4-1-2015

Seasonal Warm-Water Refuge and Sanctuary Usage by the Florida Manatee (Trichechus manatus latirostris) in Kings Bay, Citrus County, Florida

Danielle C. Sattelberger
Nova Southeastern University, ds1715@nova.edu

NOVA SOUTHEASTERN UNIVERSITY OCEANOGRAPHIC CENTER

SEASONAL WARM-WATER REFUGE AND SANCTUARY USAGE BY THE FLORIDA MANATEE (*Trichechus manatus latirostris*) IN KINGS BAY, CITRUS COUNTY, FLORIDA

By

Danielle C. Sattelberger

Submitted to the Faculty of
Nova Southeastern University Oceanographic Center
in partial fulfillment of the requirements for
the degree of Master of Science with a specialty in:

Marine Biology/Coastal Zone Management

Nova Southeastern University

April 2015

Thesis of
Danielle Sattelberger

Submitted in Partial Fulfillment of the Requirements for the Degree of

Masters of Science:

Marine Biology/
Coastal Zone Management

Nova Southeastern University
Oceanographic Center

April 2015

Approved:

Thesis Committee

Major Professor :________________________________
Curtis M. Burney, Ph.D.

Committee Member :_____________________________
Patrick Hardigan, Ph.D.

Committee Member :_____________________________
Richard Flamm, Ph.D.

ACKNOWLEDGEMENTS

I thank my committee members for their valuable insight throughout the duration of my thesis project. Dr. Richard Flamm at the Florida Fish and Wildlife Conservation Commission (FWC) – Fish and Wildlife Research Institute was very helpful providing information regarding manatees and aerial survey detection and analysis. Dr. Patrick Hardigan supplied constructive comments for statistical analyses. I thank Dr. Curtis Burney who graciously stepped in to lead my committee. Special thanks to Joyce Kleen at the United States Fish and Wildlife Service (USFWS) – Crystal River National Wildlife Refuge for providing the 30 years of aerial survey data to be analyzed; additional thanks to Amber Breland at USFWS as well. I would also like to acknowledge FWC biologist Aarin-Conrad Allen who assisted with data analysis and provided further insight on manatees and GIS technical support for this project. Lastly, and most importantly, I thank the late Dr. Edward O. Keith. Dr. Keith was immensely supportive of my desire to study marine mammals at Nova Southeastern University and further instilled my passion for these animals.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Seasonal Warm-Water Refuge and Sanctuary Usage by the Florida Manatee (*Trichechus manatus latirostris*) **in Kings Bay, Citrus County, Florida**

Abstract

The largest Florida manatee (*Trichechus manatus latirostris*) aggregation at a natural warm-water refuge occurs in Kings Bay, Crystal River, FL. Over the last 32 years, the U.S. Fish and Wildlife Service and the State of Florida have created a network of manatee protection areas within Kings Bay including a year-round refuge designation and seven Federal manatee sanctuaries during the winter manatee season (November 15 – March 31). Aerial survey data collected between 1983 and 2012 was used to examine the seasonal change in manatee distribution within Kings Bay in order to assess the effectiveness of current sanctuary sizes and locations. Regression analysis indicated a significant change in manatee abundance among the winter seasons ($p < 0.05$). The average winter manatee counts increased by 4.81 animals per year over the 30 year period. In contrast, no significant changes in average or peak manatee abundance was detected among the summer seasons ($p = 0.71$ and $p = 0.45$ respectively). The average manatee counts increased by only 0.109 animals per year over the summer periods. Spatially explicit models using Geographic Information System (GIS) analysis revealed a strong correlation between high manatee density and artesian springs during the winter seasons. Highest abundances were identified at three locations: King's Spring, Three Sisters Springs, and Magnolia Springs. These three locations coincide well with pre-existing sanctuary designations, but additional coverage is needed to support the overflow of manatees outside of sanctuary boundaries. Manatees continued to use Kings Bay in the summer seasons but in lower numbers and densities. Because density patterns were not uniform across summer periods, a heavier reliance on boat speed regulation is recommended to provide adequate protection to the endangered Florida manatee. Within a habitat type, the Magnolia Springs, South Banana Island, and Three Sisters Springs sanctuaries exhibited a significant influence on manatee density, suggesting differences in quality among sanctuaries. Years coinciding with extreme cold weather events also had a significant influence on manatee density. Using GIS to investigate seasonal shifts in manatees can be very informative regarding many issues including habitat selection and may improve the design and management of protected areas.

Key Words: Florida manatee, *Trichechus manatus latirostris*, Kings Bay, Citrus County, springs, aerial surveys, sanctuaries, kernel density analysis, conservation, management

INTRODUCTION

The Florida Manatee

Florida manatees (*Trichechus manatus latirostris*) are large (2.7 – 3.5 m long, 400 – 550 kg), slow moving marine mammals that inhabit the shallow coastal bays and estuaries throughout the state of Florida. They can be found in salt, fresh or brackish waters along the Atlantic Ocean and Gulf of Mexico (Irvine and Campbell 1978). Strictly herbivorous, the Florida manatee consumes 4 - 9% (Bengtson 1983; Etheridge *et al.* 1985) to 10 – 15% (Reep and Bonde 2006) of its body weight in a day, feeding on a wide variety of aquatic plants, marine seagrasses, and algae (Hartman 1979; Bengtson 1981, 1983; Best 1981; Etheridge *et al.* 1985; Ledder 1986, Hurst and Beck 1988). Like other K- selected species, Florida manatees mature in 3 to 7 years of age, give birth after a long gestation period of twelve to thirteen months, and have a low reproductive rate with one calf every three years (Marmontel 1995; Odell *et al.* 1995; O'Shea and Hartley 1995; Rathbun *et al.* 1995; Reid *et al.* 1995; Anderson 2002). Species with this type of life-history strategy must have high and stable adult survival rates in order to persist (MacArthur and Wilson 1967; O'Shea and Hartley 1995; O'Shea and Langtimm 1995; Langtimm *et al.* 1998). Unfortunately, the effects of natural and human-related mortalities, prominently caused by harmful algal blooms (HABs), cold stress, and watercraft strikes, continue to jeopardize the long-term existence of the endangered Florida manatee population.

Recreational activities have been encouraged in recent decades as a way of connecting humans with the natural environment and supporting local businesses. The number of registered vessels in Florida has steadily increased over the past 30 years

(FWC, unpublished data). In 2010, Florida lead the nation in number of registered vessels. Today, Florida manatees share the waterways with roughly 1 million Florida registered boats and watercraft. Florida's more than 11,000 miles of waterway attract numerous out-of state boaters and visitors for fishing and other recreational activities. It is estimated that approximately 1 million additional non-registered boats actively use Florida's waterways (FWC 2010). Not surprisingly, boating ranked number one in Florida with an economic value of $10.3 billion in 2012 (National Marine Manufacturers Association 2013). Many manatees in Florida waters bears scars on their body from collisions with boats (O'Shea 1995). According to the United States Geological Survey (USGS) manatee photo-identification database project (MIPS), by the year 2000, more than 1,000 manatees had unique scar patterns from boat collisions with 97% of those animals displaying scars from multiple boat strikes (Beck and Reid 1995; O'Shea *et al.* 2001).

Fishing, both commercially and recreationally, is an important economic resource in Florida. In fact, Florida is self-proclaimed as the 'fishing capital of the world'. With its expansive coastal environment, Florida offers vast opportunities and resources for recreational fishing. According to the Florida Fish and Wildlife Conservation Commission (FWC), over $25 million of revenue was generated from saltwater licenses in FY2011-2012 (FWC 2011a). Freshwater licenses generated over $9 million (FWC 2013a). Although fishing is a popular activity among people in the state of Florida, it greatly impacts manatees as well. Occasionally, manatees become entangled in discarded monofilament fishing lines and crab traps. Entanglement can have severe detrimental effects on the manatee as it can lead to amputation of limbs and increase the risk of drowning (Lefebvre *et al.* 1989; Beck and Barros 1991; Guillory *et al.* 2001). A potential threat to the manatee is ingestion of these items or other trash embedded in the seagrass beds they consume (Buergelt *et al.* 1984; Smith 1993). Ingesting such items can create blockages in the manatees' digestive tract, causing a slow, agonizing death.

Managing collision risk in waterways and protection of seagrass beds is crucial for the manatees' survival. One important means for protecting manatees is to minimize detrimental effects to their environment caused by anthropogenic impacts. However, manatees inhabit one of the fastest-growing states in the United States. Almost 20 million people reside in the state of Florida, representing roughly 6% of the country's entire population (U.S. Census Bureau 2014). According to the U.S. Census Bureau, over 1,000 people move to the state of Florida each day. Of those people, a majority resides close to or on the water. Due to this influx, endangered species like the manatee may face the challenge of finding safe places to inhabit and may have difficulty accessing the resources they need to survive. To support such a growing human population, actions need to be taken to reduce the stress placed on the remaining suitable habitat within the state of Florida.

