de Acosta wrote that he ate manatee meat in Santo Domingo city, possibly in 1571 or 1572 when he stopped there on his way to the Jesuit mission in Peru (de Acosta 1590; Baughman 1946; Husar 1977; Lefebvre et al. 2001). As mentioned above, two unworked manatee ribs were recently recovered by ADMAT from a 1720-1723 sunken ship known as the "Tile Wreck" in Ensenada de La Granja, Monte Cristi province, in the northwest of the Dominican Republic (Figure 8). In the early 19th century, Walton (1810) mentioned a manatee seen near Isla Beata in the south west coast, but the sighting could not be referenced to a specific coastal segment.

Unsurprisingly, recent manatee records were by far the most numerous (n=838) (Figure 7). Their location was widespread but uneven. Taken together, coastal segments 1 to 4, accounted for 13% of the database records. Coastal segment 5 alone accounted for 34% of the records (n=281), due to the multiple manatee studies conducted in Caño Estero Hondo. This segment was omitted from Figure 7 to help visualize the results for the rest of the coast. Segments 14 to 16 accounted for 11% of the records, and segments 43 to 47 accounted for 15%. Segments 20 and 39 each accounted for 3% of the records. These coastal segments concentrated most of the manatee sightings from all time periods. The remaining segments represented up to 2% of the records each.

Of the 51 coastal segments of the Dominican Republic, eight lacked data for any time period, but these were spread around the country, surrounded by other segments with manatee sightings. Possible explanations for the lack of sightings include: unsuitable habitat, such as areas exposed to wind and wave action (segments 9, 11, and 27); areas with dark murky waters and high boat traffic (segment 17); areas in which few dedicated manatee studies have been conducted (segment 33, 48); and areas where sightings were not detailed enough to create a database record. For example, there is anecdotal evidence of manatees drinking from fresh water springs on the south coast of Isla Saona (segments 29, 30) (LaBastille 1999), but with no specific date and location. The sighting of a manatee by Walton (1810) near Isla Beata could have occurred in segment 48.

Segment 15 only had historical records previous to the 1900s, but I do not believe it represents extirpated manatee habitat. This segment has a mostly exposed coastline, but is located next to segment 14, which has favorable manatee habitat (Domínguez Tejo 2009) and over 60 recent records. The archaeological site in segment

15, Río San Juan (Krieger 1929; Miller 1929; Krieger 1930b, 1931), is located close to the border with coastal segment 14. It is possible that the manatee bones found there came from manatees captured in the neighboring segment 14, or that manatees use segment 15 as a travel corridor and are simply difficult to observe.

Ten coastal segments had both historical and recent records, and the remaining thirty-two segments only had recent records (after 1900). It is unlikely that the manatee population has expanded in the Dominican Republic, because manatees were more abundant in the past, as discussed in a following section. A number of archaeological sites have been explored in the country (Veloz Maggiolo 1972), but manatee bones and bone objects are relatively rare. Manatee bones at archaeological sites show signs of cuts and fractures, evidence that carcasses were butchered to extract and transport the meat back to the settlements, while most of the heavy skeleton was left behind (Veloz Maggiolo 1976). Another possible reason for this paucity of material is related to the social structure of the Taíno, the most advanced aboriginal culture at the time of arrival of the Europeans. Ceremonial objects made of manatee bone were richly carved and detailed, and likely belonged to few individuals in positions of power in the community. Furthermore, archaeological looting is ubiquitous (Pagán Perdomo 2000), and one can expect that such beautifully carved objects have been targeted frequently.

Figure 9 shows recent records for each coastal segment, excluding segment 5 due to its large number of records (n=278). The spatial distribution of the data is virtually the same as Figure 7. Both manatee strandings and captures were widespread, and in general, occurred more frequently in coastal segments with more sightings of live and unharmed animals in the water (referred to as normal sightings in Figure 9).

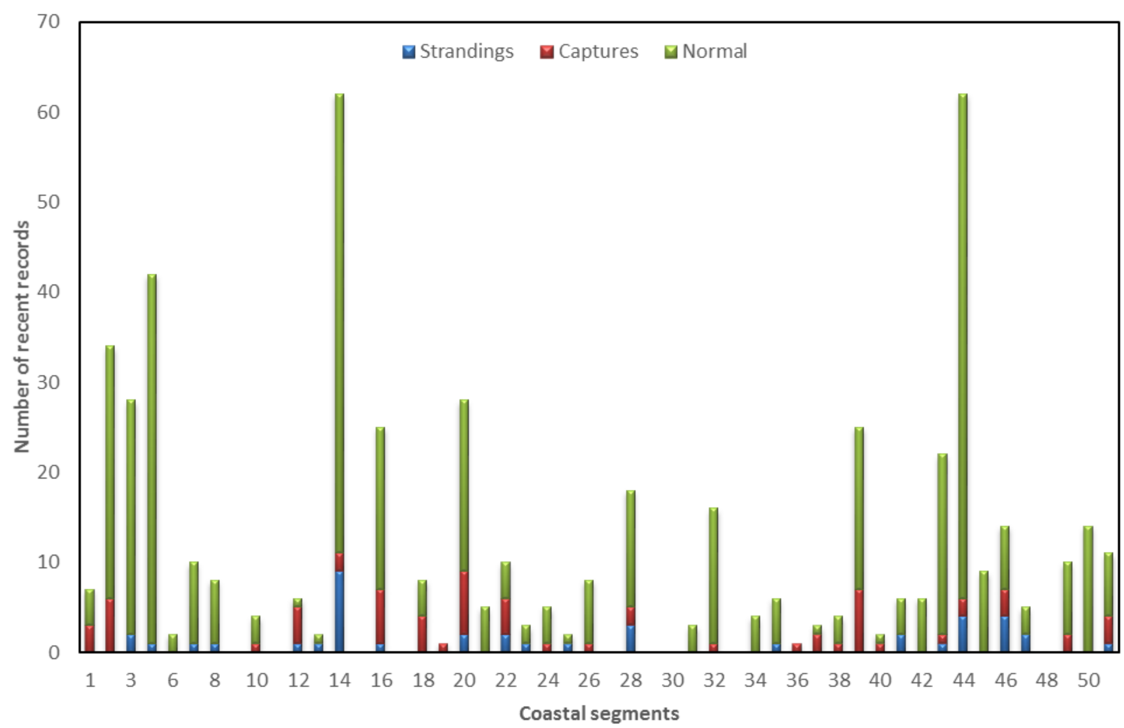


Figure 9: Number and type of recent manatee sightings in each coastal segment of the Dominican Republic. Due to the large number of records (n=278), coastal segment 5 was omitted. Normal: sightings of live, unharmed animals in the water.

Some freshwater habitats may still be occupied occasionally by manatees. Fishers have reported manatees inside Río Higuamo (coastal segment 35) since the 1960s, and as recently as in 2009. In 2012, one manatee was rescued from inside Río Haina (in coastal segment 38) and transported to Acuario Nacional for rehabilitation.

Manatee abundance, mortality, and population trend

From the pre-Columbian era to the beginning of the 19th century, manatees were considered abundant in Hispaniola (Table 6). Authors referring to the pre-Columbian era based their opinions on previous writers like Fernández de Oviedo y Valdés (Mañón Arredondo et al. 1971), or did not provide references (Veloz Maggiolo 1972; Soto-Ricart & Rodríguez 1989). However, documents from 1492 to 1900 offered stronger support. A few authors like Cuneo, who accompanied Columbus during his second voyage to America (Vega 1983), de Charlevoix (1731), and Lyonnet (1800-10), commented on the abundance of fish in Hispaniola, listing manatees among them. But other authors from that period made explicit references to the abundance of manatees. Pedro Mártir de Anglería, one of the major chroniclers of the West Indies, said that manatees were found in great numbers in the waters of Hispaniola (MacNutt 1912). Fernandez de Oviedo y Valdés (1992) testified to the abundance of manatees in Río Ozama, and also said manatees were killed frequently in the larger rivers of Hispaniola. In Haiti, Moreau de Saint-Méry (1798) mentioned how frequently manatees were fished in Port-a-Piment and Port-de-Paix. Descourtilz (1809), even noted that the best time of day to go hunting for manatees was from noon to 2 pm, when they would graze on the river banks of Rivière de l’Estère and Rivière de l'Artibonite. Manatees had been hunted since pre-Columbian times, and towards the end of the 19th century they became rare. For example, Hazard (1873) mentioned that manatees had been more plentiful before, and were now found only at rare intervals.

Table 6: Indications of manatee abundance, mortality, and population trend, extracted from documentary archives of different time periods. [a] references for time period 1492-1900 are ordered chronologically by birth year of the original author. [b] original author is in brackets.[c] indicates estimates for the Estero Hondo-Isabela area only. [d] indicates individual estimates for three areas: Las Calderas, in La Altagracia province; near Barahona town, in Barahona province; Bahía de Rincón, in Samaná province. [e] indicates estimates provided for El Estillero only, on the north coast of Samaná province. If a cell is empty, there is no information available.

Reference	Abundance	Mortality (deaths/year)	Population Trend
Pre-Columbian era			
Mañón Arredondo et al. (1971)	Abundant (rare now)		(Declining now)
Veloz Maggiolo (1972)	Abundant		
Soto-Ricart and Rodríguez (1989)	Abundant		
1492-1900 [a]			
Vega (1983) [Cuneo, 1495] [b]	Abundant		
MacNutt (1912) [de Anglería, 1530] [b]	Abundant		
Fernandez de Oviedo y Valdés (1992)	Abundant	Many	
de Charlevoix (1731)	Abundant		
Lyonnet (1800-10)	Abundant		
Moreau de Saint-Méry (1798)	Abundant	Many	
Descourtilz (1809)	Abundant	Many	
Hazard (1873)	Rare		Declining
1900-2013			
Campbell and Irvine (1975)		3 min.	Declining
Crombie (1975)			Declining
Belitsky and Belitsky (1978)	60 (41-402)		Declining
Thornback and Jenkins (1982)	Rare		
Rathbun et al. (1985)	Rare		Declining
Lefebvre et al. (1989)	Never abundant		
Woods and Ottenwalder (1992)	Rare		
Ottenwalder (1995)	<60	5-15 min.	Declining
Ottenwalder (1996)	8 [c]		
Ottenwalder and Leon (1999)		9 to 23	Declining
LaBastille (1999)			Declining
Pugibet and Vega (2000)	30-45	3 to 5	Declining
Lefebvre et al. (2001)	<200	5 to 15	Declining
D'Ocampo (2004)	7 to 8 [c]		

Lancho et al. (2006)	15 to 20 [c]		
Dominguez Tejo (2006)	<10 [d]		
Dominguez Tejo (2007)	10 to 15 [c]	1 to 2 [c]	Increasing [c]
Dominguez Tejo (2009)	<10 [e]	0 to 1 [e]	Increasing [e]
Reynoso et al. (2011)	Not abundant		Not increasing

In the most recent period, some authors have provided quantitative estimates of the manatee population size in Hispaniola, but these should be regarded with caution. To date, only a few distributional aerial surveys have been conducted, none of which were designed to generate estimates of abundance. Other estimates are derived from interviews, and represent educated guesses, at best. The lowest country-wide value of 30-45 animals by Pugibet and Vega (2000) was clearly an underestimate, because they also reported 16 manatee deaths recorded by the Dominican Stranding Network from 1995 to 2000. The largest country-wide estimates were reported by: Belitsky and Belitsky (1978), who estimated a population of 60, with 95% confidence limits of 41-402; and Ottenwalder, who estimated less than 200 animals (Lefebvre et al. 2001). The remaining quantitative estimates only apply to specific areas in the Dominican Republic, especially to coastal segment 5, with 7 to 20 animals (Ottenwalder 1996; D'Ocampo 2004; Lancho et al. 2006; Domínguez Tejo 2007).

Early estimates of the mortality of manatees in Hispaniola were also qualitative in nature (Table 6). As mentioned above, many manatees were killed from the 16th to 19th centuries. But contrary to other portions of their range, manatees were not commercially hunted in Hispaniola. From 1500 to 1800, the major island exports changed from gold to sugar, leather, livestock, ginger, cocoa, tobacco, and finally wood (Cassá 1978). It is possible that manatee meat was imported to Hispaniola, among other Caribbean islands, during that period. For example, du Tertre (1667) stated that several ships loaded with manatee meat from the continent and neighboring islands were brought every year to Saint Kitts (St. Christophe), Guadeloupe, Martinique, and other nearby islands. Lefebvre et al. (2001) also mentioned commercial exploitation of manatees in South America for export to the West Indies during the 17th to 19th centuries.

Quantitative country-wide mortality estimates in the most recent period varied from 3 to 23 animals per year. Ottenwalder (1995) mentioned that between 5 and 15 manatees were captured per year (most intentionally), in addition to an unknown level of natural mortality. Ottenwalder and León (1999) reported 56 dead animals from 1991 to 1996, for an average of 9 deaths per year. However, in the same study, interviewees were asked how many manatees were captured annually in their area on average; the sum of the annual averages was 23 for the Dominican Republic alone.

From the end of the 19th century to the present, the manatee population trend of Hispaniola decreased (Table 6). The only exceptions were Caño Estero Hondo, and El Estillero, two small areas where interviewees perceived that manatees have increased in number during recent years (Domínguez Tejo 2007, 2009).

Despite the estimates of annual mortality, manatees are still widespread in the Dominican Republic (Figure 9). And, despite the lack of dedicated manatee surveys since

1983, manatee sightings are still occasionally reported in Haiti. The latest manatee population estimate for the neighboring Puerto Rico was 342-802 individuals (Drew et al. 2012). With a coastline length six times that of Puerto Rico, the current manatee population in Hispaniola might be in the low hundreds and larger than estimated so far.

Manatee hunting methods and uses

Manatees have been hunted in Hispaniola throughout history, most commonly with nets and harpoons (Table 7). One remarkable method that persisted at least until the colonization of the West Indies, was the use of remoras or sharksuckers, *Echeneis naucrates* and *Echeneis neucratoides*. Early chroniclers like de Anglería described remora fishing for big fish and sea turtles (MacNutt 1912). Fernandez de Oviedo y Valdés (1992), and Cobo (1892), added manatees to that list. The method involved capturing and taming young remoras, and then using them to catch bigger prey. After spotting a desired prey, the fishers would release the trained remoras from their canoes tethered with a line. When the remoras attached with their powerful suction disk to a bigger fish, turtle, or manatee, the fishers would pull on the line to retrieve their catch.

The use of remoras for fishing has also been reported for Africa, Asia, Australia, South America, and the West Indies (De Sola 1932). Gudger (1919) traced back references about the use of the remora as “a living fish-hook” in Madagascar and the West Indies. The custom was still alive in the early 20th century in Cuba, where De Sola (1932) witnessed remora fishing for sea turtles in Matanzas. Remoras are commonly found associated with manatees in the Caribbean (Williams et al. 2003), and it is possible that the aborigines of Hispaniola were able to capture at least manatee calves with this ingenious method.

Table 7: Manatee hunting methods extracted from documentary archives of different time periods. [a] indicates how many times a particular method was mentioned from the total number of documentary archives that described manatee hunting (N=23). If a cell is empty, there is no information available.

Hunting method	Pre-Columbian era	1492-1900	1900-2013	Freq. [a]
Bow and arrow	x			1
Remora (sharksucker)	x	x		3
Spear	x		x	3
Net	x	x	x	17
Harpoon		x	x	10
Rifle		x	x	4
Beach seine			x	5
Diving harpoon (spear gun)			x	2
Fola			x	1
Gill net			x	2
Trap			x	1

Manatee hunting with metal harpoons started with the arrival of the Europeans, because the aboriginal peoples of Hispaniola did not use metal (except for gold ornaments). The harpoon was used from boats or canoes; a rope was attached to the harpoon on one end, while the other end carried a cork or piece of wood as a float (Fernández de Oviedo y Valdés 1992). Once harpooned, an animal would swim away rapidly. The loss of blood and the effort of the escape would fatigue the animal, while the fishers would follow the float. Animals were recovered and brought to the beach using the rope.

This method of manatee capture was similar in other Caribbean islands with some variations. For example, in the Lesser Antilles, an iron harpoon was inserted into a long wooden bar that was dropped into the water once the animal was hit. The harpoon remained attached to the rope, and the other end of the rope was tied to the canoe, such that the animal would tire out faster with the added drag of the vessel and its occupants (du Tertre 1667; Labat 1724).

Sometimes methods were combined. For example, Fernández de Oviedo y Valdés (1992) described the use of the remora with a rope and a cork or piece of wood as a float, and a harpoon. Nets were used to capture small manatees, whereas adults were caught from land, when grazing along the sea shores and rivers (de Herrera y Tordesillas 1726; de Charlevoix 1731; López de Gómara 1991). Descourtilz (1809) also mentioned how manatees were caught by using nets in the places where they grazed, or by shooting with a rifle from a canoe, but harpooning was the most common capture method.

Regardless of the method used, early authors also noted that manatee cows and calves did not separate, so if one was caught, the other one usually suffered the same fate (du Tertre 1667; Oexmelin 1774).

In the period from 1900 to 2013, specific types of nets were mentioned, like beach seines, gill nets, and folas. The fola is similar to a gill net, but has a large mesh size, is made of strong fabric thread (not nylon), and is designed to catch large animals.

Diving harpoons or spear guns, and traps, were also eventually added to the list of hunting gear.

Table 8 shows the uses given to different manatee body parts throughout the three time periods in Hispaniola. The use of manatee meat as food was the most common, and the only one that persisted throughout all time periods. In the second time period, several authors described how good manatee meat was, with its different flavors like beef, tuna, and pork (Durand 1983). Moreover, because manatees were considered fish, their meat was gladly eaten during Lent (Durand 1983).

However, eating manatee meat was not always popular. The Spanish Jesuit missionary Bernabé Cobo, ate manatee meat in Hispaniola, probably around 1596-1597. By then, manatee meat was perceived as a coarse meal, and many did not want to eat it because, if they had suffered from syphilis, they believed the illness would return (Cobo 1892). Centuries later, Sánchez Valverde (1947) repeated the belief that eating manatee meat was feared by those who had this disease, because it made them erupt. Other reasons not to eat the meat were related to the noble character of manatees: Moreau de Saint-Méry (1798) wrote that the animal's sensitivity and the affection it showed for its calves prevented some people from eating it.

Table 8: Uses of manatees extracted from documentary archives of different time periods. [a] indicates how many times a particular use was mentioned from the total number of documentary archives that described uses of manatees (N=63). If a cell is empty, there is no information available.

Body part	Use	Pre-Columbian era	1492-1900	1900-2013	Freq. [a]
Meat	Food	x	x	x	51
	Bait			x	1
Oil/ fat	Cooking		x	x	8
	Lighting (lamp fuel)		x	x	4
	Marinating the skin		x		2
	Medicinal		x	x	5
	Aphrodisiac			x	1
	Beauty			x	1
Skin	Belts		x	x	3
	Shoe soles		x	x	7
	Other leather products		x		4
	Bait for lobster trap			x	1
	Food			x	1
	Leather straps			x	3
	Machete sheath			x	1
	Whips			x	1
Bones	Amulets or idols	x			5
	Ceremonial objects (vomiting spatula, bowl, spoon, inhaler)	x			28
	Ear adornments	x			2
	Utensils (adze or hoe, anvil, arrow and spear head, bone pick, sculpting or polishing instrument)	x			9
	Pestle	x		x	3
	Medicinal (earbones)		x		7
	Aphrodisiac			x	1
	Carved ornaments			x	2
	Handcrafts (button, machete and gun handle, necklace, other)			x	5
	Medicinal (ribs)			x	5
	Sold to scientists			x	1
	Witch craft			x	1
Other	Recreational			x	3
	Selling desiccated animals			x	1

Manatee oil or fat was mainly used for cooking, lighting, and medicine, starting in the second time period, and continuing to recent times. The only medicinal use of manatee oil described in the literature was to treat chest colds (Mignucci-Giannoni 1991). In the second time period, manatee oil was also used to marinate manatee skin to make shoes (de Herrera y Tordesillas 1726). In recent times manatee oil has been used as an aphrodisiac and for beauty purposes (Ottenwalder & León 1999).

In the second time period, manatee skin was used to make shoe soles, belts, and other leather products (de Herrera y Tordesillas 1726; de Charlevoix 1731; Cobo 1892; López de Gómara 1991; Fernández de Oviedo y Valdés 1992). In the most recent time period, leather straps for paddle handles (Domínguez Tejo 2007), machete sheaths, and whips were added (Ottenwalder & León 1999). Skin was also used for food (similar to pork rinds), and as bait for lobster traps (Ottenwalder & León 1999).

The aboriginal peoples of Hispaniola had many uses for manatee bones, especially for ceremonial purposes. One of their religious rituals required them to purge before entering a temple, and to inhale powdered hallucinogenic plants. Ceremonial manatee bone objects included vomiting spatulas or swallowing sticks: long implements carved from manatee ribs that they used to induce vomit. They also carved bowls and small spoons to hold the powdered substances, and Y shaped tubes to inhale them. Other objects included small amulets or idols, and ear adornments. Examples of these objects are found in the archaeological literature (Fewkes 1907; Krieger 1929, 1930a; Herrera Fritot & Youmans 1946; Mañón Arredondo et al. 1971; Baztan Rodrigo 1972;

Veloz Maggiolo 1972; Cassá 1974; García Arévalo & Chanlatte Baik 1976; Veloz Maggiolo 1976; García Arévalo 1983; Scott 1985; Morbán Laucer 1988; Soto-Ricart & Rodríguez 1989; Veloz Maggiolo 1991, 1993). Manatee bones were also converted to utensils like adzes or hoes, or bone picks, among others (Krieger 1929, 1930a, 1931; Rainey 1941; Rouse 1941). These uses of manatee bones stopped when the aboriginal population was decimated under Spanish rule. By the year 1533, only about 600 natives were left in Hispaniola (Krieger 1930a) and their culture died out.

In the second time period, manatee ear bones acquired several medicinal uses for treating: renal and urinary lithiasis (formation of calculi and concretions) (de Herrera y Tordesillas 1726; de Charlevoix 1731; Cobo 1892; López de Gómara 1991; Fernández de Oviedo y Valdés 1992); urinary tract infections (Cobo 1892), colics (de Charlevoix 1731), and "diseases of the head" like epilepsy or falling sickness, and vertigo (Oexmelin 1774).

In recent times, manatee bones have been used for handcrafts, and for medicinal purposes. The latter requires pulverizing the rib bones and drinking the powder in a beverage to cure or treat: menses (Ottenwalder & León 1999), asthma (Ottenwalder 1995; Ottenwalder & León 1999; Domínguez Tejo 2007), arthritis, rheumatism, diverse body aches, epilepsy, cancer, and syphilis (Ottenwalder & León 1999). Bones are also used as an aphrodisiac, a contraceptive, and a guard against the evil eye (Ottenwalder & León 1999).

It is possible that some of these medicinal uses originated earlier in other areas of the Caribbean or South America, and slowly percolated into Hispaniola. For example, while describing manatees in Martinique, Labat (1724) mentioned that ribs were used for hemorrhages and the fluxes and losses of blood. When describing manatees in the Orinoco River, Walton (1810) mentioned the rib powder was administered to stop the bloody flux, and that the Spaniards used soaps made of manatee flesh as an anti-venereal. It is also possible that some earlier beliefs were transformed with time. For example, the current use of manatee ribs to cure epilepsy could have come from the use of manatee ear bones for the same purpose (Oexmelin 1774). The use of manatee ribs to cure syphilis could be related to the previous belief that manatee meat made the illness resurface (Cobo 1892).

One positive use listed in Table 8 that could help conserve the species is for recreational purposes, as the public has become more educated and sensitive to the dire situation of manatees. The tragic accident during the manatee aerial survey of 1995 in the Dominican Republic, several education and awareness campaigns, and the rescue and rehabilitation of a few manatees in the Acuario Nacional since then, have influenced people's perception of the species. Manatee watching is now the major attraction in Caño Estero Hondo, and many coastal communities proudly protect their manatees. Current initiatives in Haiti include: the creation of the first two protected areas in 2013-2014 that include optimal manatee habitat identified by Rathbun et al. (1985); the development of marine mammal ecotourism by the Haiti Ocean Project.

Threats to manatees and their habitat

Threats to manatees in Hispaniola are mainly anthropogenic in nature. The most common ones include: hunting, entanglement in fishing gear, boat strikes, contamination, habitat degradation or destruction, and lack of law enforcement (Table 9). The main driver for the illegal hunting of manatees in the Dominican Republic is the meat which is sold on the black market; bones are used for medicinal purposes, and can be retrieved later for commerce (Ottenwalder 1995). Entanglements of manatees in gill nets and beach seines occur when they are used in prohibited areas, or are left unattended for long periods. Animals caught accidentally are either discarded, to avoid problems with the law in the Dominican Republic, or retained for food.

Table 9: Threats to manatees and their habitat extracted from recent documentary archives.[a] indicates how many times a particular threat was mentioned from the total number of documentary archives listing threats to manatees (N=29).

Threat	Freq. [a]
Illegal hunting	24
Entanglement in fishing gear	17
Boat strikes	11
Contamination	8
Habitat degradation/destruction	7
Lack of law enforcement	4
Noise	3
Shark predation	3
Commerce in bones and oil	2
Hurricanes	1
Lack of freshwater	1
Marine debris, ghost nets	1
Outdated laws	1
Poverty	1
Sedimentation	1

Coastal development, especially for the tourism industry, has resulted in habitat degradation or destruction in many parts of the country. As a consequence of the growth of tourism, boat traffic has increased in coastal habitats. Small boats navigate close to the coast, increasing underwater noise levels, possibly discouraging animals from using high traffic areas, and increasing the risk of boat strikes. Examples of areas with current high boat traffic are: several kilometers of coastline west of Punta Rucia, in Monte Cristi province (coastal segment 4); the coastline from Río Naranjito to Bahía de San Lorenzo in Hato Mayor province (coastal segments 19-20); the coastline from La Romana to Isla Saona, in la Altagracia province (coastal segment 32).

Contamination is ubiquitous in the waters around the island. One area of particular concern is just north of Barahona town, in Barahona province (coastal segment 44). Manatees are sighted daily in an area that receives sewage from a sugar mill, a duty free zone, and two small creeks of putrid waters (Domínguez Tejo 2006). To date, no manatee health assessments have been conducted in Hispaniola, and their contaminant loads are unknown.

Lack of law enforcement is a complex problem. Local authorities may lack the directive and the necessary equipment, logistical support, training, and education, to patrol areas effectively and regularly, so manatee captures may be hidden. Law enforcement agents may want to avoid making enemies in their community, and can be bribed. Offenders may get away with manatee captures for political reasons or personal contacts (Ottenwalder & León 1999). Outdated protection laws and the weakness of legal sanctions are also part of this threat.

Commerce of manatee products in markets has not been formally studied in Hispaniola. But a one-time visit to the city market of Santo Domingo in 1990 showed that several stores sold polished and carved manatee ribs as ornaments, and manatee oil to treat colds (Mignucci-Giannoni 1991). Whether this illegal commerce has increased or decreased is unknown.

The only natural threats listed in the documentary archives were shark predation and hurricanes. Belitsky and Belitsky (1978, 1980) compiled a few reports of shark attacks. The most compelling one was the flight behavior of three manatees with a shark in pursuit, in the reefs east north east of El Morro, in Monte Cristi province, reported by a helicopter crew in February of 1977. The reference to hurricanes as a threat to manatees came from the country-wide interviews conducted between 1994 and 1996 (Ottenwalder & León 1999). Disease and parasites have not been formally studied, except for a single case in the Dominican Republic in 1995 (Mignucci-Giannoni et al. 1999).

Summary

In this chapter I systematically reviewed documentary archives with information about Antillean manatees in Hispaniola, from pre-Columbian times to 2013. I extracted manatee sighting records from the documentary archives, compiled them in a database, and scored their reliability based on qualitative attributes. I compared dedicated manatee studies in the island, and compared information on manatee distribution, abundance, mortality, population trend, capture methods, and uses throughout time. I also listed recent threats to the species and its habitat.

From a total of 152 documentary archives reviewed, 68% were recent, dating from the 1900s onwards. Only 13 dedicated manatee studies were conducted in Hispaniola from 1975 to 2011; one of them in Haiti in 1982-1983, and the remainder in the Dominican Republic. These studies were discontinuous in time, and lacked uniformity in spatial coverage, survey methods, and survey effort. More recent studies provided better quality data, but covered smaller areas. Few distributional aerial surveys have been completed, none of which were specifically designed to generate a population size estimate. Most studies relied on interviews, and a combination of land and boat surveys.

A total of 889 manatee sighting records were extracted from 116 of the documentary archives: 96% were recent, and almost all (98%) were located in the Dominican Republic. Most sightings lacked geographic coordinates, and were generated opportunistically, but 42% of the records were considered reliable and of high quality. In Haiti, records previous to the 1900s suggest that manatees have contracted their range, and that they occupied some freshwater habitats. Recent records were confined to two coastal departments in the country, Artibonite and Sud-Est. In the Dominican Republic, both historical and recent records were widespread. Manatees historically occupied some freshwater habitats, and manatees were reported in recent times in a few cases in two rivers in the southern coast.

Manatees were historically abundant in Hispaniola, but were hunted for centuries with nets and harpoons for their meat. Towards the end of the 19th century they had become relatively rare. Their meat is still prized, and in the Dominican Republic, their bones are used for medicinal purposes and handcrafts. Mortality estimates in recent times varied from 3 to 23 animals per year in the Dominican Republic alone, and the population is believed to be declining. But there is no reliable estimate of the manatee population size in the island.

