ABUNDANCE AND DISTRIBUTION TRENDS OF THE WEST INDIAN MANATEE IN THE COASTAL ZONE OF BELIZE: IMPLICATIONS FOR CONSERVATION

A Thesis

by

NICOLE ERICA AUIL

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

MASTER OF SCIENCE

May 2004

Major Subject: Wildlife and Fisheries Sciences

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Approved as to style and content by:

Jane Packard (Chair of Committee)	Robert Ditton (Member)
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James Powell (Member)	Robert Brown (Head of Department)

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ABSTRACT

Abundance and Distribution Trends of the West Indian Manatee in the Coastal Zone of Belize: Implications for Conservation. (May 2004)

Nicole Erica Auil, B.S., University of Southwestern Louisiana

Chair of Advisory Committee: Dr. Jane Packard

The coastal zone of Belize is home to the largest recorded number of the threatened Antillean manatee (*Trichechus manatus manatus*) within the species' Caribbean range. The objectives of my study were: (1) to determine long-term trends in aerial survey counts and indices of the manatee population in the coastal zone of Belize; and (2) to examine the seasonal change in manatee distribution among habitats in the coastal zone. Standardized extended-area aerial surveys were conducted along the entire coastline of Belize in the dry and wet seasons of 1997, and 1999 - 2002. Manatees were counted in five habitat categories: cay, coast, estuary, lagoon, and river. Total sightings per survey ranged from 90 to 338; the greatest number was counted in the 2002 wet season. Calf percentage ranged from 5 to 13. A slight negative trend in total counts was significant for dry-season, not wet-season surveys, indicating an interactive effect of season and year. Based on analysis of variance, the Abundance Index (transformed manatee sightings per hour) did not differ significantly among years, although it varied significantly within year by season and habitat by season.

In applying a spatial approach, the general survey route was buffered 1 km on both sides, and 1 km grids were overlaid and classified by habitat type. The presence or absence of each cell for each survey was used in likelihood ratio tests of the single and interactive effect of season and habitat. The Index for river habitat was higher in the dry season, while cay habitat was higher in the wet season. Overall, near-shore habitat (estuary, lagoon, and river) showed a higher Index than did the offshore habitat (cay and coast) although the total number of sightings was higher offshore. Considering the interactive effect of year, season, and habitat, long-term studies are needed, in both seasons, and among all habitats to account for variation. Continued broad-scale surveys, along with metapopulation analysis would fine-tune the understanding of specific sites, enhancing integrated coastal zone management for protected species and their habitat systems.

DEDICATION

My work, culminating into this thesis, is dedicated in loving memory to my mother, Gloria Cecilee Yvette Auil (1934 – 2002), my greatest supporter.

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CHAPTER I

INTRODUCTION

Coastal zone management (CZM) became a focus for Belize in 1989. An integrated approach has since been taken for coral reef, coastal habitat, and coastal species sustainable use. The first objective of the National Integrated Coastal Zone Management Strategy is "[to gain] knowledge and sustainable coastal resource use." This involves coastal and marine protected areas management - cornerstones of the project - coastal habitat restoration, coastal research, monitoring, and coastal wildlife conservation (CZMAI 2003). The strategy acknowledges the need for improving wildlife management, through scientific research and monitoring. In keeping with the concepts of coastal wildlife conservation, existing relevant data collected is for use on a wide range of issues in the decision-making process, by various stakeholders.

While local research of manatees began in 1994, the national manatee research project was not formally developed until 1996 by the United Nations Development Programme / Global Environment Facility (UNDP/GEF) Coastal Zone Management Project (CZMP). The project was responsible for research and management of manatees (*Trichechus manatus manatus*), as well as public education focused on manatee conservation. Aerial surveys were the primary method used to examine large-scale (countrywide) spatial distribution, and four were conducted in 1997 (Auil 1998).

This thesis follows the style and format of Conservation Biology.

The Belize Manatee Recovery Plan was thereafter developed under this project to meet the Cartagena Convention's Specially Protected Areas and Wildlife (SPAW) Protocol, of which Belize is a signatory (McField et al. 1996; Auil 1998). The goals of the manatee conservation activities in the Plan are: (1) to prevent extinction or irreversible decline of the species within the foreseeable future; and (2) to prevent decline in habitat quality. The Plan outlines activities to reduce mortality and increase research efforts, specifically determining trends in manatee habitat use to aid in the creation of protected areas and implementation of boat speed zones (Auil 1998). Recommendations were also made to keep the public updated on new findings, to aid in compliance of proposed regulations.

This research was conducted to fulfill the objectives of the Belize Manatee Recovery Plan and will thus be complying with stipulations of the CZMAI Act, under which the manatee project is now continued. It is also intended to provide benefit to species that inhabit manatees' range of habitat; including the creation of protected or special management areas (Chapter III). With increasing human population growth and increasing investment in the fishing and tourism industries, existing and potential threats to manatees and their environment increases. This is a forward step in meeting the goal set in The National Integrated Coastal Zone Management Strategy for Belize.

This investigation of the West Indian manatee is intended to provide additional information to apply to endangered species protection and integrated coastal systems management. It is also intended to aid in protected area design and special management area creation for Belize.

Study Area

Belize is situated 15 ^{o} 45' and 18 ^{o} 30' N, and 87 ^{o} 30 and 89 ^{o} 15' W, bordered to the north by Mexico, to the west by Guatemala, and to the south by Honduras. The Caribbean Sea washes the entire length of the eastern border (Figure 1). The Belize Barrier Reef runs 220-250 km long, almost parallel to the coastline, with hundreds of sand and mangrove islands creating a relatively shallow (>1 to 25 m) reef lagoon (McField et al. 1996). There are 31 major watersheds, 24 of which empty in the southern coast and seven in the northern coast. Rio Hondo, the river that demarcates the northern boundary between Belize and Mexico, has the greatest total drainage area (15,076 km^2). However, only 2618 km^2 of this empties into territorial Belize, making the Belize River the greatest supplier of fresh water for the country, with 6543 km^2 of water drainage for the country. Belize's climate is tropical with temperatures ranging from 10^{o}C to 35^{o}C, although the mean temperature varies from 27^{o}C along the coast to 21 ^{o}C in the hills (Buckalew et al. 1998). Rainfall averages from 1500 mm in the north to 3800 mm in the south annually. The dry season is between November and May, which is subdivided into a cool transition period between November and February and a warm period between March and May. The wet season begins in May in the south and June in the north, and ends in November. The transition from the wet to the dry is gradual, while the shift from dry to wet is sharp (Belize Meteorological Service).

The country has 42% of its territorial land in protected area status, 12% is mainland, coastline area (CZMAI 2003). Seven of the marine protected areas (MPAs) make up the Belize Barrier Reef System World Heritage Site, declared in 1996. It is to

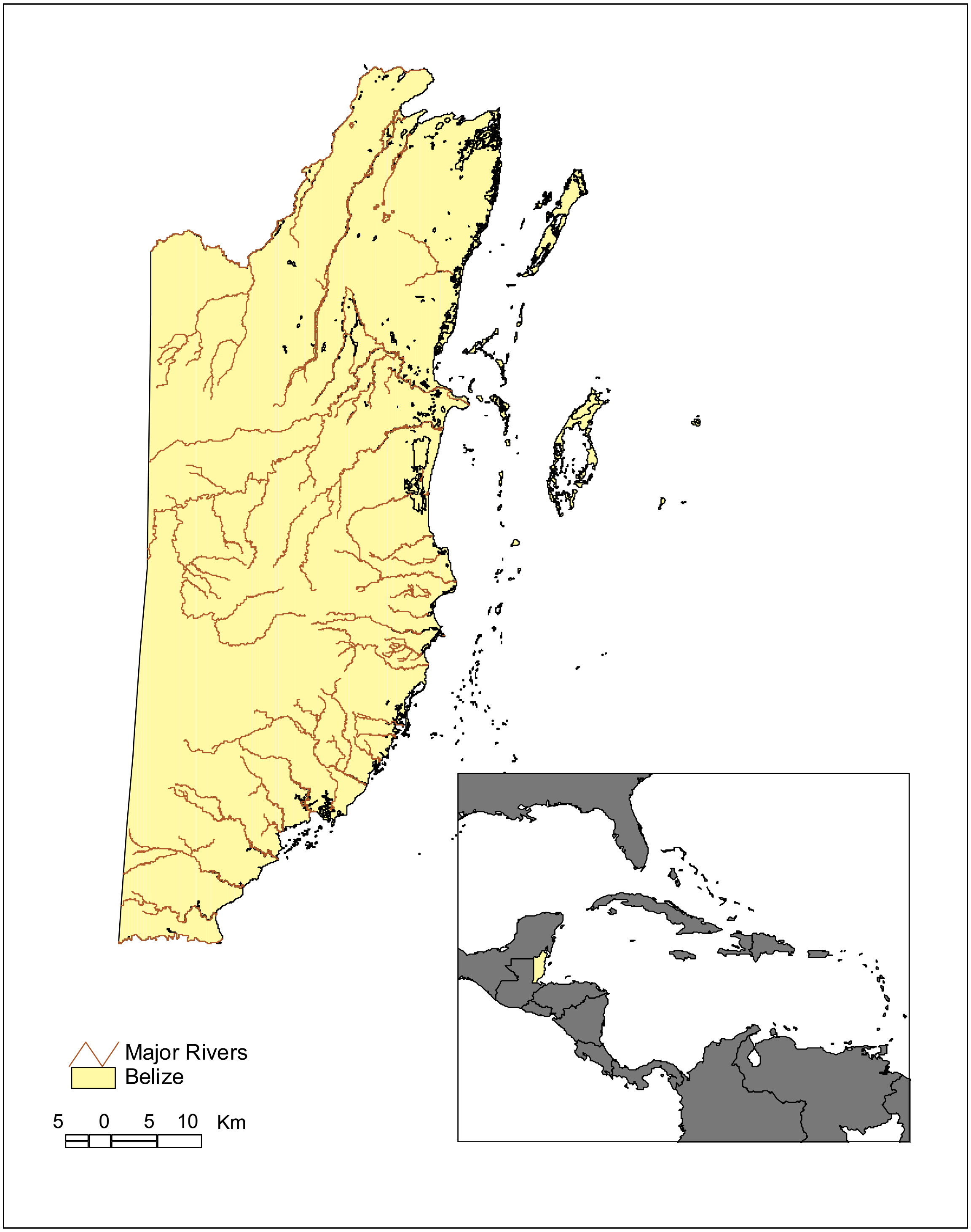


Figure 1. Map of Belize, indicating location within the Wider Caribbean (highlighted in yellow).

such international standards that Belize strives to maintain its natural resources. Unfortunately, like many protected areas worldwide, the designation of some of these is not due to conservation science, but is often determined by various political factors (Minta et al. 1990). The coastal zone management initiative in Belize aims at consolidating the sound management of these MPAs, with critical coastal habitat and species, within the realities of sustainable coastal development.

Integrating Species and Habitat Approaches

A central role of integrated coastal zone management is to give better insight into the functioning of coastal systems (Douven et al. 2003:620). This can be done using the species approach or the spatial approach. Using a species-specific approach, I will look at population changes of the West Indian manatee in Belize. I will analyze trend data of the threatened manatee with the goal of increasing the information base used to make management decisions to protect the species (Gibson et al. 1998), such as selecting dredging sites or establishing regulations for high impact tourism activities. I will use the manatee as a focal species because they inhabit coastal systems, they have legal protected status, and they are a species of special concern in Belize since 1994. Additionally, they have important economic value, as a tourist pays up to US$80 to visit manatee areas in hopes of encountering one (Auil 1998).

A focus on manatees may also help to indicate changes in habitat, by either their change in habitat use or health status. Focal species, as interpreted by Armstrong (2002) are “individual species selected for monitoring in ecosystem level management programs.” The umbrella species is one example of the focal species concept, as a species that provides a blanket of protection to many species through its protection (Lambeck 1997). This concept of umbrella species leads to further analysis based on the broader habitat approach. To do this, spatial information will be analyzed to determine manatees' use of habitat systems, as this species is wide-ranging and utilizes critical coastal systems such as mangroves hedges, seagrass beds, and even the barrier reef (Morales-Vela et al. 2000). Douven et al. (2003) demonstrated the importance of spatial data for coastal zone management, making overlay maps of seagrass beds to decide management scenarios in Indonesia. Using a Geographical Information System (GIS), spatially explicit models helped with structuring information in a logical and meaningful way, suitable for representing the interests of various stakeholders (Douven et al. 2003).

Manatee spatial data will aid in GIS format querying for various aspects of management of the coastal zone. This leads to the even broader concept of the ecosystem approach, which Mokhtar and Ghani Aziz (2003:418) propose as "a system that recognizes the complex relationships of interdependence of biotic and abiotic components". This is precisely the goal of Integrated Coastal Zone Management (ICZM) (Clark 1996; Gibson et al. 1998) and lays the foundation for which this holistic approach (Slocombe 1993) was adopted for this thesis.

Species Background

Manatees are considered a flagship species, another example of a focal species, which draw much public attention and concern. This has led to interest from organizations to fund research and management of the species.

The threatened West Indian (W.I.) manatee (Groombridge 1993) is of the order Sirenia, for which there are only two remaining families, Trichechidae and Dugongidae. There are three species within Trichechidae: *Trichechus manatus*, *T. inunguis* (Amazonian manatee), and *T. senegalensis* (West African manatee) (Bertram & Bertram 1973). W.I. manatees are found within the Wider Caribbean from North America (Florida) to South America (Brazil), with Florida having the largest number of manatees within their entire range (O'Shea & Salisbury 1991; Lefebvre et al. 2001). This species consists of two subspecies; the Antillean manatee (*T. manatus manatus*), which can be found in Central and South America and the Antilles, and the Floridian manatee (*T. manatus latirostris*), which is found from the east coast of Florida, and sometimes to Texas (Garcia-Rodriguez et al. 1998; Lefebvre et al. 2001). Floridian manatees use a variety of coastal habitat, including fresh, brackish, and saline shallow coastal systems (Hartman 1979).