Reliance on Warm-Water Refugia

Manatees in Florida are at the northernmost habitat range of any species in the Family Trichechidae (Irvine 1983; Lefebvre *et al.* 2001; Allen 2013). These animals have a seasonal thermoregulatory requirement that is not faced by other Trichechids. The high thermal conductance and extremely low metabolic rate of manatees limit their ability to thermoregulate in cold waters (Irvine 1983; Bossart 1999; FWC 2007; Halvorsen and Keith 2008). Long-term exposure to water temperatures below 20 degrees Celsius may result in hypothermia, frostbite, pneumonia, or a combination of all these factors (Laist and Reynolds 2005a, 2005b; Allen 2013). Consequently, manatees may develop cold stress syndrome (CSS), a chronic and acute cause of death in manatees which can also lead to immune suppression (O'Shea *et al.* 1985; Bossart *et al.* 2003; Walsh *et al.* 2005). Mortalities due to cold stress syndrome have had a significant impact on the manatee population (O'Shea *et al.* 1985; Ackerman *et al.* 1995; Laist and Reynolds 2005a, 2005b). Since 1974, the Florida Fish and Wildlife Conservation Commission has collected statistics on the causes of death in manatees. In the winters of 2009 and 2010, Florida experienced unusually cold temperatures that included record lows on several occasions. During this spell, 282 manatees perished due to cold stress syndrome and an additional 275 died of unidentified or undetermined causes (FWC – manatee mortality statistics). It is possible that several of these deaths attributed to unidentified or undetermined causes could have also been cold stress related. From January to April, 2010, 503 manatee carcasses were collected (FWC, unpublished data). Again, a majority of these mortalities were attributed to cold stress. This number surpassed previously recorded mortality rates from preceding years in only four months. As a result of their dependence on warm water, a seasonal migration occurs by Florida manatees (Shane 1983b; O'Shea and Kochman 1990; Reid *et al.* 1991; Deutsch *et al.* 1998). Animals seek thermal refuge in artificial sources like power plant discharge canals (Shane 1983a, 1984; Reynolds and Wilcox 1985, 1986, 1987, 1994; Laist and Reynolds 2005a, 2005b) or natural warm-water springs (Bengtson 1981; Shane 1983b; Reid *et al.* 1991; Laist and Reynolds 2005a, 2005b; Allen 2013). Many manatees exhibit site fidelity, utilizing the same warm-water sources annually (Shane 1983; Reid *et al.* 1991; Deutsch *et al.* 2003).

Calves often follow the same migration routes after weaning (Marmontel 1995).

With more than 700 freshwater springs, Florida provides warm-water refuges for species like the manatee. These natural springs, where water temperatures remain at a constant ≥ 20°- 22°C year round, allow manatees to thermoregulate during the colder months (Laist and Reynolds 2005a, 2005b; Allen 2013; Kleen and Breland 2014). Manatees occasionally appear in the springs earlier with the arrival of an early winter and may remain there longer following severe or extended winters (Reep and Bonde 2006). Nevertheless, these springs are utilized by both humans and manatees. Humans utilize the water for several purposes including water sports, drinking, lawn watering, and even manufacturing bottled water, while manatees use this resource for life-saving warmth during the colder months (Moore 1951; Samek 2004; Florida Department of Environmental Protection 2012; Flamm *et al.* 2013). Currently, these springs remain vulnerable due to human usage. Land use decisions have had the greatest direct impact on the springs' health (Samek 2004).

Study Site

With many of the power plants in Florida reaching or approaching retirement as well as many of the older plants likely to close due to increasing industrial competition, rising fuel costs, government regulations, and more efficient technology for generating electricity, it now appears that the best option for sustainable winter habitats for Florida manatees are natural warm-water springs (Laist and Reynolds 2005a, 2005b). Among these natural warm-water springs is Kings Bay, Crystal River located in Citrus County, Florida (Fig. 1). The natural springs and adjacent forage areas of Kings Bay have historically provided manatees with warmth and sustenance (USFWS 2011, unpublished report). During the winter months, Kings Bay is a designated manatee refuge. For this reason, waterborne activities are limited and slow speed zones are put into effect in order to accommodate large numbers of manatees. The aggregation of manatees at Kings Bay is one of the most studied in the world (Hartman 1971, 1979; Powell 1981; Kochman *et al.* 1985). Eventually, these areas will reach carrying capacities; therefore, a better understanding of how resources are being utilized can potentially aid in measuring how many manatees can be sustained within Kings Bay.

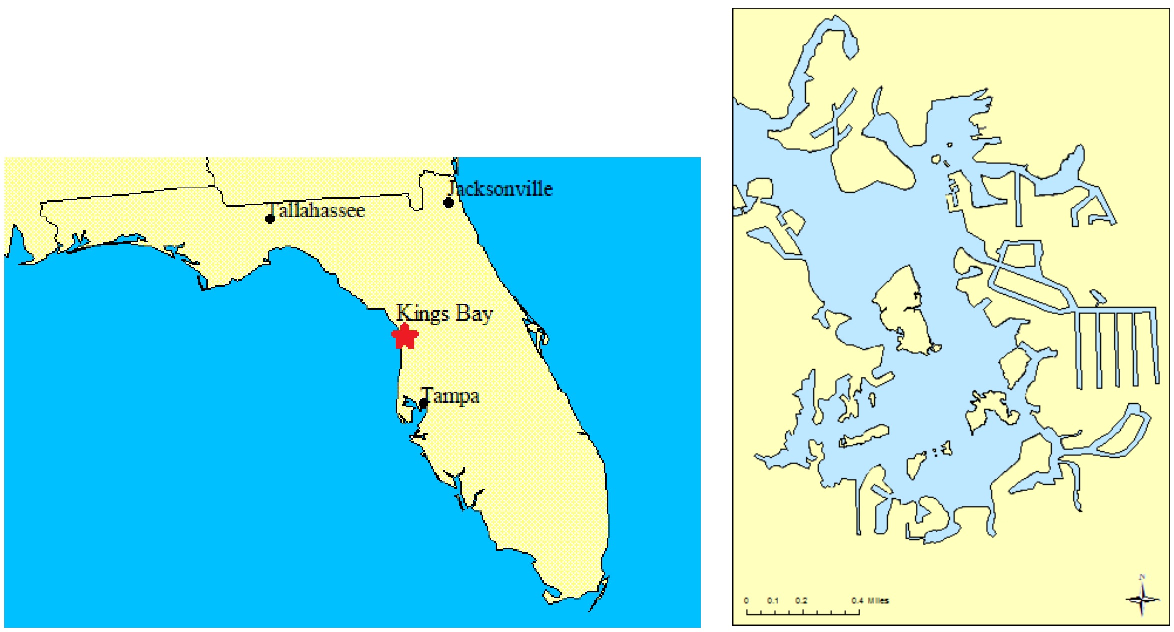

Figure 1. Map of Kings Bay located within Crystal River, Citrus County, FL.

Crystal River, Florida is home to 3,062 people (U.S. Census Bureau 2013). It is also where the Crystal River National Wildlife Refuge is located, an area set aside under the National Parks Service specifically for manatees. The area is very popular for fishing, boating, and other recreation (Buckingham 1990). On a global scale, human visitation to national parks and other protected areas like Crystal River is increasing (Blumstein and

Fernandez-Juricic 2010). The animals living there face consequences from this magnitude of visitation. Human interaction is a form of harassment, and the welfare of manatees being adversely affected by waterborne activities is of growing concern (Buckingham 1990; Sorice *et al.* 2003).

In 1983, the United States Fish and Wildlife - Crystal River National Wildlife Refuge (CRNWR) was established in Kings Bay (28°52'54"N, 82°35'41W), the headwaters of Crystal River, to protect the critical habitat that manatees migrate to each winter. The Refuge currently manages 40 acres of manatee sanctuaries within the spring-fed waters of Kings Bay. The primary spring within the wildlife refuge is King's Spring. Over the years, the population of manatees wintering in Crystal River has increased (Powell 1981; Kleen and Breland 2014), reaching 548 individuals in Kings Bay in 2015, making it the largest winter aggregation of manatees at a natural warm-water source. This number is included in the record breaking 797 manatees counted in all of Citrus County in 2015 (USFWS 2015, unpublished data). Heavy boat traffic and the danger of manatee-boat collisions have resulted in no-entry zone sanctuaries and seasonal and year-round slow and idle speed zones being adopted. To collect abundance data each year, a consortium of organizations headed by the Florida Fish and Wildlife Conservation Commission conducts aerial surveys during the winter months. In addition, aerial surveys are conducted throughout the year as a part of the U.S. Fish and Wildlife Service (USFWS) Florida Manatee Recovery Plan (USFWS 2001). Biologists at the CRNWR have conducted both weekly and monthly surveys over Kings Bay in Crystal River since 1983.

Manatee protection areas within Kings Bay have been designated over the last 32 years by the USFWS and the State of Florida to allow manatees continued access to critical warm-water areas and important foraging and resting areas. During the winter manatee season (November 15 – March 31), this network includes State protection zones and seven Federal manatee sanctuaries. U.S. Fish and Wildlife Service, State, and local law enforcement officers are responsible for enforcing manatee protection areas. Manatees within King Bays are protected under three levels: the Crystal River National Wildlife Refuge created by an act of Congress to protect the West Indian manatee; the Kings Bay Manatee Refuge created by the U.S. Fish and Wildlife Service where some activities in the water may be restricted to prevent the taking (by harm or harassment) of one or more manatees; and seven Manatee Sanctuaries, federally designated areas which restrict all activities, including human entry, during the winter months. The State protection zones include slow speed zones and a year-round idle speed zone that prevent the take of manatees from high speed watercraft collisions as well as a maximum 25 mph sports zone in the summer (June 1 through August 15) (USFWS 2010).