Threats to manatees in Hispaniola are mainly anthropogenic in nature. The most common threats are illegal hunting, entanglement in fishing gear, boat strikes, contamination, habitat degradation or destruction, and lack of law enforcement. Natural threats like shark predation and hurricanes are rarely mentioned in the documentary archives, and disease and parasites have not been well studied.

The constant presence of manatees in specific coastal segments of the Dominican Republic, combined with a more educated and sensitive public, offers hope for manatee conservation, as recreational uses become more popular. Positive initiatives in Haiti include newly created protected areas enclosing optimal manatee habitat, and plans to develop marine mammal ecotourism.

CHAPTER 2: Using fishers' traditional ecological knowledge to assess the current status of manatees in Hispaniola

Introduction

Once historically abundant in Hispaniola, Antillean manatees (*Trichechus manatus manatus*) were hunted for centuries for their meat, and became relatively rare towards the end of the 19th century. Currently, the population is believed to be small, declining, and threatened mostly by anthropogenic causes (Chapter 1). Due to the lack of ongoing research and monitoring programs in the Dominican Republic and Haiti, surveys of artisanal fishers are the best means available to obtain insight into the current status of manatees, especially with respect to fisheries-related mortality.

Fishers' Traditional Ecological Knowledge (FEK) has been widely used to complement natural science research projects, and to develop management and monitoring strategies in the marine environment (Huntington 2000; Johannes et al. 2000). The perceptions of different generations of fishers can provide insight into shifting environmental baselines (Pauly 1995; Sáenz-Arroyo et al. 2005a; Sáenz-Arroyo et al. 2005b). Most direct survey research on manatees in Hispaniola is outdated. Initial country-wide studies were based on informal interviews (Campbell & Irvine 1975; Belitsky & Belitsky 1978); only one survey was conducted in Haiti (Rathbun et al. 1985). Posterior structured interviews in the Dominican Republic were unpublished (Ottenwalder & León 1999), too few in number (Pugibet & Vega 2000), or too limited in geographic extent (Domínguez Tejo 2007, 2009; Auil Gómez et al. 2011) to represent the entire country. These previous studies targeted a mixed group of participants, and did not address the potential for shifting baselines in their study design.

In this chapter, I present the results of the first survey research in the Dominican Republic and Haiti to evaluate the status of Antillean manatees in Hispaniola based on FEK. The specific objectives of this research were: (1) to describe manatee distribution; (2) to assess the magnitude of manatee mortality; (3) to identify overlaps of manatee hotspots with potentially harmful fishing activities in the Dominican Republic; (4) to evaluate perceived trends in manatee abundance and captures; and (5) to describe the cultural value of manatees for fishers, and their attitudes towards manatee conservation. The survey was based on a standardized questionnaire, targeting over 670 small-scale artisanal fishers of three age groups, to account specifically for shifting baselines.

Methods

Questionnaire and field trials

In 2012, the Regional Activity Center for the Specially Protected Areas and Wildlife Protocol (SPAW-RAC) initiated the Manatee Bycatch Pilot Project in several Caribbean countries, including the Dominican Republic and Haiti. The goal of the project was to evaluate the use of a standardized questionnaire to assess some of the principal threats to the West Indian manatee in the Wider Caribbean Region. The questionnaire adopted by the SPAW-RAC was modeled after a general approach developed by Moore et al. (2010) to assess marine mammal and sea turtle captures in artisanal fisheries. The questionnaire was designed for in-person interviews with fishers, to collect data on their fishing practices (e.g., fishing experience, fishing gear, fishing areas), and their knowledge about Antillean manatee distribution, abundance, mortality, and cultural value. Accompanying pictures were used for species identification, and maps were employed to locate spatial data.

The SPAW-RAC questionnaire was translated to Spanish and Haitian Creole, and was pre-tested with purposive sampling (Bernard 2006). In December 2012, 14 local trained volunteer interviewers conducted 101 field trials with artisanal fishers in the Dominican Republic (Domínguez Tejo 2013). In March 2013, four interviewers conducted 48 field trials in Haiti. Minor modifications were made to the questionnaire after these field trials, but maps could not be used in Haiti due to the low literacy level of the respondents.

Survey

Final surveys were conducted with quota sampling (Bernard 2006) based on two strata: age group and geographic region. Fishers from three different age groups were targeted to account for shifting environmental baselines: young (15-30 years), middle-aged (31-54 years), and elder (55 years and older). In the Dominican Republic, the northwest and southwest regions were chosen for comparison because both have suitable manatee habitat, but manatee numbers were low in recent aerial surveys in the southwest (Reynoso et al. 2011). In Haiti, surveys were spread throughout the north, central, and south regions, because of the limited existing knowledge on manatees (Chapter 1). Specific towns were chosen based on local experts' knowledge about areas of likely manatee presence. In each town, 3-5% of the total fisher population was sampled, or at least 5-10 interviews were attempted (Pilcher & Kwan 2011). Country-wide targets of a minimum of 100 respondents in each age group, and 100 in each geographic region, were divided among the chosen towns. Respondents were then selected in each town to fulfill those quotas. In Haiti, 27 towns were surveyed from March to May 2013 by the four interviewers who conducted the field trials. Some of the respondents had not seen manatees personally, but were interviewed to collect information about other marine mammals and sea turtles, in synergy with ongoing projects in Haiti. In the Dominican Republic, 20 towns were surveyed from June 2013 to January 2014 by me. The questionnaire focused only on manatees, and all respondents had seen manatees personally.

Participation in the survey was voluntary, anonymous, and confidential, to protect the identity of the respondents. The survey protocol was approved by Duke University's Institutional Review Board for conducting research with human subjects.

Statistical analyses

Questionnaire results were digitized into an Excel spreadsheet. For most questions, results were summarized with percentages and compared between the Dominican Republic and Haiti. For questions that allowed only one answer, percentages were calculated over the total number of interviewees. For questions that allowed multiple answers, nonresponses were excluded (i.e., blanks, questions not asked, and in some cases the answer "I don't know"), and the percentages were calculated over the remaining valid answers.

Chi-square tests were used to determine whether a relationship existed between selected nominal independent variables, and either nominal or ordinal dependent variables. Cramér's V was used to indicate the strength of the relationship, ranging from 0 to 1, with 0 indicating no association, and values of 0.8 to 1 indicating a very strong association (Rea & Parker 2005).

The Kendall rank coefficient was used to establish whether two selected ordinal variables were statistically dependent. The Tau (τ) coefficient was used to indicate the strength of the relationship, ranging from -1 to 1, with negative values indicating variables that vary inversely, 0 indicating no association, and positive values indicating variables that vary in the same direction.

Statistical analyses were restricted to the level of countries, regions, departments, or provinces, because some of the surveyed towns did not meet the requirement of at least 5-10 interviews. The Grande-Anse department in Haiti was excluded from all statistical analyses because the sample size consisted of only a single fisher. In some of the tests, departments or provinces with small sample sizes were excluded. Analyses were conducted using R statistical software v. 3.1.2 (R Core Team. 2014) and contributed package lsr (Navarro 2015).

Spatial data analyses

Spatial data on hardcopy maps for the Dominican Republic were digitized in ArcGIS 10.3.1. Maps were projected in WGS84 UTM Zone 19 N. Layers of manatee sighting points, polygons of regular manatee areas, polygons of fishing areas, points of freshwater sources, and polygons of freshwater areas were created. The latter two were created for freshwater sources known by fishers, but absent in the topographic maps used with the questionnaire.

To describe manatee distribution in the country, sighting reports from fishers were filtered to keep only those that were: recorded in hard copy maps, located less than 3 km from the coastline of Hispaniola, seen personally by the respondent, seen in the water alive and unharmed, and reported to have occurred in a specific year. The filtered reports were grouped into two time periods, 1950-2009 and 2010-2014, to compare their spatial distribution.

To identify manatee hotspots, the polygons of regular manatee areas were rasterized to 100 m^2 cells, and overlaid to determine how many polygons overlapped per cell (i.e., how many fishers agreed each cell was a regular manatee area). A minimum of 5-10 fishers was interviewed per location, so cells selected by 6 or more fishers were considered manatee hotspots. To identify fishing hotspots that were potentially harmful for manatees, polygons of fishing areas for beach seines and gill nets were rasterized and overlaid, and cells selected by 6 or more fishers were considered beach seine or gill net hotspots, respectively. Fishing hotspots were not identified for other harmful gear, because too few polygons or none were mapped by the respondents. Manatee hotspots and fishing hotspots were then overlaid together to locate and quantify areas of overlap.

Mortality data analyses

Fisheries related mortality included manatee captures and boat strikes. To analyze captures, the following definitions by Hall (1996) were used: a capture was considered everything caught and retained in fishing gear; catch was the portion of the capture with economic value kept by fishers; bycatch was the portion of the capture discarded dead or seriously injured, because it had little or no economic value, or because its retention was prohibited by law; release was the portion of the capture returned to the sea alive and in good condition. Catch, bycatch, and release can contain target and non-target individuals or species. Under this scheme, intentional hunting of manatees was considered target catch. Manatees captured unintentionally but kept were considered non-target catch. Manatees captured unintentionally but discarded dead or seriously injured were considered non-target bycatch.

Non-fisheries related mortality included strandings and animals found in the water that either died from natural or unknown causes, with no signs of interactions with fisheries. Takes were cases were animals were killed intentionally, but not with fishing gear.

For Haiti and the Dominican Republic, capture records and boat strikes were filtered to keep only specific events, seen by the respondent, and reported with a specific year. To eliminate possible duplicates, if two or more records occurred in the same location and year with no additional information to separate them as different events, only one record was retained. Cases where the animal was released, and non-lethal boat strikes were filtered out. Events prior to 2010 were tabulated by decades, and the most recent events were tabulated by year, to obtain annual estimates for fisheries related manatee mortality. The same filtering process was used for dead strandings, dead animals found in the water, and takes, to obtain annual estimates of non-fisheries related manatee mortality.

For island-wide manatee mortality estimates, fisheries and non-fisheries related deaths were summed for both countries. Furthermore, relevant cases from the field trials in the Dominican Republic (Domínguez Tejo 2013), and confirmed cases from the Red Dominicana de Varamientos (RDV) and the Centro de Rescate y de Rehabilitación de Especies Acuáticas (CERREA) were added. Records reported by fishers that coincided with RDV or CERREA records were filtered out to eliminate duplicates.

Results

We surveyed 679 artisanal fishers in Hispaniola: 24% young, 53% middle-aged, and 23% elder (Table 10). Haiti represented 54% of the sample, with 38% of interviewees from the north region, 48% from the central region, and 13% from the south region. Dominican Republic represented 46% of the sample, with about half of the interviewees from each region.

Table 10: Number of interviewees by age group and geographic region in Haiti (HT) and the Dominican Republic (DR). Regions: north (N), central (C), south (S), northwest (NW), and southwest (SW).

Country	HT			DR		Total
Region	N	C	S	NW	SW	
Young (15-30)	49	30	7	42	35	163
Middle-aged (31-54)	68	124	30	64	74	360
Elder (55 and older)	25	24	11	49	45	154
Not asked	0	0	1	1	0	2
Total	**142**	**178**	**49**	**156**	**154**	**679**

For most respondents (82-87%), fishing was the main occupation year-round, and occurred almost daily (Table 11). On average, respondents had over 20 years of fishing experience. Almost all (95%) respondents used motorized boats in the Dominican Republic, compared with only 7% in Haiti. Also, most fishers in Haiti used gills nets, longlines, or traps. In the Dominican Republic, most fishers used hook and line, or diving gear, which included a speargun.

Table 11: General characteristics of the interviewees by country. Percentages were calculated over the total number of respondents per country. Mo: mode.

General characteristics	HT (n=369)	DR (n=310)
Age (years)	18-90 ($\bar{x}$=41)	16-91 ($\bar{x}$=45)
Sex	Male 95%, Female 5%	Male 100%
Frequency of fishing	Main occupation 87% All year 83%	Main occupation 82% All year 94%
Fishing experience	2-60 years ($\bar{x}$=22) 1-7 days/week ($\bar{x}$=6, Mo=6)	1-63 years ($\bar{x}$=26) 1-7 days/week ($\bar{x}$=5, Mo=7)

Boat characteristics	4-8 m long ($\bar{x}$=5) Motorized 7% 8-40 HP (Mo=40)	3-27 m long ($\bar{x}$=5.8) Motorized 95% 4-100 HP (Mo= 15)
Fishing gear used (%):		
Gill nets	48	23
Longline	42	3
Bottom longline	23	10
Hook and line	21	54
Purse seine	7	0
Beach seine	1	7
Traps	25	17
Diving gear	8	48
Other	3	8

Distribution in Haiti

On average, 14 interviews were conducted per town in Haiti (range 1-51). Figure 10 shows the location of the regions, departments, and towns surveyed. As noted above, maps could not be used in Haiti to locate manatee sightings. But 10 mapped sightings, mostly dating from 2010 to 2012, came from Dominican fishers who saw live manatees in Haitian waters, close to the international border, both in the north and south coasts.

Figure 11 shows the number of interviewees in the 27 towns surveyed in Haiti who reported manatee sightings in their lifetime, and within a year of the interview (2012-2013). Overall 43% of respondents had seen manatees in their lifetime. In the towns of Fort-Liberté, Jacquezy, Chouchou, Le Borgne, Grande-Saline, and Les Cayes, more than 70% of respondents had seen manatees in their lifetime. Gonaïves was the only town with more than 10 interviews that lacked manatee sightings. Grande Savane, Grande-Saline, and Saint-Marc, in the Artibonite department, were the only towns where manatee sightings were reported to occur every year.

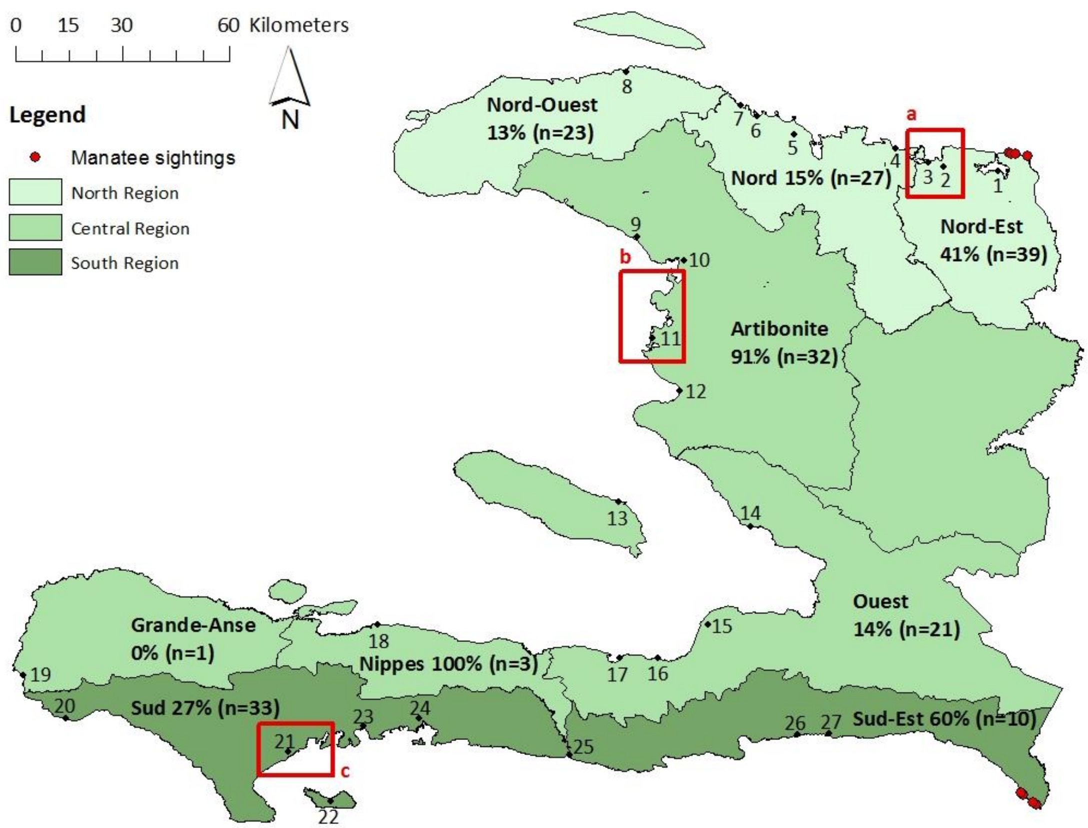


Figure 10: Percentage of interviewees in each department surveyed in Haiti who knew areas where manatees occurred regularly. a, b, and c, enclose the most well-known manatee hotspots. The map includes manatee sightings from Dominican fishers near the international border. Towns visited: 1 Fort-Liberté, 2 Jacquezy, 3 Caracol, 4 Bord de Mer de Limonade, 5 Bas-Limbé, 6 Chouchou, 7 Le Borgne, 8 Port-de-Paix, 9 Grande Savane, 10 Gonaïves, 11 Grande-Saline, 12 Saint-Marc, 13 Anse-à-Galets, 14 Arcahaie, 15 Léogâne, 16 Grand-Goâve, 17 Petit-Goâve, 18 Petit-Trou-de-Nippes, 19 Les Irois, 20 Plaine Kawan, 21 Les Cayes, 22 Île-à-Vache, 23 Saint Louis du Sud, 24 Aquin, 25 Côtes-de-Fer, 26 Cayes-Jacmel, 27 Marigot.

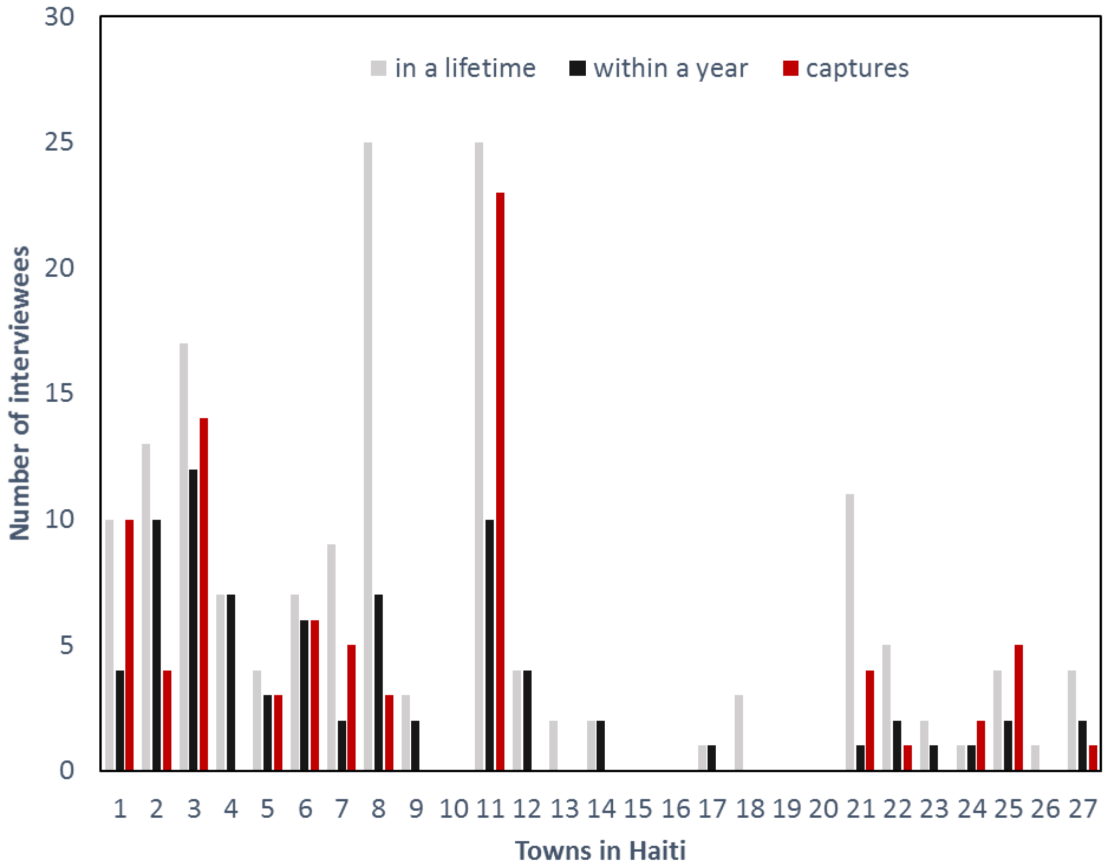


Figure 11: Number of interviewees in the 27 towns surveyed in Haiti who reported manatee sightings during their lifetime, manatee sightings within a year of the interview, and manatee captures. Towns 1-8 were in the north region, 9-19 in the central region, and 20-27 in the south region.

Manatees were sighted in 2012-2013 in 19 towns by 79 respondents (Figure 11). Gonaïves, Anse-à-Galets, and Petit-Trou-de-Nippes, were the only towns with more than 10 interviews that lacked manatee sightings within a year of the interview. No fishers reported daily, weekly, or monthly manatee sightings within a year of the interview.

Both the occurrence and the frequency of manatee sightings depended on the regions and departments surveyed in Haiti, with moderate to relatively strong associations (Table 12). More interviewees reported manatee sightings in their lifetime in the north region (65%), than in the central and south regions (23% and 57% respectively). More interviewees (53%) reported that manatee sightings in their lifetime occurred frequently or every year in the north region, compared with the central and south regions (11% and 4% respectively). Similarly, more interviewees reported manatee sightings in 2012-2013 in the north region (41%), than in the central and south regions (12% and 28% respectively).

Table 12: Independence test results for the occurrence of manatee sightings, regular manatee areas, and manatee captures, by country and geographic divisions. [a] indicates that the Sud-Est and Nippes departments were excluded due to small sample sizes. [b] indicates that the Ouest, Nippes, and Sud-Est departments were excluded. [c] indicates that Azua province was excluded.

Independent variable	Dependent variable	χ^2	p-value	Cramér's V	Association strength
HT					
Region	Occurrence of sightings in lifetime	61.9	3.5e-14	0.41	Relatively strong
Region	Frequency of sightings in lifetime	132.8	< 2.2e-16	0.42	Relatively strong
Region	Occurrence of sightings within a year of interview	31.1	1.7e-07	0.31	Moderate
Department	Occurrence of sightings in lifetime	87.0	5.7e-16	0.49	Relatively strong
Department[a]	Frequency of sightings in lifetime	150.4	< 2.2e-16	0.47	Relatively strong
Department[a]	Occurrence of sightings within a year of interview	57.9	3.2e-11	0.44	Relatively strong
Region	Occurrence of regular manatee areas	18.9	8.0e-05	0.32	Moderate
Department[a]	Occurrence of regular manatee areas	57.3	4.2e-11	0.57	Relatively strong

Region	Occurrence of village captures	0.3	0.8571		
Department[b]	Occurrence of village captures	29.5	6.2e-06	0.47	Relatively strong
DR					
Region	Frequency of sightings in lifetime	2.2	0.5416		
Region	Frequency of sightings within a year of interview	15.6	0.0080	0.22	Moderate
Province	Frequency of sightings in lifetime	17.7	0.0013	0.24	Moderate
Province[c]	Frequency of sightings within a year of interview	52.2	4.1e-08	0.25	Moderate
Region	Occurrence of village captures	0.0	0.8431		
Province	Occurrence of village captures	17.9	0.0013	0.25	Moderate

When comparing departments in Haiti, the occurrence of manatee sightings and their frequency decreased westwards with increasing distance to the Dominican Republic in the north coast. Manatee sightings in a lifetime were reported by 80% of respondents in the Nord-Est department, 57% in the Nord department, and 56% in the Nord-Ouest department. The corresponding percentages of interviewees reporting that manatee sightings in their lifetime occurred frequently or every year were 64%, 53%, and 40% respectively. The pattern also applied to sightings in 2012-2013, with corresponding percentages of 65%, 38%, and 18% respectively. Departments in the central region ranked last in terms of occurrence of manatee sightings in a lifetime, and within a year of the interview. The Ouest department in particular had the lowest percentages, with only 6% and 4% respectively. However, the Artibonite department, in the central region, had a higher percentage (24%) of recent sightings than the Nord-Ouest department (18%).

Reports of areas where manatees occurred regularly also depended on the regions and departments surveyed in Haiti, with moderate to relatively strong associations (Table 12). More respondents knew about these regular manatee areas in the central region (61%), than in the south and the north regions (35% and 26% respectively). In the north coast, the percentages of respondents who knew about these areas decreased westwards with increasing distance from the Dominican Republic: from 41% in the Nord-Est, to 15% in the Nord, and 13% in the Nord-Ouest department. A much higher percentage of respondents knew about regular manatee areas in Artibonite (91%) than in any other department (Figure 10).

Towns with more than 10 valid answers to the question about areas where manatees occurred regularly, and a high percentage of positive responses were: Jacquezy 54% (n=13), Caracol 47% (n=17), Grande-Saline 96% (n=25), and Les Cayes 40% (n=15). Figure 10 shows three manatee hotspot areas enclosing the place names mentioned by the fishers from these towns. In the area of Grande-Saline, the hotspot included the mouths of Rivière de l’Estère and Rivière de l'Artibonite (Figure 10, b).

About 10 fishers reported manatee sightings near the mouth of Rivière de l'Artibonite. But manatees are not present in freshwater habitats in Haiti: rivers are all non-navigable and inaccessible to manatees (J. Wiener, personal communication).

Distribution in the Dominican Republic

On average, 15 interviews were conducted per town in the Dominican Republic (range 3-48). Figure 12 shows the location of the regions, provinces, and towns surveyed, as well as the distribution of manatee sightings collected during interviews. In total, 799 sightings were obtained from fishers who saw manatees personally, in the water, alive and unharmed, and less than 3 km from the mainland. Sightings were reported along the northwest and southwest coasts, and reports from 2010-2014 were as widely distributed as those from 1950-2009. Sightings clustered around freshwater sources, bays enclosed by land or protected by coral reefs, and seagrass areas. In the northwest region, most sightings occurred between the mainland and the coral reef barrier parallel to the coastline of Monte Cristi province, and the western part of Puerto Plata province. But fishers also reported a few sightings in Haitian waters, between Fort-Liberté and Río Masacre, and around the offshore Cayos Siete Hermanos in Monte Cristi province. Sightings were rare east of Puerto Plata town. In the southwest region, most sightings occurred in areas protected by reefs and containing seagrass beds, like Bahía de Puerto Viejo, near Barahona town, and from Bahía Regalada to Ensenada del Refugio. Three other clusters were observed: near Punta Martín García, located in Bahía de Neiba, opposite to Barahona town; from Paraíso to Los Patos; and near mangrove areas between Pedernales and the Cabo Rojo dock, where fishers also reported freshwater seeps. A few sightings were reported around Isla Beata, and in Haitian waters west of the bordering Río Pedernales.

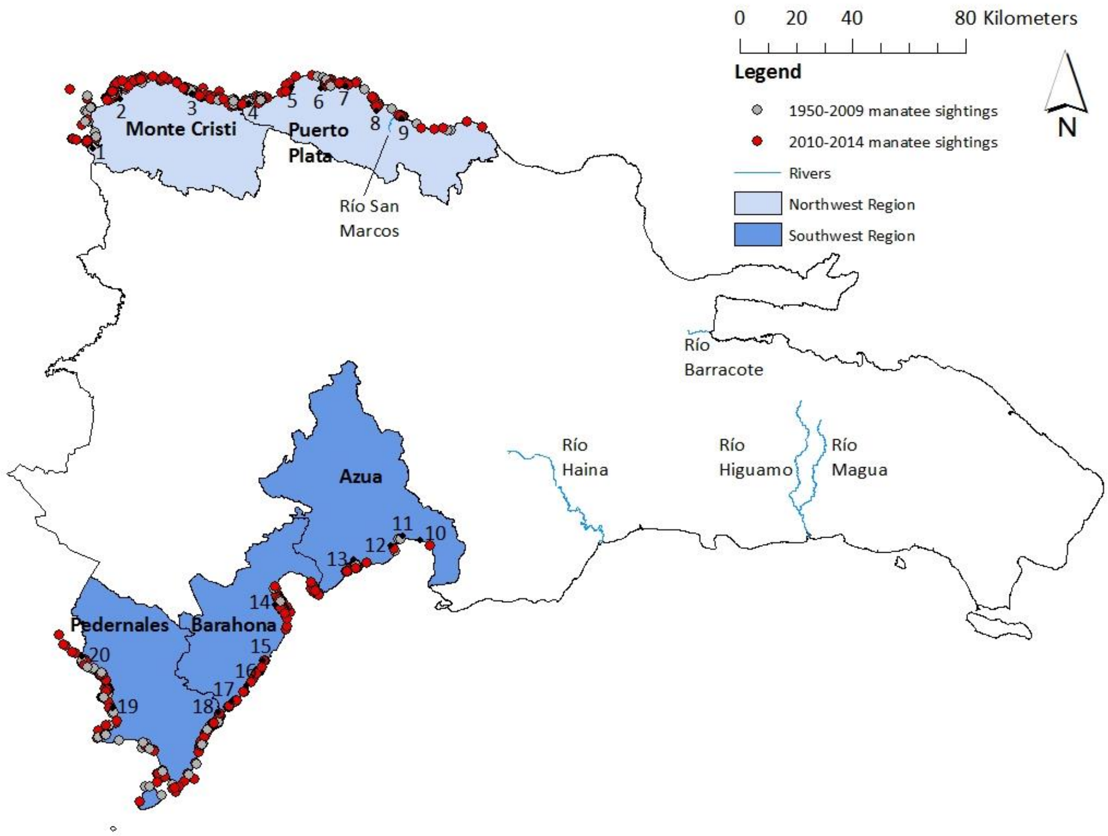


Figure 12: Distribution of manatee sightings collected from fishers in the Dominican Republic. Rivers with recent manatee sightings are included. Towns visited: 1 Pepillo Salcedo, 2 Monte Cristi, 3 Buen Hombre, 4 Punta Rucia, 5 El Castillo, 6 Luperón, 7 Cambiaso, 8 Maimón, 9 Puerto Plata, 10 Caracoles, 11 Tortuguero, 12 Monte Río, 13 Los Negros, 14 Barahona, 15 Paraíso, 16 Los Patos, 17 Los Cocos, 18 Juancho, 19 La Cueva, 20 Pedernales.