Manatee habitat preference is affected by aquatic temperature, availability of freshwater and vegetation (Hartman 1979; O'Shea & Kochman 1990; Gibson 1995). Highest manatee sightings are associated with warm waters (above 22^{o}C), a fresh water source, and abundant vegetation (Lefebvre et al. 2001). As manatees are poorly adapted energetically to cold temperatures (Irvine 1983), most studies have examined population changes of Floridian manatee aggregations in winter, and the effects of cold weather on their spatial distribution. The energetic demands or constraints of the Antillean manatee have not been studied, and may therefore differ. However, the tolerance for cold water may likely not be as high in the Antillean subspecies as in the Floridian, considering the relatively warmer climate. Manatee distribution is affected by water temperature, and in the winter, manatees move to warm water sources, primarily southward (Powell & Rathbun 1984; Kinnard 1985; Garrott et al. 1994; O'Shea & Langtimm 1995).

O'Shea and Salisbury (1991:161) compared surveys of the West Indian manatee in the Caribbean, and concluded that Belize "remains one of the last strongholds for this species in this part of the world." They determined that the high habitat quality and low poaching in Belize compared with neighboring countries supported high numbers of manatees and could potentially provide a source of repopulation for other Caribbean countries (O'Shea & Salisbury 1991). In 2002, the highest number of manatees counted in Central America and the Caribbean, 338, was tallied for Belize in October, supporting reports that manatees in Belize remain in greater numbers than all other countries in the Wider Caribbean, excluding Florida (Auil 1998).

How alarmed should managers be about risks to the Belize manatee population? Determining the increase or decline of small populations is important for establishing management and conservation regimes (Minta et al. 1990). The population size at which risk of extinction is minimal is called the minimum viable population (MVP). One way of determining MVP involves examining biogeographic patterns to determine how a metapopulation (Chapter III) is distributed among fragments of habitat thereby helping to define population and area requirements (Minta et al. 1990). After two decades of research, it is still not clear how much the manatee population of Belize has changed, let alone how it is integrated into the larger metapopulation along the western Caribbean coast.

For Belize, no assessment of the growth or decline of the species has been made. Morales-Vela et al. (2000) and Gibson (1995) described the minimum population size, presented relative abundance differences for three surveys, and suggested causes for variations in counts. With only three surveys conducted within two years, assessing a population decrease or increasing was not appropriate. Managers, therefore, did not have a sound scientific basis against which future analysis could be compared, nor did they have justification for tightening or slackening protection. Information on trends in abundance and distribution could help managers decide future management priorities.

Models used to assess population trends have been provided by both the United States and Australia; however, these models need to be adapted to Caribbean countries. Over 25 years of research has been conducted on manatees in Florida, contributing to the scientific knowledge and management approaches to manatee conservation (Reid et al. 1995; Buckingham et al. 1999). State-wide trends in abundance have been studied using standardized aerial surveys (Ackerman 1995), based on both the "intensive" and "extended-area" survey techniques (Packard 1985). As an example of an intensive survey, Wright et al. (2002) determined that manatee counts increased in the Tampa Bay between 1987 and 1994. In Australia dugongs on the great Barrier Reef have been studied using extended area and fixed-wing transect techniques (Preen 1992; Marsh 1995).

Manatees in Florida are at the northern extreme of their range; the center of the Antillean manatee range includes the tropical coastal systems of Central America and to a lesser extent the Grater Antilles and northern coast of South America (Lefebvre et al.

2001). Although Floridian manatees travel relatively long migratory routes based on seasonal temperature changes (Deutsch et al. 2003), we might not expect to find such migration in the more tropical environments, where seasons are classified primarily by rainfall, not temperature. Surveys in Belize indicate that temperature does not appear to affect manatee distribution (Gibson 1995). The single and combined effects of season and habitat on manatee distribution, however, have not been studied south of Florida which would improve our knowledge of manatee habitat use. Advances in the use of spatial models to investigate factors influencing distribution of dugong have been developed in Australia (Preen 1992; Marsh 1995) and Florida (Wright et al. 2002). However, these models need to be adapted for Belize, because dugongs are not limited by the need for access to freshwater, and Floridian manatees are at the northern extreme of manatees' range. The study of manatees under conditions of the center of their range would be more appropriate for management in countries such as Belize.

I hypothesize that manatees not limited by temperature changes, such as those in Belize, may make seasonal travels to and from freshwater sources. Manatees' need for sources of freshwater to prevent dehydration (Ortiz et al. 1998) is a possible cause for travel and seasonal shifts in distribution among habitats. Based on this "freshwater" hypothesis, manatees would be predicted to move inshore to freshwater sources in times of dry seasons and offshore during the wet seasons.

Purpose

The freshwater hypothesis, outlined above, will be tested in this thesis by comparing manatee distribution patterns between wet and dry seasons, and among habitats of known sources of freshwater (rivers, lagoons, and estuaries) in contrast to saline habitats (coast, cays). The database used to test this hypothesis is the result of a five-year manatee study that began in 1997 and continued with annual surveys from 1999 to 2002, conducted in the wet and dry seasons along the coastal zone of Belize (Chapter II).

The general goal of this thesis is to increase the information base on the threatened manatee in Belize to provide direction for future research and aid in decision-making related to coastal issues. I will use the species and habitat approaches in the following structure. In Chapter II, I will use a species conservation approach as I am interested in the direct protection of the species. I will examine the overall temporal trends of manatees in Belize, based on three indices of abundance: raw counts, count adjusted by survey time, and calf proportion. Also, I will attempt to identify sources of variation, to aid in interpretation of the trends and recommendation of future research design. To provide a better picture of manatees' use of space, in Chapter III, I will determine variation in their distribution, considering habitat and season as causal variables. Habitats will be classified based on physiographic features and sources of freshwater. This detailed study of manatee use of coastal systems will aid decision makers in choosing special management areas based on specific seasonal regulations that will balance the needs of endangered species and local people. Chapter IV will summarize the population and habitat approaches used in Chapters II and III, providing a basis to make final recommendations for integrated management of the species, key coastal habitat, and future research. I will also offer my participatory reflections on future needs for manatee conservation in Belize.

The previous five years of manatee research has placed Belize a step ahead of other Central American and Caribbean countries. My hope is that this thesis can help provide a model for developing countries responsible for co-management of this wide-ranging flagship species. Pre-existing information from studies of manatees and dugongs in developed countries have provided good background on the biology of the species. For developing countries, a focus on this coastal endangered species would ideally serve as a model leading to regional ecosystem management to protect the coastal habitat for other species that also use the river and mangrove systems protected by the Belize Barrier Reef.

CHAPTER II

TRENDS IN MANATEE ABUNDANCE AMONG FIVE YEARS

Introduction

Applying the focal species approach, I will use a flagship species that has been consistently studied along the coastal zone of Belize since 1997. The Antillean manatee subspecies found in Belize is classified as vulnerable (VU A1cd C2a) by The World Conservation Union (IUCN) (Groombridge 1993). In the past, Antillean manatee populations were reduced by extensive hunting, which continues in most countries including Belize (Auil 1998; Smethurst & Nietschmann 1999; Lefebvre et al. 2001). Today, other identified threats to manatees are watercraft collision (Ackerman et al. 1995; Auil 1998), incidental entanglement in fishing equipment (Rathbun et al. 1983), and habitat degradation (Packard & Wetterqvist 1986; Bossart 1999). As manatees utilize coast systems, they are prime targets for the increasing pressures of tourism, fishing, and coastal development that damages their habitat.

The first aerial survey in Belize was flown in September 1977 (Bengtson & Magor 1979), and 101 manatees were counted along the coast. In May 1989, O'Shea and Salisbury (1991) sighted 102 manatees. In 1994 and 1995 additional surveys were conducted, resulting in higher total counts than previous surveys. Morales-Vela et al. (2000) attributed the difference in counts to one or a combination of the following: possible changes in water levels, difference in temperature, salinity, and/or vegetation, or increased human activity. While these authors compared trends among all aerial surveys conducted in Belize, they determined that interpretation of results was difficult due to the small sample size, differences in survey methods, and decades between surveys (Morales-Vela et al. 2000). Based on this evaluation, the research design for the present study was conducted using the standard methods of Morales-Vela et al. (2000) at least twice a year, over a span of five years (1997, 1999-2002).

Various studies have looked at the trends in manatee abundance, both in localized and broad study areas. Different indices such as raw counts, transformed counts, total-count Index per survey unit, density per area, and sight-resight index, have been used to determine trends (Packard et al. 1986; Lefebvre & Kochman 1991; Garrott et al. 1995). The problem in determining true trend in any of the above indices is multiple sources of variation. For example, in Florida, the factor accounting for most variation in manatee indices is temperature, be it direct (water temperature changes) or indirect (day of survey relative to a cold front) (Packard et al. 1986; Lefebvre & Kochman 1991; Garrott et al. 1995). However, indices also vary due to sightability (Packard et al. 1985) and behavior (Packard et al. 1989).

Gibson (1995) and Morales-Vela et al. (2000) reported on three surveys conducted in 1994 and 1995. Analysis indicated minimum counts, as well as an Index of Relative Abundance (number of manatees sighted per hour) for each survey and for high use areas (Gibson 1995; Morales-Vela et al. 2000). With only three surveys conducted, the status of the manatee population could not be elucidated; however, recommendations were made for long-term standardized aerial surveys in order make meaningful comparisons (Morales-Vela et al. 2000). Changes in relative manatee abundance will therefore be determined by looking at a larger set of aerial survey data collected from 1997 to 2002. The proportion of calves sighted for each year could indicate variation in reproductive recruitment to the population. One potential constraint would be the unknown effect of season on aerial counts. As surveys were conducted during the wet and dry seasons, differences would be expected in counts due to seasonal changes in sightability as well as potential seasonal shifts in distribution. For example, in the wet season, water turbidity generally increased more in the southern estuaries and coast than in the cay habitat stratum. I believed that more detailed evaluation of the sources of variation would facilitate adjustments of trend analysis in the future.

Movement among habitats and between years were factors that affected counts among sites in Florida, making trend analysis difficult (Garrott et al. 1995). Garrott et al. (1995) concluded that count variability was problematic and identification of the environmental variables that influenced counts, including temperature, would have helped to determine true changes in the population.

My objective is to examine the degree to which variation in aerial survey counts may be used in assessment of the overall trend of the manatee population in the coastal zone of Belize. First, I will examine the variation over five years for trends in several indices of manatee abundance (number of sightings per survey, number of sightings per hour, calf proportion per survey, and group size). Second, I will examine the relative importance of sources of variation in manatee counts. Finally, I will discuss potential approaches to refining analysis of manatee survey data, taking into consideration how the inherent sources of variation should be considered in assessing overall trends in population size.

Methods

Sources of error associated with aerial surveys include visibility bias (Packard et al. 1985; Pollock & Kendall 1987; Lefebvre et al. 1995; Marsh 1995) and sampling bias (Packard 1985; Lefebvre et al. 1995). One way of controlling bias is to standardize the survey design (Packard 1985; Lefebvre et al. 1995), hence methods used in 1994 (Gibson 1995; Morales-Vela et al. 2000) were continued for these surveys.

The study area was the coastal waters of Belize between Rio Hondo at the northern border and Sarstoon River at the southern border. Aerial flights have been the most effective means of surveying manatees (Rathbun 1988) to determine relative distribution of manatees in this large area, among habitats with seasonal change (Packard 1985). The extended-area technique and survey procedures followed the standardized protocol used by Gibson (1995) and Morales-Vela et al. (2000). Surveys were conducted once in the peak of the dry (March - April) and the wet (August - November) seasons for the years 1997, 1999, 2000, 2001, and 2002.

Each flight originated in Belize City, using a Cessna 206 high-wing aircraft with the right-hand door removed. Flying altitude averaged 168 m and mean velocity was 161 km/h. The coast was flown at about 0.5 km from the shore to maintain sight of the shoreline (or clear-water line in turbid areas), and rivers were followed upstream no more than 11 km from the mouth. Average flight duration was 3.5 hours, and the entire coast was flown in three days per survey (north, central, and south).

Three observers reported sightings to one person designated as recorder. Since some observers changed between surveys, novice observers were trained to identify manatees and to record data prior to each survey. No more than one novice observer was present on each survey and was seated behind an experienced observer.

The recorder used standard data sheets to document number of manatees, their size-class, activity, environmental conditions, and time of sighting; manatee locations were drawn on a map and stored in a Global Positioning System (Garmin GPS 12). The recorder also documented flight time relative to physiographic features suitable for designating units of the survey route. This information was used to classify sightings by habitat type, hereafter also referred to as "stratum", using an approach recommended where habitat were discontinuous along aerial survey routes (Packard et al. 1986; Lefebvre et al. 1995).

Observers reported calves and the best estimate of each group size, with groups defined as the number of manatees within one body length apart. A group was classified as an "observation", with each manatee considered a "sighting". If a group size could not be estimated during the first pass, the flight-path was interrupted and the plane orbited the group until observers were satisfied with their estimate; the time during orbiting was not recorded, so the observation time was made upon identification of the group. Group size was considered a best estimate because manatees were visible only within the top meter of the surface in turbid water, and sightability varied as individuals rose to the surface at varying intervals while the plane was circling. Observers made adult and calf size-classifications; calves were identified as an individual approximately half the size or less than another manatee closely associated with it (Irvine & Campbell 1978) and included in estimates of group size.

At the end of each flight, the recorder verified each sighting and time with the observers. The GPS positions were also checked by a third party after the survey. Quality control double checking was also done when the data was entered into various formats for analysis.

For this analysis, I defined survey units along the entire survey route, with lines drawn on the map at the ecotones between habitat strata (Fig. 2). Categories of strata used to classify units along the survey route were: (1) cay, i.e. mangrove or sand island more than 1.5 km from the coast; (2) coast, i.e. within 1.5 km from the shore of the mainland; (3) estuary, i.e. convergence of fresh and marine water at the mouth of a major river; (4) lagoon, i.e. a shallow inland body of brackish water blocked from the ocean by a narrow elongate peninsula; and (5) river, i.e. flowing water in the drainage channel of a watershed (High 1966; Gibson 1995; Morales-Vela et al. 2000). Each survey unit was classified exclusively as a single stratum. Thus, each habitat stratum used in the data analysis included several discontinuous survey units located at different sites along the survey route (Packard et al. 1986).