Manatee Refuge and Sanctuary Application

Crystal River is the only area in the United States to allow tourists to swim with manatees. The tourist draw is a significant economic boost for the City of Crystal River. Each year, over 100,000 people come to the springs to have their own unique and personal encounter with these large, docile animals (USFWS, unpublished data). The swim-with-manatee tours in Crystal River do have their positive facets when performed safely and correctly. Humans are able to experience firsthand what wonderful creatures they are. They can witness up-close the scars that manatees bear from watercraft strikes and better understand their need for protection. They may also be the first to notice any injuries or behavioral changes with manatees that may require attention or rescuing (e.g., entanglements, cold stress, etc.) (Allen *et al*. 2014). However, with the growing popularity of manatee encounters comes increased concern for the well-being of manatees against the potential negative impacts resulting from harassment. Presently, manatee tour operators and the in-water interactions proceed with little regulation. Because of this, manatees face harassment from swimmers who poke, prod, kick, and step on them, as not all visitors exhibit safe and proper interactive skills. Resting manatees that visit the springs to seek warmth and conserve energy are often affected by swimmers. Furthermore, people get caught up in the interactions and often chase manatees out of the warm springs which could be hazardous to the animals' health and leave them susceptible to cold stress. This is especially detrimental to the young calves of mother manatees. Mother manatees frequently rest and nurse their calves inside the springs. Calves are dependent on their mothers, and if separated, a fatal situation for the calf can arise.

As stated in the Florida Manatee Sanctuary Act of 1978, the term "manatee sanctuary" is defined as "an area in which the Florida Fish and Wildlife Conservation Commission (FWC) has determined that any waterborne activity would result in a taking of one or more manatees, including but not limited to a taking by harassment". The term "manatee refuge" is defined as "an area in which the Commission has determined that certain waterborne activity would result in the taking of one or more manatees, or that certain waterborne activity must be restricted to prevent the taking of one or more manatees, including but not limited to a taking by harassment" (USFWS 2010; FWC 2011b). Certain standards are utilized by FWC to determine whether restrictions are necessary to protect manatees or their habitats. In order to determine whether restrictions are necessary in areas of regular or periodic manatee use, several factors are considered by the Commission, including but not limited to the number of manatees and seasonal and/or year-round patterns of manatee use. Sanctuaries have been established at manatee high-use sites such as Crystal River in areas that manatees were already using (or trying to use) to give them a place to rest and thermoregulate undisturbed.

The numbers of both visitors and manatees in Kings Bay have increased since the last sanctuary designation in 1998 (USFWS 2010, unpublished report). Researchers have also recently observed sanctuaries filled to capacity with wintering manatees, forcing dozens of manatees outside the boundaries of the seven existing Kings Bay sanctuaries (USFWS 2010). With manatee habitat often coinciding with recreational areas, manatee conservation zones that effectively provide refuge and preserve critical habitat may be crucial to the long-term survivability of the species.

King and Heinen (2004) examined behavioral patterns of manatees in and around Crystal River National Wildlife Refuge in the presence of recreational swimmers and boaters. The relative risks of human–manatee interactions, the frequency of harassment of manatees by swimmers, and the use of protected sanctuaries by manatees were also recorded. The authors found that as the number of swimmers and boaters increased, and when water temperatures were lower in surrounding areas, manatee use of protected (no-entry) sanctuaries was significantly greater in comparison to when swimmers were absent. An increase in the number of swimmers furthermore influenced a decrease in bottom resting and nursing and an increase in milling and swimming by manatees. King and Heinen (2004) emphasize the importance of no-entry sanctuaries for the conservation of manatees in the area and propose expanding the sanctuary network.

Objectives

Objectives of this study are to:

1) Identify seasonal patterns in habitat use by manatees throughout Kings Bay;

a) determine if these locations are in sanctuaries/refuges;

b) identify new locations that could potentially be designated as sanctuaries/refuges;

c) document sanctuaries/refuges that manatees less frequently use or where usage has declined over time;

2) Estimate the rate of change in the annual population of King Bay's manatee population from 1983-2012.

Hypotheses

Objectives call for testing the following null hypotheses:

1) The densities of wintering manatees is equal among the seven pre-existing sanctuaries.
2) The winter and summer manatee populations occupying Kings Bay remain equal over time.

METHODS

Aerial Survey Data

A primary approach to assessing population trends in manatees is the use of aerial surveys (Ackerman 1995). Aerial surveys are a crucial component in the management of threatened or endangered species (Edwards *et al.* 1997). Since 1967, aerial surveys have been used to gather information on the distribution and trends in abundance of the endangered Florida manatee (Hartman 1979; Packard *et al.* 1985, 1986; Lefebvre and Kochman 1991; Garrott *et al.* 1994, 1995). Crystal River National Wildlife Refuge staff have conducted aerial surveys since 1983 when the refuge was established for the protection of the West Indian manatee. Unlike many marine mammals, manatees often inhabit narrow, irregularly shaped bodies of water that are difficult to survey when using standard methods like line transects (Calambokidis and Barlow 2004). Aerial surveys have been useful in obtaining minimum population counts in small areas like winter manatee aggregation sites (Shane 1984; Packard *et al.* 1989; Garrott *et al.* 1994, 1995; Reynolds and Wilcox 1994; Ackerman 1995). Environmental conditions and the behavior of the manatees influence the number detected and counted during aerial surveys (Wright *et al.* 2002).

Aerial survey data analyzed in this study was provided by the U.S. Fish and Wildlife Service - Crystal River National Wildlife Refuge headquarters in Crystal River, Florida under Permit No. 13005. The aerial survey methods used to collect this data are described by Kleen and Breland (2014). Aerial surveys were conducted weekly or biweekly year round using a Cessna 172 traveling at 80 knots at an altitude of 304 m. Manatee locations were plotted by an experienced observer with the count of animals at each location, yielding a minimum count for the area. Photographs were taken and later reviewed to verify the counts where high numbers of manatees occurred.

Spatial Analysis

A Geographic Information System (GIS) provides an opportunity to quantify and detect spatial patterns in broad scale (Robbins 1997) and delivers a method for analyzing spatial shifts by integrating multiple layers of habitat data into a framework (Hooge *et al.*

2001). Meigs-Friend (2003) utilized GIS to examine manatee winter distribution from aerial survey data collected between 1997 and 2002 in order to suggest speed zone and sanctuary implementations within Kings Bay. However, this method has never been extensively applied to manatee aerial survey data conducted during both the summer and winter months within Kings Bay since the refuge was first established there in 1983. By examining the seasonal spatial and temporal trends of manatees in Kings Bay, the information provided by this study will aid in management decisions and will provide evidence as to whether existing manatee sanctuaries are adequate or if there is a need for protection in other locations at this natural warm-water spring system.

All GIS techniques utilized in this study were performed using GIS software ArcInfo version 10.2.2. Manatee locations within Kings Bay, Crystal River as noted by jpg files and GPS locations were exported as point shape files into the GIS database. Each shape file was projected in Albers Conical Equal Area (Florida Geographic Data Library). In total, 711 surveys containing 18,793 points between the years 1983 and 2012 were mapped. Each point signifies the number of manatees in a given location of close proximity. A group of manatees within the same area was considered as a single sighting (point) if the animals were less than 50m apart. Group sizes of manatees ranged from 1 – 212 manatees. The survey data was then merged and organized into two periods: winter (November 15 – March 31) and summer (April 1 – November 14) to reflect season shifts. These seasonal designations were used to create new layers containing data specific to each year an aerial survey was conducted. Environmental and biological data associated with each survey were also included as attributes (i.e., date, time, water temperature, air temperature, tide, water clarity, mating, number of adults, and number of calves). Along with the survey data point shape files, shape files of the seven existing manatee sanctuaries and major springs in Kings Bay were also projected onto the base map to better visualize the utilization of these areas by manatees (Fig. 2). Using the Spatial Analyst extension, kernel density analysis was then performed to generate a surface representing areas of high manatee use for each season per year. In addition, kernel density analyses were generated for layers depicting all winters and summers between 1983 and 2012. The kernel density tool creates a “kernel” or probability density over each point (Seaman and Powell 1996) to transform each sighting into a smoothly tapered surface with the highest density value in the cell where the sighting occurred and a diminishing density with increasing distance from the point (FWC 2013b). Areas of high and low density are depicted by color intensity (dark red to dark green respectively). An output cell size of 2 and a search radius of 120 square meters were applied to all analyses to generate density estimates for each survey point. Manatee density is reported in square meters. An analysis mask representing only the waters surveyed was included in the Environment settings. Existing and future manatee sanctuaries will be reported as appropriate in areas shown to be occupied by a high to medium abundance of manatees with continued seasonal use and areas with high rates of increase.