Fishers reported 19 manatee sightings located more than 3 km from mainland, at shoals with seagrasses, in rocky habitats, and near smaller islands and keys. Two sightings were reported by Dominican fishers during fishing trips in Turks and Caicos, and one in the Bahamas.

As a requirement for the interview, all Dominican fishers (n=310) had seen manatees at least once in their lifetime (Figure 13). Manatee sightings were reported to occur every year in all towns visited, except for Caracoles and Tortuguero in Azua province, where sample size was small (3 and 5 interviews respectively). In Azua province, except for Los Negros, a town near Bahía de Puerto Viejo, most manatee sightings were reported to occur only once or a few times in a lifetime.

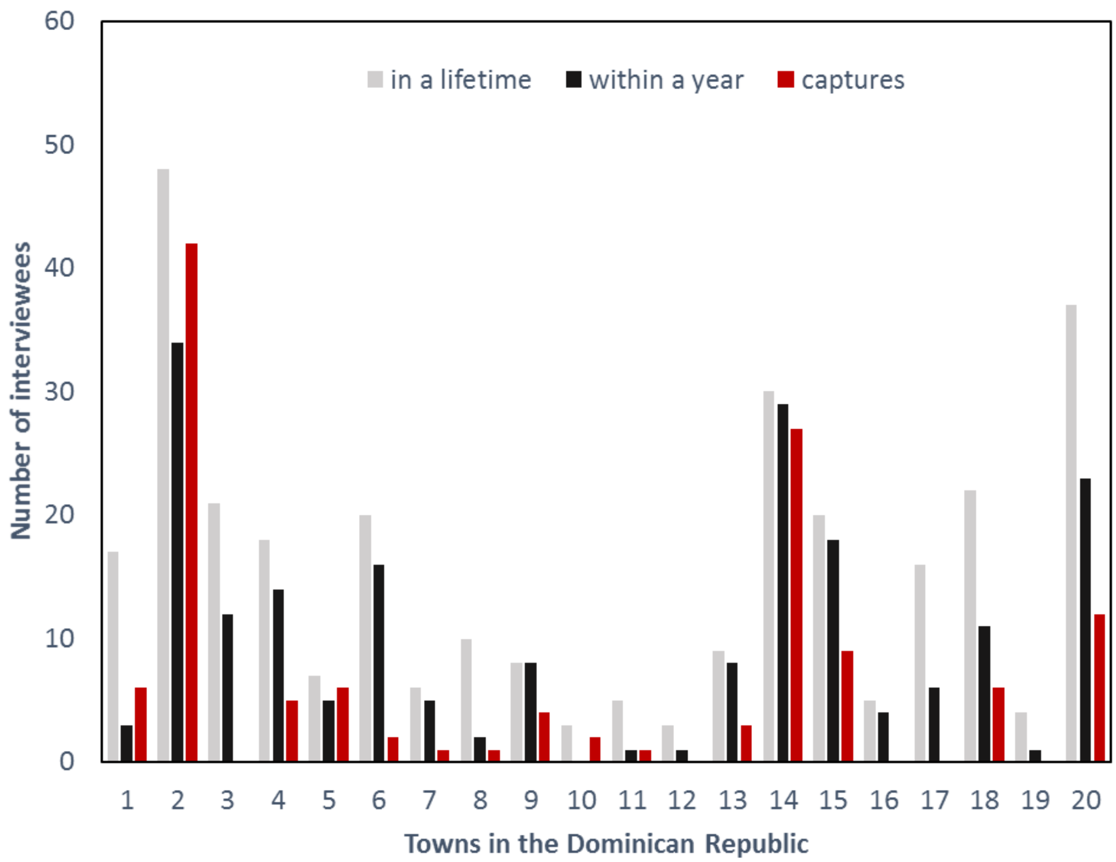


Figure 13: Number of interviewees in the 20 towns surveyed in the Dominican Republic who reported manatee sightings during their lifetime, manatee sightings within a year of the interview, and manatee captures. Towns 1-9 were located in the northwest region, and 10-20 in the southwest region.

Manatees were sighted within a year of the interview in 19 towns by 201 respondents (Figure 13). Caracoles was the only exception. Daily, weekly, and monthly manatee sightings were reported within a year of the interview in half of the surveyed towns. Daily sightings were reported in the towns of Monte Cristi, Los Negros, Barahona, Paraíso, and Pedernales.

The frequency of manatee sightings in a lifetime did not depend on the region surveyed (Table 12). The largest percentage of interviewees in the northwest and southwest regions reported that manatee sightings occurred every year (47% and 55% respectively). However, the frequency of manatee sightings within a year of the interview depended moderately on the region. A larger percentage of fishers reported that manatee sightings occurred daily in the southwest region, compared with the northwest region (10% and 1% respectively).

The frequency of manatee sightings in a lifetime and within a year of the interview depended on the provinces, with a moderately strong association (Table 12). The percentage of fishers who reported that manatee sightings in their lifetime occurred frequently or every year increased westwards in the north coast, from 62% in Puerto Plata to 72% in Monte Cristi. In the southwest, the corresponding percentages were 86% for Barahona, 64% for Pedernales, and 45% for Azua. The frequency of manatee sightings within a year of the interview followed a similar pattern. The percentage of fishers who reported that manatee sightings within a year of the interview occurred daily, weekly, or monthly, increased westwards in the north coast from 3% in Puerto Plata to 19% in Monte Cristi. In the southwest, the corresponding percentages were 39% for Barahona, and 6% for Pedernales. Azua province was excluded due to small sample sizes (Table 12). Overall, manatees were sighted more frequently in Monte Cristi and Barahona than in the other provinces.

The overlay analysis of the polygons representing areas where manatees occurred regularly, yielded a total of 67 km^2 of manatee hotspots in the Dominican Republic. Figure 14 and Figure 15 show the distribution of the hotspots along the northwest and southwest regions respectively.

Notably, in the southwest region, a manatee hotspot area coincided with an area where fishers repeatedly reported the presence of freshwater seeps that were not included in the topographic maps used with the questionnaire (Figure 15).

Two fishers reported manatee sightings in freshwater habitats in the Dominican Republic during the survey: one in Río Barracote, in Samaná province, around 2003; a second one in Río San Marcos, in Puerto Plata province, in 2010. In both cases manatees were sighted inside the rivers.

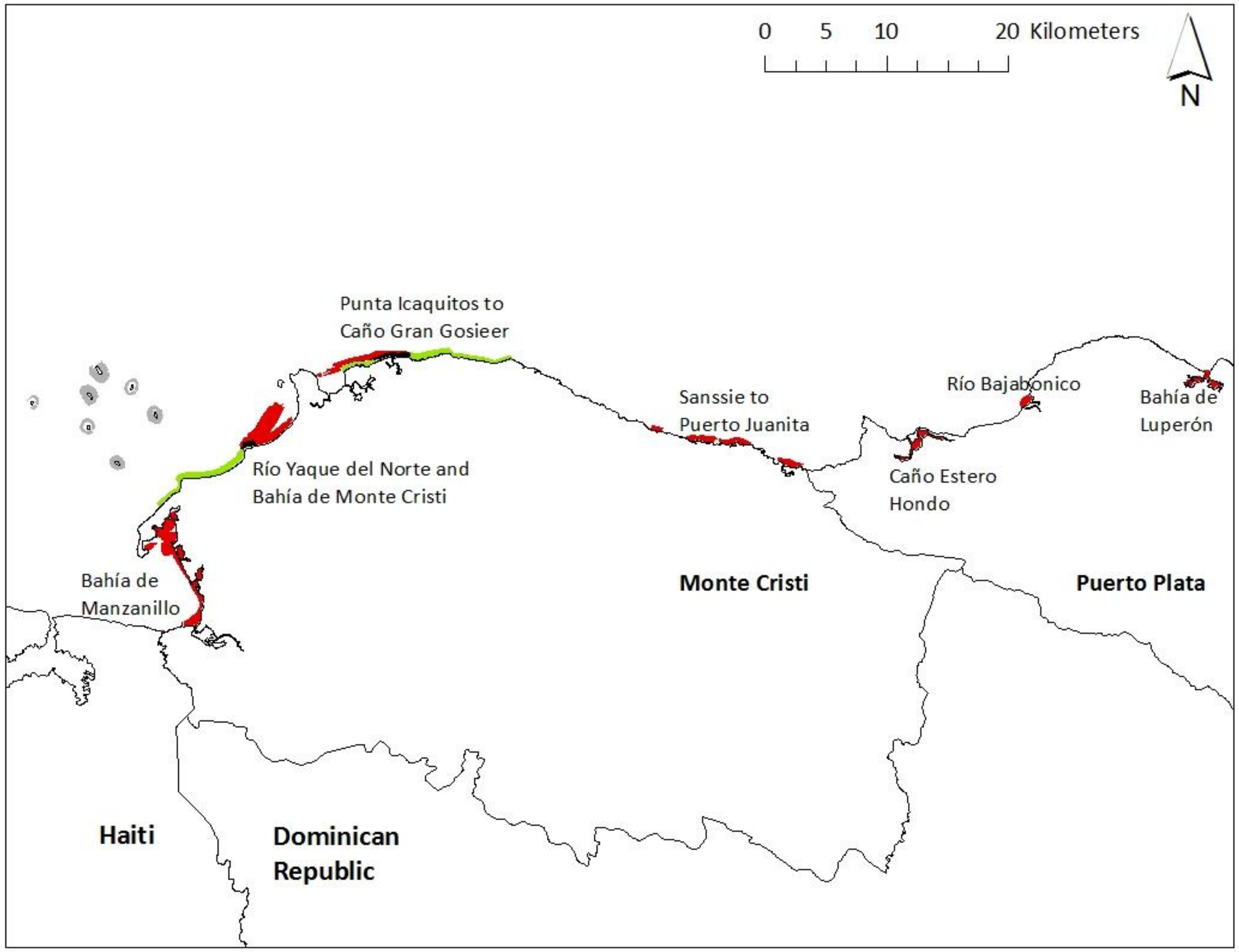


Figure 14: Manatee hotspots (red), gill net hotspots (grey), beach seine hotspots (green), and overlap of manatee and beach seine hotspots (black), in the northwest coast of the Dominican Republic.

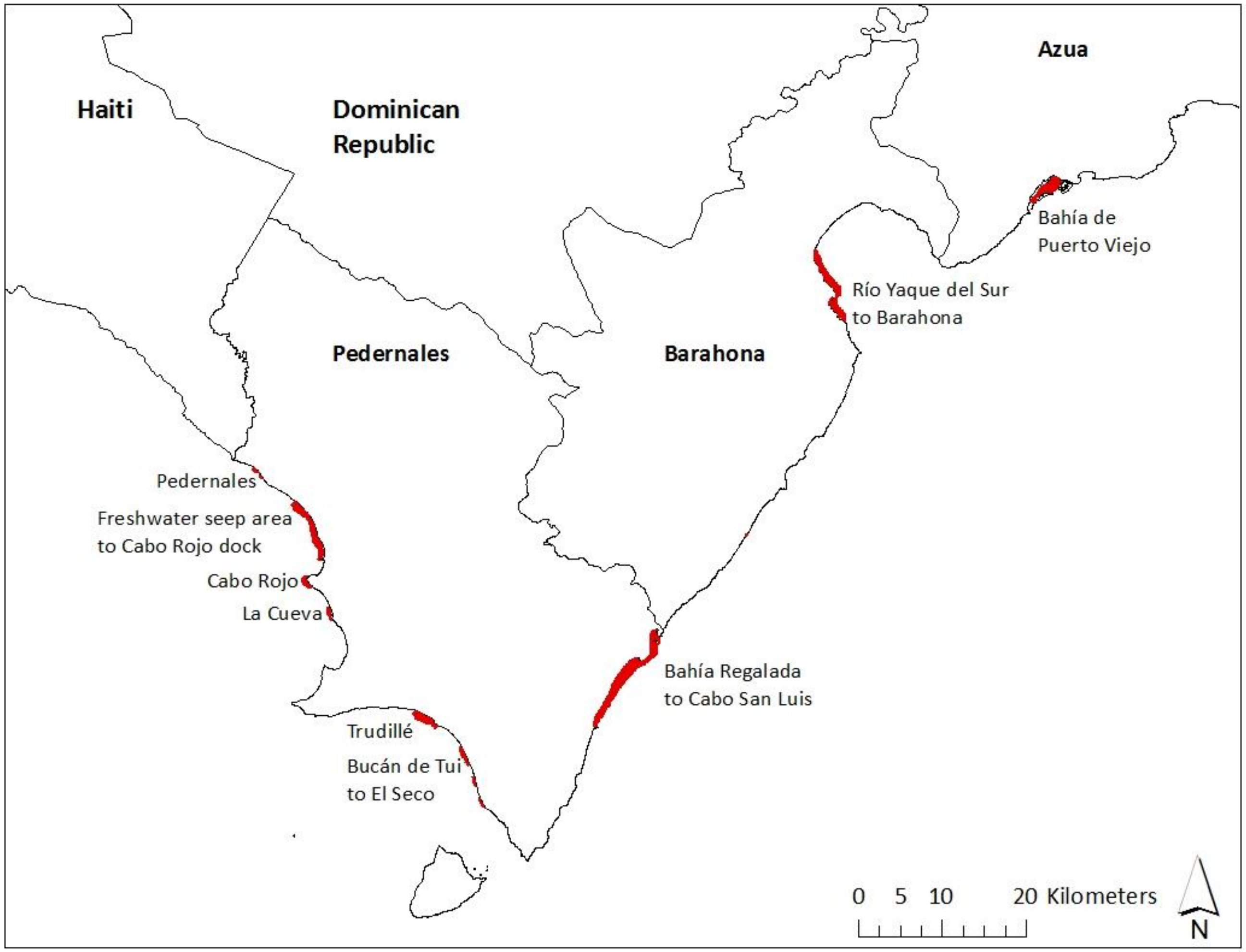


Figure 15: Manatee hotspots (red) in the southwest coast of the Dominican Republic.

Mortality

Figure 11 shows the number of interviewees who reported that manatee captures occurred in their town in Haiti. Towns with more than 10 valid answers and a high percentage (>80%) of positive answers included: Caracol, Fort-Liberté, and Grande-Saline. Fourteen towns, 10 from the central region, lacked reports of manatee captures. Grande-Saline was the only town in the central region with capture reports.

Three fishers reported personal accidental captures of one or two manatees within a year of the interview in Chouchou, Petit-Trou-de-Nippes, and Marigot. In addition to those three towns, fishers reported personal manatee captures in the last five years in Grande-Saline, and Côtes-de-Fer. When asked about personal captures over their lifetimes, three more towns were added: Fort-Liberté, Le Borgne, and Les Cayes. Grande-Saline and Côtes-de-Fer were the only towns where fishers reported capturing more than 10 manatees in a lifetime. Both towns are located near river mouths.

The occurrence of manatee captures did not depend on the region surveyed in Haiti (Table 12). In all regions, about half of respondents reported manatee captures in their village. In contrast, there was a relatively strong association between captures and departments. The percentage of respondents who reported captures in their village decreased westwards with increasing distance from the Dominican Republic along the north coast: with 76% in the Nord-Est, 56% in the Nord, and 14% in the Nord-Ouest department. The corresponding percentage was 77% for Artibonite, and 35% for the Sud department (Ouest, Nippes, and the Sud-Est departments were excluded because of small sample sizes).

All but one of the 70 filtered capture events in Haiti reported between 1957 and 2013 were catches (Table 13). Non-target catches predominated (91%). Only four of the capture events involved more than one animal. Two vaguely described boat strikes were reported in Petit-Goâve and Île-à-Vache, but without information on which year these occurred. It was not possible to determine if these boat strikes were lethal. After filtering the non-fisheries related manatee deaths, 13 strandings and 2 cases of dead manatees in the water were reported, most without a year, and in the Sud department, in the south region.

In the Dominican Republic, Monte Cristi and Barahona were the towns with more than 10 valid answers about manatee captures, and a high percentage (>80%) of positive answers (Figure 13). Five towns lacked reports of manatee captures: Buen Hombre, Monte Río, Los Patos, Los Cocos, and La Cueva.

Only two fishers from Monte Cristi town reported personal captures within a year of the interview. In addition to Monte Cristi, fishers reported personal manatee captures in the last five years in Punta Rucia, Caracoles, and Los Cocos. When asked about personal captures over their lifetimes, six more towns were added: Pepillo Salcedo, El Castillo, Luperón, Barahona, Juancho, and Pedernales. Monte Cristi, Juancho, and Pedernales were the only towns where fishers reported capturing more than 10 manatees in a lifetime.

Table 13: Reported cases of manatee deaths in Hispaniola from the 1940s to 2013 collected from artisanal fishers. Releases and non-lethal boat strikes from the Dominican Republic are excluded. Non-fisheries related deaths in Haiti are excluded. [a] indicates that data for 2013 are incomplete due to the timing of the surveys.

								2010s				
Source	**1940s**	**1950s**	**1960s**	**1970s**	**1980s**	**1990s**	**2000s**	**2010**	**2011**	**2012**	**2013[a]**	**Total**
Haiti												
Survey captures	0	1	0	6	8	13	21	1	7	7	6	70
Dominican Republic												
Survey captures	0	0	9	8	12	12	11	2	1	4	1	60
Field trials captures	1	0	0	0	1	0	3	0	1	0	0	6
Survey lethal boat strikes	0	0	0	1	0	0	10	1	1	0	0	13
Field trials lethal boat strikes	0	0	0	0	0	0	2	0	0	0	0	2
Survey non-fisheries related	0	0	2	0	5	7	19	6	3	6	0	48
Field trials non-fisheries related	0	0	0	0	0	0	1	0	1	0	0	2
Hispaniola												
Subtotal fisheries-related	1	1	9	15	21	25	47	4	10	11	7	151
Subtotal non-fisheries related	0	0	2	0	5	7	20	6	4	6	0	50
Total	**1**	**1**	**11**	**15**	**26**	**32**	**67**	**10**	**14**	**17**	**7**	**201**

The occurrence of manatee captures did not depend on the region surveyed in the Dominican Republic (Table 12). About 40% of respondents reported manatee captures in their town in both regions. There was a moderate association between captures and provinces. The percentage of fishers who reported manatee captures in their town increased westwards on the north coast, from 28% in Puerto Plata to 57% in Monte Cristi. In the southwest, the corresponding percentages were 51% for Barahona, 34% for Pedernales, and 32% for Azua.

Of 82 filtered capture events in the Dominican Republic reported between 1960 and 2013, 57% were catches; 27% were releases (Table 14). Compared to the 1960s-1990s, fewer numbers of target and non-target catches were reported in the 2000s. Non-target bycatches and releases showed the opposite trend, with more reports in the 2000s. Target catches occurred mostly with harpoons and beach seines. Non-target catches and releases also occurred mostly with beach seines.

Table 14: Types and timing of manatee capture events reported by fishers in the Dominican Republic.

Capture Type	**1960s**	**1970s**	**1980s**	**1990s**	**2000s**	**2010-2013**	**Total**
Target catch	7	1	5	4	3	3	23
Non-target catch	2	6	6	3	1	2	20
Unclear if target catch or non-target catch	0	1	1	2	0	0	4
Non-target bycatch	0	0	0	1	7	2	10
Unclear if non-target catch or non-target bycatch	0	0	0	2		1	3
Release	0	0	2	5	8	7	22
Total	**9**	**8**	**14**	**17**	**19**	**15**	**82**

Excluding the releases, only five of the 60 remaining capture events that resulted in manatee deaths involved more than one animal (Table 13). Boat strikes were more common than in Haiti, with 13 lethal and 8 non-lethal cases. Of 48 filtered non-fisheries related manatee deaths, 42 were dead strandings, 4 were dead manatees found in the water, and 2 were takes. Most cases occurred in Pedernales province, in the southwest region. Additional mortality cases from the survey field trials in the Dominican Republic were included in Table 13.

Overall for Hispaniola, 201 manatee mortality events were reported by fishers from the 1940s to 2013; most (75%) of these cases were fisheries-related (Table 13). The number of reports increased by decade, from one in the 1940s and the 1950s, to 67 in the 2000s. From 2010 to 2012, the number of annual reports also increased from 10 to 17. Due to the timing of the surveys, data for 2013 were incomplete.

In generating the most recent annual island-wide manatee mortality estimate, the following assumptions were made: mortality events involved only one animal; boat strikes were negligible in Haiti; the 15 non-fisheries related manatee deaths reported in Haiti occurred within the same time frame as the reported manatee captures in Haiti (from 1957 to 2013), for an average of 0.26 annual deaths; mortality data for 2012 were the most accurate and complete.

For 2012, therefore, the estimate of manatee mortality for Hispaniola was 19 animals: 17 cases reported by fishers (Table 13); one non-fisheries related death in the

Dominican Republic, extracted from the database developed in Chapter 1, and not reported by fishers; one potential non-fisheries related death from Haiti.

Fishers were the most important contributors to manatee mortality reports. For the Dominican Republic, in a 15-year period from 1995, when the RDV was created, to 2009, 75 manatee mortality cases were identified: 52 (69%) were reported by fishers interviewed during field trials or final surveys in the Dominican Republic, but were absent from the RDV and CERREA records. Out of the remaining 23 (31%) cases confirmed and recorded by the RDV or CERREA, 8 were also reported by fishers.

In Haiti, the most important manatee capture methods involved the following fishing gear: harpoons, locally known as “apon”, “fren”, or “frennen” (62%); purse seines (36%) with a very small mesh size, deployed from the water, usually in shallow areas near mangroves, seagrasses, and coral reefs; Caribbean Z traps (24%) used for fish or lobster (Figure 16). In the Dominican Republic, the most important manatee capture methods involved: beach seines (67%); gill nets (29%); harpoons, locally known as “figa” (24%).

The use of beach seines was more widespread in the past in the Dominican Republic, and manatee captures were common during the 1960s-1980s. The most extreme examples came from Monte Cristi and Barahona towns. One interviewee stated that in the 1970s and 1980s fishers in Monte Cristi would capture manatees of all sizes near the mouth of Río Yaque del Norte in Bahía de Monte Cristi, and in Bahía de Manzanillo. They located the animals from the sediment plumes they made while feeding. They would encircle up to 10 animals, most of which would escape, but one or two were left. The interviewee reported catching one or two per year during that period. Other interviewees mentioned 40-50 animals captured per year.

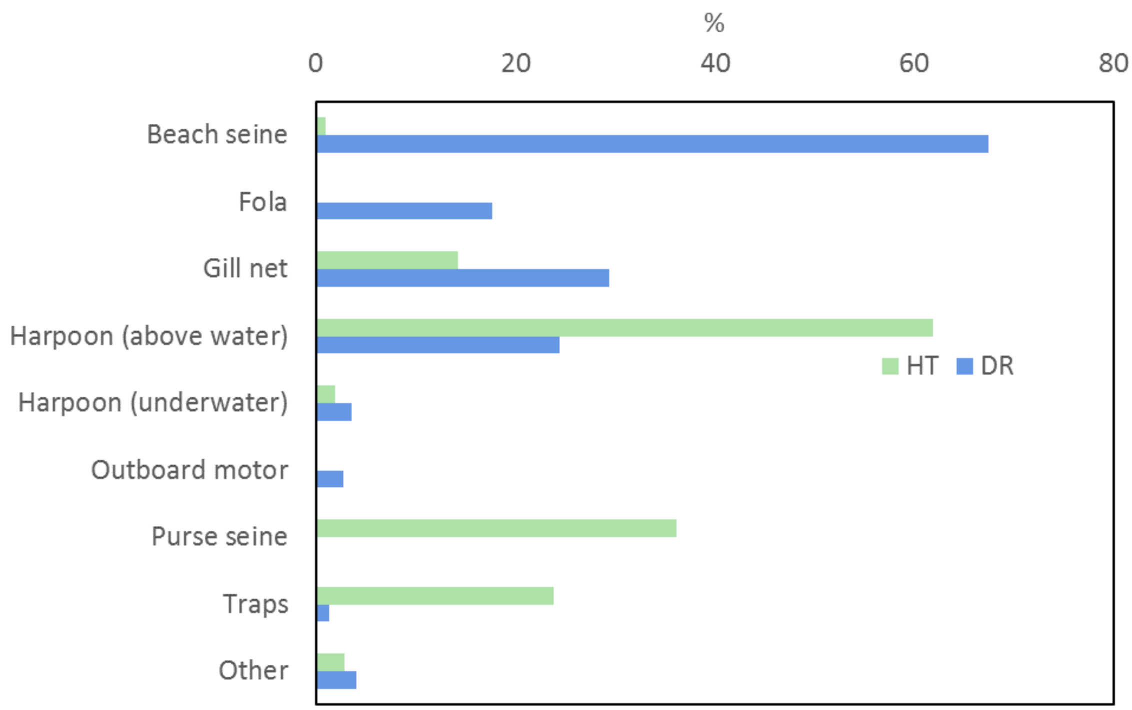


Figure 16: Percentage of respondents who chose each fishing gear as a manatee capture method. Percentages were calculated based on the total valid answers in Haiti (n=105) and the Dominican Republic (n=221).

In Barahona town one interviewee witnessed manatee captures with beach seines in the mid-1960s. Four or five fishers set the nets in front of freshwater sources (e.g., Río Biran, El Matadero), and captured manatees were killed on the beach and butchered. There was no restriction, and the meat was sold openly for cents apiece. Another interviewee witnessed as a child several manatee captures in the 1980s—even two animals at once—just north of Barahona town, near a natural spring called La Zurza.

Another interviewee witnessed similar events near the mouth of Río Yaque del Sur, where about 10 fishers would capture up to three manatees per day in the mid-1980s. Estimates of captures varied from 8 to 25 animals per year. But fishers mentioned beach seines have not been used in Barahona in the last 15-20 years, and that surviving manatee hunters were retired. Beach seines were also used in other areas like Caño Estero Hondo, El Castillo (near the mouth of Río Bajabonico), and Bahía de Luperón.

The figa is a sharp iron or steel harpoon, custom-made by a smith, with a ring or eye on one end, and one or three barbed points on the other end (Figure 17). The use of the figa as described by Dominican fishers was similar to reports of manatee harpooning that occurred from the 15th to 19th centuries (see Chapter 1). The harpoons were thrown from wooden boats; a rope was tied to the eye of the harpoon on one end, and to the boat or to a buoy on the other end. Some fishers described the use of a heavy wooden shaft used to throw the harpoon. When an animal was hit, the harpoon would detach from the shaft, but remain attached to the animal. The figa was used for other animals as well, such as the Atlantic goliath grouper (*Epinephelus itajara*), and other large fish.

The use of the figa was widespread geographically, but fishers described a few specialized manatee hunters—usually family members who hunted together—who were active a long time ago. For example, in the northwest coast, one family was repeatedly mentioned as specialized manatee hunters in the 1970s-1990s (reportedly killing from 2-3 animals a year, up to 40), but only two of these individuals are still alive, and they are retired. In the southwest coast, one 82-year-old interviewee used to capture 10-12 manatees per year in the area of Juancho to Ensenada del Refugio, in Pedernales province, with his wife, or with his father and brother. The meat was salted, dried, and sold in the towns of Juancho and Enriquillo. Manatee hunting with the figa was also reported in the past in Punta Rucia, Caño Estero Hondo, El Castillo, Bahía de Luperón, Puerto Plata, and Pedernales.

Figure 17: Figa from the Dominican Republic. The reference ruler is 1 m long. The figa was obtained by Jose A. Ottenwalder from previous manatee research.

Overlap of manatee and fishing hotspots in the Dominican Republic

The most common fishing gear used by the interviewees in the northwest and southwest of the Dominican Republic were hook and line and diving harpoons. These gears were used in 30-40% of the fishing areas mapped during interviews. Beach seines and gill nets were used respectively in 11% and 18% of the fishing areas mapped in the northwest region of the Dominican Republic (n=368). In the southwest, beach seines and gill nets were used respectively in 1% and 15% of the mapped fishing areas (n=299).

Fishing hotspots potentially harmful for manatees were located in Monte Cristi province (Figure 14). Gill net hotspots (about 9 km^2) were only identified surrounding the offshore Cayos Siete Hermanos, and there was no overlap with manatee hotspots in the area. Beach seine hotspots (about 10 km^2) were identified in two areas: from Punta Presidente to the mouth of Río Yaque del Norte, and from Punta Icaquitos to Gran Mangle. Beach seine hotspots overlapped with manatee hotspots near the mouth of the Río Yaque del Norte, and from east of Punta Icaquitos to east of Gran Gosieer. The extent of the overlap was approximately 2 km^2. The beach seines used in Monte Cristi province belonged to fishers interviewed in Monte Cristi town. No gill net or beach seine hotspots were identified in the southwest region.