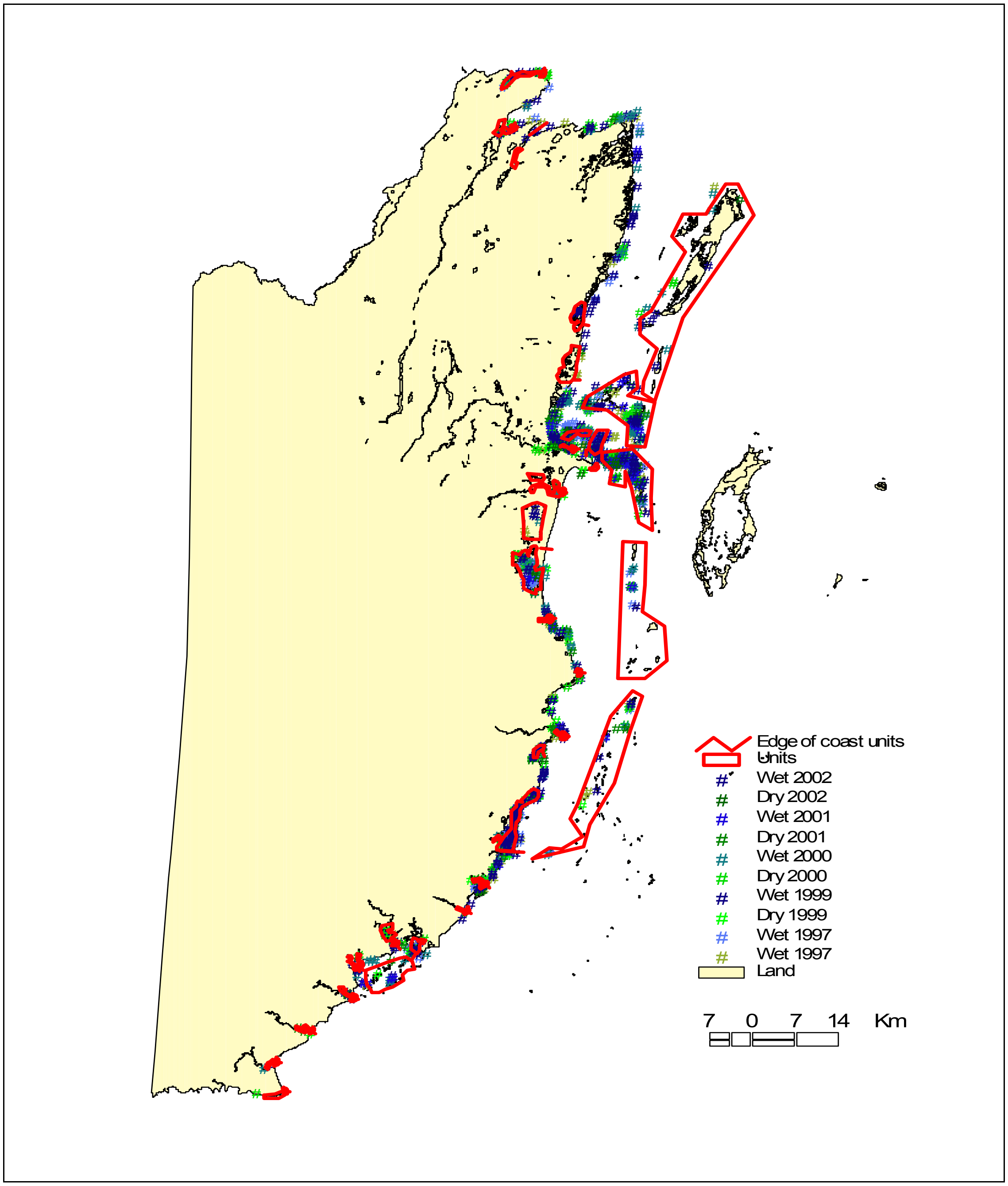


Figure 2. Coastline of Belize with manatee observations for each survey. The survey units are identified in red, with lines demarcating coastal units, and polygons demarcating lagoon, cay, river, and estuary units.

Statistical Methods

Indices of abundance were calculated as: (1) a Total Count (TC) of manatee sightings per survey or year (sum of the wet and dry survey for each year), (2) the Index of Relative Abundance (IRA), calculated as the number of manatee sightings per hour per survey unit (Gibson 1995; Morales-Vela et al. 2000), 3) Calf Count per survey or % Calf (number of calf sightings divided by total sightings on a given survey), and (4) estimated Group Size per observation (including both calf and adult sightings). Calculations were performed with the database in the format of an Excel workbook.

Descriptive statistics were examined for all variables, including tests for normality (Kolmogorov-Smirnov test) and homogeneity of variance (Levene's test). Values of the IRA Index were not normally distributed (Kolmogorov-Smirnov = 0.388, $p < 0.001$). No manatees were sighted in 60% of survey units (median and mode values were zero) and a few values were relatively high (up to 1473). The variance around the mean of 33 was high (SD = 96). Skewness and kurtosis were high (7.6 and 86.1, respectively).

Three transformations were calculated to determine which would best approximate the assumptions of analysis of variance: (1) $\log_{10}$ (IRA + 1) as suggested by Packard et al. (1986), (2) $\log_{10}$ (IRA + 0.5) as suggested by Lefebvre et al. (1995), and (3) square root (IRA + 0.5) suggested by Powell and Rathbun (1984). The square-root transformation resulted in values greater than zero, whereas zero values remained in the dataset when the log transformation was applied. Since there was relatively little difference in the distribution of $\log_{10}$ (IRA + 1) and $\log_{10}$ (IRA + 0.5), the former was arbitrarily chosen.

For the log-transformed IRA, skewness (0.9) and kurtosis (-0.8) were within acceptable ranges; values ranged from 0 to 3.2 (mean IRA = 0.6, SD = 0.9, mode = 0, median = 0). The variance was not homogeneous (Levene's test = 7.639, $p < 0.001$). Since the assumptions of the mixed-model approach to Analysis of Variance (ANOVA) were not met, the nature of the statistical analysis in this study was designed to be more exploratory (inferred development of hypotheses) than explanatory (deductive testing of hypotheses).

Statistical analyses were performed using a standardized statistical package (SPSS 1998-2001). Trends in the Total Count and Calf Count indices were examined across five years using a non-parametric measure of correlation suitable for the small sample size (Kendall's Tau). The dataset also was partitioned by season to calculate correlations separately for wet-seasons and dry-seasons. Correlations were considered significant at $p \leq 0.05$.

A hierarchical approach was used in exploratory data analysis. To examine the relative effect of year on the variance in the IRA Index for the overall dataset as well as the dataset partitioned by season (wet, dry), one-way analysis of variance (ANOVA) was performed. The ANOVA model was $\log_{10}$(IRA + 1) = YEAR.

A mixed-model ANOVA was applied to examine the relative contribution of the following fixed effects: YEAR, HABITAT, SEASON(YEAR), YEAR * HABITAT,

HABITAT*SEASON(YEAR). This approach was an extension of the general linear model, useful for correlated data with non-constant variability, and appropriate for multi-level or hierarchical modeling (SPSS 1998-2001). SEASON was nested within YEAR, but YEAR and HABITAT were considered as separate effects. The units of analysis were the survey units defined along the survey route. An Index of "relative effect on variance" (1 - Sig) was calculated for each fixed effect, where the formula for Sig was the same as the p value as specified in the SPSS output for mixed-models (SPSS 1998-2001). The Index values were ranked within each set of Fixed Effects, to emphasize the exploratory nature of this analysis, since it was not appropriate to report the values of F tests and p values. Post hoc comparisons were explored using the LSD statistic.

Results

Manatees were observed in all habitat types (Fig. 2), and the Total Count per year peaked in 1997 (Fig. 3). Total manatee sightings per survey ranged from 90 to 338 (mean TC = 231, SD ± 81), peaking in the wet season of October 2002. Total Calf Counts ranged from 7 to 38 (mean TC = 23, SD ± 10), with the highest % Calf Index of 13% in the dry season of 1999 (Fig. 4).

Although not significant, there was a slight negative correlation of year with the indices of Total Count (Kendall's Tau = -0.60, $n = 5$, $p = 0.14$) and Calf Count (Kendall's Tau = -0.11, $n = 5$, $p = 0.62$). The downward trend was significant for dry season surveys but not for wet season surveys' Total Counts (dry: Kendall's Tau = -0.8, $n = 5$, $p = 0.05$; wet: Kendall's Tau = 0.02, $n = 5$, $p = 1.0$), and Calf Counts (dry: Kendall's Tau = -0.95, $n = 5$, $p = 0.02$; wet: Kendall's Tau = 0.4, $n = 5$, $p = 0.33$).

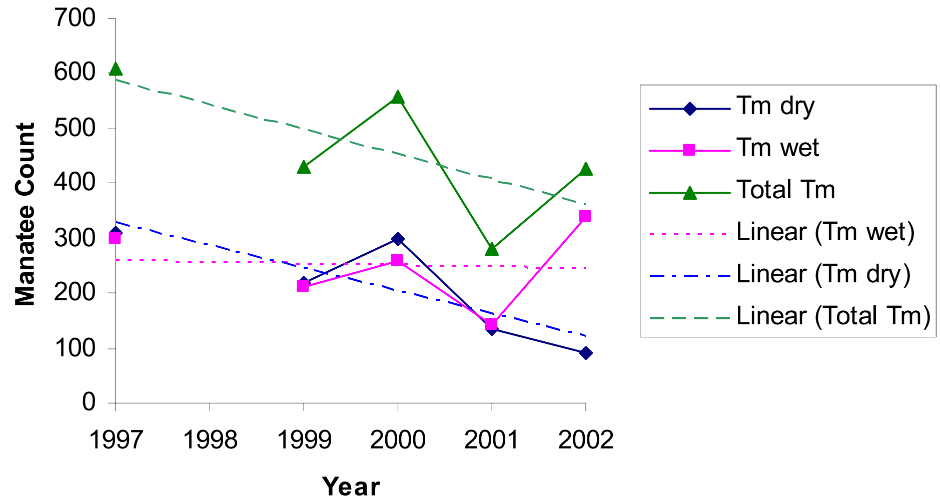


Figure 3. Total number of manatees sighted for each survey with a fitted linear regression line for each season. The total number for each year and its linear fit regression is also indicated.

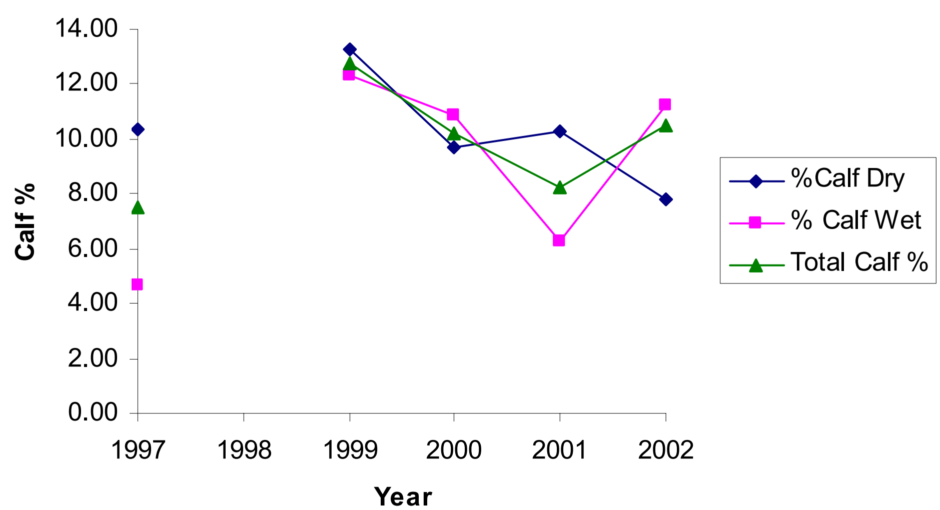


Figure 4. Percentage of manatee calves sighted among all manatees per season. Calf percentage for each year is also presented.

Most observations were of solitary manatees, although 60% of the sightings were in groups larger than one manatee (Fig. 5). Small groups of 2-5 manatees were more frequent than large groups. Twenty-four observations were of groups larger than five. Large groups were sighted in all years, but were absent in the 2002 dry and 1999 wet season surveys. Overall, large groups were less likely in the wet season (33%) than the dry season (67%).

Unusually large groups were sighted four times. A group of 22 (including four calves) and a group of 16 were observed in the Placentia Lagoon in the 2001 wet and the 1999 dry season surveys, respectively. Also in the dry season, a group of 19 manatees was recorded along the north coast, east of Bulkhead Lagoon in the year 2000. A group of 17 manatees were observed in the dry 1997 survey near the cays south of Little Rocky Point.

The variation among years was not greater than the variation within years, for the transformed IRA Index (ANOVA; $F = 1.69$, $p = 0.15$; Fig. 6). The dataset was partitioned by season for further examination of the effect of year.

For dry-season surveys, year had a relatively higher effect on the transformed IRA Index (ANOVA; $F = 3.085$, $p = 0.016$) than for wet-season surveys (ANOVA; $F = 2.482$, $p = 0.043$). In the dry-season dataset, the mean for 2002 was lower than all other years (LSD; $p \leq 0.014$ for each), except for 2001. For wet-season surveys, the mean was relatively low for 2001 compared to all years, particularly 1999 and 2002 (LSD: $p = 0.016$ and $p = 0.011$, respectively). Thus, the variance around the mean for each year differed for data from the wet season and the dry season.