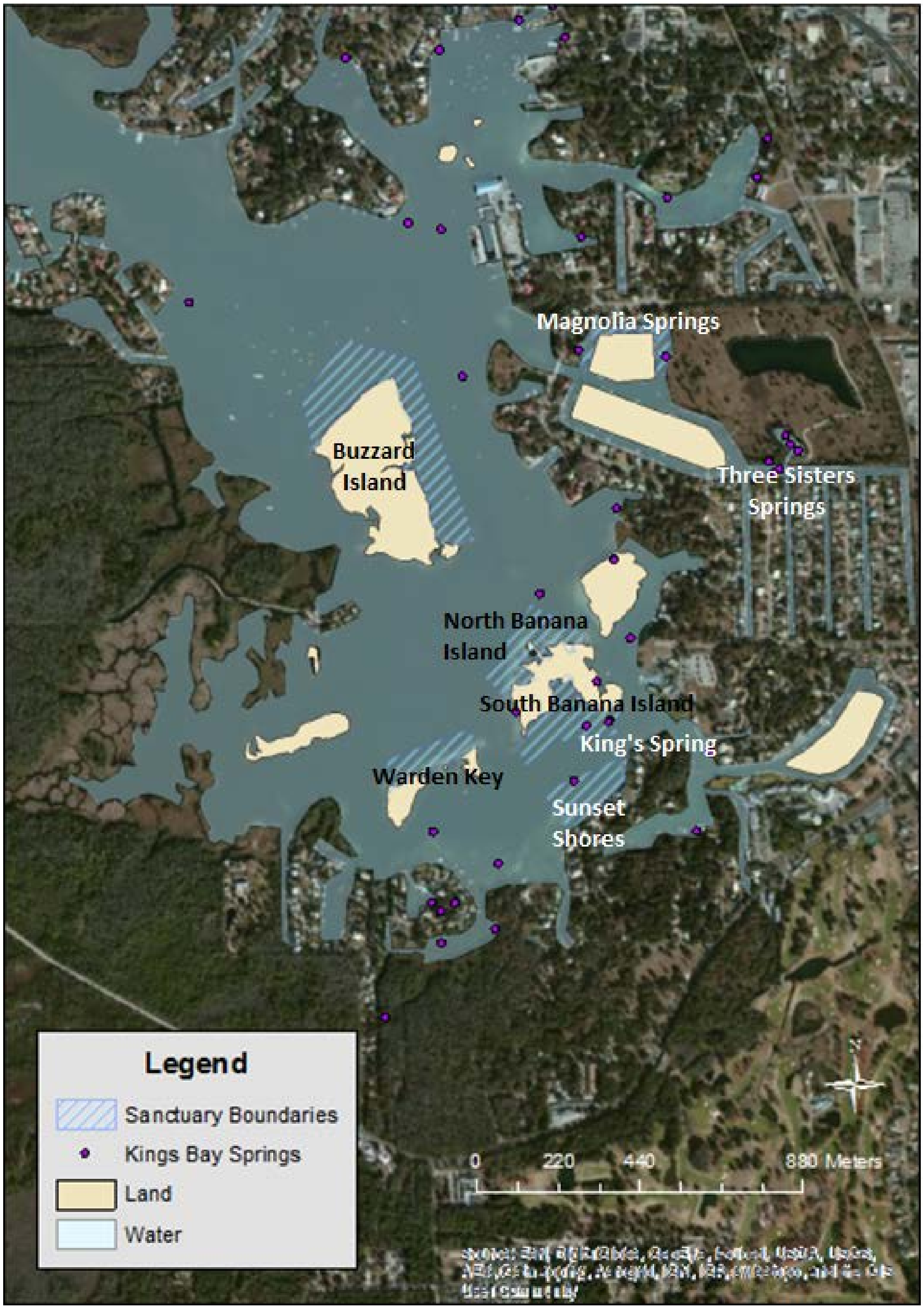

Figure 2. Locations of the seven pre-existing manatee sanctuaries and major springs located within Kings Bay.

Statistical Analysis

For purposes of analyzing and summarizing data, aerial survey data collected between 1983 and 2012 was first systematized in Microsoft Excel by season. Because manatee use of Kings Bay varies significantly by season, data were analyzed using a cold (winter) season and warm (summer) season. Winter data consisted of surveys flown between the dates of November 15 and March 31. Summer data consisted of surveys flown between April 1 and November 14. With this data, average manatee counts were calculated for each winter and summer season. The peak count for each season was also calculated to compare maximum observed counts across time. Regression analysis was used to assess changes in trends over time. The rate of change in the annual population of manatees occupying Kings Bay during both the winter and summer seasons was calculated by averaging the percent change (difference in the total number of manatees between the previous and subsequent year divided by the total number of manatees of the previous year) of succeeding years between 1983 and 2012. In addition, data for the seven winter sanctuaries were pooled to test the hypotheses that there were no significant differences in manatee density among sanctuaries and year through a generalized linear model (GLM) with a Poisson distribution including an overdispersion parameter. The Poisson distribution is the most commonly used discrete distribution for modeling count data (McCullagh and Nelder 1989). All statistical analyses were performed using JMP version 12.0.0.

RESULTS

Spatial Analysis

Manatee density distribution as assessed by kernel density analysis is illustrated in

Figures 3 and 5. These maps illustrate a broad distribution in summer and a more focused distribution in winter. Data produced different density scales for the winter and summer seasons. The red area (high density) represents 0.53 – 0.58 manatees per sq. meter in the winter and 0.025 – 0.027 manatees per sq. meter in the summer. Manatees were found throughout all of Kings Bay during the winter months, however, manatees were most densely clustered at three locations: King's Spring, Three Sisters Springs, and Magnolia Springs. These three locations overlap well with pre-existing sanctuaries, however, the waters situated between South Banana Island and Sunset Shores support a very dense cluster of manatees surrounding King's Spring that does not lie within sanctuary boundaries. The largest and densest aggregations (0.53 – 0.58 manatees per sq. meter) occurred at King's Spring, the largest source of warm water within the bay (Buckingham 1990). The remaining three sanctuaries, North Banana Island, Warden Key, and Buzzard Island, did not support such high densities of manatees as compared to the other four mentioned. The areas occupied by high densities of manatees display a consistent pattern of winter use across the 30 year timespan (Fig. 4).

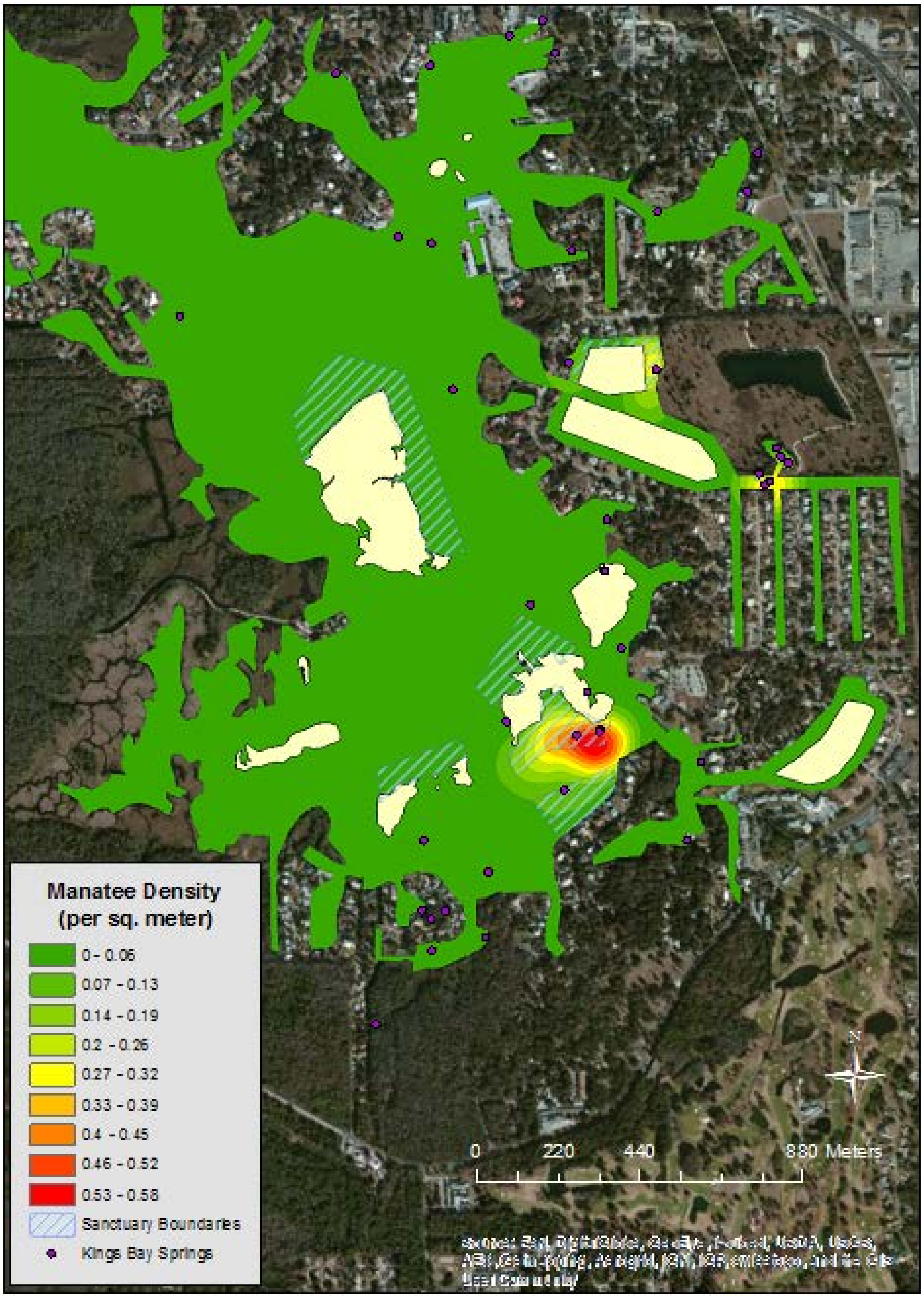

Figure 3. Kernel density map showing relative densities of manatee group sightings in Kings Bay during winter surveys from 1983 – 2012.