Abundance and capture trends

Most fishers (62%) in Hispaniola perceived that manatee abundance had decreased over the course of their careers, independent of the country (Table 15).

The perceived abundance trend was weakly associated to the geographic region surveyed, but only in the Dominican Republic: in the northwest, a higher percentage (70%) of fishers perceived a decrease in manatee abundance compared with the southwest (54%); in the southwest, a higher percentage (40%) of fishers perceived an increase in manatee abundance compared with the northwest (24%) (Table 15).

For Hispaniola as a whole, and for the Dominican Republic, the perceived abundance trend showed a low inverse association to age group (Table 15). More elders reported a decreasing trend in manatee abundance (Figure 18). Conversely, a larger percentage of young fishers reported an increasing trend.

Table 15: Independence test results for manatee abundance trend, and capture trend, by geographic divisions and age groups. τ: Tau coefficient. [a] indicates the south region was excluded.

Independent variable	Dependent variable	χ^2 or z	p-value	Cramér's V or τ	Association strength
Country	Manatee abundance trend in Hispaniola	0.0	1.0000		
Region[a]	Manatee abundance trend in Haiti	0.9	0.3403		
Region	Manatee abundance trend in the Dominican Republic	8.2	0.0165	0.17	Weak
Age	Manatee abundance trend in Hispaniola	-3.1	0.0017	-0.14	Low inverse
Age	Manatee abundance trend in Haiti	-1.2	0.2149		
Age	Manatee abundance trend in the Dominican Republic	-2.9	0.0036	-0.16	Low inverse
Region	Manatee capture trend in the Dominican Republic	1.9	0.1722		
Age	Manatee capture trend in the Dominican Republic	-2.4	0.0147	-0.17	Low inverse

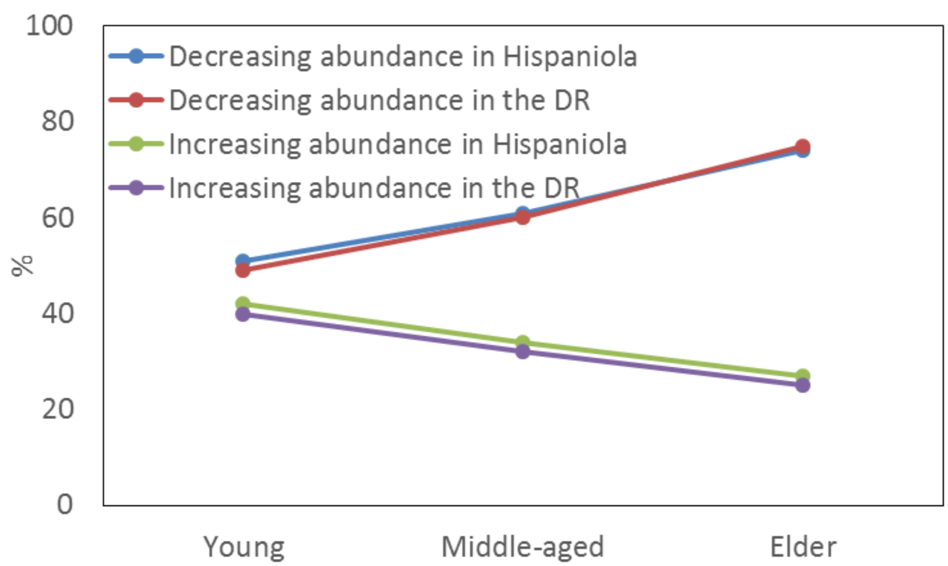


Figure 18: Perceived trend in manatee abundance by age group.

In Haiti, the most popular reasons given for the perceived decrease in manatee abundance were: noise (36%), fewer sightings (23%), and disturbance (16%). In the Dominican Republic, the most popular reasons were: captures (57%), disturbance (17%), and the movement of manatees to other areas (16%) (Figure 19 top panel). About 34% of fishers in Hispaniola perceived that manatee abundance had increased over the course of their careers. The most popular reasons given for the increase in both countries were the lack of captures, and manatee reproduction (Figure 19 bottom panel).

Most fishers (94%) in the Dominican Republic perceived that the number of manatee captures had decreased during their careers. The perceived capture trend did not depend on the region surveyed, but showed a low inverse association to age group (Table 15): more elders (99%) reported a decreasing trend in manatee captures, compared to middle-aged (93%) and younger fishers (87%). A larger percentage of younger fishers (13%) reported an increase in captures, compared to middle-aged (3%) and elder fishers (1%).

The most popular reasons given for the perceived decrease in manatee captures were: fear of the laws (47%), the existence of fewer manatees (23%), and the present lack of captures (20%) (Figure 20).

Results could not be analyzed for Haiti due to translation errors in the manatee capture trend question.

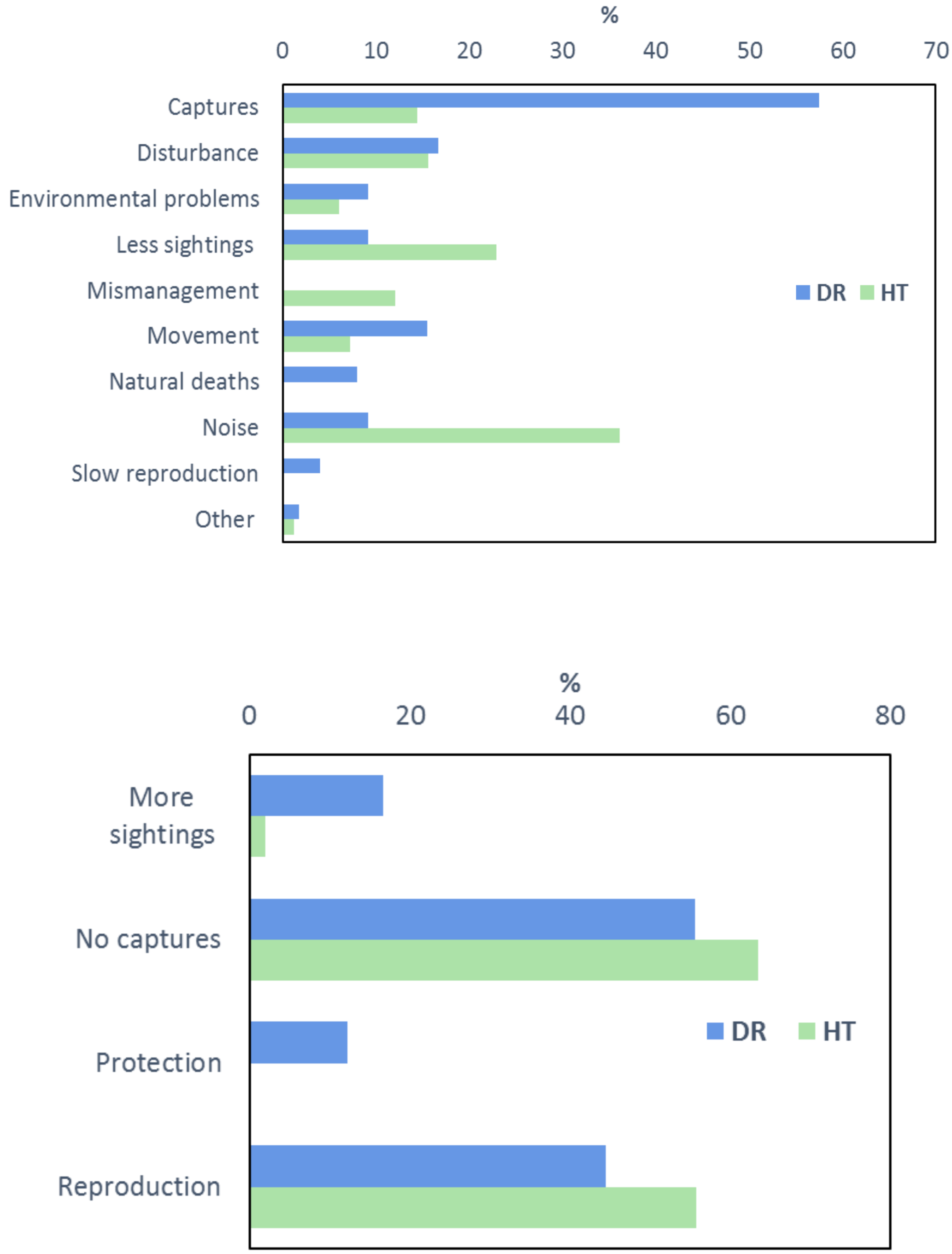


Figure 19: Main reasons for the perceived decrease (top panel) and increase (bottom panel) in manatee abundance by country. Percentages calculated over the maximum number of responses for each trend in each country: HT n=83 and DR n=174 for the decreasing trend; HT n=52 and DR n=90 for the increasing trend.

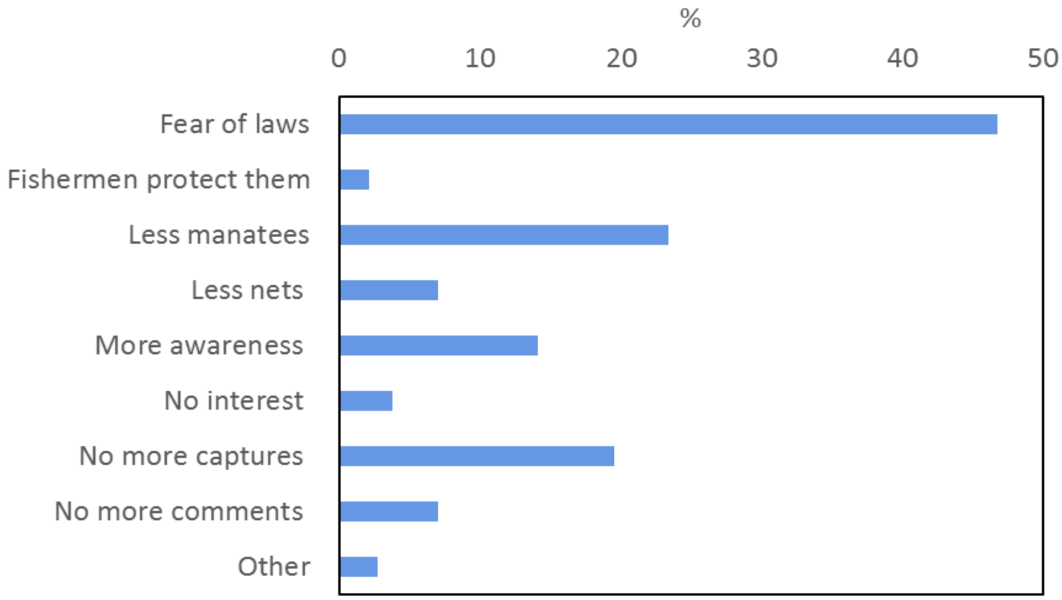


Figure 20: Main reasons for the perceived decrease in manatee captures in the Dominican Republic. Percentages calculated over the maximum number of responses (n=184).

Cultural value and attitudes towards conservation

When asked if manatees were important, of 473 fishers in Hispaniola who provided a valid answer, 99% said yes. In Haiti, the main reasons given were: that manatees were found with a lot of other fish (i.e., that a lot of other fish came with manatees, or that manatees came when the fishing season began) (45%); that manatees were important for eating and selling (26%). In the Dominican Republic, the main reasons were: that manatees were harmless or playful (30%); that they were part of Nature (22%); that they were amusing, or a beautiful species that people wanted to see (22%) (Figure 21).

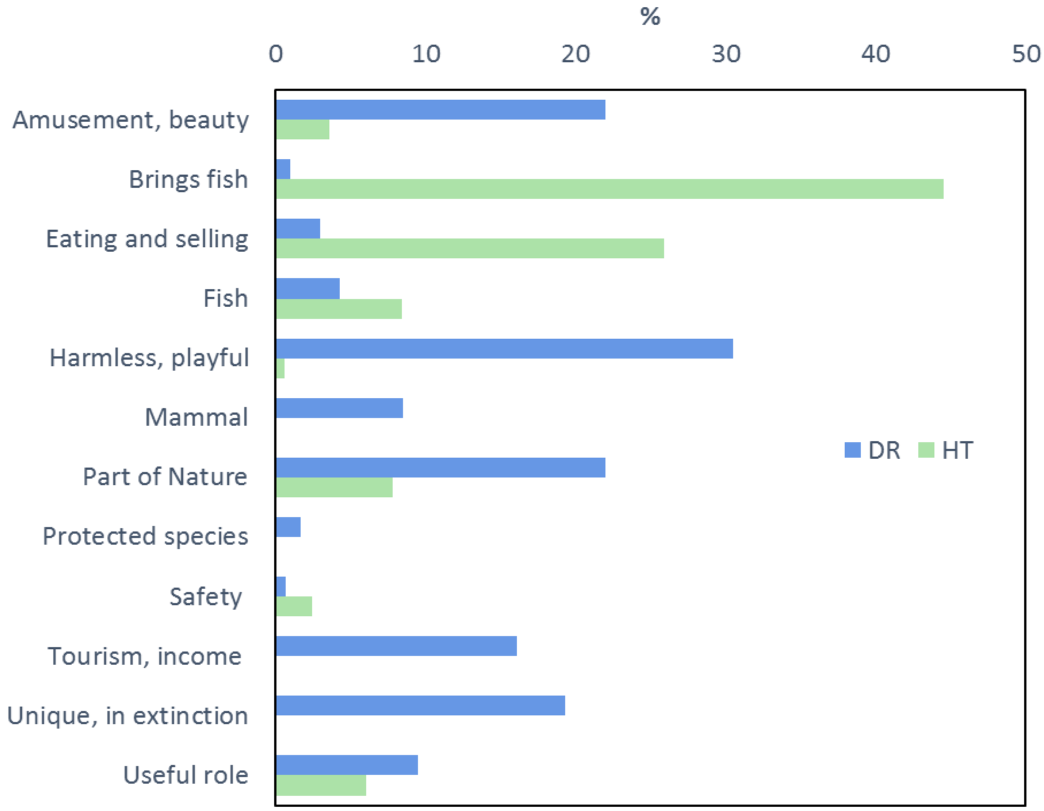


Figure 21: Main reasons why manatees were considered important in Hispaniola. Percentages were calculated based on the total positive answers in Haiti (n=166) and the Dominican Republic (n=305).

When asked if they had any beliefs, customs, or stories about manatees, of 485 fishers who provided a valid answer, only 41% said yes. In Haiti, the most common answer was that manatees broke fishing gear (64%). In the Dominican Republic, it was that manatee meat was good and that it had different flavors (71%) (Figure 22).

One unpopular but interesting belief shared by both countries was that areas with manatees were safe (i.e., that there were "no bad fish around", like sharks). A few Dominican fishers believed that manatees, like dolphins, displaced or attacked sharks; others mentioned manatees being attacked by sharks. In Monte Cristi, one fisher witnessed a manatee fleeing from a shark by traveling to shallow waters. Another fisher mentioned that sharks frequented the mouth of Río Yaque del Norte, and that he had caught a shark with a piece of manatee in its stomach.

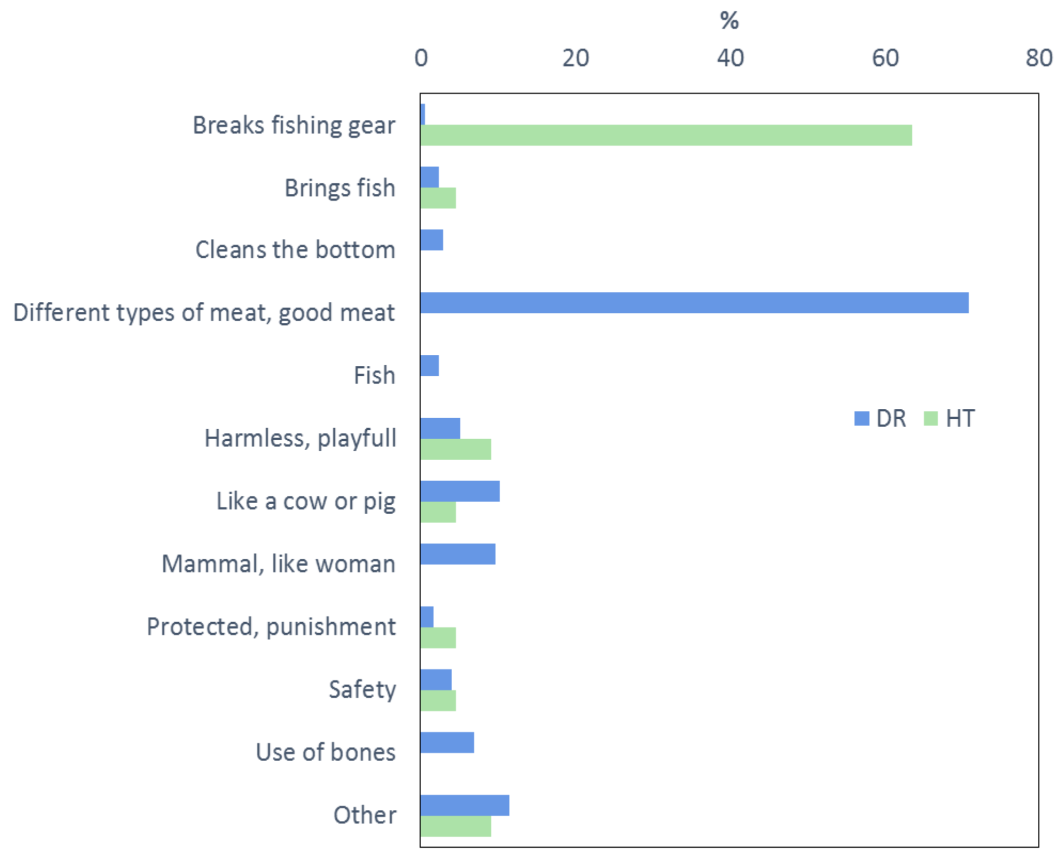


Figure 22: Most common beliefs about manatees in Hispaniola. Percentages were calculated based on the total positive answers in Haiti (n=22) and the Dominican Republic (n=175).

When asked what manatees were used for, the most popular answers for both countries were to eat and to sell, with corresponding percentages of 91% and 97% in Haiti, and 76% and 41% in the Dominican Republic, respectively (Figure 23). In the Dominican Republic, the use of manatee bones was more popular (26%) and diverse than in Haiti (2%). Bones were mainly used for folk medicine. The process involved burning and grinding the bones to a powder and drinking it with coffee, tea, or bay rum; or putting one piece of bone in a clay pot full of water and drinking it. Remedies were reported for cold, asthma, menses, epilepsy, body aches, and rheumatism. Bones were also used for handcrafts (e.g., dominos, buttons, rings, knife handles) and were sold. Less popular uses of bones included for witchcraft, as an aphrodisiac, and for cooking.

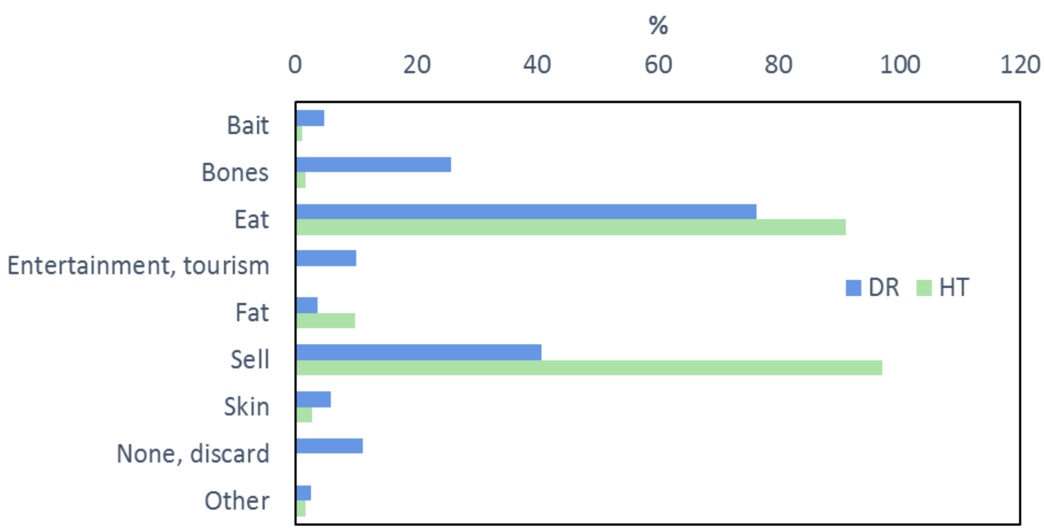


Figure 23: Most common uses of manatees in Hispaniola. Percentages were calculated based on the total valid answers in Haiti (n=182) and the Dominican Republic (n=267).

In the Dominican Republic, manatee skin was used as bait, in most cases for lobster traps. In both countries the skin was also eaten. In the Dominican Republic, manatee fat was used for cooking or for medicinal purposes (e.g., for treating asthma and rheumatism). In Haiti, the fat was used for cooking, and for manufacturing candles in Arcahaie town. The use of manatees for entertainment and tourism was not mentioned in Haiti. No Haitian fishers mentioned that manatees were discarded.

Overall, in the Dominican Republic, smaller percentages (less than 18%) of young fishers reported destructive uses of manatees (i.e., uses of manatee body parts, selling and eating), compared to middle-aged and elder fishers (more than 37%) (Table 16). A similar percentage (more than 40%) of young and middle-aged fishers reported manatee use for entertainment, or no use of manatees, compared to elder fishers (less than 14%). In Haiti, similar percentages (about 20%) of young and elder fishers reported destructive uses of manatees, compared with middle-aged fishers (about 60%).

Table 16: Uses of manatees by age group in the Dominican Republic.

Age group	Bait, skin, fat, bones		Eat		Sell		Entertain		None or discard	
	f	%	f	%	f	%	f	%	f	%
Elder	53	49.5	76	37.4	46	42.6	3	11.1	4	13.3
Middle-aged	49	45.8	92	45.3	49	45.4	11	40.7	14	46.7
Young	5	4.7	35	17.2	13	12.0	13	48.1	12	40.0
Total	**107**	**100.0**	**203**	**100.0**	**108**	**100.0**	**27**	**100.0**	**30**	**100.0**

Fishers were asked what they would do if they caught a manatee intentionally and accidentally. In Haiti, more than 80% of respondents said they would eat or sell it either way, versus 10% in the Dominican Republic. Most Dominican fishers (71%) said they would not do it intentionally (Figure 24 top panel); if caught accidentally, most (57%) said they would release it.

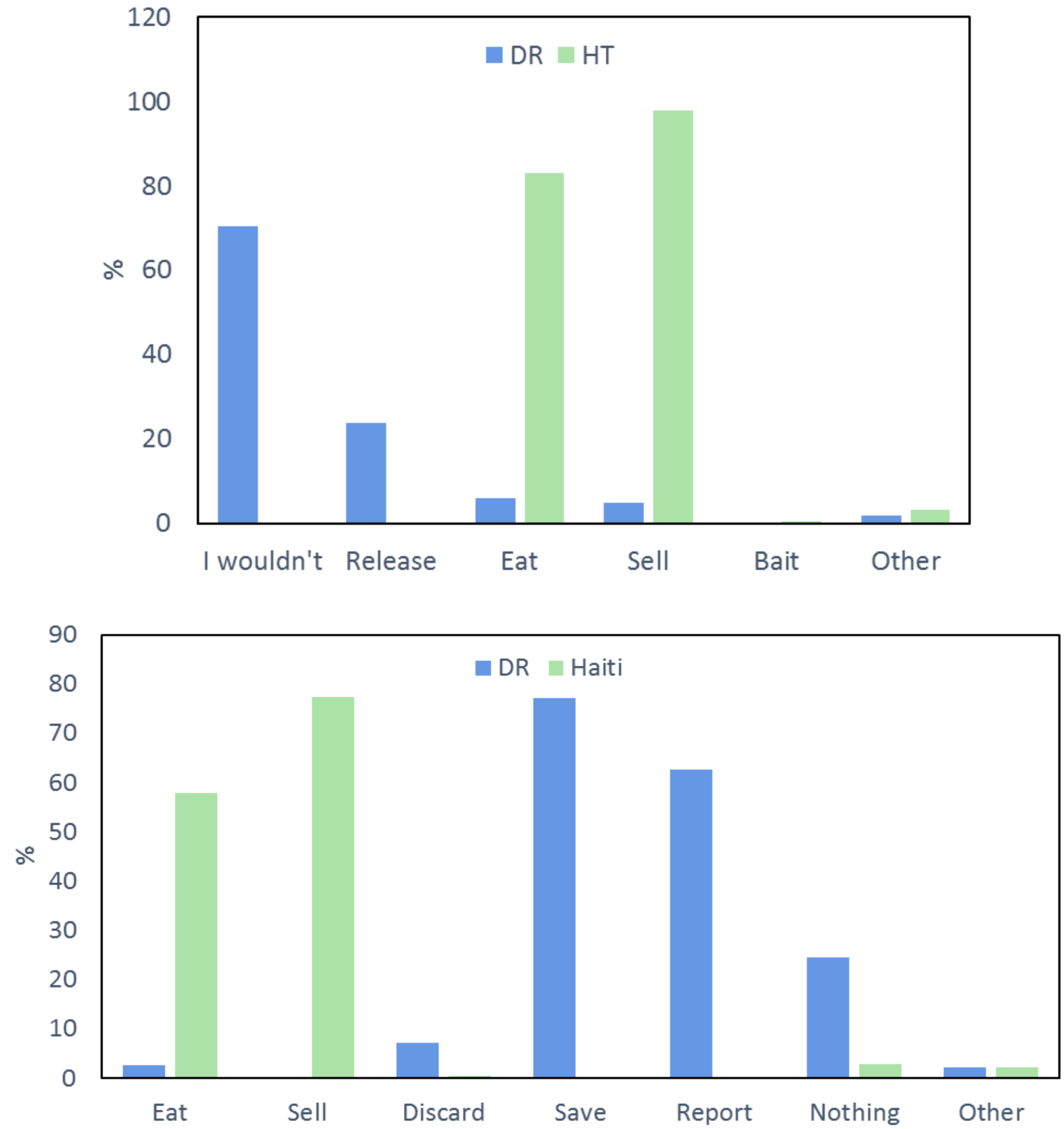


Figure 24: Fate of manatees caught intentionally (top panel), or stranded (bottom panel) by country. Percentages calculated over the maximum number of valid responses in each country: HT n=182 and DR n=285 for intentional captures; HT n=173 and DR n=302 for strandings.

In the case of stranded animals, the majority of respondents in Haiti said they would eat it (58%) or sell it (77%). In the Dominican Republic, the majority said they would save it (77%), or report it to the authorities (63%) (Figure 24 bottom panel).

Dominican fishers were asked about manatee protection in the country. Of 310 interviewees, 99% said that killing manatees intentionally was illegal. Only 62% said they would report an accidental manatee death to the authorities. The main reason given for not reporting an accidental death was fear of the law (i.e., that they would be found guilty and sent to jail for many years). Only half of the fishers reported there was patrolling in manatee areas, and 73% of them said that penalties were not imposed on offenders.

Discussion

To assess the current status of Antillean manatees in Hispaniola, I analyzed over 670 interviews with artisanal fishers of different age groups in the Dominican Republic and Haiti. This was the first dedicated manatee study in Hispaniola to account for shifting baselines, and only the second in Haiti, following the initial work of Rathbun et al. (1985) over 30 years ago.

In general, fishers were more knowledgeable about manatees in the Dominican Republic, where they are more common. Manatee sightings were reported to occur every year in 19 of the 20 towns visited (Figure 13), and monthly, weekly, or daily sightings were reported within a year of the interview in half of the towns. In Haiti, the situation was opposite. Only 43% of interviewees had ever seen manatees. Manatee sightings were reported within a year of the interview in 19 of the 27 towns visited (Figure 11), but none of the respondents reported manatee sightings on a daily, weekly, or monthly basis.

Manatee sighting reports showed a relatively strong association to the departments sampled in Haiti, and a moderate association to the provinces sampled in the Dominican Republic (Table 12). The distribution of the manatee sighting reports suggests that Monte Cristi province in the north coast, and Barahona province in the south coast, are the focal areas from which sightings decrease eastwards to other provinces in the Dominican Republic, and westwards to departments in Haiti. In the north coast of Haiti, the decreasing trend with increasing distance to the Dominican Republic applied to several measurements: the percentage of respondents who had ever seen manatees in their lifetime; the percentage who reported that during their lifetime manatees were sighted frequently or every year; the percentage who had seen manatees within a year of the interview; the percentage who knew about regular manatee areas. The spatial pattern was not as clear in the south coast of Haiti, due to small sample sizes in the Sud-Est department (n=10), which was excluded from most statistical analyses (Table 12).

Another possible focal area for manatees was the Artibonite department, in the central region of Haiti. It was the only department where manatee sightings were reported to occur every year (in the towns of Grande Savane, Grande-Saline, and Saint-

Marc). Artibonite had the highest percentage of interviewees who knew about regular manatee areas (91%), and the highest percentage of manatee captures (77%). It is also the department where Rivière de l'Artibonite–the most important river in Haiti–reaches the sea, and several fishers reported manatee sightings near its mouth. Rivière de l'Artibonite was historically inhabited by manatees (Descourtilz 1809), and likely remains an important freshwater source for manatees at present.