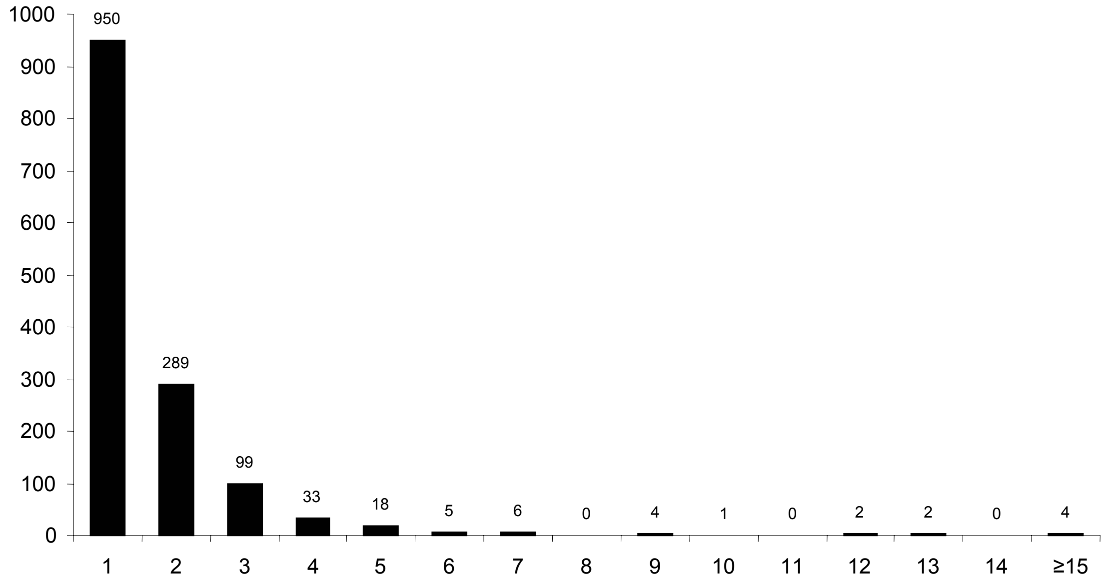


Figure 5. Frequency distribution of manatee group size. The largest group size sighted was 22 animals.

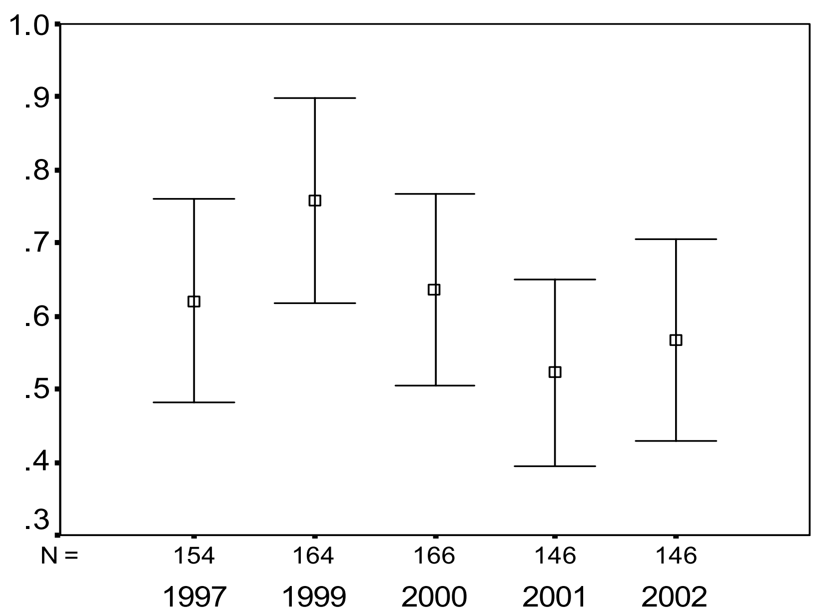


Figure 6. Annual variation in the IRA Index of manatee sightings (adjusted for effort within survey units), showing means with 95% confidence intervals.

In the mixed model analysis of variance (Table 1), two terms emerged as having the highest value associated with the sources of variation in the IRA Index of manatee sightings: (1) Habitat and (2) Habitat by Season nested within Year. Which of these two sources ranked higher was dependent on the type of transformation, e.g. the log transformation was assigned a rank of "1" for Habitat and the square-root transformation was assigned a rank of "2" for the same effect. The type of transformation did not affect the relative rank of three other Fixed Effects specified in the model. The sources of variation with the least explanatory value were: (1) Year and (2) Habitat by Year.

Table 1. Relative importance of specified Fixed Effects as sources of variation explained by the mixed-model analysis of variance.

Source of variation[a]	*Degrees of freedom*[b]		*Index of variance*[c]		*Relative rank*[d]	
	Num.	*Den.*	*Transform SQ*	*Transform LOG*	*Transform SQ*	*Transform LOG*
Habitat * Season(Year)	20	726	.995	.996	1	2
Habitat	4	726	.987	1.000	2	1
Season(Year)	5	726	.925	.972	3	3
Year	4	726	.655	.688	4	4
Habitat * Year	16	726	.528	.651	5	5

[a] *entered into the Mixed Model ANOVA; the asterisk indicates an interaction between two terms and the parentheses indicate the preceding variable was nested within the variable inside the parentheses (e.g. Season nested within Year)*
[b] *The number of categories for each variable were as follows: Habitat (5), Season (2), Year (5); "Num" refers to the numerator and "Den." refers to Denominator.*
[c] *This Index was calculated as (1-Sig), where Sig was the value for significance in the SPSS output table documenting Type III Tests of Fixed Effects. Low values of "Sig" indicated relatively more of the variance was associated with a specified effect; thus high values of this Index indicate the source was associated with relatively more variance.*
[d] *The numbers in each column indicate the relative rank for each source of variation (rows) based on the value of the Index of variation within the column for the respective transformation (eg. SQ or LOG)*

Discussion

The results of surveys conducted in Belize between 1997 and 2002 indicate an overall decline in manatee sightings in the dry but not the wet season total counts. Habitat and Season emerged as important variables to examine further in understanding the sources of variation in the Index based on sightings adjusted for effort within survey units (IRA Index). Recording and understanding the effect of these factors on indices of trends in abundance is important for assessment of the status of the population and consequently, comprehensive management of this endangered species within broader coastal systems.

Assessment of Population Status

Based on these results, several factors need to be considered when evaluating the status of the Belize manatee population. Clearly, results suggest low confidence in the possibility that the Belize population might be increasing. The overall trend in manatee counts per year appeared to be negative. The degree to which the Total Count Index accurately reflected the actual status of the population remains to be determined. Manatee counts varied from survey to survey, with a fairly large difference in counts both within and among years. The difference between wet season and dry season counts was inconsistent from year to year, complicating interpretation of the status of the population based on the Total Count Index.

The % Calves Index could have been useful in distinguishing between a declining and stable population if it had indicated low recruitment due to reproduction. Calf % was highest in 1999 for both seasons, corresponding with the results recorded for the overall population. While calf numbers did fluctuate between years, only two surveys had less than 8% calves, suggesting the population was healthy. Rathbun et al. (1990) identified a steady population increase with at least 8% calves in Florida. The level of certainty associated with the % Calves Index is moderate since calves are harder to see than adults (Morales-Vela et al. 2000).

Group size also may have been an indicator of the status of the population. With 60% of the sightings in groups, a few of these were large groups; overall, 24 groups contained more than five manatees. This strongly suggests that manatees are not as solitary as previously indicated (Hartman 1979). These large groups may have been aggregations of individuals at clumped resources. Although there are not consistent aggregation sites, a larger proportion of groups observed in the dry season suggests some effect of rainfall. Therefore, a more detailed spatial analysis considering season is recommended.

Factors Influencing Interpretation of Results

If turbidity affected sightings, lower indices would have been expected in the wet season. The dry season did have higher total counts for three of the five years. In 2001, the wet season difference was only greater by eight animals, but in 2002, the wet season sightings were 248 more manatees than the dry season. This could have been explained by very poor environmental conditions in the dry 2002 survey, which resulted in termination of the survey southward of Monkey River. Furthermore, the wet 2002 survey was of excellent condition.

The Index of manatee sightings adjusted for effort within survey units was not very useful for assessing population trends, due to the non-normal distribution, high variance associated with habitat strata, and the varying effect of season within year. Further drawbacks for using IRA as the dependent continuous variable were (1) the data setup took a lot of effort, therefore was subject to error, and (2) the interpretation of patterns in transformed data was not direct, which complicated interpretation of graphs. The non-parametric tests (Kendall's tau), while simpler to run, provided the same information with greater confidence in interpretation.

A hierarchical approach to analysis of variance using mixed models was useful in identifying the relative importance of influencing variation in the IRA Index. Compared to the low effect of year, the relatively higher influence of habitat, interacting with season, may be related to changes in sightability of manatees.   Regardless of season, visibility differed among habitat strata. The river habitat was subjectively ranked as most turbid, followed by the estuary and lagoon habitats. Overall, the cay habitat had the greatest visibility. Increased rainfall resulted in increased turbidity in all habitat types.

Implications

Due to the high variation in the Index adjusted for effort in survey units (IRA) it is difficult at this time to determine whether the Belize population might actually be stable or declining. There is no cause for alarmist reactive steps for manatee management in Belize, as there is not an unequivocal decrease in manatees. However, wildlife managers do need to take a conservative approach: monitoring of the population and conservation efforts should be continued. Although there was a failure to detect a true decline, the variability in the data may actually be masking a true decline. Continual monitoring will provide further insight on manatees' use of the coastal zone, which can then be used for management decisions.

Overall changes in relative abundance should be examined since environmental or anthropogenic factors might be associated. Changes in group aggregations among resource sites could indicate changes in quality of such sites. Site-specific monitoring would enhance decision-making capacity. For example, if the population decreases in zones of high boat traffic, speed zone establishment would be necessary. This is particularly relevant for the Belize City region, where tourism activities make the waterways high traffic areas. If declines are observed in coastal areas where poaching occurs, then implementing greater enforcement there is appropriate. Calf-ratio declines would indicate the need to protect possible nursery sites, sigh as lagoons. Integrated coastal zone management would then be a step in this process where threats are identified and managing actions reflect the needs of the people, balancing the needs of the species.

In Central America, Belize's manatee population was evaluated as relatively abundant compared to other countries (Lefebvre et al. 2001). Based on a metapopulation perspective, Belize might potentially serve as a source of manatees emigrating to other habitat fragments in adjacent countries. If this were the case, the metapopulation might be increasing at the same time the counts in Belize remained stable or slightly declining.

The variability in these data made it difficult to directly assess trends in the Belize manatee population. From this analysis and others (Packard et al. 1986; Garrott et al. 1995) it is clear that multiple interactive factors may be associated with variation in indices used to measure trends in manatee abundance. For future trend analysis, habitat and season need to be accounted for and used in regression analysis (Wright et al. 2002) to improve results (Garrott et al. 1995). In addition, other factors and combinations of factors that contribute to manatee counts need to be identified. Other covariates, such as survey condition for each unit and an observer calibration factor, could also be assessed (Garrott et al. 1995). Finally, to improve interpretation of the data, applying a spatial approach (Preen 1992; Wright et al. 2002) to analysis of survey data will provide information on spatial trends in manatee distribution (Chapter III). These survey techniques associated with trend analysis in Florida and Australia may need to be adapted for areas with less extreme temperature variations, as occurs in the Caribbean basin.

This exploratory analysis indicates that if tested, we would fail to support the hypothesis of an increasing population. A comprehensive examination of calf ratios, indices of the aerial survey counts and survivorship, with associated data of within and among year variability is needed to confidently state whether or not the manatee population is decreasing. Due to the uncertainty associated with trends in count data, manatees are not a good indicator species. One would also need to know whether it is a closed population, or is part of a larger regional population. Such a finding would bring in the need for multilateral research and conservation efforts.

CHAPTER III

SEASONAL DISTRIBUTION OF MANATEES AMONG HABITATS

Introduction

Among the coastal systems in Belize, the Belize Barrier Reef system is the greatest focus for conservation. This system is made up of a myriad of coral and fish life (McField 2001) To protect these species, Belize has established 26 marine protected areas (MPAs), seven of which make up a World Heritage Site. A primary purpose of these MPAs are to preserve precious fisheries stocks, which contribute a significant portion of the country's yearly income (Berre 2002). Within this system of the coastal zone, there are also a few outstanding and threatened megafauna. Wildlife Sanctuaries (WS) are protected areas designated for such species including the Antillean manatee and their habitat. There are currently three WS established specifically for the protection of manatees. To contribute to the information base used for protected area planning, I have studied the change in distribution of manatees among different coastal habitats, during two seasons, over a period of five years.

A habitat representative approach to biodiversity protection would be more appropriate in a multi-habitat system such as the coastal zone. This can be applied by selecting replicated representatives of habitat that will not only benefit fish species, but an array of species in order to manage native biological diversity (Roberts et al. 2001). Most MPAs represent the marine environment, and not a range of habitat including coastal, estuarine, and riverine systems, which make up the coastal zone. Shallow seagrass beds, littoral forests, mangrove hedges and wetland systems are all located away from marine systems, yet links among them that would safeguard ecological processes are not present (Mokhtar & Ghani Aziz 2003).

Because they make use of marine, fresh, and brackish waters; manatees, could be used as an umbrella species within the coastal zone. Umbrella species are wide ranging species selected because of their protected status, and their range encompasses that of many other species, consequently protection of this one species provides an umbrella of protection for others (Andelman & Fagan 2000). Furthermore, much funding and research has been invested in manatees. The umbrella species approach is another management strategy that would not only benefit the species, but also include representative habitat.

Distribution studies are useful because they reveal areas of high manatee density suitable for protection and management (O'Shea & Ackerman 1995; Melzer et al. 2000). Previous surveys in Belize suggested that most manatees were observed in the rivers and lagoons; the Index of relative abundance of manatees (count per effort) in these freshwater habitats was significantly different than in the offshore cay habitat (Morales-Vela et al. 2000). Freshwater systems are classified as those that have sources of freshwater, while offshore systems are those that are more distant from freshwater sources.

Aerial surveys provide this distribution information on a large-scale, justifying protection for areas of high manatee density, either by reserves or regulation of human activity. For example (Packard & Wetterqvist 1986) identified activity centers, as well as links between them, based on aerial survey data layered with spatial habitat information and human-use. Although manatees generally move freely between freshwater and marine habitats, Hartman (1979) observed that they prefer rivers and estuaries. In Costa Rica and Columbia, manatees were found to spend most time in riparian systems, although trips to the coast were made (Smethurst & Nietschmann 1999; Montoya-Ospina et al. 2001). In Honduras, manatees were sighted in lakes, rivers and lagoons (Rathbun et al. 1983). More information is needed about the importance of linkages between freshwater and more saline habitat strata. It has been reported that freshwater is essential for manatees (Hartman 1979; Montoya-Ospina et al. 2001). I will examine the "freshwater" hypothesis that manatees will be found in habitats that have sources of freshwater.

I hypothesize that manatee distribution varies in relation to the freshwater systems, defined by coastline physiography (High 1966); manatees likely make greater use of near-shore coastal habitat than they do offshore habitat. High density areas in Belize have been identified as Southern Lagoon, Placentia Lagoon, and the cays near Belize City (Bengtson & Magor 1979; O'Shea & Salisbury 1991; Morales-Vela et al. 2000). The Belize River, Corozal Bay, and Indian Hill Lagoon have also been reported as fairly high density areas (Auil 1998; Morales-Vela et al. 2000). These sites represented lagoon, cay, river and coast habitat.