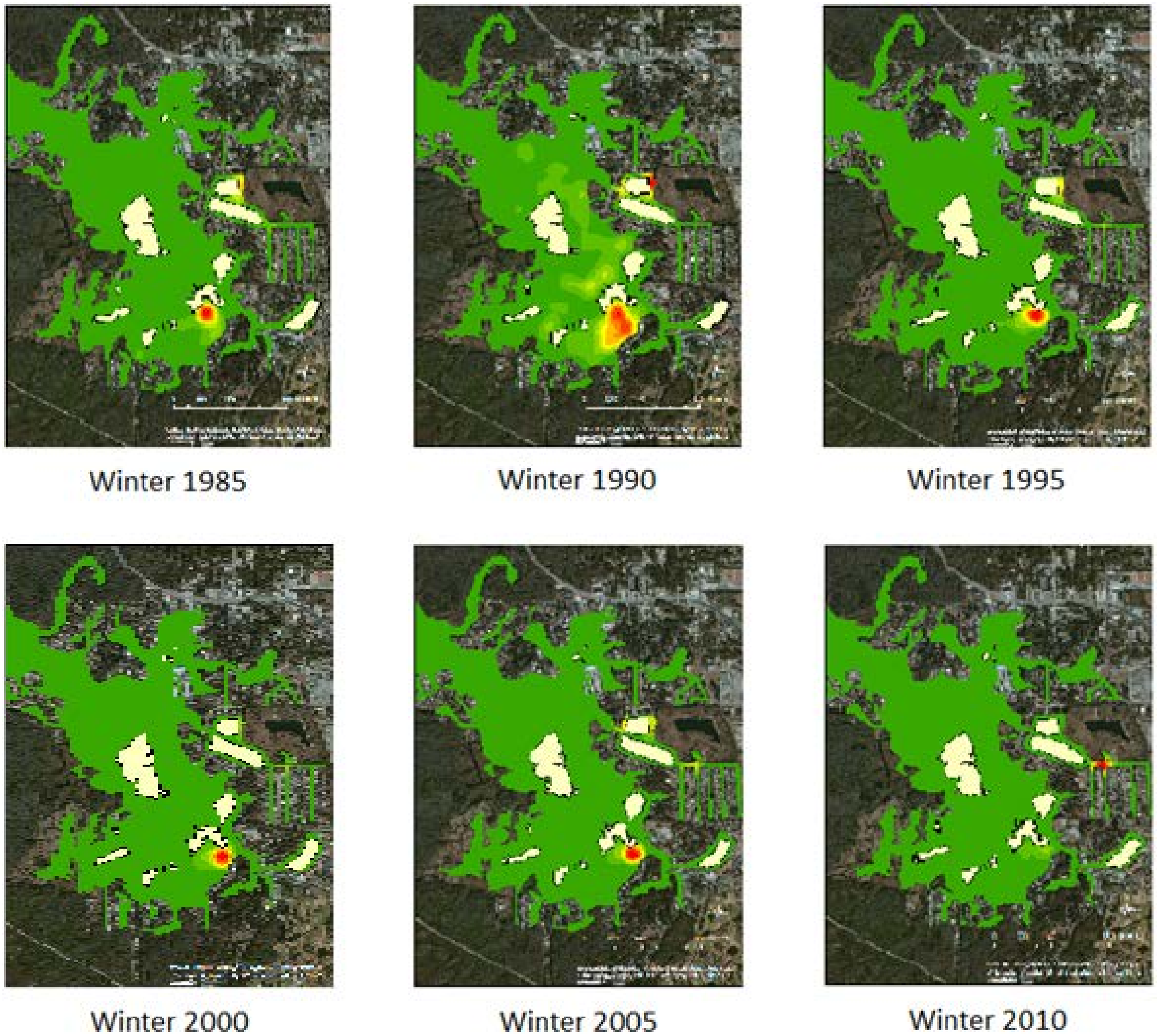

Figure 4. Examples of kernel density maps showing the relative densities of manatee group sightings in Kings Bay during winter periods over time. All maps display a generally uniform seasonal pattern over the 30 year period, with high densities at the South Banana Island, Magnolia Springs, and Three Sisters Springs sanctuaries.

A dramatic shift in distribution was observed during the summer months. Manatees were widely distributed throughout Kings Bay, yet a dense concentration of manatees (0.025 – 0.027 manatees per sq. meter) occupied King’s Spring, similar to observations made during the winter months. However, the summer densities were much lower than in winter. A dense cluster (0.016 – 0.018 manatees per sq. meter) was also detected just northwest of Parker Island, closely situated next to the Parker Island North Spring complex. Scattered throughout the rest of the bay, density values ranged from 0 – 0.015 manatees per sq. meter. Though, when analyzing each season individually, the densities and distributions varied greatly and did not display regular seasonal patterns (Fig. 6). This shows that manatees ranged far beyond the high density areas depicted in the kernel density analysis of all summers from 1983 to 2012.

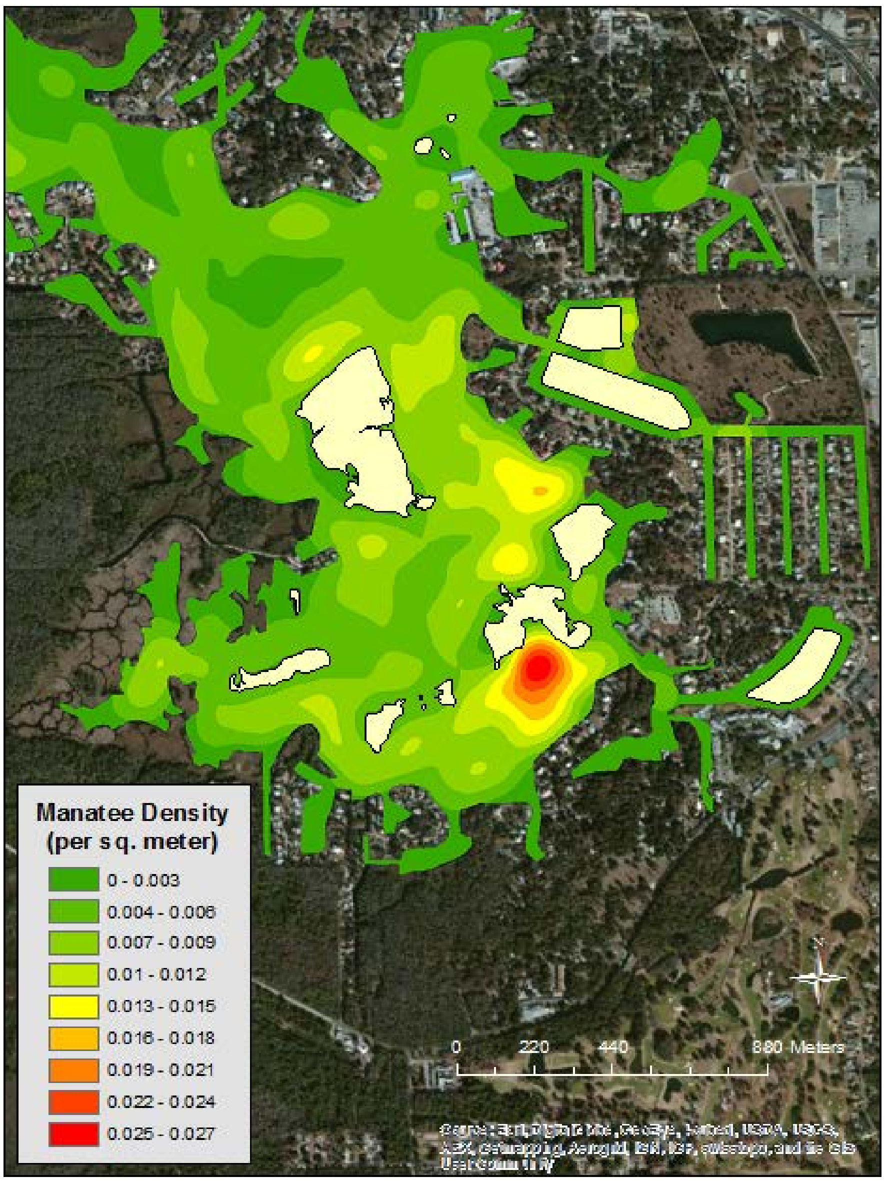

Figure 5. Kernel density map showing relative densities of manatee group sightings in Kings Bay during summer surveys from 1983 – 2012.