The results presented here are in good agreement with previous dedicated manatee surveys from land, boat, or aircraft. In Haiti, manatee sightings from aerial surveys by Rathbun et al. (1985) were limited to the Artibonite department. In this study, a manatee hotspot was identified within that department (Figure 10). In the Dominican Republic, results from aerial surveys conducted in 1977 (Belitsky & Belitsky 1980) showed that manatee distribution was focused near Monte Cristi town, and in Bahía de Ocoa and Bahía de Neiba. Land and boat surveys by Domínguez Tejo (2006, 2007) resulted in frequent manatee sightings near Monte Cristi town, inside Caño Estero Hondo, and near Barahona town. Most manatee sightings from aerial surveys conducted in the southwest coast in 2010-2011 were located in Bahía de Puerto Viejo, near Barahona town, and in the Beata Channel (Reynoso et al. 2011). Manatee hotspots were identified by fishers in all the above mentioned areas (Figure 14 and Figure 15).

Manatees occasionally occupy freshwater habitats in the Dominican Republic. In addition to the two cases reported in this study, in Río San Marcos, and Río Barracote, previous examples include: one sighting in the late 1980s about 12 km upriver at the confluence of Río Magua with Río Higuamo; multiple sightings of two animals about 2 km upriver in Río Higuamo in 2009; one juvenile found about 2 km upriver in Río Haina in 2012. The extent and frequency of use of these freshwater habitats by manatees is unknown. Notably, fishers reported the use of currently unmapped freshwater seeps by manatees in Pedernales province, in an area lacking superficial rivers. Similar anecdotes have been reported in the provinces of Samaná, La Altagracia, and Barahona (Belitsky & Belitsky 1978; LaBastille 1999). Manatees can obtain freshwater from coastal groundwater springs (Drew et al. 2012), and from small point sources. For example, manatees in Puerto Rico have been documented drinking water from a wastewater treatment plant outflow pipe at Cape Hart, by literally "sticking their heads" in the pipe opening for a couple of minutes (Rathbun et al. 1985, as cited in Drew et al. 2012). Further research on the use of freshwater seeps by manatees in the Dominican Republic would be useful.

In general, more manatee captures were reported in areas that supported relatively high numbers of manatee sightings in both countries. The spatial pattern was evident at the level of departments in Haiti, and provinces in the Dominican Republic (Table 15). In the Dominican Republic, more captures were reported in Monte Cristi and Barahona provinces. In Haiti, the percentage of interviewees reporting manatee captures along the north coast followed the same pattern of the sighting reports: decreasing westwards with increasing distance to the Dominican Republic, from 76% in the Nord-Est, to 14% in the Nord-Ouest department. The percentage was highest in

Artibonite (77%), and Grande-Saline stood out as the only town with manatee capture reports in the central region of Haiti, and one of the two towns where fishers reported capturing more than 10 manatees in a lifetime. One potential explanation for the elevated number of captures in Grande-Saline is the proximity of the mouth of Rivière de l'Artibonite. Future conservation efforts should focus in this area.

About three-quarters of the reported mortality events in Hispaniola were fisheries-related (Table 13), highlighting the need to continue educating, supervising, and working with fishers to reduce manatee mortality. Non-target catches predominated (91%) in Haiti: manatees were not hunted intentionally, but if found, they were captured and kept for eating and selling. In the Dominican Republic, about the same number of target catches, non-target catches, and releases were reported (Table 14). Catches decreased over time, with fewer reports in the 2000s, whereas reports of non-target bycatches and releases increased in the 2000s, probably due to widespread conservation efforts that began in the 1990s (e.g., education and awareness campaigns, dedicated manatee studies, the rescue and rehabilitation of a few manatee calves, and a handful of examples of strict law enforcement).

The estimated island-wide annual mortality of about 19 manatees in 2012, was close to the average of 23 animals estimated for the Dominican Republic, by summing annual captures reported by fishers during interviews in 1994-1996 (Ottenwalder & León 1999). However, the mortality estimate in the present study should be considered a minimum because: capture events were assumed to involve a single animal, but on rare occasions, more than one was involved; mortality reports that lacked a year were not counted; sampling was non-probabilistic and did not cover both countries completely; in the Dominican Republic, part of the northeast region was sampled during field trials, and only the northwest and southwest regions were included in the final surveys; in Haiti, sample sizes for some departments were small; finally, not all manatee deaths are reported by fishers to authorities or to interviewers because of fear of the law. Research is needed on the size of the manatee population in Hispaniola to evaluate the impact of the minimum annual mortality estimated in this study.

Importantly, the present study showed that fishers reported more manatee mortality events than those passively collected by the RDV and CERREA. The latter data sets should not be used to estimate manatee mortality in the Dominican Republic. The RDV and CERREA do not offer complete coverage, do not organize active patrolling of beaches, and do not record nor maintain a constant search effort (Wilkinson & Worthy 1999). They also lack the resources needed to attend to all reports.

In the Dominican Republic, most manatee captures with figa occurred previous to the 1990s, and most of the specialized manatee hunters who used it have passed away, or are retired. Thus, the figa is now obsolete. Currently, the most harmful fishing gear in use are beach seines and gill nets, with the former mostly restricted to Monte Cristi province. In Haiti, harpoons, purse seines, and traps were the most popular manatee capture methods (Figure 16). But no details were offered to determine if the use of harpoons has declined with time, and spatial data about the use of these fishing gears could not be mapped.

In the Dominican Republic, the overlap of manatees and beach seines in Monte Cristi province is of concern (Figure 14). The first overlapping area was located near the mouth of Río Yaque del Norte, the most important river in Monte Cristi province. The second one, from east of Punta Icaquitos to the east of Gran Gosieer, included seagrass beds located between the mainland, and a barrier reef system running parallel to the coast. The use of beach seines has decreased in the Dominican Republic, but they are still employed by some fishers from Monte Cristi town, creating conflicts with users of other gear types. Beach seines can capture more than one animal at a time, and result in non-target catches. No beach seine hotspots were identified in the southwest region, because beach seines were seldom used in these fishing areas.

Similar analyses could not be performed for Haiti because fishing areas were not mapped. However, the amount of Caribbean Z traps used for fish or lobster near Aquin town, in the Sud department, is concerning because: a manatee hotspot was identified in the vicinity (Figure 10); traps were the third most common method of manatee capture mentioned in Haiti (Figure 16); the density of traps is such that it is almost impossible to maneuver boats (Jean Wiener, personal communication). Florida manatees become entangled in crab trap lines (Haubold et al. 2006), and Antillean manatees become entangled in the ropes connecting the Z traps to buoys at the surface, resulting in non-target catches.

Most (62%) of the fishers interviewed in Hispaniola believed that manatee abundance had declined over the course of their career, but this perceived abundance trend was associated with region and age group in the Dominican Republic. More fishers perceived a decline in the northwest region (70%) compared with the southwest region (54%), perhaps due to the combination of beach seines and figa used intensively in the past, especially in Monte Cristi province. Conversely, more fishers perceived an increase in manatee abundance in the southwest region (40%) compared to the northwest region (24%), perhaps related to the discontinued use of beach seines in the southwest.

The shifting baseline syndrome was evident only in the Dominican Republic (Table 15, Figure 18). Elder fishers remembered more manatees in the past—and more frequent manatee captures—and perceived a decreasing trend, both in manatee abundance and manatee capture rates. If we had interviewed only young fishers, the results would have been misleading, because fewer of them perceived a decrease in manatee abundance and capture rates. The decrease in captures can be partially explained by laws protecting manatees, and the cessation of activity from older manatee hunters, but it is also simply due to the fact that there are fewer manatees to capture (Figure 20). In Haiti, it is possible that manatees have been rare for so long, that elder fishers did not perceive a decline in manatee abundance any more than young fishers.

Fishers largely agreed that manatees were important, but their reasons differed by country, as well as the beliefs associated with manatees, their uses, and the attitudes of fishers towards captured and stranded animals.

In the Dominican Republic, national laws protecting manatees have been in place since 1938 (Ley de Pesca No. 1518 1938). In addition, a larger number of dedicated manatee studies (Chapter 1, Table 4), and more education and awareness campaigns have been conducted than in Haiti. The Acuario Nacional has hosted the RDV since 1995, and CERREA since 2008, responding to manatee strandings around the country, rescuing and rehabilitating a handful of manatees, and maintaining educational programs for the public. Sightings, dead strandings, captures, and more recently, manatee watching in Caño Estero Hondo, have received considerable media attention. All these efforts help explain why the intrinsic value of manatees was perceived as greater in the Dominican Republic than in Haiti (Figure 21). Consequently, there are reasons for optimism in the Dominican Republic: fishers are aware that manatees can attract tourism (Figure 21 and Figure 23); manatee captures are perceived to be decreasing (Figure 20); fishers respect (or fear) manatee protection laws (Figure 20); destructive uses of manatees are mentioned less by younger fishers (Table 16); fishers are aware that hunting manatees is illegal; and fishers are more likely to refuse capturing manatees, release captured animals, and save and report stranded animals (Figure 24).

In Haiti, the lack of national laws protecting manatees, the lack of conservation efforts directed towards the species, and the level of poverty of coastal communities may explain why manatee importance was more economic in nature: manatees “bring in fish”, or they are eaten and sold (Figure 21). Entertainment for tourism was not considered as a use (Figure 23); destructive uses of manatees were equally mentioned by about 20% of young and elder fishers; and fishers were more likely to eat and sell captured or stranded animals (Figure 24). In Haiti, the Fisheries Division of the Ministry of Agriculture is concerned mainly with fisheries exploitation, and there is no Haitian coast guard; therefore, fisheries are not monitored, and fishers do not receive support from the government (J. Wiener, personal communication).

The low number of fishers who mentioned beliefs about manatees in both countries (22 in Haiti, and 175 in the Dominican Republic) was unexpected. Perhaps beliefs associated with manatees have diminished along with manatee abundance in Hispaniola. From interviews in 1982-1983 in Haiti, Rathbun et al. (1985) noticed that the widespread belief that manatee meat had different flavors was only mentioned by a very small number of elder fishers. In the present study, no Haitian fishers interviewed mentioned it, and the most common belief, expressed by only 14 fishers, was that manatees broke nets (Figure 22). In the Dominican Republic, the belief that manatee meat was good and that it had different flavors was widespread, but most fishers interviewed had only heard about it second-hand, or would say manatee meat was eaten in the past and not now, because it is prohibited.

Some traditional uses of manatees were still present in the Dominican Republic but not reported in Haiti, like the use of manatee bones and fat for folk medicine (Table 8, Figure 22 and Figure 23). Besides consuming manatee meat, the only old tradition identified in Haiti was the use of manatee fat to manufacture candles, mentioned in the town of Arcahaie. Uses of manatee body parts reported by Dominican fishers in the present study were the same as those reported by Ottenwalder and León (1999) from interviews in 1994-1996. Dominican law enforcement agencies need to address and stop the illegal trade in manatee body parts, and future education and awareness campaigns should discourage their use for folk medicine and handcrafts.

The quota sampling method used for field surveys in this study was non-probabilistic, and results cannot be generalized to the entire universe of fishers in Hispaniola. Random sampling was not possible due to the lack of complete lists of fishers for each town visited in Haiti and the Dominican Republic. Nevertheless, non-probability samples are appropriate for large surveys, and for studies that seek to collect data from expert informants, instead of random respondents (Bernard 2006). Manatees are relatively rare in Hispaniola, so I aimed to interview fishers knowledgeable about the species. I also selected fishers of different age groups to examine the potential for shifting baselines. The sample size was large (n=679), and covered wide areas of both countries, including 8 of the 9 coastal departments in Haiti, and 5 provinces in the Dominican Republic. Statistical analyses were only performed with broadly grouped data (at the level of departments, provinces, geographic regions, and countries) (Table

12 and Table 15), and resulted in clear and consistent spatial patterns in manatee distribution and manatee captures. The contrast between Haiti and the Dominican Republic regarding the cultural value of the species, and the attitudes of fishers towards manatee conservation was also evident.

The need to integrate FEK into quantitative fisheries assessments and conservation assessments of threatened marine species is widely recognized (Huntington 2000; Johannes et al. 2000), but challenging. Some studies have shown good agreement between fishers' observations, and data from more traditional scientific sources (Neis et al. 1999; Rochet et al. 2008), but this is not always the case (Daw et al. 2011). In Hispaniola, at least for manatee mortality, there are no other sources of data available to compare with the results of this study (e.g., hunting log books, records from commercial exploitation, or results from observer programs). Of 13 previous dedicated manatee studies in Hispaniola, 11 have completely or partially relied on interviews (Chapter 1, Table 4). However, the minimum island-wide annual mortality estimated in this study, was similar to that estimated by Ottenwalder and León (1999) from interviews in 1994-1996 in the Dominican Republic.

The present study, like all interview-based research, was based on self-report and was subject to memory error. Generalities that apply to memory error include that: memory for dates is poor; the level of reporting and the accuracy of dating decline with time elapsed since an event; rare or personally atypical events are more often exactly dated (Bradburn 2000; Tourangeau 2000). Because manatees are currently rare in

Hispaniola, sightings and captures can be considered atypical events more likely to be dated accurately, compared to events involving more common species. Nevertheless, to aid memory retrieval, we provided ample time for interviews, and we asked fishers to recall events in reverse chronological order (Tourangeau 2000). I also took additional measures when analyzing the data: I separated recent manatee sightings (2010-2014) from older ones (1950-2009) to compare manatee distribution in the Dominican Republic (Figure 12); I analyzed manatee sightings within a year of the interview separately from sightings in a lifetime (Table 12); I tabulated older manatee mortality reports by decades (Table 13); I provided an annual manatee mortality estimate for Hispaniola based on the most recent and complete year of reports (2012).

Future conservation efforts in Haiti should focus first on reducing human related manatee mortality. For conservation measures to be successful in an impoverished country like Haiti, the use of economic tools (e.g., microfinance lending, performance-based incentives) is highly recommended to alleviate poverty and provide alternative livelihoods for fishers (Marsh et al. 2011). Rathbun et al. (1985) believed that an education campaign aimed at fishers in Haiti might worsen the situation for manatees, by drawing the attention of younger people to an already drastically reduced manatee population. These researchers also suggested that the best chance of manatee survival in Haiti was that hunting expertise would gradually end with the older generation. Thirty years have passed but the attitudes of fishers in Haiti towards manatee conservation is still generally negative, and is not influenced by the age of the respondent (Figure 21,

Figure 22, Figure 23 and Figure 24). In light of these results, extensive education and awareness campaigns are recommended to inform coastal communities about the dire conservation situation of manatees in Haiti, and to help change their perceived value.

More dedicated manatee studies are needed to further our knowledge of the species in Haiti. Due to the low literacy level of fishers and their inability to interpret maps, future studies should combine interviews with reconnaissance boat trips with local guides to the general areas where manatees are reported to occur regularly (Figure 10). Researchers should be equipped with GPS units to locate these areas, and identify coastal features with their local names. Once the manatee hotspots are narrowed down geographically, more detailed land, boat, or aerial surveys should be conducted to confirm manatee presence and identify high-use areas.

Estimating the total size of the manatee population in Hispaniola would be useful for several reasons: first, to understand the impact of the estimated minimum annual manatee mortality on the population, and set realistic goals to reduce it; second, to provide a baseline for measuring the success of future conservation actions; and, finally, to understand the importance of the manatee population of Hispaniola within the context of the Wider Caribbean Region.

The use of a standardized detailed questionnaire, and quota sampling by age group and geographic strata, proved efficient for collecting a wealth of information on manatee distribution, mortality, and perceived trends in abundance and captures. The cultural value of the species, and the attitude of fishers towards manatee conservation were also captured. Hopefully, this research serves as a starting point to propose concrete conservation actions, and guide future scientific studies, tailored to the contrasting situation of manatees in Haiti and the Dominican Republic.

CHAPTER 3: Ensemble modeling of Antillean manatee distribution in the Dominican Republic

Introduction

The Antillean manatee (*Trichechus manatus manatus*) is currently listed as critically endangered in the Dominican Republic (MIMARENA 2011). An essential step towards the recovery of this species is to identify and protect important habitat. One of the country-specific recommendations in the regional management plan for the West Indian manatee is a comprehensive study of manatee distribution (UNEP 2010). In Chapter 1, I presented the most comprehensive manatee distribution database and map to date for the Dominican Republic (Figure 6), including sightings dating from the pre-Columbian era to 2013. In Chapter 2, I presented maps of manatee distribution and manatee hotspots in the Dominican Republic derived from interviews with artisanal fishers in 2013-2014 (Figure 14 and Figure 15). But these research efforts did not quantitatively explore the reasons why manatees are likely to be present in certain areas more than others.

Species distribution modeling is a quantitative approach used to describe the relationships between species and their environment (Franklin 2009). Many algorithms are available that model species responses to predictor variables in different ways (Guisan & Zimmermann 2000; Elith et al. 2006), and it is not always clear *a priori* which method will work best for a particular case. Comparative reviews have found that the best modeling approach often varies geographically or by taxa (Elith et al. 2006). In general, however, more complex models tend to have higher predictive accuracy, as long as adequate data are available to parameterize them (Elith et al. 2006; Tsoar et al. 2007). Currently, there is a growing interest in ensemble modeling, which capitalizes on the strengths of different modeling algorithms, and reduces the predictive uncertainty of single models, by combining the predictions of several models (Araújo & New 2007; Thuiller et al. 2009; Grenouillet et al. 2011; Forester et al. 2013). However, ensemble modeling has not been used to predict manatee distribution.

Critical components of manatee habitat in marine environments include: shallow water; proximity to deeper waters to escape from danger; availability of freshwater sources and aquatic vegetation; warm water; shelter from waves, strong winds, currents, and storms; and travel corridors between habitat areas (Moraes-Arraut et al. 2012). In the few studies that have assessed Antillean manatee habitat in Caribbean marine environments, different combinations of these habitat requirements have been found to influence manatee distribution (Axis-Arroyo et al. 1998; Olivera-Gómez & Mellink 2005; LaCommare et al. 2008; LaCommare 2011).

In the Dominican Republic, the only manatee habitat modeling study conducted to date used generalized linear models and simulations to relate manatee presence to habitat variables in Caño Estero Hondo, a coastal lagoon in the northwest coast (Domínguez Tejo & Rivas 2011). No country-wide manatee habitat models have been developed.

In this chapter, I present a country-wide model of Antillean manatee distribution for the Dominican Republic, and the first to use an ensemble modeling approach for the species. Specifically, I: (1) identify areas of high predicted probability of manatee presence; (2) identify the most important predictors of manatee habitat; and (3) compare modeled manatee distribution with that observed in past country-wide aerial surveys, and with manatee distribution derived from fishers' ecological knowledge.

Methods

Spatial analyses for this study were conducted in ArcGIS 10.3.1, and statistical analyses were conducted using R statistical software v. 3.1.2 (R Core Team 2014), and contributed package biomod2 (Thuiller et al. 2014) for ensemble modeling. All GIS layers used and derived maps were projected in WGS84 UTM Zone 19 N.

Manatee presences and pseudo-absences

Binary ungrouped data, consisting of manatee presences and pseudo-absences, were used for species distribution modeling. Manatee sightings from aerial surveys, and from land and boat surveys in the Dominican Republic were combined for model training. These surveys did not extend beyond 2 km of the coastline. Only sightings confirmed by more than one observer or by pictures, and recorded with geographic coordinates were used.

A total of 38 sightings were selected from two dedicated manatee aerial surveys. The first survey was conducted in 2009 in the northeast coast, covering approximately

160 km of the coastline of Bahía de Samaná, from Punta Balandra to Punta Gorda, and about 50 km of the north coast of Samaná peninsula, from Cayo Jackson to Punta Los Yerbasos, using a distributional survey (Auil Gómez et al. 2011). The second survey was conducted in 2010-2011, covering approximately 300 km of the southwest coast, from Río Nizao to Cabo Rojo, combining distributional and intensive search surveys (Reynoso et al. 2011). Two opportunistic sightings recorded by commercial helicopter pilots in 2013 in Barahona province, in the southwest coast, were added to the training set for a total of 40 sightings from aerial surveys.

A total of 54 sightings in the northwest (in Monte Cristi and Puerto Plata provinces), northeast (in Samaná province), and southwest (in Barahona province) coasts were selected from dedicated manatee land and boat surveys conducted in 2006-2008 (Domínguez Tejo 2006; Lancho et al. 2006; Domínguez Tejo 2007, 2009), and during field work for Chapter 2 in 2014. Land surveys were conducted by at least two observers from an elevated vantage point near the shoreline. Boat surveys consisted of 30-minute point scans, as described in LaCommare et al. (2008), in areas of likely manatee presence. Manatees were also searched while traveling between point scan locations. Only sightings where the estimated distance to the animal was 100 m or less were kept for model training. If two sightings occurred within 100 m of each other, the sighting with the smallest estimated distance to a manatee was kept.

Pseudo-absences (PA) were used to contrast the environmental conditions under which manatees occurred, against those available near the coastline of the Dominican

Republic. In ArcGIS 10.3.1, I created polygons from the coastline of the Dominican Republic out to 2 km from shore, around the areas where the aerial, and the land and boat surveys for manatees were conducted. Inside those polygons, I created over 8,000 PA, each separated by a minimum distance of 100 m. To maintain a balanced dataset, half of the PA were created inside the polygons buffering the aerial survey areas, and half inside the polygons buffering the land and boat survey areas; PA were also created in proportion to the size of the polygons, so that more PA were created in larger polygons. PA were chosen randomly to create constrained predictive maps of species distribution, and to maximize specificity (Chefaoui & Lobo 2008; Stokland et al. 2011; Barbet-Massin et al. 2012). PA were also allowed to be drawn from presence sites (i.e., within environmentally suitable areas) (Chefaoui & Lobo 2008; Stokland et al. 2011).

Predictor variables

Predictors were selected according to the species' requirements in marine habitats (Drew et al. 2012; Moraes-Arraut et al. 2012), focusing on availability of freshwater sources, aquatic vegetation, and shelter from wave action, strong winds, and currents. Manatees prefer shallow areas (Moraes-Arraut et al. 2012), but bathymetric data were not available country-wide at the required resolution to include depth among the predictors.

The most up to date GIS layers of seagrasses, coral reefs, and mangroves of the Dominican Republic were obtained from The Nature Conservancy (TNC). These layers were created by TNC under a contract from UNESCO for the Caribbean Large Marine Ecosystem Project in 2013. TNC contractors compiled the best available datasets for the Dominican Republic in 2011, and checked them against high resolution satellite imagery from Bing and ESRI Imagery Basemaps, using heads up digitization to correct errors and omissions. The polygon layer of seagrasses was not classified by species, and did not include measures of abundance. GIS layers of the rivers and the coastline of the Dominican Republic were obtained from the Ministerio de Medio Ambiente y Recursos Naturales (MIMARENA).

I converted line or polygon GIS data layers of the rivers, seagrasses, coastline, coral reefs, and mangroves of the Dominican Republic to raster layers of the predictor variables used for modeling: distance to freshwater sources (e.g., to river mouths, artificial canal mouths, known freshwater seeps), distance to seagrass, area of seagrass in a 5 km radius, distance to land, distance to coral reefs, and distance to mangroves. The rasters were created from the coastline out to 10 km from land, with a cell size of 100 m to match the resolution of the presences and PA. The 5 km spatial reference for the seagrass area was used because it captured the local movements of most manatees derived from telemetry studies in the neighboring island of Puerto Rico (Drew et al. 2012).

Euclidean distances were calculated from land; all other distances were calculated around land. A cost surface was created where land cells and water cells farther than 10 km from land were assigned a value of “no data”, and valid water cells from the coastline out to 10 km from land were assigned a value of 1. With the cost surface as input, the “cost distance” tool (ArcGIS Spatial Analyst, ESRI 2011) was used to calculate a least cost path from valid water cells to the closest resource (e.g., a seagrass cell, a freshwater cell, a coral reef cell, or a mangrove cell), but going around and not across land forms. A limitation of the “cost distance” tool is that it only creates paths in 8 directions (vertically, horizontally, and at 45 degree angles) from the center of a cell to an adjacent cell, resulting in greater distances than the actual distance between two points if they are not located in any of these 8 directions relative to each other (Dunphy-Daly 2015). A correction factor (C. MacLeod, personal communication) was used to account for this issue, reducing the cost distance error to 4% or less in this study.

Among other ecological services, coral reefs dissipate wave energy (Moberg & Folke 1999); therefore distance to reefs was one way to represent distance to shelter for manatees in this study. However, because manatees have been frequently reported in shallow, calm areas near mangroves in the Dominican Republic (Domínguez Tejo 2006, 2007, 2009), it was important to determine if distance to mangroves was also a proxy for distance to sheltered waters. A raster-based approach was used to calculate a topographical relative wave exposure value for each coastal cell around the country, taking into account the presence of coral reefs. The method only required a vectorbased digital coastline, to calculate wave fetch for every coastal cell as the distance to the nearest land cell in 16 angular sectors (Burrows et al. 2008). Wind data for the Dominican Republic (e.g., average wind speed, and proportional occurrence) were not available, so the wave exposure index was based solely on the openness of the coastline. The maximum fetch considered was 20 km, and coral reefs were treated as land, so that exposure values would be lower in the real coastal cells protected by the reefs. Fetch values were added for the 16 angular sectors of each coastal cell, and the results were divided by the highest value, to obtain a normalized relative exposure index with values ranging from 0 to 1, with 1 being the most exposed. Mann Whitney tests were then used to compare the relative wave exposure values of mangrove versus non-mangrove coastal cells.

Multivariate tables were created by sampling each predictor variable at the locations of the 94 manatee presences, and the over 8,000 PA drawn from surveyed areas out to 2 km. To prepare the data for ensemble modeling, rows of PA with missing values for any predictor variable were deleted. The remaining rows of the PA multivariate table were shuffled randomly, to allow drawing 8 sets of 1000 PA: each set with spatially dispersed PA, and approximately half from aerial survey areas, and half from land and boat survey areas. The multivariate table of manatee presences was added to the 8 PA sets, creating 8 multivariate tables. The rows of each table were shuffled randomly again before using them as input for ensemble modeling.

Ensemble modeling strategy

The general approach used in the present study was to first build many cross-validated models to compare the results of different modeling algorithms; afterwards, to build several full models only using the best performing modeling algorithms; finally, to build an ensemble model by combining only full models meeting a quality threshold criteria. All models were built using the R package biomod2 (Thuiller et al. 2014).

Table 17 shows the strategy used for model cross-validations. Five modeling algorithms were used. The chosen algorithms were classified as intermediate to high performing in a comparative study of species distribution models (Elith et al. 2006): Generalized linear models (GLM), Generalized additive models (GAM), Boosted regression trees (GBM), and Maximum entropy modeling (MAX). Random forest (RF) was also included because of its high classification accuracy compared to other classification methods (Cutler et al. 2007). Details of the model parameterization used for each algorithm are presented in Appendix A. For each modeling algorithm, 80 replicate models were built using 8 sets of 1000 PA, and for each set, doing 10 cross-validation runs with 70% of the data used for training, and 30% for verification.

Three measures of model performance were used to compare the cross-validated models created with the different modeling algorithms. Sensitivity and the True Skill Statistic (TSS) were selected as threshold dependent measures of predictive accuracy. Sensitivity is equal to the probability of detection (POD) of a model. TSS is equal to Sensitivity + Specificity - 1 (Allouche et al. 2006). TSS values range from -1 to 1, where 1 indicates perfect agreement between model predictions and a validation data set, while 0 or less indicate model performance no better than random. The area under the Receiving Operator Characteristic (ROC) curve was selected as a threshold independent measure of predictive accuracy (Fielding & Bell 1997). This metric reflects the ability of a model to discriminate between sites where a species is present versus where it is absent, or versus background sites. Values range from 0.5 to 1, where 0.5 represents a performance that is no better than random, and 1 is perfect discrimination.

Table 17: Model cross-validation strategy. PA: pseudo-absences; GAM: generalized additive models; GBM: Boosted regression trees; GLM: generalized linear models; MAX: Maxent; RF: random forest.

5 Algorithms	**x**	**8 PA sets**	**x**	**10 Cross-validations**
GAM GBM GLM MAX RF		8 sets of 1000 random PA each, and equal weight of presences and PA (Barbet-Massin et al. 2012)		For each PA set, 10 cross-validation runs with a 70% data split

Models were cross-validated using different sets of PA to test their predictive accuracy: to determine if they met a quality threshold criteria of mean POD, TSS, and ROC values of at least 0.7; and to identify modeling algorithms too sensitive to the choice of PA (i.e., if the performance measures of any modeling algorithm varied widely with different sets of PA). The predictions of models with TSS >0.7 were averaged across the different modeling algorithms to create an ensemble or consensus model. Measures of model performance were averaged across the 10 cross-validation runs of the 8 sets of PA to compare the modeling algorithms and the consensus model.

After eliminating any low performing modeling algorithm, full models were built with the 8 sets of PA, but no data partitioning. The performance of the full models was assessed using the percent deviance explained for the individual GLM and GAM models, and the percent of out of bag error for RF models.

An ensemble model was then created by averaging the predictions of the full models with TSS >0.7 across modeling algorithms and PA sets. The variable importance of the predictors in the ensemble model was calculated in biomod2 following the same principle as in RF models (Cutler et al. 2007). Modified model predictions are obtained by shuffling the values of one variable at a time, and calculating a Pearson correlation coefficient (cor) between the original and the modified model predictions. The variable importance is scored as 1 - cor; if an important variable is shuffled, the correlation coefficient will be low and the importance value will be closer to 1. In the present study, the variable importance value was averaged for three randomizations of each predictor variable.