Seasonal changes in manatee distribution also need to be evaluated for Belize. In Florida, the cold temperatures cause manatees to aggregate at warm water sources (Deutsch et al. 2003). A site-specific study in a year-round warm river, Crystal River, indicated that more manatees used the site in the colder months, and least in the warm months (Kochman et al. 1985). Some seasonal movement of dugongs was documented in Australia, also based on temperature (Anderson 1982).

Based on documented movements of manatees along the coast of Florida, site-specific management has been recommended (Reid et al. 1991). There are four long-term site-specific manatee research projects in Belize. One is conducted in the Southern Lagoon, where manatees are observed to be strongly residential year-round (Powell et al. 2001). Along the Belize Barrier Reef, two surveys are on-going by an independent researcher and an Earthwatch project (Self-Sullivan et al., 2004). In a northern site at the Basil Jones Reef cut, manatees were consistently observed between the end of the dry season to the end of the wet season, while manatees were sighted more in the "summer" (warm transitional) than "winter" (cool transitional) season in the Gallows Reef cut located in the center of the country.

In Belize, year-round temperature variations are relatively small (average maximum near 85^{o}F and minimum in low 70s), particularly on the coast (Gibson 1995). Testing for the effect of temperature by comparing counts taken in cool January and in warm May, there was no difference in manatees seen per hour between northern and southern sections of the Belize coast, nor near-shore and offshore habitats (Gibson 1995). Therefore, seasonal factors such as rainfall or vegetation presence may be more important to understand the variation in manatee distribution within Belize coastal systems.

Previous analysis of aerial survey data in Belize indicated that manatees were not randomly distributed among habitat types, and the patterns of distribution varied with both season and year (see Chapter II and Morales-Vela et al. 2000). Sites believed to be important for manatees in Belize have been identified; however, the factors or the sources of variation that influence manatee distribution among habitat strata have not been determined.

Procedures for analyzing spatial distribution on a finer scale than survey units have been developed for dugongs (Preen 1992), although they have not yet been applied to manatees. There is an inherent statistical problem when a survey route is divided into survey units based on physical characteristics such as water temperature (Lefebvre & Kochman 1991), sampling effort (Packard et al. 1989) or geophysical features (Packard et al. 1986). The survey units are not statistically independent, since the features of an adjacent unit may influence the probability of manatee presence in a given unit. For example, not all units of estuarine habitat are homogeneous. This inherent spatial dependence can be examined using statistics appropriate for spatial analysis, such as log-likelihood models and logistic regression (X. Wu, personal communication).

The present study will illustrate how to address the information gaps about spatial distribution of manatees in Belize, by applying the grid-cell approach developed by Preen (1992) for analysis of dugong habitat. This approach to categorical data analysis is appropriate for examining the interactive effects of year, season and habitat on the probability of manatee presence or absence in given locations. Previous studies using parametric statistics suggested that distribution was affected by the interaction of several variables; however, such exploratory data analysis was not appropriate for testing the interactive nature of the effects on a site by site basis (Chapter II).

The primary purpose of the spatial analysis in this chapter was to determine the consistency of seasonal effects on changes in manatee distribution among sites. My objective was to determine how year and season interacted in influencing distribution among habitat types. Answering this question would help to direct when and where to focus management efforts.

To determine the interaction between seasonal (wet and dry) and habitat (physiographic strata) factors affecting spatial distribution of manatees, the following questions were examined.

(1a) Are manatees sighted more in freshwater habitat types during dry seasons compared to wet seasons?

(1b) Do coastal systems in the south attract more manatees compared to those in the north?

(2) Within near-shore versus offshore groups, north and south regions and in rivers and cays, are manatees consistently sighted more in the dry than the wet season?

(3) Are there significant effects of year and season in strata?

(4) How might physical parameters of salinity and temperature explain the interaction of habitats and seasons?

Methods

The extended area survey technique was performed as described in Chapter II. Using GIS software ArcView 3.2 (ESRI 1992-2000), the base-map of Belize (CZMAI) was used for spatial display of manatee observation points recorded as points collected on a Trimbley (Trimbley Navigation) or Garmin (Garmin GPS 12) Global Positioning System (GPS). This was then entered into a GIS database after downloading or manually inputting the manatee position, along with habitat and other information collected on the standardized data sheets. A 1 km buffer was created around the survey route collected in 1997 and a 1 km square grid was then clipped to this theme. Each defined strata shape file was adjusted using the grid route theme (Fig. 7). Each cell within a habitat of the grid was assigned a unique value. The presence or absence of manatee and calf observations for each cell was recorded for each survey, and tallies of the relevant cells were compared in specified log-likelihood ratio tests (G^2) as recommended by (Preen 1992). Probability of presence was calculated by taking the ratio of presence given absence. Cells were not weighted by number of sightings (manatees per observation), consistent with the analysis by Preen (1992).

Based on exploratory data analysis using hierarchical log-linear modeling, the distribution of manatee observations depended jointly on interactive effects of Year, Season and Habitat Strata. Since a full analysis based on log-linear models was beyond the scope of this thesis (J. Packard, personal communication), non-parametric tests were used to explore specific predictions about the interactions among the factors that influenced manatee sightings. Categorical data analysis and non-parametric tests were used for indices based on observations of manatees within grid cells. Analysis of Variance (ANOVA) procedures were used for analysis of survey indices based on counts corrected for effort within survey units (see Chapter II).

For the analysis, to compare near-shore and offshore distribution, the strata were merged into two types: (1) near-shore consists of rivers, lagoons, estuaries; and (2) offshore includes the cays and coast. Although Gibson (1995) classified the coast strata as near-shore, the temperature and salinity ranges of the coast stratum more resembled the cay stratum than the others. This distinction will test the hypothesis that manatees aggregate near sources of fresh water during the dry season; estuaries are classified differently than coast because coastal habitat near watersheds could provide sources of freshwater. When results of the G^2 test, binomial Z-scores were calculated to determine the direction and magnitude of the difference (Bishop et al. 1975; Bakeman & Gottman 1986). The Excel workbook (Microsoft® Excel 2002) designed for this type of analysis is available from the Ethology Lab at Texas A&M University (J. Packard, personal communication).

To compare distribution between the north and south coast, the coast stratum was divided into south and north at 1 km north of the Sibun River mouth (17^{o} 26’ 08” N, 88^{o} 15’ 33” W). The south coast has five times more rivers than the north, and is further differentiated by its greater annual rainfall (3800 mm in the south and 1500 mm in the north), steeper depth contours, greater turbidity, and its larger waves (High 1966). By these features, High (1966) found the dividing the country into north and south coast was appropriate just south of Belize City. Log-likelihood ratio tests were computed

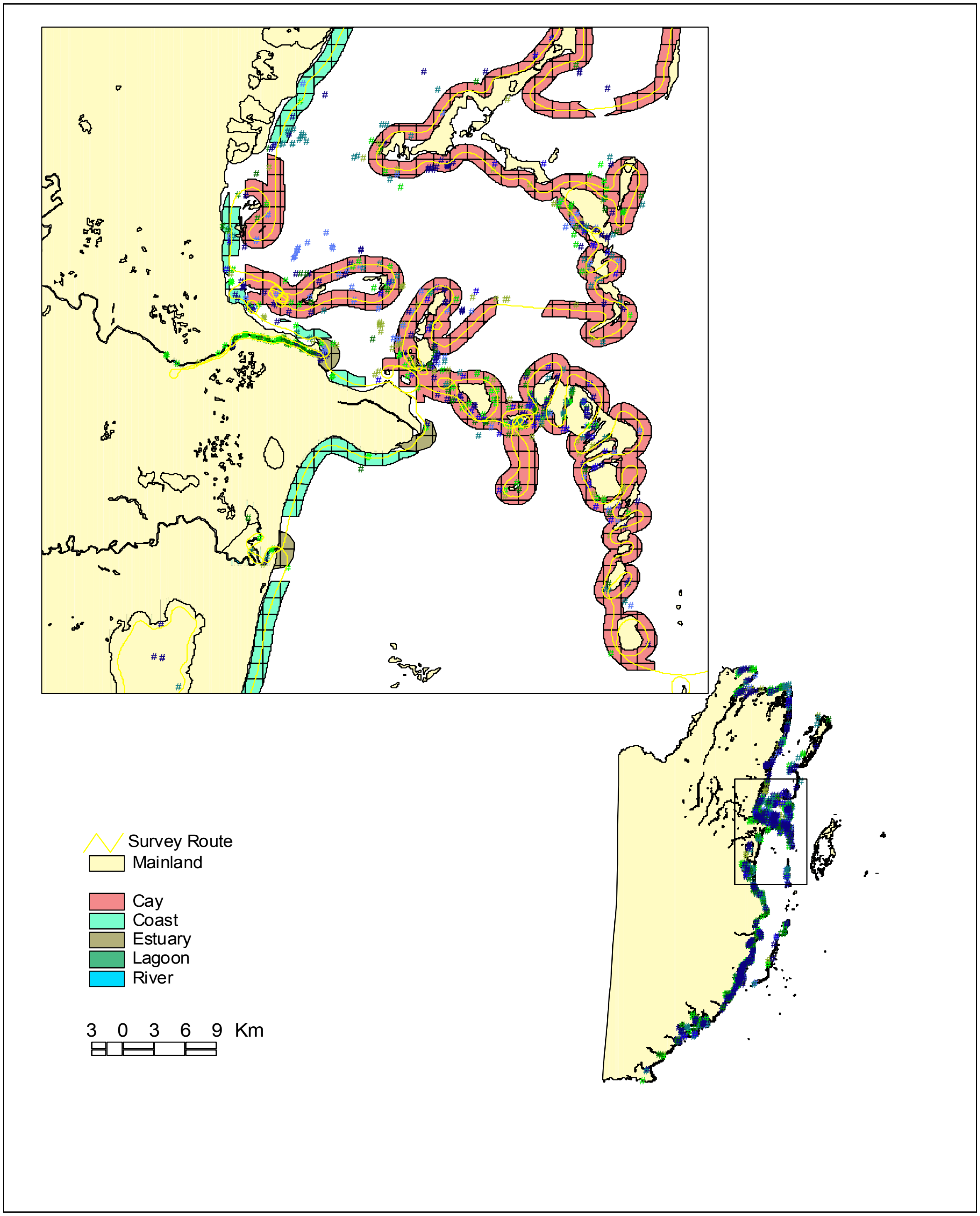


Figure 7. Coastline with grids for each habitat and manatee observations (also in Fig. 2). Ballooned caption is of the Belize City area, including the Belize River and Drowned Cays.

comparing presence and absence of observations of north and south in the wet and dry season; if the result of each G^2 test was different than expected by chance, then binomial Z-scores were reported.

To test the effect of season on manatee distribution within habitats, G^2 and Binomial Z-scores were computed using presence tallies of each habitat in the dry and wet seasons. To compare rivers, the Wilcoxon sign-rank test was used to determine if manatee distribution was the same among seasons for each year. I used the number of manatees sighted per hour or Index of relative abundance (IRA) (Morales-Vela et al. 2000) for each river in each season. Friedman's test was used to test if the five related samples of each year were from the same population. For both the dry and wet seasons Wilcoxon sign rank test was also used with IRA pooled within each season. SPSS statistical program was used to conduct these analyses. The cay habitat was examined in isolation by using G^2 and Binomial Z-scores of only presence tallies comparing wet and dry seasons. Surveys were conducted on the same population of manatees in five habitat types, between two seasons and among five years (see Chapter II). Log-linear analysis was conducted to determine which of these factors or interaction of factors may have contributed to the observed results.

I assessed water quality data collected by CZMAI, during the range of dates of the aerial surveys. The dates used in the analysis are March 1 to April 30 (dry season) and August 1 to October 31 (wet season) for 1997 and 1999 to 2002. Each sample point was given a habitat classification based on its location, and assigned a season. One-way ANOVA was used to compare the effect of habitat type on salinity and temperature, as separate dependent variables. Two-way ANOVA was run to examine interactive effects of variables (season, habitat, and season by habitat) on salinity and temperature, respectively. These tests were using the General Linear Models procedure of SPSS.

Results

Manatee Sightings in Freshwater Habitat Types

Probability of sighting manatees in lagoon and river habitat were over twice that of the other habitats (Figure 8a). Comparing manatees in cells for each habitat, presence of manatees were different than expected by chance among all years ($G^2 = 224.24$, $df = 4$, $p < 0.001$). There were less manatees in the coast ($Z = -7.29$) and more in the lagoon ($Z = 12.54$) and river ($Z = 7.61$) habitats than expected by chance (Fig. 8a).

There was a total of 1374 (59.58%) manatee sightings in the off-shore habitats, and 932 (40.42%) for the near-shore habitats. The offshore strata had 15260 cells without manatee observations, and 490 with manatee observations. The near-shore habitat had fewer cells; 3776 without manatees and 321 with manatees. Of the near-shore cells, 7.9% had manatees, and of the offshore cells 3.1% had manatees. There was a significant difference between absence and presence of manatee in cells between the near-shore and offshore habitats ($G^2 = 162.29$, $df = 1$, $p < 0.001$). Presence of manatees offshore was less than expected by chance ($Z = -6.26$) and those near-shore were more than expected by chance ($Z = 12.36$).

Summing all surveys, a total of 352 (59.36%) manatees was sighted in north coast, and 241 (40.64%) in the south coast. The north and south coastal observations do not differ than expected by chance ($G^2 = 0.53$, $df = 1$, $p = 0.53$). With a total of 41 (65.08%) calves sighted in the north, and 22 (34.93%) in the south, calves were as expected by chance ($G^2 = 2.43$, $df = 1$, $p > 0.05$) between the two regions.

Manatee Sightings Between Seasons

The probability of sighting manatees in the wet season was slightly higher than in the dry season (Fig. 8b). Comparing total cells with manatee presence among seasons for each habitat, observations were not as expected by chance ($G^2 = 35.96$, $df = 4$, $p < 0.001$). The river habitat was higher than expected by chance in the dry season ($Z = 5.49$) and lower than expected by chance in the wet season ($Z = -5.49$). Measuring only cells with observations, near-shore there were more observations in the dry season than expected by chance ($Z = 2.36$) and less in the wet season than expected by chance ($Z = -2.36$). Comparison of the dry and wet season, there was no difference in the north and south observations than expected by chance ($G^2 = 0.52$, $df = 1$, $p > 0.05$).