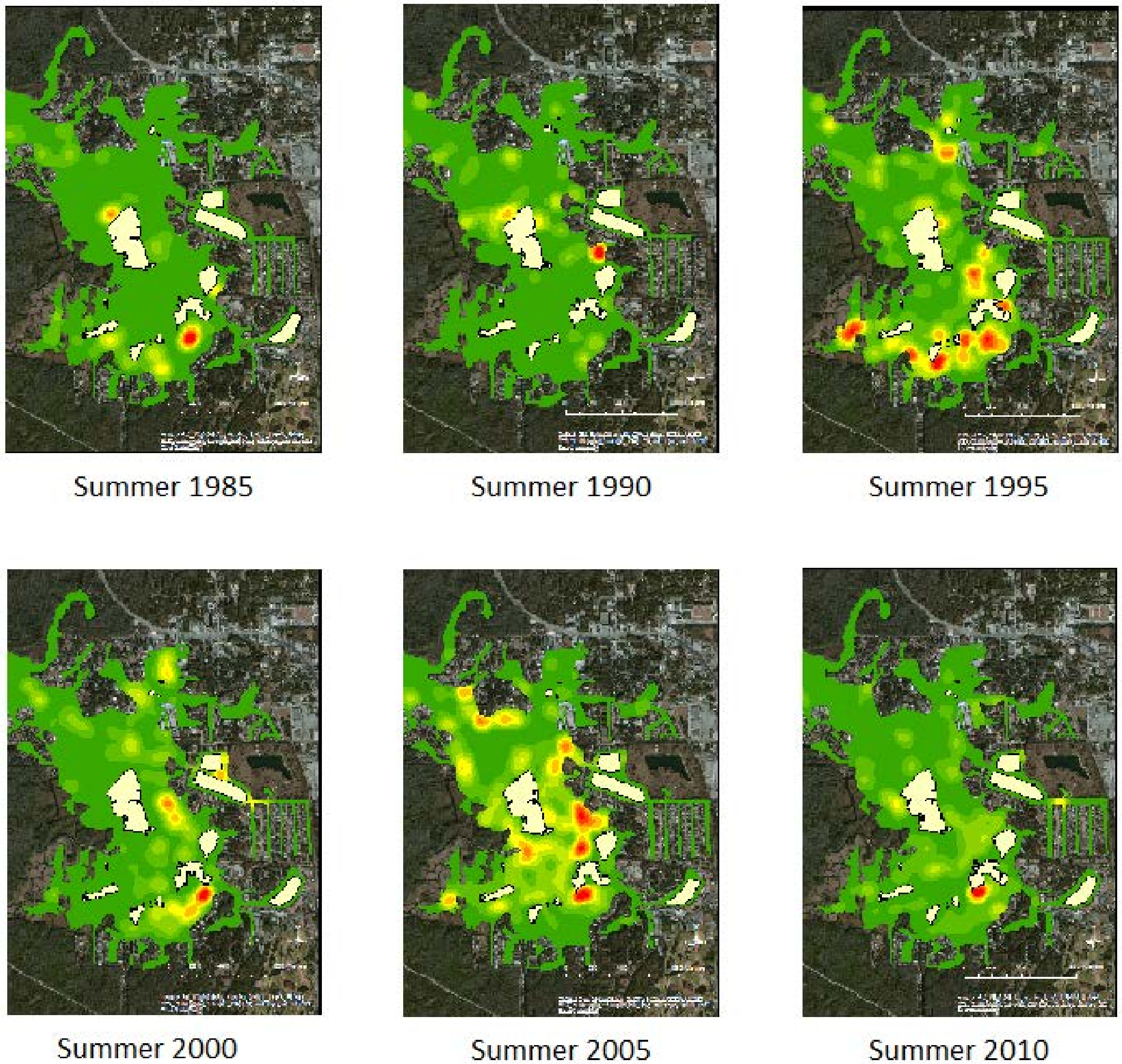

Figure 6. Examples of kernel density maps showing the relative densities of manatee group sightings in Kings Bay during summer periods over time. The maps do not display a uniform seasonal pattern over the 30 year period.

Statistical Analysis

The number of manatees using Kings Bay has grown since the implementation of refuges and sanctuaries. Considerably more manatees are present in winter months than in summer months (see Appendices A and B). In order to find significant relationships between year and season, statistical analyses were performed. Statistical analysis was also expanded to determine the primary locations that manatees utilize during winter months when sanctuary boundaries are in place.

A total of 58,535 sightings were recorded over 412 surveys during the winter seasons between 1983 and 2012; 13,792 sightings were recorded over 299 surveys during the summer seasons. A simple linear regression was performed using the winter survey data to examine manatee abundance in Kings Bay over time. Positive correlations between the average and peak number of manatees and time (year) were also observed. Winter manatee counts within Kings Bay increased significantly between 1983 and 2012 (Fig. 7), with significant increases in both average and peak observed manatee counts (Average: $R = 0.81$, $p < 0.001$; Peak: $R = 0.80$, $p < 0.001$). Most noticeable is the significant increase in magnitude of recent peak events. When surveys began in 1983, the peak number of manatees observed was 120. Recently, more than 500 manatees have been observed occupying Kings Bay throughout the winter seasons. The largest influx of manatees occurred in 2009 with 566 manatees which coincided with a cold winter event. The annual average rate of increase of the total number of manatees occupying Kings Bay over the 30 year timespan (1983-2012) was 7%; the average manatee counts increased by 4.81 animals per year over the 30 year period, as indicated by the linear regression slope (Fig. 7).

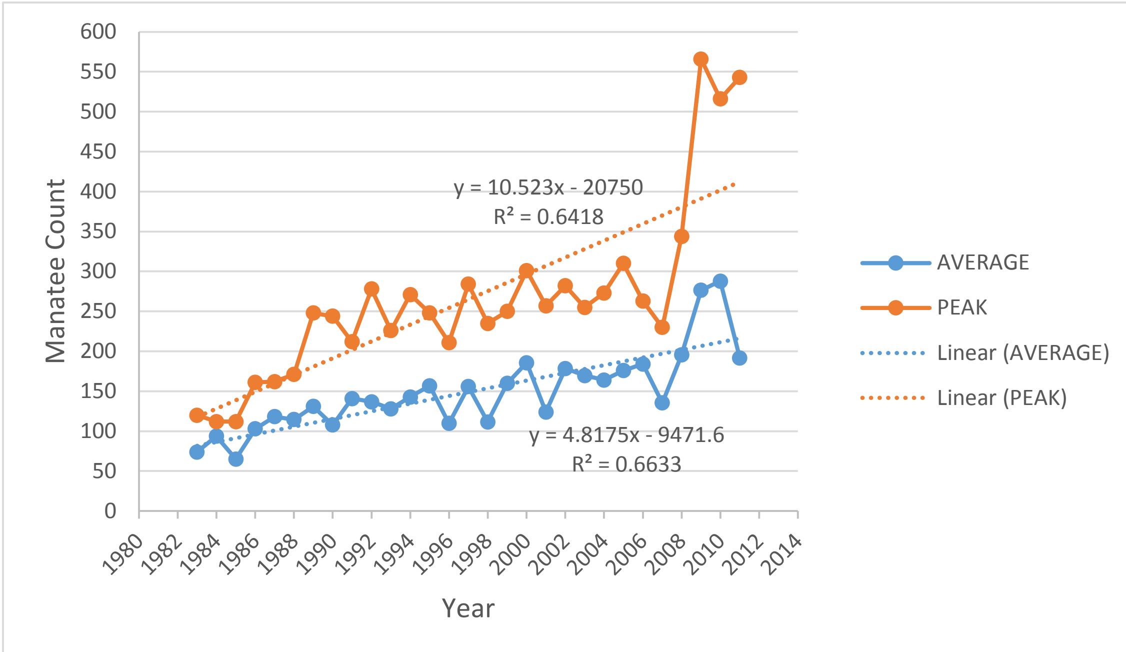

Figure 7. Peak and average manatee counts in winter from 1983 – 2012 in Kings Bay, Florida.

The same methods were applied to summer manatee data analysis (Fig. 8). Kings Bay experienced no significant change in manatee counts during the summer months (Average: R = 0.05, p = 0.76; Peak: R = 0.24, p = 0.19). The average number of manatees observed per survey throughout summer survey seasons was 48. Observed manatee counts reached a peak of 235 and a minimum of 20 animals within the bay. The average manatee counts increased by only 0.109 animals per year, which was not significantly different from zero. There have been significant fluctuations in the summer counts over the years, however, there is no evidence of a significant increase in the regression data.