Species response curves were created for the ensemble model of mean probability of manatee presence following Elith et al. (2005), by setting n-1 variables to the mean, and allowing the remaining one to vary across its range of values. The obtained curve shows the sensibility of the model to that specific variable.

Two maps of the ensemble model were created, predicting manatee habitat out to 2 km from land. The first was calculated by averaging the predictions of the full models for each raster cell. The second was created to account for spatial uncertainty in the predictions of the full models. Using the TSS as the cutoff value, individual model predictions were converted to binary outcomes, which were mapped and added to show how many models agreed that a cell was manatee habitat.

Model evaluation

Two data sets were used for model evaluation. The first set comprised 66 manatee sightings from 6 country-wide aerial surveys conducted in 1977 (Belitsky & Belitsky 1978). Individual hand drawn maps of the aerial surveys were scanned and geo rectified, with a maximum root mean square error of 1.3 km. The digitized sighting points were moved either vertically or horizontally until reaching a distance of 500 m from land, to place them within the 1 km wide aerial survey path from the coastline described in the study. The second set comprised 449 manatee sightings from artisanal fishers interviewed in the northwest and southwest coasts in 2013-2014 (Chapter 2). Only mapped, recent (2012-2014), sightings of animals in the water, seen alive and unharmed, and within 2 km from the mainland were chosen for model evaluation. The approximate spatial resolution of these sightings was 1 km, referencing the gridded topographic maps used to draw them during interviews.

The approach used for model evaluation involved building two frequency curves of predicted probabilities of manatee presence from the ensemble model (Figure 25): the first curve sampled from a background that matched the spatial extent of each evaluation data set; the second curve sampled from buffered areas around the sightings of the evaluation data, with buffer sizes matching the spatial resolution of the sightings in each data set, and thus accounting for the uncertainty in the sighting locations. The expectation was that if the model correctly predicted the sightings, the curve of probabilities sampled in the buffered sighting locations would lean towards the upper boundary of the sighting probability scale, and would differ from the background curve. A one-sided test of binomial proportions was used to test for an enrichment of high predicted probabilities of manatee presence at the buffered sighting locations relative to the background. First, the point in the probability scale below which lay 95% of the data in the background curve was found. Then the percent (p) of data in the buffered manatee sighting locations falling above that point was calculated. If the model predicted the sightings well, then $p > 5\%$.

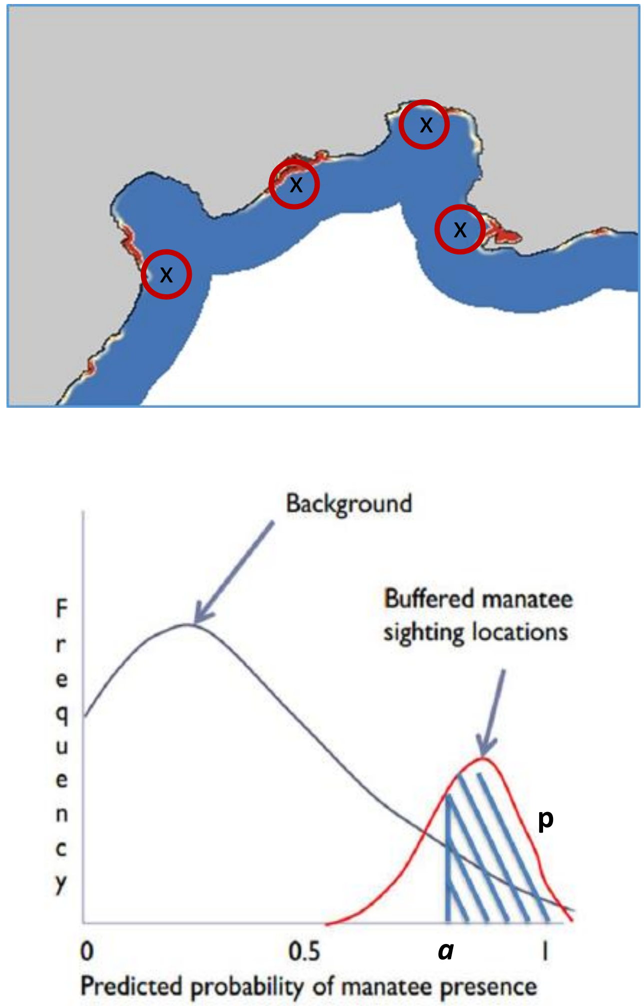


Figure 25: Strategy for using evaluation data to test the final consensus model. Top panel: hypothetical final consensus model showing the probability of manatee presence from low (blue) to high (red) values; the Xs represent manatee sighting locations from an evaluation data set; buffered red circles represent the spatial uncertainty of those sighting locations. Bottom panel: hypothetical distribution of predicted probabilities of manatee presence sampled from the background (blue curve), versus the buffered sighting locations (red curve); *a* represents the point on the x-axis below which 95% of the background data are observed; the hatched area represents the percentage of data, p, that fall above point *a* in the buffered manatee sighting locations curve. If the model predicts the sightings, then p >5%.

The background of model predictions around the country was clipped to 1 km from the coastline to match the aerial survey path; the diameter of the buffers created around the aerial survey sightings was 1.3 km.

The background of model predictions going out to 2 km from land was restricted to the northwest and southwest coast of the country, to match the extent of the fisher evaluation data set; the diameter of the buffers created around the sightings from the fishers was 1 km.

Relative wave exposure at modeled manatee hotspots

From the ensemble model, manatee hotspots were extracted as the cells identified as manatee habitat by over 90% of the full models. Coastal cells within 100 m of manatee hotspot cells were selected. Mann Whitney tests were then used to compare the relative wave exposure values of coastal cells adjacent to manatee hotspots versus all other coastal cells.

Comparison of modeled and fishers' manatee hotspots

The layer of modeled manatee hotspots was overlaid with the manatee hotspots identified by interviewed fishers in Chapter 2 (Figure 14 and Figure 15). The comparison of the extent, location, and agreement of both types of manatee hotspots was restricted to the northwest and southwest coasts, where the fishers were interviewed.

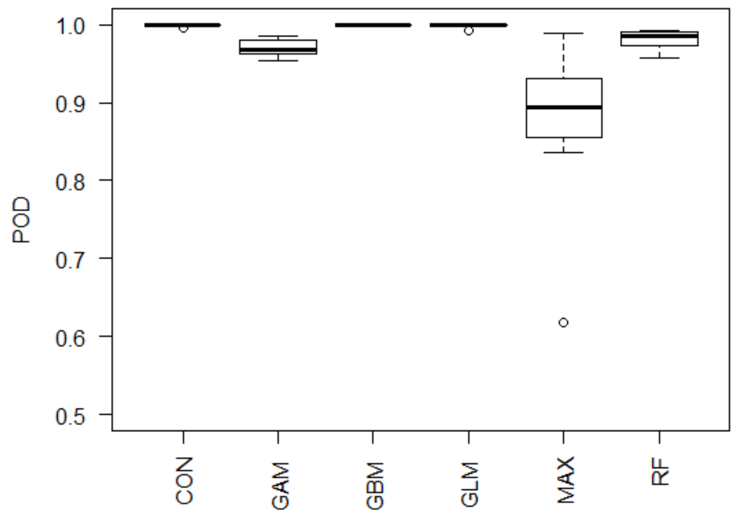
Results

Mangroves as a proxy for shelter

Mann Whitney tests showed significant differences in the medians ($W=26773530$, p-value $< 2.2e-16$), with lower values of relative exposure for the coastal cells located within mangrove areas (Md=0.09), compared with non-mangrove coastal cells (Md=0.23).

Cross-validated models

In general, cross-validated Maxent models showed the lowest measures of model performance and were the most sensitive to the choice of PA. Maxent models had the lowest and widest range of POD values (Figure 26 top panel), with models falling below the quality threshold criteria of mean POD above 0.7. All other modeling algorithms and consensus models had mean POD values above 0.95. Maxent models also had the lowest values of TSS (Figure 26 bottom panel). Only 6 out of the 80 Maxent models had TSS values above 0.7; for each of the other modeling algorithms, at least 13 or more of the 80 models had TSS values above 0.7, and therefore they contributed more to the consensus model. All modeling algorithms met the quality threshold criteria of mean ROC values above 0.7, but Maxent models had the lowest and widest range of values (Figure 27). The consensus model outperformed all single modeling algorithms in terms of TSS and ROC values.



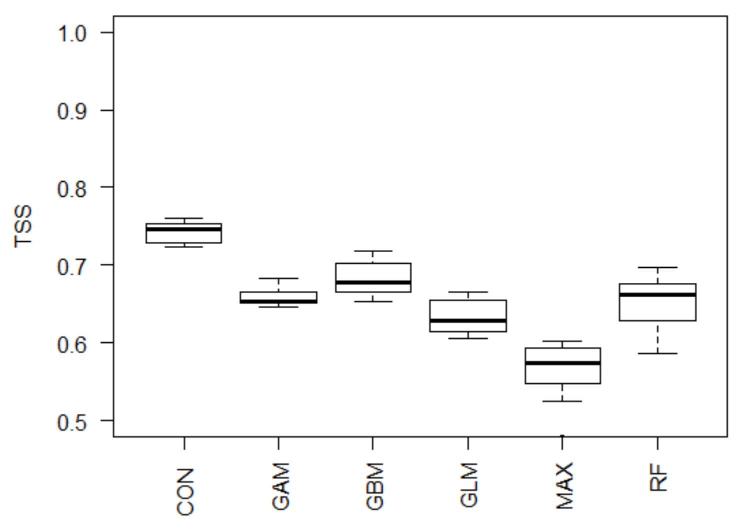


Figure 26: Threshold dependent performance measures of cross-validated models. Boxplots show the mean probability of detection (POD) (top panel), and the mean true skill statistic (TSS) (bottom panel), for models built with 8 sets of 1000 pseudo-absences, each set cross-validated 10 times with a 70% data split. CON: consensus model.

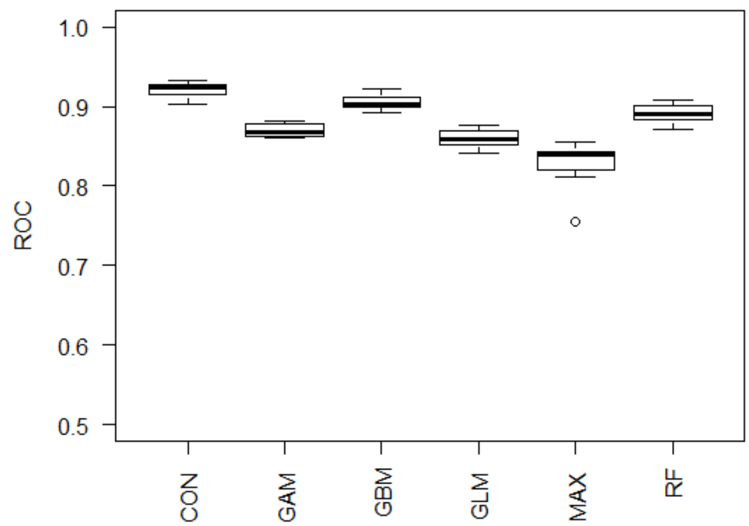


Figure 27: Threshold independent performance measure of cross-validated models. Boxplots show the mean area under the curve (ROC), for models built with 8 sets of 1000 pseudo-absences, each set cross-validated 10 times with a 70% data split. CON: consensus model.

Full models

Full models were built with only four modeling algorithms, GAM, GBM, GLM, and RF, and 8 sets of PA, for a total of 32 models. The mean percent deviance explained was 48.94 ± 1.17 % SD for GAM models, and 36.03 ± 1.60 % SD for GLM models. The mean percent out of bag error with RF models was 6.23 ± 0.35 % SD.

Ensemble model

Of the 32 full models, 22 (6 GAM, 8 GBM, and 8 RF models) had TSS values above 0.7 and their predictions were averaged to create the final ensemble model. Table 18 shows the mean variable importance value of the predictors of the ensemble model calculated from three randomizations. The most important predictor was distance to seagrass, followed by distance to land, distance to mangroves, and distance to freshwater sources. Distance to coral reefs, and seagrass area in a 5 km radius were the least important predictors.

Table 18: Mean predictor variable importance values for the final ensemble model. Means were calculated from three randomization runs.

Predictor	Mean variable importance	Rank
Distance to seagrass	0.271	1
Distance to land	0.218	2
Distance to mangroves	0.209	3
Distance to freshwater sources	0.158	4
Distance to coral reefs	0.037	5
Area of seagrass in a 5 km radius	0.027	6

Species response curves showed that, when keeping other predictors at their mean, the probability of manatee presence was most sensible to distance from land, decreasing rapidly and reaching predicted values of 0 from about 1.5 km onwards (Figure 28). Probabilities increased slightly with increasing area of seagrass in a 5 km radius. For the remaining predictors, the species response curves were not monotonic. Species response curves were similar for the distance from mangroves, freshwater sources, and seagrasses: probabilities decreased rapidly in the first 15 km, and gradually increased to a second maximum value between 30-40 km. The probability of manatee presence was less sensible to distance from coral reefs, and showed the opposite pattern: increasing in the first 15 km, then decreasing towards 30-40 km.

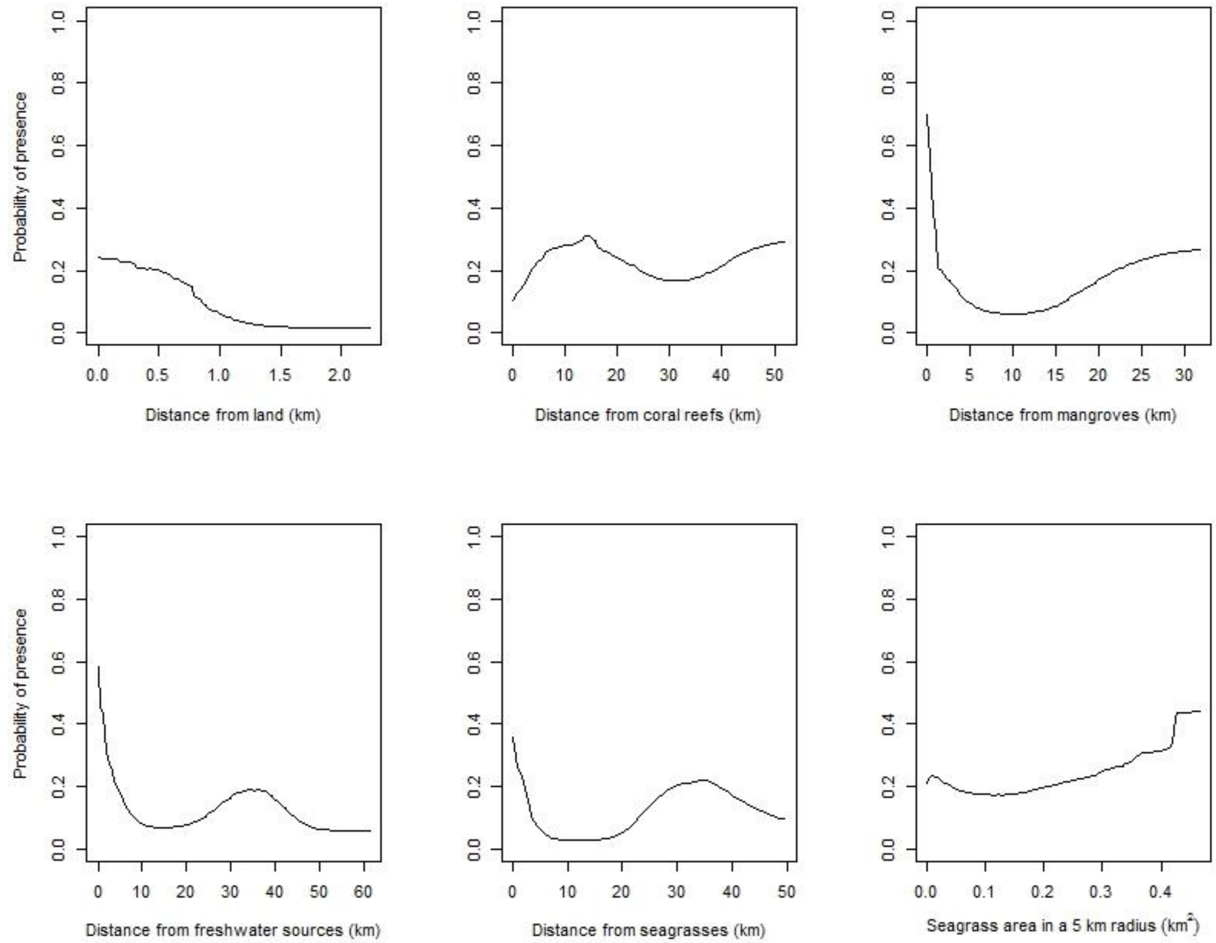


Figure 28: Species response curves to predictors for the ensemble model of mean probability of manatee presence.

Figure 29 shows the mean probability of manatee presence in the Dominican Republic from an ensemble averaging the predictions of the 22 full models with TSS above 0.7. Areas of high probability of manatee presence were more continuous in the northwest coast, from Río Masacre to Bahía Isabela, and from Bahía de Luperón to east of Bahía de Puerto Plata. Important areas in the northeast coast extended from El Portillo to Punta Morón, and from Bahía the San Lorenzo to Miches town. In the southeast coast, one important area was identified from the northwest coast of Isla Saona to Peñón Gordo. Along the southwest coast, important areas included Bahía Las Calderas, Bahía de Puerto Viejo, near Barahona town, from Bahía Regalada to Ensenada del Refugio, from Piticabo to Trudillé, and from Cabo Rojo to Río Pedernales.

The ensemble model built by adding the binary outcomes of the 22 full models shows that 90-100% of the models agree that the above mentioned areas are manatee habitat (Figure 30). Together, these manatee hotspots amounted to approximately 205 km^2.

Both maps of the ensemble model showed long stretches of coastline with low predicted probabilities of manatee presence in the easternmost part of the country (from east of Miches town to Punta El Algibe), and in the south east coast (from Peñón Gordo to east of Bahía Las Calderas). The longest uninterrupted stretch of coastline with 0 predicted probability of manatee presence was about 23 km long, located in the exposed eastern side of the Samaná peninsula, from Cabo Samaná to Bahía Clara.

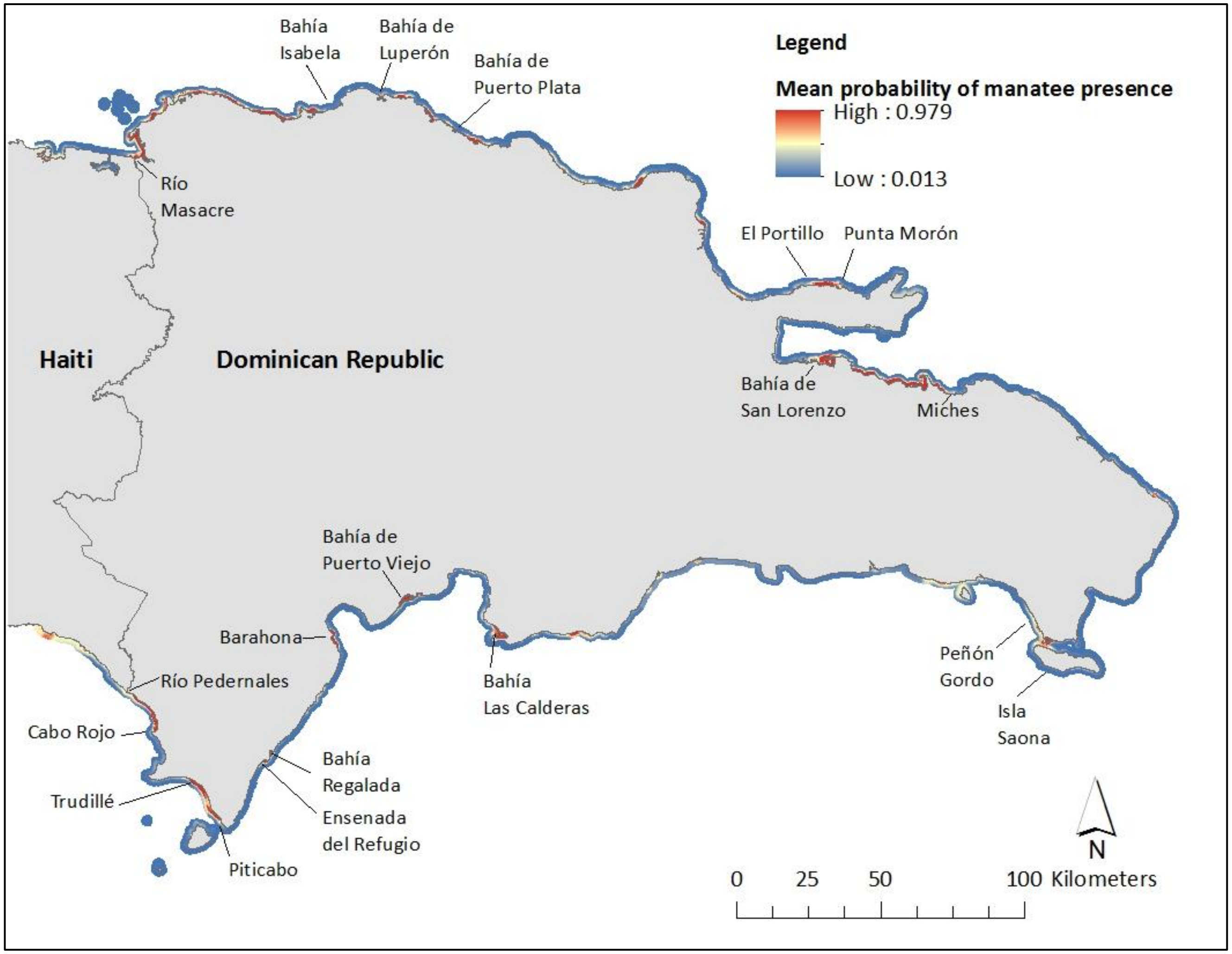


Figure 29: Predicted mean probability of manatee presence in the Dominican Republic.

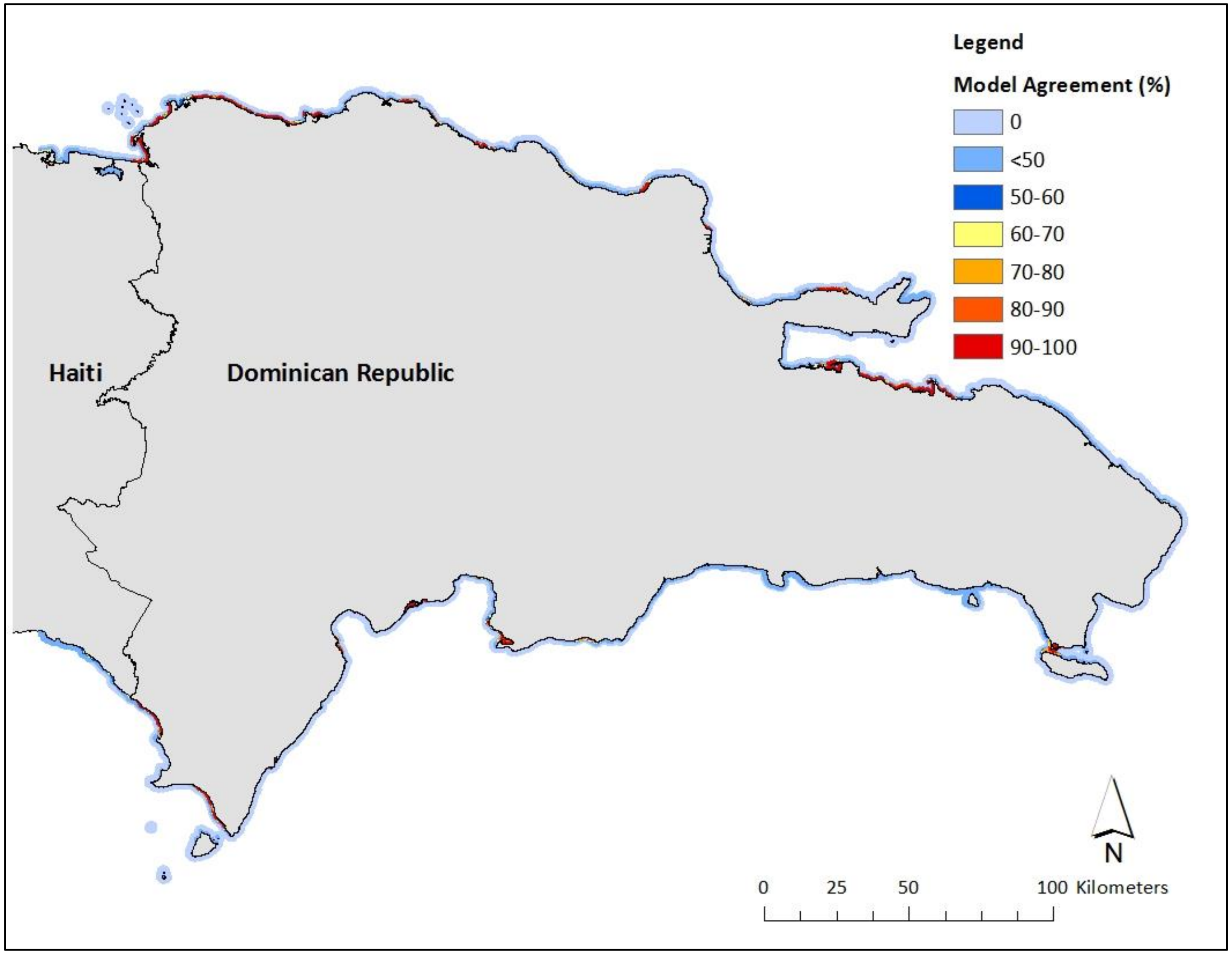


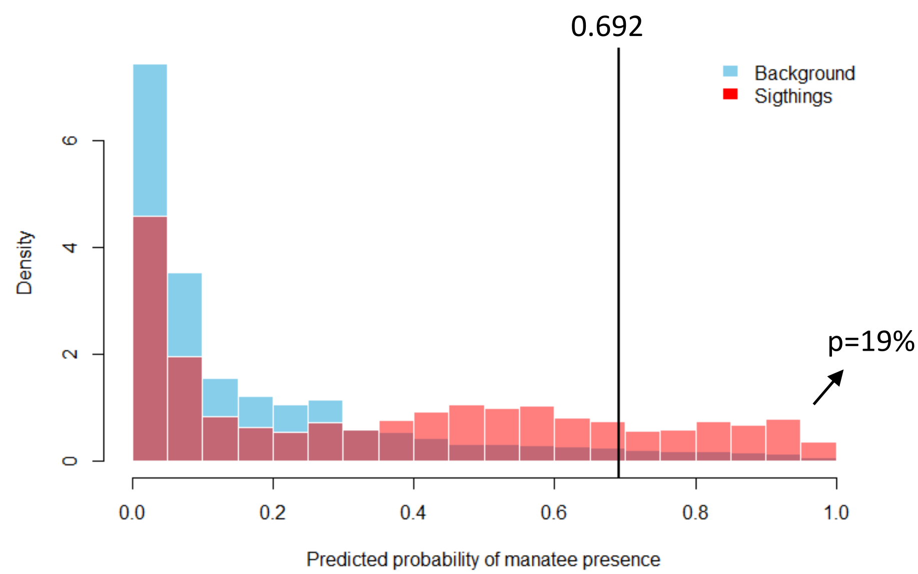
Figure 30: Percentage of full models that agree an area is manatee habitat in the Dominican Republic. Percentages were calculated based on 22 models.

Model validation

The ensemble model was a good predictor for both past and recent manatee sightings (Figure 31). For the 1977 aerial survey data (Belitsky & Belitsky 1978), 95% of the background predicted probabilities of manatee presence fell below 0.692, and more than 5% (about 19%) of predicted probabilities at the buffered manatee sighting locations fell above 0.692 (χ^2 = 2809.9, p-value < 2.2e-16). For the 2012-2014 manatee sightings by artisanal fishers (Chapter 2), 95% of the background predicted probabilities of manatee presence fell below 0.740, and more than 5% (about 10%) of predicted probabilities at the buffered manatee sighting locations fell above 0.740 (χ^2 = 1511.2, p-value < 2.2e-16).

Relative coastline exposure at modeled manatee hotspots

Mann Whitney tests showed significant differences in the medians (W=43249966, p-value < 4.299e-16), with lower values of relative exposure for coastal cells located within 100 m of manatee hotspots (Md=0.19), compared with coastal cells not adjacent to manatee hotspots (Md=0.21).