Combining all years, 229 manatees including 36 calves were sighted in rivers in the dry season surveys, and 49 manatees including 6 calves in the wet seasons (Table 2). Total IRA for the dry and wet seasons was 39.71 (6.24 calves per hour) and 8.50 (1.04 calves per hour) respectively. Three of five years show a significant difference in distribution between manatees seen per hour, suggesting that rainfall has a significant effect on manatee sightings (Table 3). There was, however, no significant difference in calf distribution between the wet and dry seasons for any of the five years (Table 4). To compare sample distributions, all years were pooled per season because there was no significant difference in total IRA for all rivers between the five dry season surveys

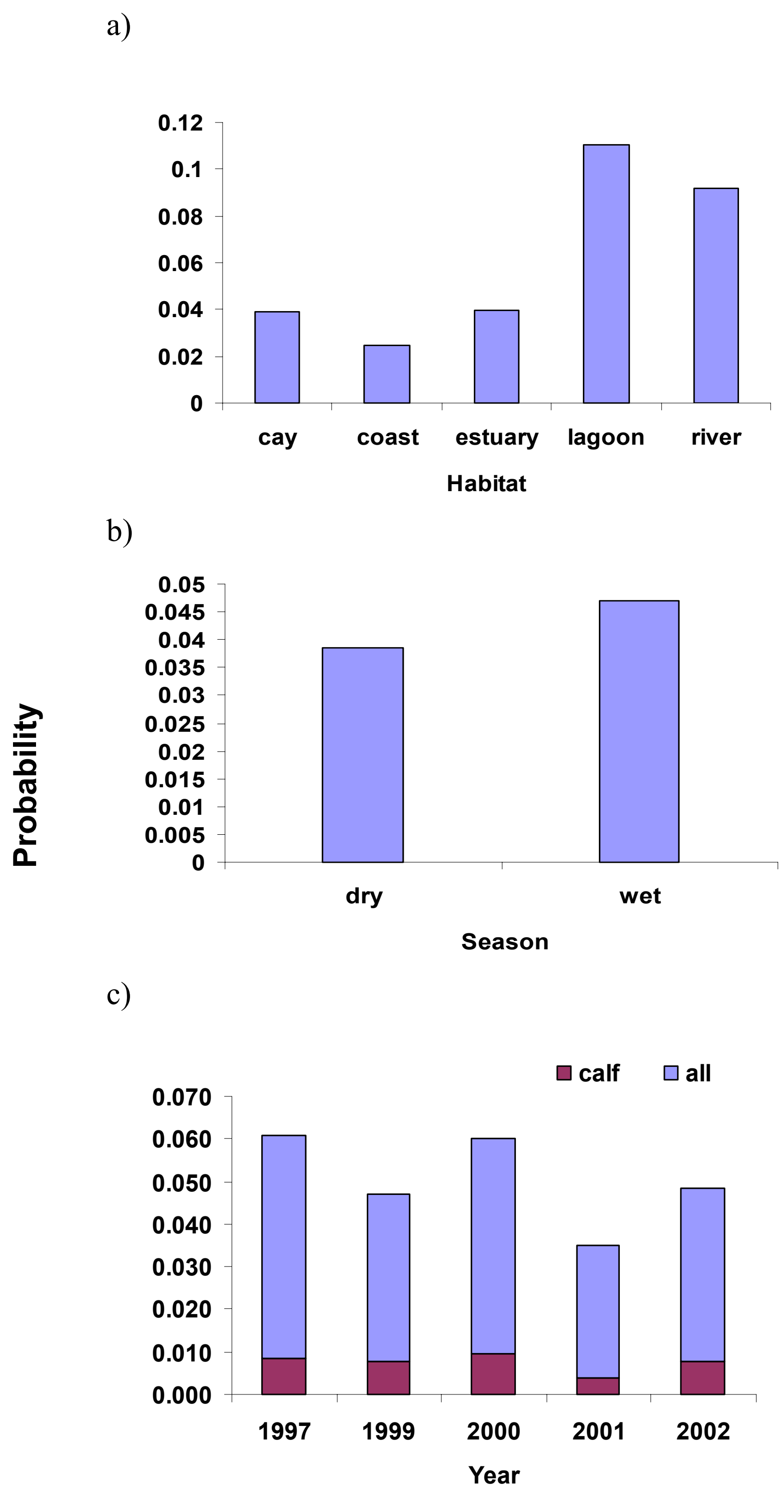


Figure 8. Single factor effects on probability of manatee presence on (a) habitat, (b) season and (c) year.

Table 2. Manatee (Tm) and calf totals, percentage, and IRA for each river surveyed in both seasons.

River	*Tm dry*	*%Tm dry*	*Calf dry*	*Tm wet*	*% Tm wet*	*Calf wet*	*Tm dry IRA*	*Calf dry IRA*	*Tm wet IRA*	*Calf wet IRA*
Hondo	20	9	3	20	41	2	26	4	25	3
New	12	5	2	4	8	0	22	4	7	0
Belize	124	54	22	8	16	1	139	25	9	1
Sibun	11	5	0	6	12	1	21	0	11	2
Mullins	2	1	1	0	0	0	10	5	0	0
Sittee	20	9	1	2	4.	0	71	3	7	0
Sennis	9	4	1	n/s*	n/s	n/s	137	15	n/s	n/s
Monkey	0	0	0	0	0	1	0	0	0	5
Deep	9	4	1	1	2	0	22	2	2	0
Golden	3	1	1	0	0	0	17	6	0	0
Middle	1	0	0	1	2	0	7	0	7	0
Grande	9	4	1	5	10	1	35	34	19	4
Moho	4	2	1	0	0	0	12	3	0	0
Temash	0	0	0	2	4	0	0	0	6	0
Sarstoon	5	2	2	0	0	0	8	3	0	0

** Not surveyed*

Table 3. Wilcoxon sign-rank test comparing total manatee relative abundance (IRA) between the seasons for each year.

	W97[a] IRA – D97 IRA	W99 IRA – D99 IRA	W00 IRA – D00 IRA	W01 IRA – D01 IRA	W02 IRA – D02 IRA
Z	-2.073[b]	-.415[b]	-1.886[b]	-2.366[b]	-0.535[b]
Asymp. Sig. (2-tailed)	0.038	0.678	0.059	0.018	0.593

[a] *The abbreviations are as follows: Wet (W) / Dry (D); year indicated as last two numbers (e.g. 97 is year 1997)*
[b] *Based on positive ranks.*

Table 4. Wilcoxon sign-rank test comparing total calf IRA between the seasons for each year.

	W97[a] IRA – D97 IRA	W99 IRA – D99 IRA	W00 IRA – D00 IRA	W01 IRA – D01 IRA	W02 IRA – D02 IRA
Z	-1.069[b]	-1.000[b]	-1.572[b]	-1.604[b]	-1.342[c]
Asymp. Sig. (2-tailed)	.285	.317	.116	.109	.180

[a] *The abbreviations are as follows: Wet (w) / Dry (D); year indicated as last two numbers (e.g. 97 is year 1997)*
[b] *Based on positive ranks.*
[c] *Based on negative ranks.*

(Friedman's $X^2 = 6.483$, $n = 7$, $p = 0.166$), or the wet season surveys (Friedman's $X^2 = 7.208$, $n = 8$, $p = 0.125$). Nor was there significant difference for calf IRA in the dry season surveys (Friedman's $X^2 = 5.895$, $n = 9$, $p = 0.207$) or wet season (Friedman's $X^2 = 1.826$, $n = 10$, $p = 0.768$). Sightings of manatees per hour did differ in distribution between the overall wet and dry season samples (Wilcoxon sign-rank z = -2.845, $p = 0.004$) as did calves sighted per hour (Wilcoxon sign-rank $z = -2.045$, $p = 0.041$).

Manatees are not often seen in the river habitat during wet seasons. Using the river grid-cells, manatee presence was significantly different from manatee absence ($G^2 = 22.93$, $p \leq 0.001$). The dry season had greater manatee presence than expected by chance (Binomial z = 4.51), and less than expected by chance in the wet season (Binomial z = -4.51). In contrast, by and large manatees are seen in the cay system year-round. In the cays, there was also a significant difference in manatee observations within grids ($G^2 = 8.41$, $p \leq 0.01$). A greater number of grid-cells with manatees present were observed in the wet season (Binomial z = 2.84) and less in the dry season (Binomial z = -2.84).

Interactive Relationships of Variables

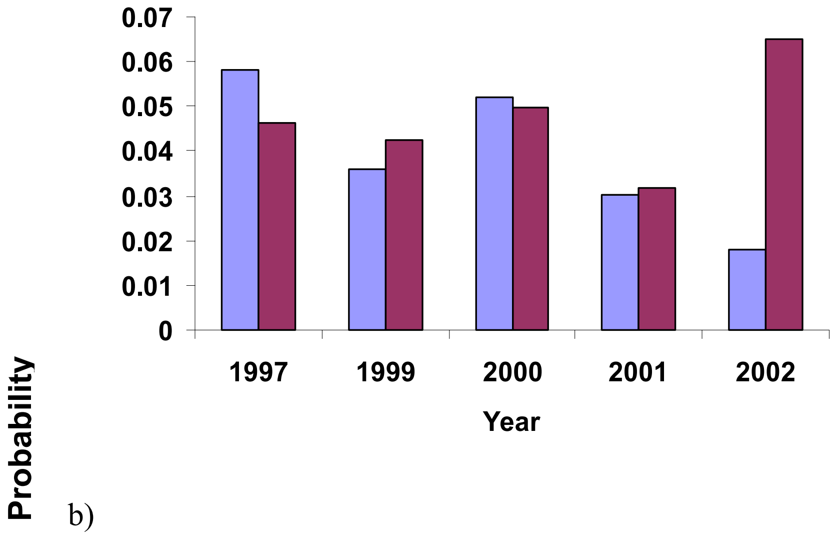
The probability of observation for year was highest for 1997, for season, wet was greater than dry, and for habitat, lagoon had the greatest probability of observation. This trend changed when each variable was examined by season (Fig. 9). Log-linear models showed single effects existed for strata ($X^2 = 13103.42$, $df = 4$, $p < 0.001$), but not for year or habitat. There were two-way interactions for year by presence / absence ($X^2 =$

27.48, *df* = 4, *p* < 0.001), season by presence / absence (X^2 = 7.53, *df* = 1, *p* = 0.006) and strata by presence / absence (X^2 = 224.71, df = 4, p < 0.001). Three-way interactions existed for year by season by presence / absence (X^2 = 49.94, df = 4, p < 0.001), year by strata by absence / presence (X^2 = 49.27, *df* = 16, *p* < 0.001) and season by strata by presence / absence (X^2 = 39.41, *df* = 4, *p* < 0.001).

Salinity and Temperature

Salinity differed between seasons (ANOVA; F = 61.90, df = 1, p < 0.001) and habitat (ANOVA; F = 231.98, df = 4, p < 0.001) (Fig 10a). In the dry season, mean salinity values were greater for each habitat type. Multiple comparison tests indicated that cay and coast habitats did not differ significantly, but both habitat types had higher salinity than the estuary, lagoon, and river habitats (Dunnet's T3; p ≤ 0.001 for each). In the two-way ANOVA tests, season by habitat did have an interactive effect on salinity (ANOVA; F = 23.63, df = 4, p < 0.001). Temperature also differed significantly among season (ANOVA; F = 14.96, df = 1, p < 0.001) and habitat (ANOVA; F = 4.369, df = 4, p = 0.002) (Fig. 10b).

a)



b)

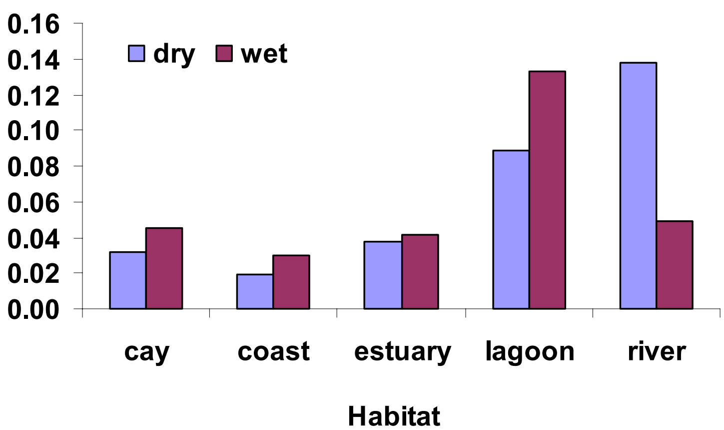
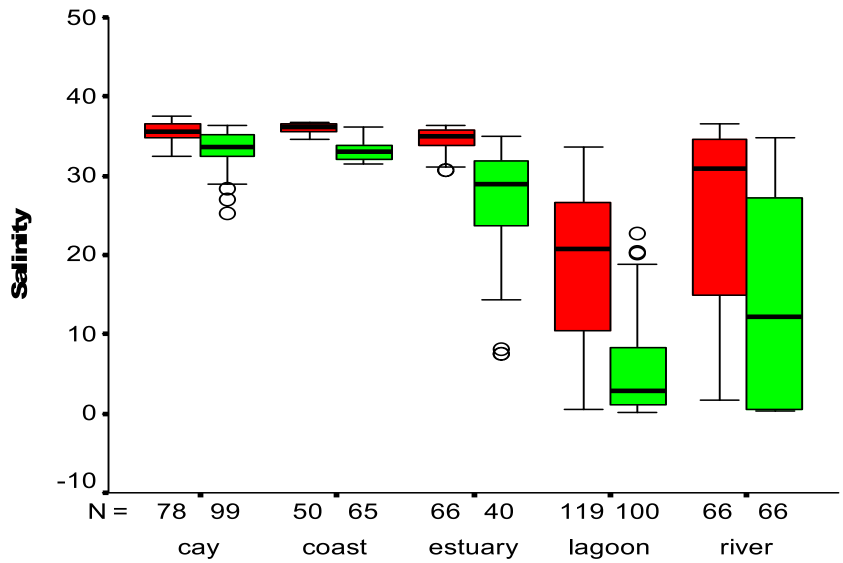