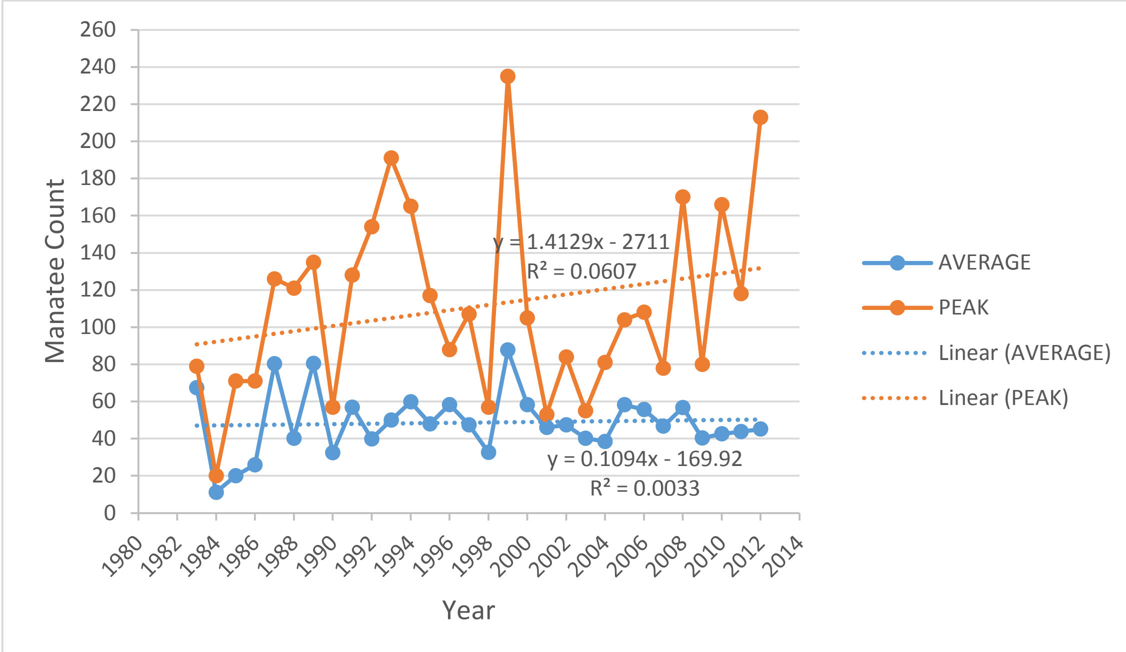

Figure 8. Peak and average manatee counts in summer from 1983 – 2012 in Kings Bay, Florida.

The results of the GLM showed that there is a significant relationship between sanctuaries and manatee density ($p < 0.001$) (Table 1). The parameter estimates indicate that there were significantly higher densities in the South Banana Island ($p = 0.01$), Magnolia Springs ($p < 0.0001$), and Three Sisters Springs ($p < 0.0001$) sanctuaries. These sanctuaries displayed positive trends in manatee density over time (Figures 10a, 10c, and 10d). Overall manatee densities in the Sunset Shores, Warden Key, North Banana Island, and Buzzard Island sanctuaries were much lower and showed negative trends in manatee density over time (Figures 10b, 10e, 10f, and 10g). The generalized linear model also detected significant differences between manatee densities in the years of 1997-1998, 1998-1999, 2000-2001, 2003-2004, 2006-2007, 2009-2010, 2010-2011, and 2011-2012 ($p < 0.001$). These years coincided with severe winter events and exhibited higher manatee densities.

Variables in the model	L-R Chi-Square	Significance
Dependent Variable		
Manatee Density		
Independent variables		
Sanctuary		
Buzzard Island	3.3746	0.0662
Magnolia Springs	22.0881	<.0001*
North Banana Island	2.9617	0.0853
South Banana Island	6.6263	0.01*
Sunset Shores	0.0222	0.8816
Three Sisters Springs	917.3286	<.0001*
Year		
1984-1983	0.0491	0.8247
1985-1984	0.5085	0.4758
1986-1985	0.1033	0.7479
1987-1986	0.0768	0.7817
1988-1987	0.0831	0.7731
1989-1988	0.1284	0.7201
1990-1989	0.0286	0.8657
1991-1990	0.0017	0.9675
1992-1991	0.0709	0.79
1993-1992	0.0122	0.9122
1994-1993	0.0097	0.9216
1995-1994	0.066	0.7973
1996-1995	0.0033	0.9543
1997-1996	0.0079	0.9292
1998-1997	4.2161	0.04*
1999-1998	4.2577	0.0391*
2000-1999	1.1021	0.2938
2001-2000	7.6639	0.0056*
2002-2001	0.099	0.753
2003-2002	0.0292	0.8643
2004-2003	5.0383	0.0248*
2005-2004	0.1959	0.6581
2006-2005	0.0789	0.7789
2007-2006	6.2268	0.0126*
2008-2007	2.0437	0.1528
2009-2008	1.7761	0.1826
2010-2009	10.0466	0.0015*
2011-2010	11.9106	0.0006*
2012-2011	29.7893	<.0001*

*Indicates a significant variable.

Table 1. Results of the generalized linear model relating manatee density (dependent variable) to sanctuaries and year (independent variables). Significant variables indicate significant differences in densities among sanctuaries and years across the 30 year timespan.

DISCUSSION

Spatial and Temporal Distributions

Obtaining a measure of the abundance and distribution of Florida manatees within Kings Bay is essential for the management and conservation of the species. Wintering manatee use continues to increase within Kings Bay as is evidenced by significant increases in both average and maximum manatee numbers across the 30 years. Peak winter use, most prominently, has increased at an even greater magnitude. Average winter manatee abundance within the Kings Bay area increased from 65 to 288 animals, while peak counts rose from 112 to 566 animals (Fig. 7). Due to the significant increases in number of manatees during the winter seasons, the null hypothesis that the winter manatee populations occupying Kings Bay have remained equal over time is rejected. High winter manatee abundance in Kings Bay has been proposed to be attributed to increased manatee survival and population growth and increasingly severe winter events (Kleen and Breland 2014). Summer manatee abundance has also increased within the Kings Bay area. The average summer manatee abundance ranged from 11 to 88, while peak counts have varied between 20 and 235 (Fig. 8), but overall trends in both were not statistically significant. Due to the insignificant increases in number of manatees during the summer seasons, the null hypothesis that the summer manatee populations occupying Kings Bay have remained equal over time fails to be rejected. As Kleen and Breland (2014) found, peak usage during the summer months was typically attributed to late cold fronts which bring manatees back to the springs. Within a habitat type, the Magnolia Springs, South Banana Island, and Three Sisters Springs sanctuaries exhibited significantly higher manatee density (Table 1). Due to heterogeneity in the distribution, the densities of manatees was not equal among the seven sanctuaries ($p < 0.05$), suggesting differences in habitat quality. As a result, the null hypothesis that the densities of manatees are equal among the seven sanctuaries is rejected. Manatee density was also not equal among years ($p < 0.05$), likely influenced by cold weather events (Table 1). The null hypothesis that the densities of wintering manatees is equal among years is therefore rejected.

Spatial Analysis and Management Implications

Manatee densities as depicted in Figures 3, 4, 5, and 6 and Table 1 provide a clear comparison of spatial and temporal changes in numbers and habitat use in Kings Bay. The spatial distribution of manatees within Kings Bay varies seasonally and is influenced by several natural and anthropogenic factors including the abundance and distribution in vegetation (USFWS 1980), altered behavior (Hartman 1979; Kochman *et al.* 1985; Allen 2013), the availability and condition of warm-water refuges (Powell and Rathbun 1984), and increased injury and mortality (Odell and Reynolds 1979; O'Shea *et al.* 1985). Most important is the location of artesian springs (Kochman *et al.* 1985). With the onset of colder weather, manatees concentrate in the eastern and southern portions of the bay, aggregating near major springs to sustain lower temperatures. This information has important management implications. For instance, the waters situated between the South Banana Island and Sunset Shores sanctuaries encompassing King's Spring support a very dense cluster of manatees that do not lie within sanctuary boundaries. Therefore, additional coverage is recommended in this area to better protect the large aggregations of manatees utilizing King's Spring for warmth (Fig. 9). These waters permit boat access, however, expanding the southern portion of the South Banana Island sanctuary will allow for greater protection, yet still allow boaters access to navigate between the two islands (Fig. 10). The South Banana Island and Sunset Shores sanctuaries, along with the Magnolia Springs sanctuary, were first established in 1980 after reported observations of manatee harassment. This prompted the Service to designate manatee protection areas where certain waterborne activities could be prohibited to prevent any take or harm of manatees (USFWS 2014). Since 1980, manatee densities within the South Banana Island sanctuary have steadily increased by 0.003 per year (Fig. 11a), which was significantly greater than zero ($p = 0.0087$). Sunset Shores revealed an increasing trend in manatee density until 1994 when the Buzzard Island, Warden Key, and North Banana Island sanctuaries were designated, suggesting a shift in usage. It is likely that manatees place a heavier reliance on the South Banana Island sanctuary for warmth as King's Spring lies within its boundaries. Over time, the Sunset Shores sanctuary has displayed a negative trend in manatee density with a slope of -0.0002 manatees per sq. meter per year (Fig. 11b), which was significantly less than zero ($p < 0.0001$).

Figure 9. Locations of proposed sanctuaries withing Kings Bay.

Figure 10. Location of the proposed addition to the South Banana Island sanctuary.