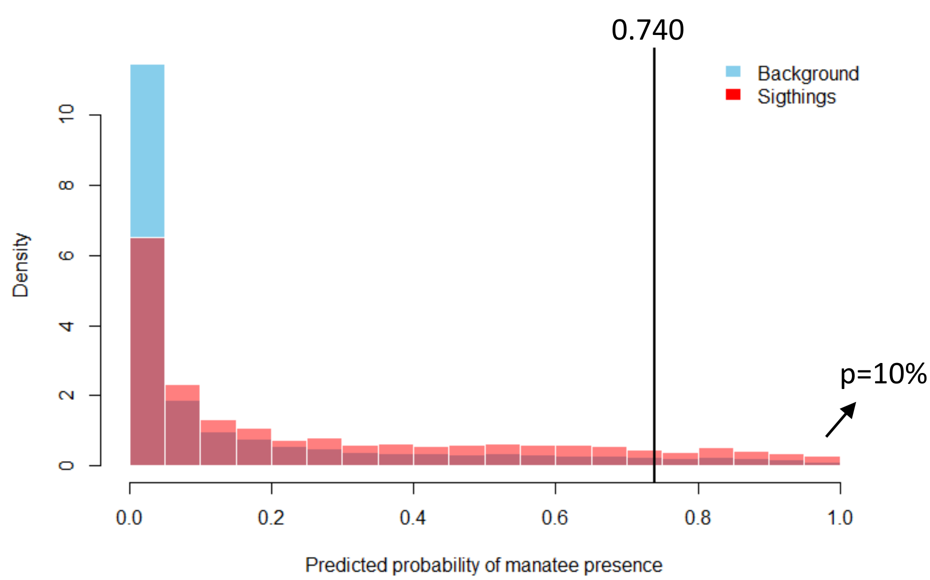


Figure 31: Predicted probability of manatee presence in the background (blue) versus the buffered manatee sighting locations (red) of the evaluation data sets. Top panel: sightings from aerial surveys in 1977 (Belitsky and Belitsky, 1978). Bottom panel: sightings from fishers in 2012-2014 (Chapter 2). The vertical black lines mark the point below which lay 95% of the background data; p is the percent of data from the buffered manatee sighting locations that fall above the black line.

Modeled versus fisher's manatee hotspots

Figure 32 and Figure 33 show overlays of modeled manatee hotspots versus manatee hotspots identified with fisher's ecological knowledge (FEK) in the northwest and southwest coasts of the Dominican Republic respectively. More extensive manatee hotspots were modeled compared with those identified by fishers (117 km^2 versus 67 km^2 respectively). Approximately 37 km^2 of coastal habitat were identified as manatee hotspots with both methods; but an additional 30 km^2 were identified only by fishers, and 80 km^2 were identified only with ensemble modeling.

Most manatee hotspots identified by fishers were included in the modeled hotspots, with some discrepancies. In the northwest coast, fishers identified larger manatee hotspots in Bahía de Monte Cristi, and from Punta Icaquitos to Caño Gran Gosieer. Fishers also identified a hotspot near the Río Bajabonico mouth area that was not modeled. In the southwest coast: the hotspot near Barahona town extended more to the north than the modeled hotspot, reaching the Río Yaque del Sur mouth area; the hotspot starting in Bahía Regalada extended more to the south, reaching Cabo San Luis; the areas near La Cueva and near the Cabo Rojo Hotel were identified by fishers but not modeled.

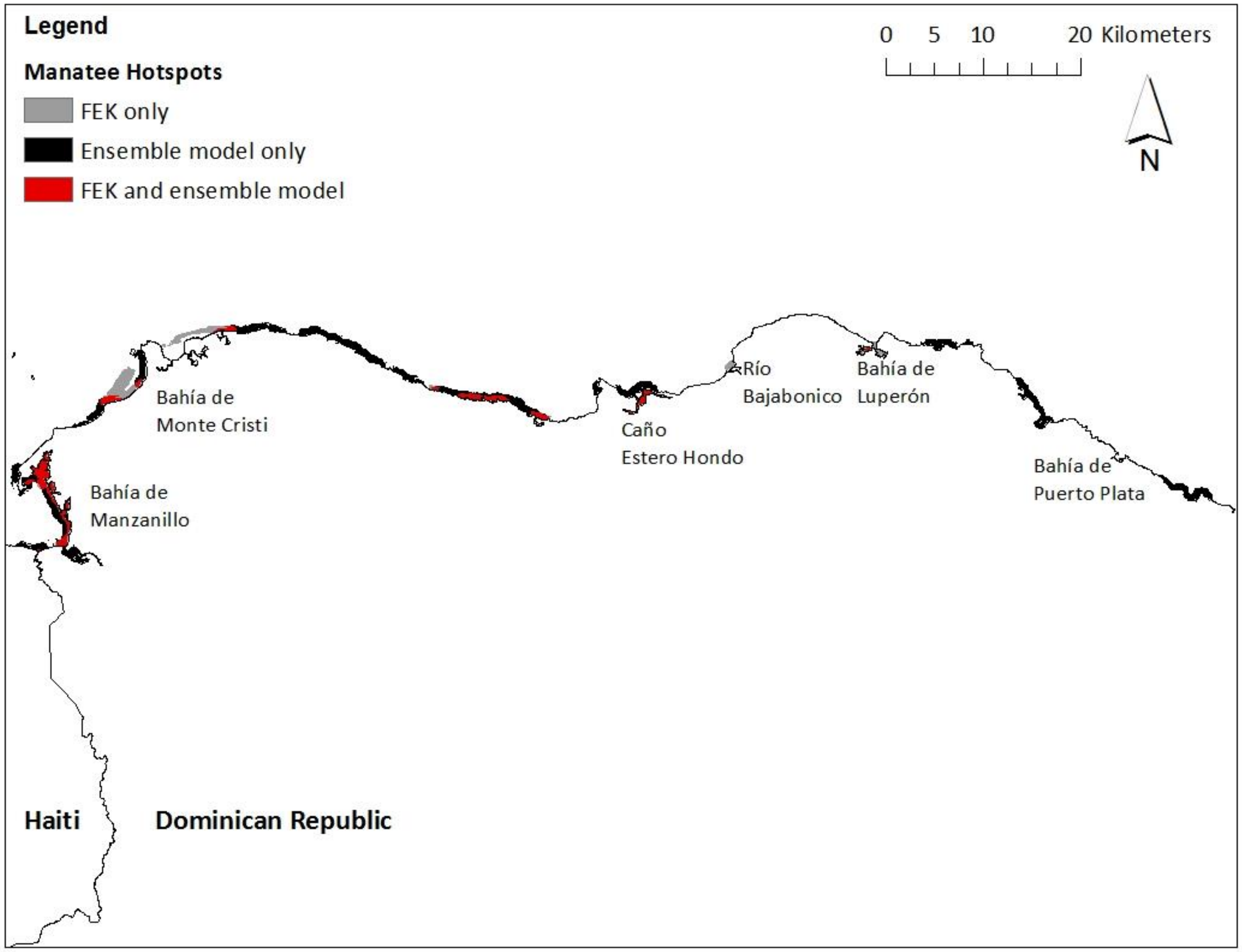


Figure 32: Manatee hotspots identified with fisher's ecological knowledge only (gray), ensemble modeling only (black), and with both methods (red), in the northwest coast of the Dominican Republic.

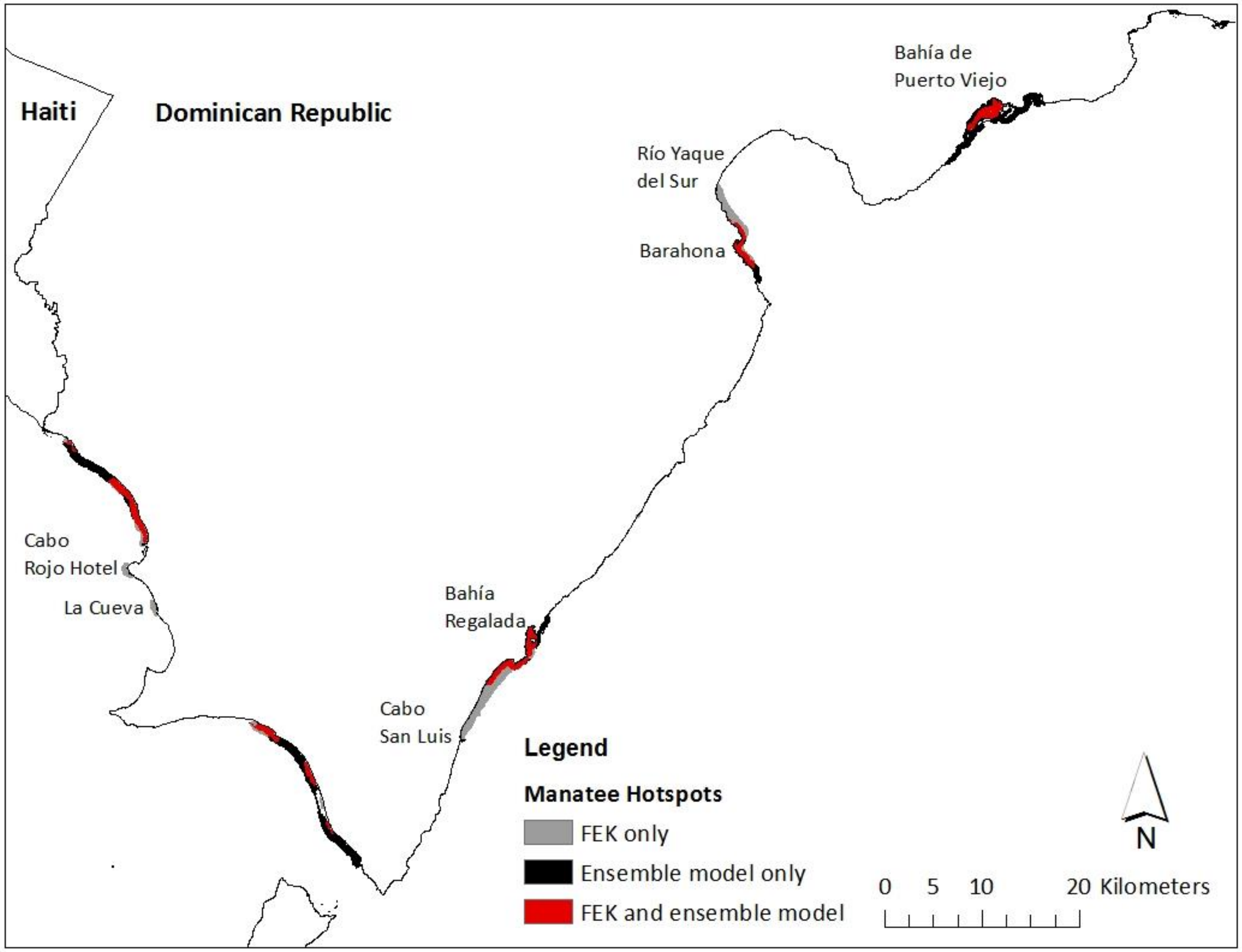


Figure 33: Manatee hotspots identified with fisher's ecological knowledge only (gray), ensemble modeling only (black), and with both methods (red), in the southwest coast of the Dominican Republic.

Discussion

I used an ensemble modeling approach to identify areas with a high probability of manatee presence in the Dominican Republic, and to determine the most important predictors of manatee habitat. Using 94 manatee presences, and pseudo-absences (PA) drawn randomly from areas surveyed for manatees, I compared cross-validated models built with different modeling algorithms. I then built full models using the best performing modeling algorithms, and combined the predictions of the best full models to create the first country-wide manatee distribution model.

Model cross-validation with a 70% data split showed that Maxent models had the lowest predictive accuracy, and were the most sensitive to the choice of PA set (Figure 26, Figure 27). Most Maxent models did not meet the quality threshold criteria of TSS >0.7, and therefore did not contribute to the consensus model. For these reasons, I did not use Maxent to build full models. In terms of ROC values (Figure 27), GBM and RF models performed almost as well as the consensus model. Internally, these two algorithms average the predictions from many decision tree models, and thus can be considered ensembles themselves (Franklin 2009).

The performance measures of the full models were mid-range between the lowest and highest values reported in the literature for Antillean manatee habitat models. I obtained 49% of deviance explained with GAM models, and 36% with GLM models. The best GLM models developed in a study of Antillean manatee distribution in freshwater habitats in Costa Rica and Nicaragua, explained 73-79% of the deviance (Jiménez 2005). The best Poisson regression model of manatee distribution in Bahía de Chetumal, a mesohaline estuary in Mexico, explained about 16% of the deviance (Olivera-Gómez & Mellink 2005). The best GLM model developed in a detailed study of Antillean manatee distribution in marine habitats in Belize, explained 22% of the variability in sighting probability (LaCommare et al. 2008).

The final ensemble model combined the predictions of the 22 full models that met the quality threshold criteria of TSS above 0.7: six of the GAM models, and each of the eight GBM and RF models. None of the GLM models were included. The simple GLM models I constructed (see model parameterization in Appendix A), assumed monotonic relationships between the response and the predictors (Matthiopoulos & Aarts 2010). On average, full GAMs explained a larger percent of the deviance compared with GLMs (49% versus 36%). Therefore, the increased flexibility of GAMs, and the ability of GBM and RF to model non-linear, non-additive, and threshold species responses to predictors (Franklin 2009) were better suited for the dataset used in this study.

The most important predictors of manatee habitat for the ensemble model were distance to seagrass, followed by distance to land, distance to mangroves, and distance to freshwater sources (Table 18). As large herbivores, Antillean manatees in marine environments depend heavily on seagrasses (Lefebvre et al. 2000; Alves-Stanley et al.

2010). Individual sirenians consume about 4-25% of their body weight per day (Aragones et al. 2012a), and Florida manatees can spend about 20-25% of the day feeding during warm seasons (Marsh et al. 2011). Therefore, the high importance value of distance to seagrass was expected. In addition to vegetation, manatees can obtain freshwater and shelter close to land. In the Dominican Republic, 95% of the manatee sightings reported by artisanal fishers occurred within 1 km from shore (Chapter 2). Thus, distance to land is an important variable separating manatee habitat from non-habitat. The variable importance value for shelter (0.209), represented by distance to mangroves in the present study, was almost the same as that for distance to land (0.218), highlighting the need to include shelter as a predictor in manatee habitat models. Manatees also require regular access to freshwater. In areas where freshwater was available nearby, radio tagged manatees in Puerto Rico accessed a freshwater source about every 24-36 h (Drew et al. 2012). In southwestern Florida, tracked manatees accessed freshwater sources every 2-8 days (Stith et al. 2006).

The species response curves (Figure 28) offered some insight into how manatees respond to predictors, a knowledge gap previously identified by experts when designing manatee protection areas in Puerto Rico (Drew et al. 2012). Focusing on the most important predictors, the response resembled a logistic curve for distance from land. Response curves for the distances from mangroves, freshwater sources, and seagrass were not monotonic: the probability of manatee presence initially decreased with increasing distance; but the three curves showed a second peak around 30-40 km. Seagrasses and freshwater sources may interact because the growth of the two predominant seagrass species, *Thalassia testudinum* and *Syringodium filiforme*, is negatively impacted by low salinity (Lirman & Cropper 2003). Therefore, the probability of manatee presence could increase with distance to freshwater sources in areas with seagrass, and vice versa. Because of the limited species presences used in this study, and because interactions among predictors were not accounted for in the species response curves, these initial efforts should be followed by further studies to better assess the shapes of the responses.

In addition, it would be very useful to develop ensemble models of manatee distribution and construct species response curves for Puerto Rico. Such an approach could take advantage of a large dataset of high-quality species occurrences, the opportunity to include depth as a predictor, and the availability of a refined wave exposure model that incorporates bathymetry and wind data (Drew et al. 2012).

The ensemble model of mean probability of manatee presence (Figure 29), developed by combining the predictions of 22 full models, correctly emphasized known manatee areas, such as: near Monte Cristi town, and Caño Estero Hondo lagoon in the northwest coast (Domínguez Tejo 2006, 2007, 2009); the north side of Samaná peninsula (Domínguez Tejo 2009; Auil Gómez et al. 2011), and Bahía de San Lorenzo (Auil Gómez et al. 2011) in the northeast coast; Bahía de Puerto Viejo, and near

Barahona town (Domínguez Tejo 2006; Reynoso et al. 2011) in the southwest coast. The ensemble model built by adding the binary outcomes of the 22 models (Figure 30), accounted for the spatial uncertainty in the predictions of individual models, and showed that areas classified as manatee habitat by 90-100% of the models coincided with areas of high probability of manatee presence (Figure 29).

Both mapped ensemble models were more realistic, detailed, and useful for conservation planning than previous manatee distribution maps for the Dominican Republic (Belitsky & Belitsky 1980; Lefebvre et al. 1989; Ottenwalder 1995; Pugibet & Vega 2000; Lefebvre et al. 2001; UNEP 2010). One limitation of the ensemble models was that they predicted stretches of coastline with 0 probability of manatee presence, dispersed around the country, and ranging from 1 to 23 km long. These stretches of coastline are not long enough to prevent the transit of manatees, and therefore should be interpreted as areas of very low probability of manatee presence. Manatee sightings have occurred occasionally in these areas. For example, in the easternmost part of the country, characterized by low probabilities of manatee presence, I received sighting reports from volunteer diving instructors near Bávaro in 2005, and four reports in 2006 (some including pictures or videos); also, an orphaned manatee calf was rescued in the area in 2008 (Féliz 2008). In the southeast coast, I received manatee sighting reports from diving instructors in Juan Dolio beach in 2011 and 2012. In Puerto Rico, telemetry studies have shown variability in manatee movements, with some wide ranging individuals, including an animal that traveled almost half way around the island, and animals that swam frequently through open water from Puerto Rico to Vieques Island (Sloan et al. 2006). In Mexico, telemetry studies have shown long distance movements of manatees, including an animal that traveled about 240 km, with several stops, from Chetumal Bay in Mexico to Belize, and then back to Chetumal Bay (Castelblanco-Martínez et al. 2013). Therefore, occasional sightings should be expected in areas of low probability of manatee presence as a result of animals traveling between hotspots.

Manatee habitat modeling in the Dominican Republic was successful in part because I included predictors representing known habitat requirements of manatees in marine environments (Moraes-Arraut et al. 2012). Manatees feed on seagrasses (Lefebvre et al. 2000; Alves-Stanley et al. 2010), they need regular access to freshwater sources for drinking (Sloan et al. 2006; Drew et al. 2012), and both of these resources are found close to land. Manatees also require sheltered waters for feeding and resting (Drew et al. 2012). In the present study, I included distance to mangroves as a proxy for distance to shelter. Mangroves are listed among the foods eaten by West Indian manatees, including in the Antilles (Marsh et al. 2011), but previous manatee feeding behavior studies, and isotope analyses studies in Puerto Rico, concluded that the diet of the Antillean manatee was composed primarily of seagrasses (Lefebvre et al. 2000; Alves-Stanley et al. 2010). The stomach content of necropsied stranded animals in the Dominican Republic confirm that seagrasses are the main component of their diet (F. de la Rosa, personal communication). On the other hand, mangroves in the tropics often dominate intertidal muddy shores (Nybakken 2005; Hogarth 2015), which in turn develop in areas free of strong wave action. I demonstrated that values of a topographical relative wave exposure index were significantly lower in mangrove versus non-mangrove coastal cells in the Dominican Republic. I also demonstrated that coastal cells adjacent to the modeled manatee hotspots were significantly less exposed compared with other coastal cells. Future habitat modeling studies of Antillean manatees should incorporate environmental predictors that represent sheltered waters.

Model evaluation with the one-sided test of binomial proportions showed that the ensemble model of mean probability of manatee presence was a good predictor of both the country-wide 1977 aerial survey data, and sightings by artisanal fishers in the northwest and southwest coasts in 2012-2014 (Figure 31). These results suggest that the distribution and patterns of habitat use of manatees in the Dominican Republic have not changed dramatically in over 30 years. Other studies support this tendency for site fidelity of Antillean manatees. In a feeding behavior study of manatees in Puerto Rico, a high frequency of locations from telemetry and field observations occurred in shallow coves and bays protected from wave action, and animals were repeatedly observed at specific locations (Lefebvre et al. 2000). In a more recent telemetry study in Puerto Rico, many animals—although not all—exhibited restricted movement patters, and typical local movements were observed between seagrass beds and freshwater sources (Sloan et al. 2006). A telemetry study of manatees tagged in Chetumal Bay, Mexico, also demonstrated that some manatees exhibited restricted movements (staying within the bay during a tracking period less than one year), and that "individual manatees typically occupied few, and relatively small core areas" (Castelblanco-Martínez et al. 2013). Evidence is stronger for Florida manatees: telemetry studies have shown that calves adopt the migratory patterns of their mothers, and that individuals exhibit site fidelity to the same warm season and winter destinations every year (Deutsch et al. 2003). If part of the manatee population in the Dominican Republic exhibits restricted movement, and calves adopt the movement patterns of their mothers, then we would expect manatee hotspots to persist in time, but telemetry studies are needed to confirm this prediction.

When comparing hotspots in the northwest and southwest coasts of the Dominican Republic, ensemble modeling predicted larger hotspot areas than those identified by fishers (Figure 32 and Figure 33). A possible explanation is that, although modeled hotspots meet the environmental conditions required by manatees in terms of food, freshwater, and shelter, not all potential hotspots may be currently occupied by manatees. The absence of animals in suitable habitat is a common event in small populations, and it is also possible that other factors not considered in this study may render some hotspots suboptimal, such as heavy boat traffic, high noise levels, or areas that are too shallow for manatees to maneuver.

Fishers, on the other hand, only reported hotspots occupied by manatees (i.e., areas where they observed manatees frequently). For this reason, I believe the hotspot areas identified only by fishers are accurate. However, the observations of fishers are limited because they are not intentionally looking for manatees while fishing, and they may not visit modeled manatee hotspots outside their normal fishing areas. Until modeled hotspots not identified by fishers are validated in the field, a precautionary approach is to consider both types of hotspots for manatee conservation planning.

Island-wide ensemble modeling for Antillean manatee distribution was not possible due to the lack of complete GIS layers of the predictor variables for Haiti. As a consequence, the mapped ensemble models of manatee distribution for the Dominican Republic (Figure 29 and Figure 30) are less reliable near the northern and southern border with Haiti, and should be interpreted with caution until results are validated in the field.

The present study was based on a limited number of species occurrences from aerial, and land and boat surveys, and no real absences. Given the small data set, I took the following measures to build the best predictive models: I only combined presence data with an approximate spatial resolution of 100 m or less; I tested the effects of using different sets of PA drawn randomly from the areas surveyed for manatees; I used few and simple predictors relevant to the species' requirements; I compared the performance of cross-validated models using several modeling algorithms; finally, I built full models and only combined those meeting a quality threshold criteria to create an ensemble model. Bathymetric data were not available for modeling, but depth should be included as a predictor in future models, given the species' preference for shallow waters.

This research is one of a small number of multivariate habitat use studies of Antillean manatees in marine environments. It is the first application of ensemble modeling of manatee distribution, and the first country-wide manatee habitat modeling effort for the Dominican Republic. Importantly, the modeling process required only a few high-quality sightings and simple mapped predictors to create distribution maps that: emphasize manatee hotspots; correctly identify known manatee areas; account for the spatial uncertainty in the predictions of single models; and are detailed enough for conservation planning. This study also ranked the predictors with variable importance values, and offered insight into species response curves. The modeling strategy is replicable and readily transferable to other countries in the Caribbean or elsewhere with limited data on a species of interest.

CONCLUSIONS

The Antillean manatee (*Trichechus manatus manatus*) is listed as endangered on the IUCN Red List of Threatened Species (Self-Sullivan & Mignucci-Giannoni 2008). In the latest regional management plan for the West Indian manatee (UNEP 2010), Haiti and the Dominican Republic were among the Wider Caribbean Region countries that: were believed to support 100 or fewer Antillean manatees; had a probably declining or unknown trend in manatee abundance; and needed current information on the status, distribution, and local threats to manatees.

I used a multi-disciplinary approach to evaluate the distribution and conservation status of Antillean manatees in Hispaniola. I reviewed the state of knowledge of the species on the island based on documentary archives dating from the pre-Columbian era to 2013. Then I conducted a survey of more than 670 artisanal fishers in Haiti and the Dominican Republic to assess the current status of the species. Finally, I developed a country-wide ensemble model of manatee habitat in the Dominican Republic, and compared modeled manatee hotspots with those identified by fishers.

The documentary archive review showed that manatees were historically abundant in Hispaniola, but became rare towards the end of the 19th century due to hunting (Table 6). Manatee meat was prized historically in Hispaniola, but other manatee body parts were also used in the past and continue to be used in coastal communities of the Dominican Republic for folk medicine and handcrafts, among other uses (Table 8, Figure 23). There have been a relatively small number of dedicated manatee studies conducted in Hispaniola, which lacked uniformity in survey methods, survey effort, and spatial coverage (Table 4). Nevertheless, these studies all agreed that the manatee population was declining (Table 6). The results presented here suggest that this trend continues: most fishers (62%) perceived that manatee abundance had decreased during the course of their careers. The shifting baseline syndrome was evident only in the Dominican Republic, where more elder fishers perceived a decrease in manatee abundance than young fishers (Figure 18).

Threats to manatees and their habitat in Hispaniola are mostly anthropogenic in nature (Table 9), and fisheries-related deaths were, perhaps unsurprisingly, the most commonly reported by fishers (Table 13). Harpoons, gill nets, beach seines, purse seines, and Caribbean Z traps are the fishing gear that pose the most risks to manatees in Hispaniola (Figure 16). I estimated an island-wide minimum annual mortality of approximately 20 manatees, similar to the estimate of 23 animals derived from interviews conducted in 1994-1996 in the Dominican Republic (Ottenwalder & León 1999). Without a reliable estimate of the population size in Hispaniola, however, the impact of this level of mortality cannot be assessed.

In Haiti, the review of documentary archives suggested that manatees contracted their distribution range to only two coastal departments, Artibonite and Sud-Est (Figure 5). However, the survey of fishers described in this dissertation showed a wider distribution. Manatees were sighted in seven of the nine coastal departments of the country during 2012 and 2013 (Figure 11). Three manatee hotspot areas were identified (Figure 10), two of which are now part of protected areas declared in 2013 and 2014. The Artibonite department in the central coast, contained the highest percentage of fishers who knew about regular manatee areas (91%), and the highest percentage of manatee captures (77%). The Artibonite department holds promise for manatee conservation in Haiti, if manatee captures are reduced, and the identified manatee hotspot (Figure 10b) is included within a well-managed protected area (i.e., a protected area with a management plan that ensures the protection of manatee habitat, and with adequate funding and personnel to gain the support of local communities and enforce protective measures). The documentary archive review and the survey of fishers agreed that manatees no longer occupy freshwater habitats in Haiti. But, in general, more dedicated manatee studies employing aerial, land, or boat surveys are needed to confirm the results of the interviews.

In the Dominican Republic, manatees are more common, and fishers were more knowledgeable about the species. Recent sightings were widespread throughout the country (Figure 6, Figure 9, Figure 12), and manatees were reported consistently in several coastal areas. The general pattern of sighting and capture reports suggests that manatees are still relatively abundant in Monte Cristi province in the north coast, and Barahona province in the south coast: the number of reports decreased eastwards and westwards from these two focal areas; and reports consistently decreased with increasing distance to the Dominican Republic along the north coast of Haiti. Manatees occasionally occupy freshwater habitats in the Dominican Republic, but the extent and frequency of use of these freshwater habitats is unknown.

The ensemble modeling approach used in the present study required a relatively small number of confirmed sightings and simple mapped predictor variables, and produced accurate and detailed maps of manatee distribution that will be useful for conservation planning in the Dominican Republic. There was good agreement among the modeled manatee hotspots, the hotspots identified by fishers (Figure 32, Figure 33), and the hotspots identified during previous dedicated manatee studies (Figure 31). These results suggest that the distribution and patterns of habitat use of manatees in the Dominican Republic have not changed dramatically in over 30 years. Telemetry studies would provide a strong empirical test of the site fidelity of manatees in Hispaniola.

The cultural value of manatees, and the attitudes of fishers towards manatee conservation, differed substantially between the two countries. Manatees have been legally protected in the Dominican Republic since 1938. The country also has supported more marine protected areas, a greater number of dedicated manatee studies, and more manatee education and awareness campaigns than Haiti. Almost all (99%) fishers interviewed in the Dominican Republic were aware that hunting manatees is illegal, and were more likely to forgo capturing manatees, release captured animals, and save and report stranded animals to local authorities (Figure 24). In contrast, manatees are not protected in Haiti. Haiti has supported only a single dedicated manatee study (Rathbun et al. 1985), and recently declared two protected areas that are primarily marine. Most Haitian fishers valued manatees as a source of food and income (Figure 23), and were likely to eat and sell captured or stranded animals (Figure 24).

Past conservation efforts through legislation, education and awareness campaigns, and research, help explain why the intrinsic value of manatees was stronger among Dominican than Haitian fishers. But economic factors also play an important part. The Dominican Republic is an upper middle income country with the largest economy of Central America and the Caribbean (The World Bank 2015a), and a high Human Development Index (HDI=0.715, Rank: 101 of 188) (UNDP 2015). In contrast, Haiti is a low income country (The World Bank 2015b) with a low Human Development Index (HDI=0.483, Rank: 163 of 188) (UNDP 2015). Haiti is the poorest country in the Americas and, in fact, one of the poorest in the world (The World Bank 2015b). In this context, the predominant economic value of manatees for Haitian fishers was expected.

The situation of manatees in Haiti is dire but not irreversible, and resembles the situation in the Dominican Republic before the 1970s, when the first dedicated manatee studies and the first wide-spread conservation campaigns began. Organizations based in Haiti, like Fondation pour la Protection de la Biodiversité Marine (FoProBiM), and The

Haiti Ocean Project, have been working on coastal and marine environmental issues, including research, education, monitoring, conservation planning, and public policy since the early 1990s and the late 2000s respectively. With these elements now in place, the newly declared protected areas, and the results of the present study, Haiti is in a better position to start promoting manatee conservation.

The public has become more educated and sensitive to the situation of manatees in the Dominican Republic. Most Dominican fishers (94%) perceived that the trend of manatee captures was declining in the country. In addition, the Dominican Republic supports: national and international legislation protecting manatees; a well-developed system of protected areas; several local authorities and non-governmental organizations involved in manatee research and conservation; a stranding network; infrastructure and staff with experience in the rescue and rehabilitation of manatees. With these elements in place, and the results of the present study, the Dominican Republic is relatively well-equipped to take manatee conservation to the next level, and to go beyond studies on status and distribution of the species.