Figure 9. Probability of manatee observation for (a) each year given season, and (b) each habitat given season.

a)



b)

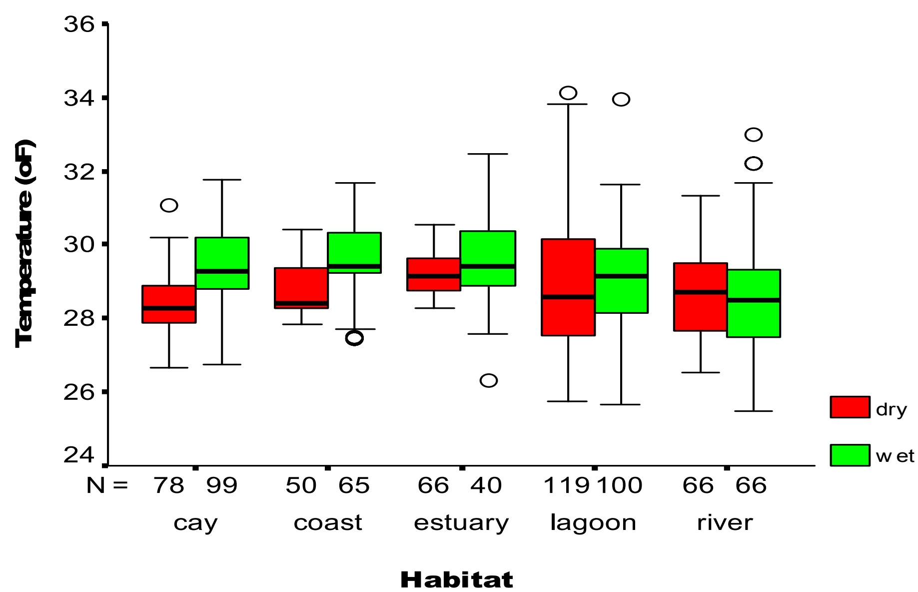


Figure 10. Salinity (a) and temperature (b) (median, interquartile range, minimum and maximum values, and outliers) in relation to the five habitat types, calculated for the wet and dry season of five years.

Discussion

The effect of habitat was evident; manatee sighting probabilities in lagoon and rivers were higher than expected, in contrast to the coast. Also, the proportion of cells with manatees in the near-shore habitat was more than twice that of offshore habitat. The examination of north versus south coast, however, did not show the expected difference. The south coast observations were expected to be higher than those in the north coast as the south has more rainfall and sources of freshwater. A true difference would have further demonstrated higher manatee use of the freshwater system. While this lack of difference was also seen in previous surveys, the comparison by Gibson (1995) did not include a wet season survey, but compared the dry to the cool transitional season. There is no difference in north and south coast based on temperature or salinity. The lack of difference between seasons could be due to the increased turbidity and larger waves in the south, both reducing visibility of manatees. The southern coastal area is characterized as turbid, which does not change between seasons, probably due to high wave activity seen throughout the year (Nunny et al. 2001). Because of these factors, I believe that manatees may be undercounted in the south. Removing the 2002 dry season survey, which was aborted along the southern route, there still was no difference between regions. A poor south survey did not affect results, indicating that although manatees are in the south, they are not well counted in flight in sub-optimal conditions.

It is evident that near-shore systems have greater probability of manatee presence (density) than do offshore systems. A closer look at rivers and cays strengthens our knowledge on the effect of season, and manatee use of freshwater systems. Variability between significance was seen comparing seasonal manatee observations in rivers for each year; however, comparing rivers cumulatively resulted in significant difference. Exploring manatee counts in only the cay habitat also shows difference between seasons, with more observations made in the wet season. The greater use of rivers in the dry season and conversely of cays in the wet season may indicate manatees need for water to drink (Powell et al. 1981; Ortiz et al. 1998). Having more rainfall may also mean that manatees spend less time in inshore habitats as their water needs are met. Manatees may also avoid the rivers in the wet season due to faster water currents from river outflow. Manatees are thought to use near-shore systems since they are sheltered from the open ocean, provide a source of fresh water, have abundant aquatic food, and experience low environmental degradation (Rathbun et al. 1983; Smethurst & Nietschmann 1999).

The manatee shift from the inshore river to the offshore cay in the wet seasons may be a pattern. Changes in vegetation cover may be a factor yet to be explored. Food sources are also important factors that interlink with water balance needs. In the wet season, there is increased turbidity, which decreases some submerged aquatic vegetation (Kaldy & Dunton 1999). Another theory is that rivers with low disturbance and environmental degradation compared with other locations will have more manatees (Smethurst & Nietschmann 1999). This is the case for most of the southern rivers in Belize, however, the Belize River with the greatest number of manatee sightings, has high boat traffic, as does Rio Hondo and New River. In other systems in Central America, manatees have moved out of rivers in the dry season because the water levels become too low (Morales-Vela et al. 2000). This is not observed in Belize, posing a different dynamic in habitat use.

Season does have an effect on manatee counts within habitat. The three-way interaction existed for season by year and manatee presence / absence, which is seen in the change in overall distribution among habitat. The interactive effect of season and habitat does not make for direct data interpretation, but indicates that both factors should be combined when reporting manatee distribution. The patterns of distribution among habitat, however, do not change drastically given season. While lagoon has the highest probability of manatee presence in the wet season and river for the dry season, the other habitats are lower than both within both seasons (Fig. 9b). To afford the best protection for the manatees in Belize, knowledge of their seasonal movements within various habitat systems is valuable. There is existing literature that supports the temporal changes in distribution of the manatee as recorded in interviews with local fishers (Rathbun et al. 1983; Smethurst & Nietschmann 1999). Although my analyses of temperature values indicates significant difference among habitat and among year, this difference is not biologically meaningful for manatees, as temperature remains far above threshold limits (Irvine 1983). However, Irvine studied the Floridian manatee, which may differ in thermoregulatory behavior compared to the Antillean manatee. The effect of season based on rainfall, related to distribution of manatees among habitat types along the coastal zone, is now demonstrated through these distribution surveys.

While the mean salinity for estuary is almost as high as the cay and coast and not lagoon and river (Fig. 10a), the water quality sample points measured for estuary during my selected time frame were not distributed along all rivers (43% taken at the Deep River bar and 14% from Sibun River bar). I still classify estuary as near-shore because a manatee within 1 km of the river mouth could easily access the river, and because lower values also fell within range of the river and lagoon systems (Figure 10a).

The effect of habitat indicates that near-shore systems should be classified as primary manatee areas and these areas can provide a larger umbrella of protection to other species. The wet season had higher counts, so the wet season surveys surely need to continue. With the interactive effect, habitats indicate differing trends for a given season; for that reason I recommend that each habitat should be studied and temporal changes within each explored. Year-round protection may be needed for high use habitats, such as lagoons, that do not display seasonal change, while we know that the river habitat needs to be protected in the dry season.

Implications

The National Park System for Belize allows for the establishment of nature reserves or wildlife sanctuaries which, broadly, are reserved areas for biological communities, nationally significant species, or physical environmental features (National Park Systems Act 2000). Historically, they are set up after public consultation to determine the boundaries and, following official declaration, a management plan is expected to be written. Marine reserves are established under the Fisheries Act, and protect aquatic flora and fauna and breeding grounds. Marine reserves are established after a management plan is completed, and usually have various activity zones, from conservation to general use. It is under these protected area systems, particularly the national parks that biodiversity conservation can expand to encompass non-marine systems that do support the various stages of reef and non-reef organisms. This can be established for manatees, other organisms, and ecological processes that occur in their habitat.

When creating protection areas for the management of many species and processes, corridors or links between reserves are recommended for persistence of species within each reserve (Roberts 1997). The current reserves declared for the protection of manatees are located: (1) at the northern border (Corozal Bay WS), adjacent to Mexico's manatee reserve, including coastal and estuarine habitat; (2) in the second largest lagoon located in the center of the country (Gales Point (Southern Lagoon) WS), and; (3) around a cay (Swallow Cay WS) heavily used for manatee observations lead by licensed guides. The results from this analysis show movement between habitats. Tracking data show that individual manatees travel from the Southern Lagoon system (Powell et al. 2001) towards the Swallow Cay area, through a river heavily used by manatees (Belize River). However, there are no links such as this river, considered for management between these reserves. While Roberts' (1997) discussion on the need to link reserves was for the purpose of aiding in larval dispersal, the concept is still applicable for manatees and their habitat (Self-Sullivan et al. 2004). Seagrasses and mangrove are important for aquatic primary consumers, as well as for shoreline stabilization. Dispersal or pollination is important for these aquatic plants (Kaldy & Dunton 1999). These links are also directly important for their management between manatee activity and core cites (Packard & Wetterqvist 1986).

In situations where more protected areas cause more coordination problems, special management areas or special areas of conservation (Thompson et al. 2001) may be more appropriate. As over 50% of Belize land is in protected area (PA) status, the public may become more resistant to the establishment of more PAs. This system may help to alleviate that potential problem. The Belize Forest Department is shifting from designating numerous protected areas to establishing special management areas. The movement trends of the manatee can also be used in such a system. It is this type of management that enforces regulations and can make it easier for the successful conservation of an area, applying less stringent methods that would require fewer resources to manage.

CHAPTER IV

SUMMARY AND CONCLUSIONS

The broad goals of this research were (1) to investigate trends in abundance of manatees in Belize, using various indices based on aerial-survey data, and (2) to develop an approach to refine understanding of factors influencing changes in the spatial distribution of manatees within the coastal zone. To address these goals, sources of variation and interactive effects on manatee observations were identified. The management options and future research needs recommended below are based on integrating the results of these population and spatial analyses. In this chapter, the results of the population trend analysis will be summarized first, followed by a summary of the results of the spatial analysis. Finally, recommendations will be presented.

Trends in Manatee Abundance

Trend analysis based on total counts from aerial surveys suggested the Belize manatee population is stable or slowly declining (Chapter II). This was determined by the significant negative correlation across years for dry-season surveys, but not wet-season surveys. This trend was mirrored in overall calf counts.

In contrast, the analysis of reproductive indices (% Calves) was consistent with what would be expected from an increasing population. Calf percentages for most years (except 1997 and 2001) were near or above the 8% described by Rathbun et al. (Rathbun et al. 1990) as an indication of a growing population. The discrepancy in results using different indices of the manatee population makes decision making difficult.

The dry season Index (log transformed IRA values) showed greater variation among years than values for the wet season. In the dry season, 2002 manatee counts were lower than all other years, but 2001. Habitat and Habitat by Season nested in Year were the greatest sources of variation in transformed Index of manatee sightings. Within survey season, the dry show a decreasing trend, while the wet does not. The 2002 dry season survey is the reason for the results, and I think that the poor survey conditions may be more of a factor than actual manatee sightings. On the other hand, the very good survey conditions and high count in the 2002 wet season may have masked a declining overall trend.

When the tallies from all surveys are considered from 1979, there is an increasing trend in counts per survey. There are some differences in survey method and route between the earlier and later surveys, so this overall description is only to show a general picture. Firstly, only the 1994 (# 3 & 4 in Fig. 11) and 1995 (# 5) surveys include the Turneffe Atoll. Secondly, the 1989 (# 2) dry season survey did not cover then entire coastline, only Four Mile Lagoon and lower New River (which was not surveyed in any other survey), the lower Belize River, the coast and cays off Belize City, Southern Lagoon, and the Placentia Lagoon (O'Shea & Salisbury 1991). I used the IRA of total manatee numbers given total survey time to better compare surveys with different survey effort. The dry 1997 (# 7) and wet 2002 (# 17) surveys had greatest total IRA (Fig. 11). All surveys calculated numbers of manatees, but details on the times of particular surveys units to calculate unit IRA were not done for all and observations positions were not reported, therefore more detailed comparisons are difficult.

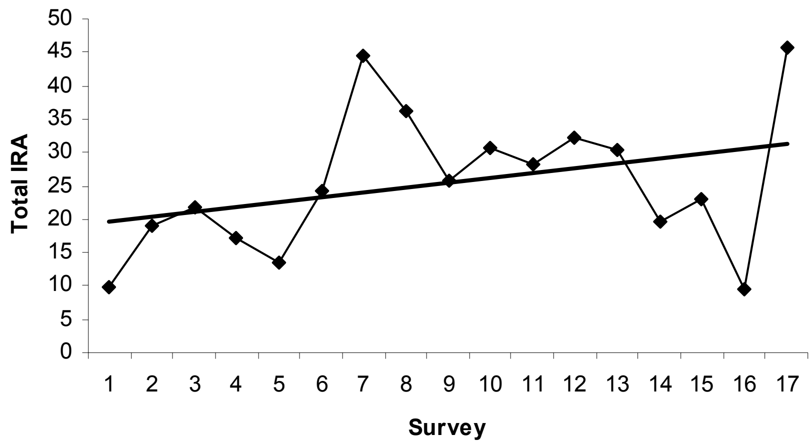


Figure 11. Trends in total IRA (total counts / total survey time) for all aerial surveys conducted in Belize. The solid line is a linear fit of IRA.

Based on these results, I recommend the following:

(1) Due to the difficulty in determining true trends, because of the seasonal and habitat variations and existing survey biases (Packard et al. 1985; Lefebvre et al. 1995), long term studies are recommended. As the countrywide or synoptic surveys are costly and do result in variable data, it would be optimal to conduct them every few years (4-5) to assess the overall population. Site specific surveys should then be conducted seasonally, on a more regular basis, where more time spent in an area can give larger sample size and improved manatee trend analysis. The surveys should be conducted along the same route, so that the

representation of habitat types does not change; consistency is important. These should only be conducted when environmental conditions are optimal (Packard 1985), with winds below 12 knots, on clear days with low cloud cover, and with experienced observers.

(2) Other variables contributing to variations in counts, such as survey conditions and observer difference, should be recorded and measured to estimate their influence on manatee sightings. Count indices should then be adjusted for these covariates (Garrott et al. 1995).

(3) The decrease in one season and not the other may indicate movement into and out of the study area. Wright et al. (2002) attributes similar seasonal difference in annual manatee trends, although their survey was site-specific. The uncertainty in trends emphasizes the need to explore an approach more consistent with analysis of metapopulations.

Seasonal Distribution of Manatees among Habitats

The interactive effects of season and year, on manatee observations related to habitat, were evident (Chapter III). Overall, the near-shore sites had higher probability of manatee observations than off-shore sites. Cumulatively, manatees were more likely to be observed in the wet season compared to the dry season. Examining specific habitat, the river showed greater likelihood of manatee presence in the dry season, while the cay habitat showed greater likelihood of manatee presence in the wet season. Interactive effects of season, habitat, and manatee presence are significant, as are first order effects.

While these effects prevent straightforward management application, it does suggest direction. I therefore, recommend the following:

(1) Manatees utilize the near-shore systems of lagoon and river; these should be considered primary manatee habitat. These systems also provide habitat for other important coastal species, including tarpon, grouper, and crocodiles, and are enclosed by littoral forests. I recommend that these areas are considered for priority concern.

(2) The spatially explicit model can incorporate additional environmental data, including a number of other habitat features yet unexplored. These can be used as covariates in analyzing manatee distribution trends. For instance, dugong surveys indicate variables that influence dugong presence, including habitat, season, and distance to deep water and their interactive effects (Preen 1992).

(3) Application of the spatial method of analysis, and using non-parametric tests tell the same story as we see using IRA, but with more confidence. I suggest using the presence / absence count date for each cell, which is assigned a spatial description for analysis.

(4) The resulting analysis should feed into the planning process for protecting the threatened manatee, and for zoning and managing coastal protected areas, linking the near-shore systems to the offshore ones. Sightings from distribution studies are useful because they reveal high use areas for protection (O'Shea & Ackerman 1995). Targets of success should be established, and could include reporting of increased manatee trends. Understanding the distribution of threatened species is

necessary to optimize the location of protected areas that can contribute to their conservation (Preen 1992:187).

(5) Water quality and vegetation surveys should be prioritized for the future. While the general analysis of temperature and salinity showed difference among seasons and habitat, sample sizes were not equal for each variable, and surveys were made in the south near-shore and north offshore. Increasing water quality monitoring sites to include the northern coast is necessary as the physiographic features in the north coast differ from the south. This expansion will also benefit overall monitoring of coastal processes. Vegetation coverage, composition and changes between seasons also need to be evaluated within the various coastal habitat systems. These are recommended as test variables to contribute to analysis of manatee distribution.

Integration of Population and Spatial Approaches

To fully realize plans for integrated coastal zone management, knowledge derived from population and spatial approaches would ideally be integrated in conceptual models of coastal systems. These serve the needs of focal species as well as a network of special areas within coastal reserve systems. From previous analyses (Gibson 1995, Morales-Vela et. al. 2000, Chapter II, Chapter III), the following conceptual model emerged to explain the separate and interactive effects of four factors potentially influencing the probability of manatee observations in grid cells (Table 5).

(1) Freshwater. The probability of manatee observations would be greater in the less saline areas (e.g. rivers, lagoons, and estuaries) due to manatees' need for fresh

water. This probability is likely to increase during the dry season due to changes in salinity. Since the south coast of Belize has five more rivers than the north coast, a higher probability of observing manatees in the south would be predicted based on this "Freshwater" hypothesis. However, variation between years also would be predicted, to the extent that rainfall directly influences pulses in freshwater flow from watersheds, hence indirectly influences spatial patterns of salinity.

(2) Turbidity. High water turbidity decreases the probability of manatee observations, and this is likely to vary with location, season and year. When turbidity is low in the dry season, the probability of manatee sightings should be relatively high, independent of location. According to this "Turbidity" hypothesis, a higher probability of manatee observations would be predicted in clearer offshore waters compared to coastal waters near the plume of sediments carried by rivers, independent of season. Predictions of interactive effects based on the "Turbidity" hypothesis may be tested by comparing the change in observations between seasons, for grid-cells classified as (a) within versus adjacent to estuaries, (b) northern versus southern coastline, and (c) near-shore versus offshore.

(3) Current Flow. Manatees may be carried out of rivers during pulses of high current due to heavy rainfall in upstream watersheds, or they may be pushed into the coast during offshore hurricanes. Based on this "Current Flow" hypothesis, the following predictions would be logical: (a) the probability of manatee

observations would increase in estuaries affected by high runoff from inland rainfall, (b) following periods of strong river currents, manatee observations would increase more in the southern coastline than the northern coastline where there are fewer rivers, and (c) during strong offshore winds, manatee distribution would shift from cays to coastline, with no difference between the northern and southern coastlines.

(4) Activity. Visibility of manatees varies with activity to the extent that manatees engaged in bottom-resting or feeding activity are less likely to be observed than those active near the surface of the water (e.g. mating, traveling in shallow water, milling, sunning). Activity may be influenced by the resources available at different sites (e.g. food, shelter from currents, transport by currents, freshwater sources) as well as seasonal changes in resource availability and physiology (e.g. reproduction). For example, if manatees are more reproductively active during the dry season, then the probability of observations would be predicted to increase in lagoons where some females have small calves and others are in a state of estrus, likely to attract males. Roving males may be more likely to be observed traveling along coastlines and chains of offshore islands as they move between female activity centers if there is a dry-season pulse in breeding activity.

Table 5. Conceptual model of predicted effects on probability of manatee observations in grid cells of coastal systems.

Effect	*Prediction of effect on probability of manatee observations, based on conceptual model*			
	"Freshwater" hypothesis	*"Turbidity" hypothesis*	*"Current Flow" hypothesis*	*"Activity" hypothesis*
1st Order				
year	inverse association with annual rainfall; manatees attracted to freshwater sources in dry years	inverse association with inland rainfall; manatees harder to see in wet years due to higher turbidity	positive association with river flow and hurricanes; manatees in more visible locations in years of high storm activity	more reproductive activity associated with an increasing annual trend in observations and/or emigration
season	more manatees observed in dry compared to wet season	manatees harder to see in wet season due to higher turbidity	stronger currents during the wet season is associated with higher probability of manatee observations	manatee observations more likely if there is a peak in reproductive activity in dry season
habitat	positive association with location of freshwater sources	negative association with location of freshwater sources that are more turbid	negative association with areas of strong current flow, e.g. estuaries, deep channels	positive association with areas of reproductive activity, e.g. lagoons, travel routes

continued

Table 5 (continued)

Effect	*Prediction of effect on probability of manatee observations, based on conceptual model*			
	"Freshwater" hypothesis	*"Turbidity" hypothesis*	*"Current Flow" hypothesis*	*"Activity" hypothesis*
2nd order				
year x season	difference between the wet and dry season depends on timing of rainfall in a given year	location of rainfall in a given year influences seasonal changes in turbidity due to surface runoff combined with coastal erosion	positive association with the frequency of storm events in a given year	positive association with dry season is more likely in years after high calf mortality (more females cycle)
year x habitat	in years of low rainfall, manatees more likely in freshwater locations	in years of high inland rainfall, manatees less likely sighted in estuarine locations with turbid water	in years with frequent storms, manatees shift to protected lagoons and coastline, away from cays and estuaries	quality of food resources in a given type of habitat may change among years
season x habitat	in dry season, manatees closer to rivers and other freshwater sources	in wet season, lower visibility in southern vs. northern coastline, inshore vs. offshore	in wet season, fewer manatees in areas of strong currents, e.g. estuaries, deep channels	in dry season, more manatees in locations of reproductive activity, eg. lagoons, cay bogues
3rd Order				
year x season x habitat	association of manatees with freshwater in the dry season is more likely in years of low rainfall	reduced visibility in areas of high turbidity is more likely in years of high rainfall and wave activity	reduced observations of manatees in areas with strong currents is more likely in years with frequent/severe storms	observation of reproductive activity in sheltered areas more likely in years of low rainfall and/or high storm activity

Education and Management

The purpose of the manatee research project is to provide decision makers and the public with the sound scientific information needed to prevent the decline of this charismatic species. In Belize and other countries, manatees have been used as a "flagship" symbol to raise public awareness of the need for protection of coastal systems.

The following themes need to be included in educational outreach related to coastal zone management in Belize. Improving population viability is the management goal for species at risk of extinction (Knight 1998). The declining trends in many marine mammal populations have been attributed to anthropogenic effects, particularly historical hunting and current incidental take (Read & Wade 1999). Threats to manatees in Belize are primarily human related. Legal restriction of hunting has probably prevented the extinction of manatees in Belize, but other anthropogenic threats have taken the forefront. In contrast to Belize, the trend in manatee counts over the last decade has been increasing in Florida, associated with the resources and effort allocated to conservation and monitoring activities (Read & Wade 1999).

It is recognized that the results from this thesis should reach the agency decision-makers as well as educators and the general public. The nature of manatee abundance and distribution trends is complex, and the message is therefore not a simple one. One take-home message is that the manatee population in Belize is not increasing; therefore protection measures will be continued. Realizing that it is beyond the scope of this thesis to make definitive statements on an education policy, based on my participatory experience over the last several years, I do recommend the following:

(1) Stakeholder perspectives relating to coastal species need to be better understood. This can be approached by using a method based on naturalistic inquiry (Lincoln & Guba 1985), where a model for information transfer is derived based on participants' perspectives.

(2) Additional information is needed on what has been the best method of delivering the desired information. While there have been many approaches for public awareness on manatees (e.g. news articles, class presentations, displays) there is no feedback on what has been effective. This includes levels from government agencies to school children.

(3) Increase community involvement by establishing data collection by coastal communities may be important to regain their interests.

Without specific management allocated to protect coastal systems in the Caribbean region, this charismatic flagship species may indeed be lost from the developing countries in the center of its range. Manatee management should be "cooperative, long-term, and vigilant" (Rinne & Stefferud 1999), to meet the goals of a single-species management approach. The species approach is used for particularly notable species that the public has embraced as a "flagship", or that are thought to be indicators of ecological effects, or a surrogate for other vulnerable species. The charismatic flagship species appeals to public sympathy (Simberloff 1998), and can open the door for broader information transfer on coastal systems and biodiversity management. This should include multi-species management.

There is evidence of seasonal variation in manatee movements among habitat types, and sightings were made in the northernmost and southernmost borders of the country. This pattern suggests that manatees may also move between national boundaries. If the population is not closed to emigration and immigration from adjacent habitat fragments, international projects would be very beneficial to better understand metapopulation dynamics. Although this would inevitably introduce management problems due to different legislations, priorities, and capacity among countries, the rewards will be greater. Forming links can lead to bilateral connections of reserves that will mean networks of protection. If Belize indeed has more manatees than its neighbors, these links will potentially allow greater movement and possibly repopulation, as suggested by O'Shea and Salisbury (1991).

Due to their wide range of habitat use, creating protected areas for manatee conservation will benefit other local fauna. Manatees utilize habitat where Cetaceans, the Central American otter (*Lutra annetans*), the American crocodile (*Crocodylus acutus*), Morlets crocodile (*C. moreleti*), and birds can be found. While trying to protect biodiversity, a larger scale system of protection is needed, which will simultaneously incorporate the needs of the parts, as well as the whole (Simberloff 1998). I am not suggesting that reserves be based solely on manatee use of habitat, but rather, available species data, such as that from manatees, should be used to aid in protected area designation. Information gaps are inevitable, particularly in Belize where relatively little research is conducted on coastal fauna; we therefore need to start where information exists for ecosystem management. Using a multi-species approach, more funding can be attracted to continue research on a larger scale. This increases the number of interested stakeholders of such research programs, and is therefore likely to continue for longer durations.

There are many protected areas in Belize, and the relevant agencies responsible for implementation are facing a public hesitant to establish more. This is also due to financial and managerial constraints. How do we confine species and ecosystem approach in designing regulations on broad-scale and system reserves? This can be done with boat-speed zones, limiting fishing nets and traps, and soliciting support of local communities in reporting of offences and of manatee casualties. The establishment of special management areas can also prove beneficial as regulations are established, which allow waters to remain open for sustainable use.

Ultimately, as Lindenmayer (2002) suggests, a variety of methods for manatee and ecosystem management may be most suitable, because even with their downfalls, each can accomplish certain goals. When the outline of objectives is made, the realistic atmosphere, be it financial, political, social, or human capacity usually direct research and conservation efforts, particularly in small countries. It is hoped that this research using both the species and habitat approach, can provide useful steps along the way.

Conclusions

(1) Based on aerial survey data from the last decade, there is no evidence that the manatee population in the coastal zone of Belize is increasing. However, high variation in aerial counts (adjusted for effort within survey units) made it difficult to distinguish whether the population was stable or declining. Since this

variation was more associated with season and habitat than with year, development of more explicit spatial approaches to analysis of aerial survey data is recommended for the Belize coastal zone. Continuation of standardized country-wide surveys every four to five years was justified based on results of this analysis. Site specific surveys are recommended in the dry and wet seasons each year.

(2) Spatially explicit analysis of aerial survey data within grid cells was effective for understanding the interactive effects of Year, Season and Habitat on the probability of manatee observations. Manatee distribution among habitats varied not only by season, but also the relative effect of season changed from year to year. This would be relevant to design of a reserve system, because the sites that might be important for manatees during the dry season may differ from the wet season. Furthermore, sites that offered protection one year might not attract manatees the next year.

(3) The spatially explicit analysis provided a sound scientific basis for a site-specific management approach. The hypothesis that manatee counts were solely influenced by seasonal freshwater availability was rejected. An alternative conceptual model explaining the interactive effects of freshwater, turbidity, current flow and behavioral activity was proposed.

(4) In the design of future monitoring efforts, spatial analysis of manatee sightings is recommended as more efficient and effective than analysis based on units of the survey route. Specific recommendations for procedures to enhance the quality of

data collected during aerial surveys were outlined to streamline this spatially explicit basis for analysis of manatee sightings.

(5) The potential linkages for manatees moving among activity centers within the Belize coastal zone system of protected areas should be further examined, as well as potential emigration to and immigration from habitat fragments in adjacent countries. This broader perspective could provide the basis for international cooperation in meta-population management.

(6) An integrated approach to data collection for several focal species was recommended to implement the goal of integrated coastal zone management for the Belize Barrier Reef system. The approach demonstrated for manatees, in this thesis, could be extended to other focal species within the coastal system, e.g. sea turtles and crocodiles. Geographic Information Systems could provide useful tools for integration of such knowledge in future efforts to monitor and protect biodiversity in coastal systems.

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