In the following sections, I present a summary of the legislation protecting manatees in Hispaniola, and recommendations to conserve the species in the Dominican Republic and Haiti.

Summary of legislation protecting the Antillean manatee and its habitat in Hispaniola

The Dominican Republic has ratified or acceded to more international agreements that protect manatees and their habitat compared with Haiti (Table 19). The Convention on Wetlands of International Importance especially as Waterfowl Habitat (1971), or Ramsar Convention, promotes the conservation and wise use of wetlands. The convention is relevant to manatee conservation because wetlands are broadly defined to include freshwater habitats, estuaries, and coastal areas. Of the four currently listed Ramsar sites in the Dominican Republic, the Humedales de Jaragua site includes important manatee habitat in the southwest coast.

The International Convention for the Prevention of Pollution from Ships (1973), or MARPOL, and the United Nations Convention on Law of the Sea (1982), or UNCLOS, protect manatee habitat by controlling pollution in the marine environment. The Dominican Republic has ratified both conventions, Haiti has only ratified the latter.

Table 19: Participation of the Dominican Republic and Haiti in international treaties relevant to the conservation of manatees and their habitat.

International treaties and agreements	DR	HT
Ramsar Convention, 1971	Accession	Non-Party
MARPOL, 1973	Contracting State	Non-Party
CITES, 1973	Accession	Non-Party
CMS, 1979	Non-Party	Non-Party
UNCLOS, 1982	Ratification	Ratification
SPAW Protocol, 1990	Ratification	Non-Party
CBD, 1992	Ratification	Ratification

The West Indian manatee is listed as endangered in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973), or CITES. The species is also listed in Annex II of the Protocol Concerning Specially Protected Areas and Wildlife to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (1990), or SPAW Protocol. When it ratified these two international agreements, the Dominican Republic prohibited the taking, possession or killing, and the commercial trade of manatees, their parts or products.

Parties to the Convention on the Conservation of Migratory Species of Wild Animals (1979), or CMS, are obliged to provide strict protection to threatened species listed in Appendix I. The West Indian manatee is listed in the Appendix, but only populations restricted to Honduras and Panama are currently included. However, transboundary movement of manatees has been confirmed between Mexico and Belize (Castelblanco-Martínez et al. 2013). It is likely that future telemetry studies will show manatee movements across other international boundaries, so the CMS will broaden the West Indian manatee populations included in the convention. Transboundary movement of manatees likely occurs between the Dominican Republic and Haiti, so it would be beneficial for both countries to become party to the CMS.

The Convention on Biological Diversity (1992) promotes the conservation and sustainable use of biological diversity. As contracting parties, the Dominican Republic and Haiti should promote the recovery of threatened species, and develop or maintain legislation for their protection. However, without ratifying CITES or the SPAW Protocol, and without national legislation specifically designating manatees as a threatened species, they are not officially protected in Haiti.

In contrast, manatees have been protected by national legislation in the Dominican Republic since 1938 (Table 20). In 2000, the general law of the environment (Ley General sobre Medio Ambiente y Recursos Naturales No. 64-00) offered total protection to manatees in harmony with the international conventions ratified by the Dominican government. It also integrated Decree 233-96 as part of the law, protecting all marine mammals in Dominican jurisdictional waters, inside or outside protected areas.

In 2004, the most recent fisheries law (Ley de Pesca No. 307-04) represented a setback for manatee protection, because it left the exploitation of marine mammals at the discretion of the Dominican Council of Fisheries and Aquaculture (CODOPESCA). The 2004 fisheries law contradicts the general law of the environment, as it attempts to regulate a prohibited activity. But to date, no exploitation of manatees has been authorized by CODOPESCA. More recently, the Dominican Republic listed the manatee as a critically endangered species in the national Red List of species in danger of extinction, threatened or protected (MIMARENA 2011).

Table 20: National legislation relevant to manatee protection in the Dominican Republic.

Year	Legislation	Importance
1938	Ley de Pesca No. 1518	Prohibited following, wounding, capturing and killing manatees, and introducing manatee remains in all the waters of the country.
1962	Ley de Pesca No. 5914	Maintained the same prohibitions as the previous fisheries law.
1987	Decreto No. 289-87	Assigned the protection of manatees in the coasts and territorial waters of the country to the Marina de Guerra Dominicana and the Dirección Nacional de Parques.
1996	Decreto No. 233-96	Prohibited the hunting and any type of harassment of marine mammal species in all Dominican jurisdictional waters outside of the Marine Mammal Sanctuary of the Dominican Republic.
1999	Decreto No. 136-99	Created the National Commission for the Protection of Marine Mammals to formulate protection measures and actions.
2000	Ley General sobre Medio Ambiente y Recursos Naturales No. 64-00	Prohibited the hunting, fishing, capture, harassment, mistreatment, killing, traffic, import, export, commerce, the manufacture or elaboration of handcrafts, exhibition, and illegal possession of species declared threatened by the Dominican government or other country, in agreement with the international treaties subscribed by the Dominican government.
2004	Ley de Pesca No. 307-04	Created the Dominican Council of Fisheries and Aquaculture (CODOPESCA), to manage fisheries and/or the extraction of the biotic resources of the country. Prohibited the unauthorized exploitation of all the biological aquatic resources, as well as those that have legal protection in the Dominican Republic or by virtue of international treaties signed by the country.
2011	Resolución No. 16/2011	Established a national Red List, categorizing the manatee as critically endangered. Prohibited the hunting, fishing, capture, harassment, mistreatment, killing, traffic, import, export, commerce, manufacture or elaboration of handcrafts, and/or illegal possession of listed species.

Other national legislation protects manatee habitat in the Dominican Republic and Haiti mainly through the creation of protected areas (Table 21). The Dominican Republic's system of protected areas was established in 1974, and has been expanded multiple times since then. By 2008, the system counted 38 coastal marine protected areas (Domínguez et al. 2008) encompassing about 56,000 Km^2 according to the 2004 sectorial law on protected areas (Ley Sectorial de Areas Protegidas No. 2002-04).

The 2004 sectorial law had both positive and negative impacts on manatee protection. It extended the limits of the Marine Mammal Sanctuary of the Dominican Republic in the northeast coast. It also created the Marine Mammal Sanctuary Estero Hondo in the northwest coast, primarily to protect manatees in Caño Estero Hondo lagoon. Both sanctuaries were classified as strictly protected areas. However, the extent of the protected area around Caño Estero Hondo was decreased because the area of the National Park Monte Cristi was reduced in size. Other coastal marine protected areas were also reduced in size. Furthermore, the 2004 sectorial law on protected areas did not integrate the Decree 233-96 that protected marine mammals in all Dominican jurisdictional waters.

The national system of protected areas was expanded through a decree in 2009 (Decreto No. 571-09), including two marine sanctuaries that include manatee habitat in the southeast and southwest coasts.

Table 21: National legislation relevant to the protection of manatee habitat in Hispaniola.

Year	Legislation	Importance
		Dominican Republic
1974	Ley No. 67	Created a system of protected areas and prohibited hunting or capturing wild animals or extracting their products or remains.
1996	Decreto No. 233-96	Created the Marine Mammal Sanctuary of the Dominican Republic by amplifying the limits of a former offshore humpback whale sanctuary, including coastal areas important for manatees in the northeast coast.
1999	Decreto No. 136-99	Established the limits of the sanctuary created by the previous decree.
2000	Ley General sobre Medio Ambiente y Recursos Naturales No. 64-00	Established the national system of protected areas.
2004	Ley Sectorial de Areas Protegidas No. 2002-04	Extended the limits of the Marine Mammal Sanctuary of the Dominican Republic. Created the Marine Mammal Sanctuary Estero Hondo (primarily for manatees). Reduced the area of some existing coastal marine protected areas important for manatees, like the National Park Monte Cristi.
2009	Decreto No. 571-09	Created two marine sanctuaries that include manatee habitat in the southeast and southwest coast of the country: Santuario Marino Arrecifes del Sureste, and Santuario Marino Arrecifes del Suroeste.
		Haiti
2013	Arrêté déclarant l' "Aire Protégée de Ressources Naturelles Gérées de Port-Salut/Aquin"	Created an extensive and primarily marine protected area in the southern coast of Haiti, including a manatee hotspot area identified in Chapter 2 (see Figure 10c).

2014	Arrêté déclarant l' "Aire Protégée de Ressources Naturelles Gérées des Trois Baies"	Created an extensive and primarily marine protected area in the northeast coast of Haiti, including a manatee hotspot area identified in Chapter 2 (see Figure 10a).

In Haiti, two protected areas were created in the south coast (Arrêté déclarant l'Aire Protégée de Ressources Naturelles Gérées de Port-Salut/Aquin 2013), and the northeast coast (Arrêté déclarant l'Aire Protégée de Ressources Naturelles Gérées des Trois Baies 2014), that enclose extensive coastal areas, including two of the manatee hotspots identified in Chapter 2 (Figure 10a,c). New marine protected areas are expected in the near future in Haiti, following the ecosystem services assessment and the proposed sites by FoProBiM (Wiener 2013).

Finally, a 1978 fisheries decree in Haiti (Décret réglementant l'exercice du droit de pêche en Haiti 1978) prohibited the use of harpoons for fishing. This legal instrument is not specific to manatees, but if strictly implemented, it would help protect the species because harpoons were the most popular gear for manatee capture mentioned by artisanal fishers interviewed in Haiti (Figure 16).

Recommended conservation measures for Antillean manatees in Hispaniola

Conservation measures for the Antillean manatee in Hispaniola should focus on mitigating anthropogenic threats to the species and its habitat (Table 9), and especially reducing fisheries-related manatee mortality (Table 13). Due to the contrasting status of manatees and their legal framework in the Dominican Republic and Haiti, I present country-specific recommendations based on the results of my dissertation, and the regional management plans for the West Indian manatee (UNEP 1995, 2010). The recommendations are prioritized taking into account their potential for reducing manatee mortality, as well as the current economic status of each country.

Conservation measures in the Dominican Republic

Priority recommendations

Reduce human-related injuries and mortality

Fisheries-related manatee mortality (i.e., from target catch, non-target catch, non-target bycatch, and boat strikes) in the Dominican Republic should be reduced by implementing the following measures near and within manatee hotspots: decreasing the use of beach seines and gill nets, regulating boat traffic, increasing patrolling, reinforcing the need for manatee protection through education and awareness campaigns in nearby coastal communities.

The use of beach seines and gill nets should not be allowed inside confirmed manatee hotspots. In recent years fishers have reported more manatee releases than retained catches (Table 14), but it is best to avoid the interaction of manatees with fishing gear altogether. Specific recommendations arising from my dissertation include: banning beach seining near the mouth of Río Yaque del Norte, and from east of Punta

Icaquitos to east of Caño Gran Gosieer (Figure 14), and offering the displaced fishers alternative economic opportunities (see below).

To reduce the risk of boat strikes, reduce underwater noise, and avoid displacing the animals from preferred habitat, speed zones and designated boat areas should also be established near confirmed manatee hotspots. I recommend establishing speed zones for boat traffic in Bahía de Monte Cristi and from Puerto de Sanssie to Punta Rucia in Monte Cristi province, in Bahía de Puerto Plata and its surroundings in Puerto Plata province, from Río Naranjito to Bahía de San Lorenzo in Hato Mayor province, and from La Romana to Isla Saona in La Altagracia province.

I also recommend strengthening and expanding the stranding network. The Centro de Rescate y de Rehabilitación de Especies Acuáticas (CERREA) should continue attending manatee strandings and rescuing animals. CERREA should also adopt reintroduction protocols to return rehabilitated animals into the wild population.

Provide alternative livelihoods

Manatee watching has proven to be a successful enterprise in the Caño Estero Hondo lagoon, where visitors can observe the animals from a tower, or from kayaks or paddleboards. Visitors are supervised by local guides or park rangers of the Marine Mammal Sanctuary Estero Hondo. Other potential locations where similar activities could be developed are: from El Morro mountain in Monte Cristi town; in El Estillero, on the north side of the Samaná peninsula; at Bahía de Puerto Viejo; north of Barahona town. These and similar options should be explored for developing responsible ecotourism operations that educate visitors, enhance the intrinsic value of manatees to the public, and generate income for protected areas and local communities. Such activities should employ guidelines to ensure that manatees are safely observed in the wild, and should be carefully monitored to ensure that manatees are not displaced from preferred habitat.

For displaced fishers (e.g., fishers banned from beach seining in Monte Cristi province), an alternative economic activity could be the use of offshore fish aggregating devices (FADs), which have been successful in the southwest region of the Dominican Republic. An exchange of fishers could be organized, where fishers from the southwest instruct fishers from the northwest on how to build and maintain FADs, and share their experiences.

Enforce relevant laws

The most popular reason for the perceived decrease in manatee captures in the Dominican Republic according to fishers was fear of laws (Figure 20), highlighting the importance of maintaining, improving, and enforcing manatee protection laws as a conservation tool.

Coastal inspectors from CODOPESCA and Marina de Guerra should increase patrolling near confirmed manatee hotspots to reduce manatee target catches that would otherwise go unnoticed. It is important that local law enforcement agents stationed in coastal communities know and follow a strict course of action against offenders to discourage further infractions of the law.

The traditional use of manatee body parts for folk medicine continues in coastal communities in the Dominican Republic (Table 8, Figure 23), but illegal commerce of manatee products in markets has not been assessed, except for a one-time visit by Mignucci-Giannoni (1991). The Ministerio de Medio Ambiente y Recursos Naturales (MIMARENA) should enforce existing laws regarding the illegal trade of manatee products.

To improve protection of manatee habitats, MIMARENA should also strictly enforce existing laws regarding environmental permits for coastal development projects that may negatively impact manatee habitat (e.g., by causing pollution, dredging seagrass beds). These projects should include environmental impact assessments and measures to prevent or mitigate damages to the environment.

The summary of the national legislation protecting manatees and their habitat presented in the above sections revealed some weaknesses that should be addressed. The 2004 fisheries law (Ley de Pesca No. 307-04) should be amended to eliminate the ambiguity regarding the exploitation of marine mammals: the possibility of CODOPESCA authorizing the exploitation of manatees should be excluded. In addition, the 2004 sectorial law on protected areas (Ley Sectorial de Areas Protegidas No. 2002-04) should be amended to reinstate the protection of all marine mammal species in Dominican jurisdictional waters.

I recommend a detailed review of regulations on the use of gill nets and beach seines, and regulations on nearshore boat traffic. Additional measures to protect manatees (e.g., banning beach seining or establishing boat speed limits in certain areas) could be officially proposed as decrees, or as part of the management plans of existing marine protected areas that include manatee hotspots.

At an international level, the Dominican Republic should become party to the CMS, because it may provide a platform to promote binational manatee conservation actions with Haiti in the future.

Improve manatee awareness

MIMARENA, the Ministry of Education, and local non-governmental organizations should continue organizing public education and awareness campaigns for manatees. Education and outreach programs should be carefully designed to target school children, adults, and fishers, and should focus on coastal communities near manatee hotspots. Local residents should be informed about the history and cultural value of manatees, their conservation status, and the national and international legislation protecting the species. The use of manatee body parts for folk medicine and handcrafts is illegal and should be discouraged. Community members should be encouraged to report sightings, strandings, and captures to the relevant authorities.

These campaigns should include an evaluation component to assess their effectiveness as a tool for manatee conservation.

I recommend joint law enforcement workshops and training sessions with the government organizations involved in manatee protection (e.g., Marina de Guerra Dominicana, MIMARENA, Acuario Nacional, CODOPESCA), to resolve ambiguities regarding the responsibilities of each organization, and streamline the course of action to follow in case of: manatee catches (i.e., target catch, non-target catch, non-target bycatch), boat strikes, strandings, and sightings occurring under risky conditions (e.g., repeated sightings of a group of animals in areas with high boat traffic).

The Dominican Republic should start participating in the annual celebration of the International Manatee Day in September to promote the conservation of the species. The Acuario Nacional in Santo Domingo, which is ascribed to MIMARENA, is currently hosting two wild animals in rehabilitation, and should take the lead in planning activities for International Manatee Day celebration. With the help of non-governmental organizations, the activities could be expanded every year to include local schools and local communities near manatee hotspots. For example, the communities of Punta Rucia, Estero Hondo, and La Isabela, could participate in International Manatee Day activities organized at Caño Estero Hondo lagoon.

Protected areas

Marsh et al. (2011) compiled a series of attributes that increase the value of protected areas as conservation tools for sirenians. Following their recommendations, management plans for marine protected areas that include manatee hotspots in the Dominican Republic should be developed or expanded to include goals and objectives specific to the conservation of manatees and their habitat, and measures of success for those objectives (e.g., maintaining or restoring seagrass beds to a certain spatial extent and vegetation cover). Community buy-in should be ensured both through education and awareness programs, and alternative livelihoods that compensate for restricted or prohibited activities within the protected areas (e.g., incorporating community members as rangers or guides).

I recommend the following approach: first, validating the manatee hotspots identified in the present study (Figure 32, Figure 33) in the field; then, identifying marine protected areas that include confirmed manatee hotspots; for those protected areas, identifying current activities that pose risks to manatees; and finally, developing or expanding the management plans of those protected areas with objectives that reduce risks to manatees (e.g., by establishing speed zones, no-entry zones), protect their habitat, and ensure community involvement.

Prepare a national recovery plan

The Dominican Republic should develop a national recovery plan for the Antillean manatee. The plan should be developed and endorsed by MIMARENA, with the participation of government officials, policy-makers, managers, conservationists, researchers, and community organizations, among other stakeholders. The plan should include prioritized activities to preserve the species, and an implementation schedule. I recommend reviewing existing plans from other developing countries in the Caribbean as examples, and adopting strategies suited to the conditions in the Dominican Republic.

Long-term research and conservation measures

Assess and improve the effectiveness of existing laws

An in-depth review of the national laws protecting manatees and their habitat in the Dominican Republic is recommended. The review should help: identify weaknesses and ambiguities not addressed in the legislation summary included in this dissertation; overcome overlaps in responsibilities of government organizations involved in manatee conservation; clearly identify the sanctions applicable to offenders, and whether they need to be updated compared with the fines established in other WCR countries. I recommend a review of past sanctions applied to offenders to determine if they correspond with the established laws. Results of the review of past sanctions might be used during manatee education and awareness campaigns to help deter manatee captures.

Future survey research in coastal communities should include evaluation components to assess the effectiveness of protection laws (and education and awareness campaigns) as tools for manatee conservation. The effectiveness of areas with new boat speed regulations or no entry zones could be evaluated with measures of boater compliance, and some measure of habitat use by manatees.

Research on manatees

The Centro de Rescate y de Rehabilitación de Especies Acuáticas (CERREA) should continue collecting manatee sighting and capture reports, as well as biological information from recovered carcasses, including samples for future genetic and contaminant studies.

Building from the database presented in Chapter 1, I recommend that a formal data repository be created to continue collecting information on manatee sightings, and facilitate data sharing for future manatee research and conservation work.

Land or boat surveys should be conducted to validate modeled manatee hotspots described in this dissertation, especially those not identified by fishers (Figure 32, Figure 33), and those that have not been surveyed recently. Characterizing unoccupied modeled hotspots would also increase our knowledge on what factors, other than the environmental predictors used in the present study, could influence manatee habitat use.

Telemetry studies would be useful to: identify specific resources or habitats used by manatees (e.g., rivers, seagrass beds, secluded mangroves channels and coves); assess site fidelity; and determine if manatees move frequently between the Dominican Republic and Haiti.

Health assessments and genetic sampling of wild animals could be conducted in concert with telemetry studies to establish a baseline of manatee health, and identify potential concerns for the manatee population regarding diseases, contaminant loads, and genetic structure.

Further research on the use of freshwater sources by manatees in the Dominican Republic would be useful to protect critical resources for manatees. Boat surveys are recommended in the following rivers: Río Yaque del Norte, Río Bajabonico, Río Higuamo, Río Haina, and Río Yaque del Sur. Freshwater seeps in Pedernales province should be mapped and monitored to determine whether manatees use these seeps in areas lacking superficial rivers. Understanding the use of freshwater seeps by manatees has implications for other Caribbean Islands that lack rivers, which are occasionally or frequently visited by manatees, like the Turks and Caicos and the Bahamas.

The Dominican Republic and Haiti should work together to obtain a reliable estimate of the total size of the manatee population in Hispaniola, or at least a reliable estimate of the population trend. These estimates would provide a baseline against which the success of future conservation actions could be measured.

Conservation measures in Haiti

Priority recommendations

Provide alternative livelihoods

Impoverished coastal communities are more likely to protect the species if manatees become a sustainable source of income. Manatee ecotourism has been a successful enterprise in Caño Estero Hondo, in the Dominican Republic. Attracting tourism requires a confirmed manatee hotspot, in an accessible area, with basic infrastructure and services. Until suitable manatee hotspots are confirmed in Haiti, other alternatives should be explored. The use of economic tools (e.g., microfinance lending, performance-based incentives) is recommended to alleviate poverty and provide alternative livelihoods for fishers (Marsh et al. 2011).

First, I recommend reviewing past community development projects in Haiti, and consulting with experts from local NGOs, to create an initial list of viable economic alternatives (i.e., activities that are sensitive to the local culture, that take into account the resources available in different coastal communities, and that have been successful in the past). Then I recommend starting pilot projects with one or two coastal communities, preferably in the Nord-Est and the Artibonite departments, where there have been more manatee sighting and capture reports, and engaging community members to add their insights and ideas on potential economic alternatives that they would support. The activities could be ranked through a participative process, to choose and implement the best option. In addition to community buy-in, these pilot projects require long-term commitment from local organizations, to coordinate, monitor, and modify the activity as needed.

Reduce human-related injuries and mortality

Conservation measures should focus on reducing the number of manatee captures, especially in the Artibonite and the Nord-Est departments. Manatees are not officially protected in Haiti, so a community partnership approach for manatee conservation would be helpful (Marsh et al. 2011). A successful example of a grassroots approach, working with the community in a participative program, is the Manatee Conservation Program, developed by Sarita Kendall, to conserve Amazonian manatees in Colombia. The program is briefly described in Aragones et al. (2012b), but key elements include: gaining the support from local communities, especially former manatee hunters, through interviews, community meetings and workshops; broad-based education efforts to develop a conservation ethic; benefits to locals in the form of part-time wages, or recognition in kind or in subsistence for their work; constant feedback of the project results to the community; and long-term commitment from the project organizers.

I recommend using a similar approach in Haiti. Community-based manatee conservation projects should start in the same communities chosen for pilot projects on alternative livelihoods, because it would help gain their trust and support. Fishers who have captured manatees could provide invaluable assistance for locating animals and their preferred habitat, and for identifying threats to the species in their fishing areas. After establishing community agreements and goals for manatee conservation, selected fishers could receive economic and/or in kind incentives to become community rangers in charge of locally based monitoring and enforcement.

If a community-based manatee conservation program is developed in the town of Aquin, in the Sud department, one recommended protection measure is to regulate the use of Caribbean Z traps to reduce non-target catches caused by accidental entanglements of manatees with trap lines.

Improve manatee awareness

One of the major challenges for manatee conservation in Haiti is changing the attitude and behavior of fishers towards the species. I recommend education and awareness campaigns to inform coastal communities about the dire conservation situation of manatees in Haiti. Education programs should focus first on fishers, with the goal of reducing manatee captures, especially in the coastal communities near the mouth of Rivière de l'Artibonite. The education program could then be expanded to include coastal communities near the manatee hotspots in the northeast and the south coast of Haiti.

Due to the limited staff and funding capacity of the Haitian Fisheries Service (Mateo & Haughton 2003; Ramdeen et al. 2012), education and conservation efforts should involve non-governmental organizations with a history of successful environmental work in Haiti, like FoProBiM. An educational program can build up on the Haiti Ocean Project Sea Camp, a recent initiative to enroll local youth in summer camp, to learn about the marine environment and marine mammals.

There have been no previous manatee education and awareness campaigns in Haiti; manatees are not officially protected, and protection laws will most likely lag behind education efforts. Therefore, Haiti is in a unique position to evaluate the effectiveness of education and awareness campaigns as a conservation tool for manatees.

Enforce/create relevant laws

Haiti should develop national legislation that specifically protects manatees in the country. At an international level, Haiti should ratify CITES and the SPAW Protocol, and should become party to the CMS, because it may provide a platform to promote binational manatee conservation actions with the Dominican Republic in the future.

The prohibition of harpoon fishing under Haiti's fisheries law (Décret réglementant l'exercice du droit de pêche en Haiti 1978), needs to be enforced. But, in general, Haiti's fisheries law needs to be updated, including the regulations on the use of other fishing gear like gill nets, purse seines, and traps.

Protected areas

Haiti should develop and implement management plans for the two recently declared protected areas in the south (Aire Protégée de Ressources Naturelles Gérées de Port-Salut/Aquin) and the northeast coast (Aire Protégée de Ressources Naturelles Gérées des Trois Baies). New marine protected areas should be created at the sites proposed by FoProBiM (Wiener 2013), especially around the mouth of Rivière de l'Artibonite. As described for the Dominican Republic, the management plans of these protected areas should include goals and objectives specific to manatee conservation, and measures of success.

Long-term research and conservation measures

Assess and improve the effectiveness of laws

If national manatee protection laws are created in Haiti, future survey research should evaluate the effectiveness of the laws, including questions to fishers about their knowledge of the laws, and the implementation of the laws on the ground (e.g., if there is patrolling in regular manatee areas, if sanctions are applied to offenders).

Research on manatees

More dedicated manatee studies are needed to further our knowledge of the species in Haiti. The present study was based exclusively on interviews, and sample sizes were small in the southern coast. Future studies should combine interviews with reconnaissance boat trips with local guides to the general areas where manatees are reported to occur regularly (Figure 10). Once the manatee hotspots are better documented, surveys should be conducted to confirm manatee presence and identify high-use areas. Boat surveys are recommended near the mouth of Rivière de l'Artibonite to confirm manatee use of this freshwater source, and identify specific threats to the species in that area.

A data repository could be created by the Haiti Ocean Project and/or FoProBiM, to collect and centralize manatee –and other marine mammal–sightings as research and conservation projects grow, such as the marine mammal sighting network initiative by the Haiti Ocean Project.

Regarding species distribution modeling efforts, once confirmed manatee occurrences and complete GIS layers of predictor variables become available for Haiti, I recommend ensemble modeling of manatee habitat, followed by field work to confirm the modeled manatee hotspots.

APPENDIX A: Model parameterization used in biomod2

Ensemble modeling was conducted in R statistical software v. 3.1.2 (R Core Team 2014), and contributed package biomod2 (Thuiller et al. 2014). Five modeling algorithms were used with the following specifications:

Generalized linear models (GLM): using a binomial distribution, logit link, linear terms only, no interactions among predictors, and stepwise AIC.

Generalized additive models (GAM): using a binomial distribution, logit link, four degree smoothing splines, no interactions among predictors, and allowing terms to be penalized to zero (i.e., allowing terms to be removed from the model).

Random Forest (RF): using 750 classification trees, four predictors available as candidates at each split, and a minimum size of 5 for the terminal nodes.

Boosted regression trees (GBM): using a Bernoulli distribution, 5000 trees, an interaction depth of 4, a minimum size of 5 for the terminal nodes, a 0.001 shrinkage or learning rate, a bag fraction of 0.5, and 5 cross-validations.

Maximum Entropy (MAXENT): using 200 iterations, and allowing linear, quadratic, product, threshold and hinge features.

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BIOGRAPHY

Haydée María Domínguez Tejo

Born: May 9, 1979, Santo Domingo, Dominican Republic

Education

Doctor of Philosophy, Marine Science and Conservation (2016)
  Duke University, Nicholas School of the Environment, Durham, NC, USA
Master of Science, Ecological Marine Management (2005)
  Vrije Universiteit Brussel & Universiteit Antwerpen, Brussels, Belgium
Bachelors in Science, Marine Biology (2002)
  Fundación Universidad de Bogotá Jorge Tadeo Lozano, Bogotá, Colombia

Publications

Domínguez Tejo, H. M. 2013. Fishers' ecological knowledge of Antillean manatees around the Samaná Bay area, Dominican Republic. Abstracts 20th Biennial Conference on the Biology of Marine Mammals, Dec 9-13, 2013. Dunedin, New Zealand.

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Domínguez H. and K. Belpaeme. 2006. Manual beach cleaning in Belgium: an ecological alternative. In: Tubielewicz, A. ed. Living marine resources and coastal habitats. EuroCoast - Littoral 2006. p. 131-135.

Fellowships and Awards
Faculty for the Future Fellowship, Schlumberger Foundation (2014-2016)
Fulbright Scholarship (2010-2012)
Researcher of the Year, Universidad Autónoma de Santo Domingo (2008)
Maximum Academic Distinction and Honors thesis, Vrije Universiteit Brussel (2005)
VLIR Scholarship, Vlaamse Interuniversitaire Raad (2003-2005)
Maximum Academic Distinction, Honors thesis, and Jorge Tadeo Lozano Prize, Fundación Universidad de Bogotá Jorge Tadeo Lozano (2002)

Professional Affiliations
IUCN Sirenia Specialist Group in Meso-America. Regional Co-Chair
Sirenian International, Inc. Member of the Board of Directors
Society for Conservation Biology
Society for Marine Mammalogy