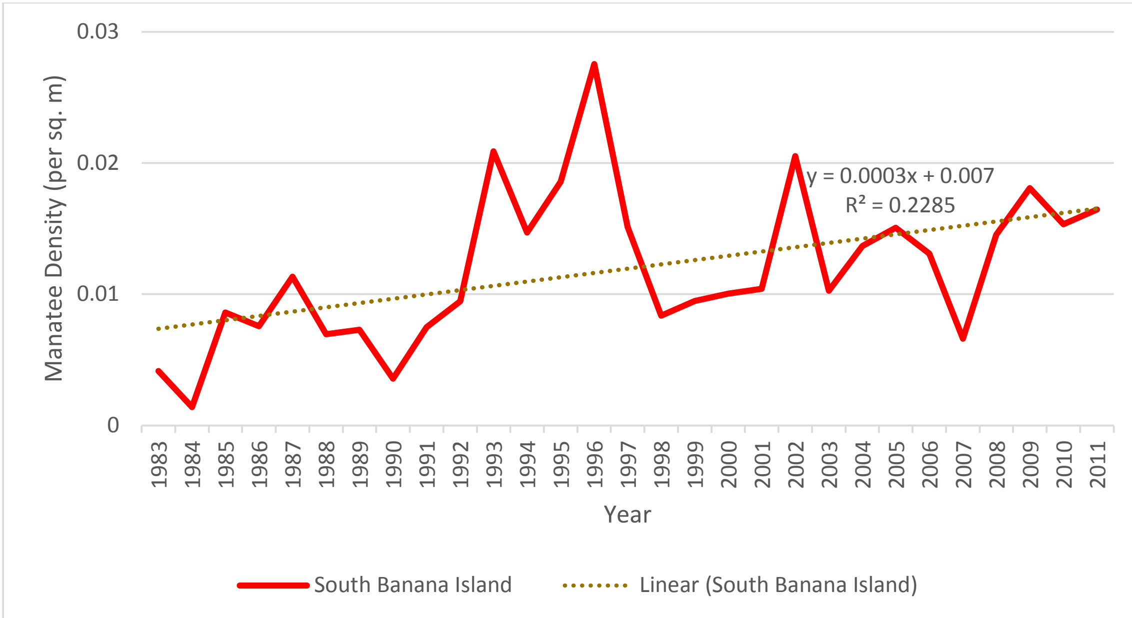

Figure 11a. Manatee densities within the South Banana Island sanctuary from 1983 – 2012.

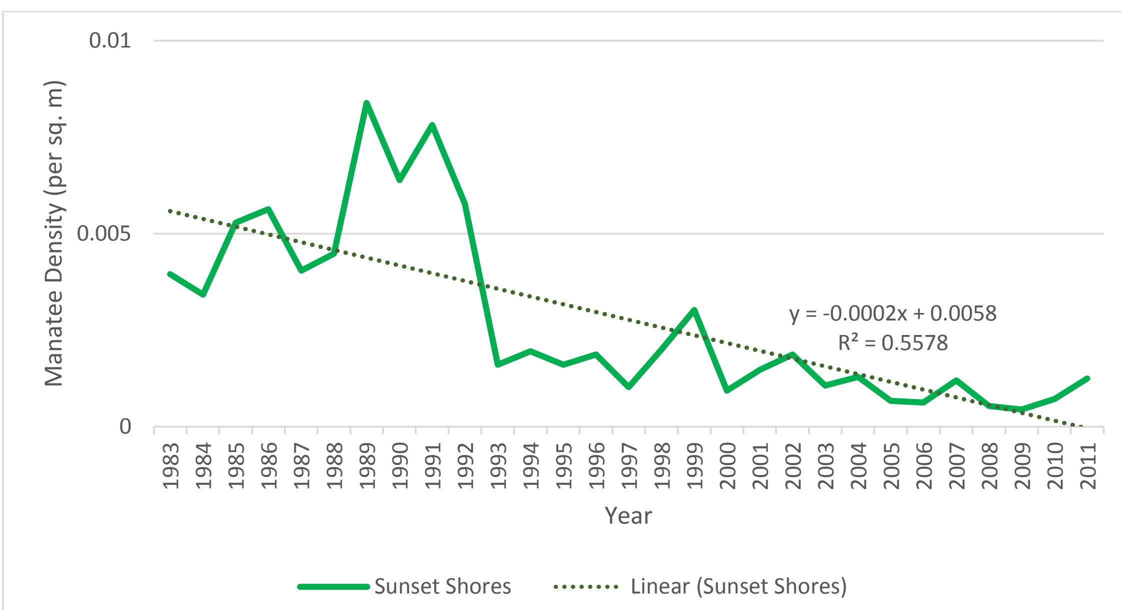

Figure 11b. Manatee densities within the Sunset Shores sanctuary from 1983 – 2012.

Three Sisters Springs and Magnolia Springs are also areas with pre-existing sanctuaries that provide vital protection to manatees. However, based on the high density usage of these areas by manatees, I propose expansions of these two sanctuaries. Additional area positioned at the southeast portion of the Magnolia Springs sanctuary is advocated (Fig. 12). Human disturbance at King's Spring may be the source of groups developing at Magnolia Springs (Kochman *et al.* 1985). Other springs within the bay are less important to manatees due to unfavorable conditions such as smaller size, limited discharge, or narrow passes (Hartman 1979). Since the sanctuary was designated in 1980, a small positive trend in manatee density has been observed at the Magnolia Springs sanctuary with an increase of 0.0007 manatees per sq. meter per year (Fig. 11c), which was significantly greater than zero ($p = 0.0072$). Three Sisters Springs attracts thousands of visitors each year as it is the only confined waterbody in the United States that allows encounters with wintering manatees to the public. The Three Sisters Springs sanctuary was first made permanent in October 1998 due to observations of increasing numbers of manatees, recreational divers, and snorkelers and reports of increasing harassment. The confined area had long been a resting spot for manatees, and the restrictions were proposed to allow sufficient space for manatees to rest free from harassment (USFWS 2014). Since its existence, the Three Sisters Springs sanctuary has had significant increases in manatee densities over time with 0.0432 manatees per sq. meter per year (Fig. 11d), which was significantly greater than zero ($p < 0.001$). Today, between the months of November and March, as many as 100 swimmers and paddlers enter Three Sisters Springs per hour to see the manatees (USFWS, unpublished data). The U.S. Fish and Wildlife Service has proposed measures to protect manatees occupying

Three Sisters Springs from adverse impacts associated with watercraft and manatee viewing activities during the winter months while still allowing public access, including the creation of two expanded no-public entry areas within the spring heads by closing the eastern and western lobes known as Pretty Sister and Little Sister. The Service's recommendation is consistent with the results of the kernel density analysis (Figures 3 and 5) which suggests that further protection is advisable within this area. The results of the kernel density analysis also encourage improvement of the existing Three Sisters Springs sanctuary with additional area to the west (Fig. 13). A new sanctuary designation is proposed across the waterway from the existing Three Sisters Spring sanctuary as well to further protect the increasing population of manatees occupying these springs from human disturbance and activity.

Figure 12. Location of the proposed addition to the Magnolia Springs sanctuary.

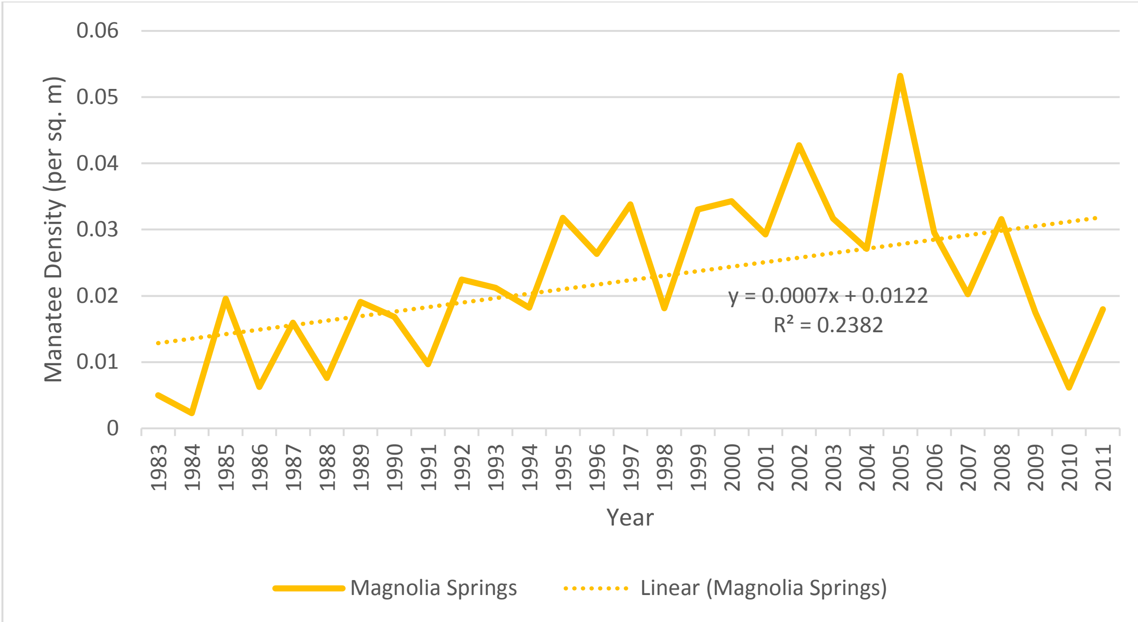

Figure 11c. Manatee densities within the Magnolia Springs sanctuaries from 1983 – 2012.

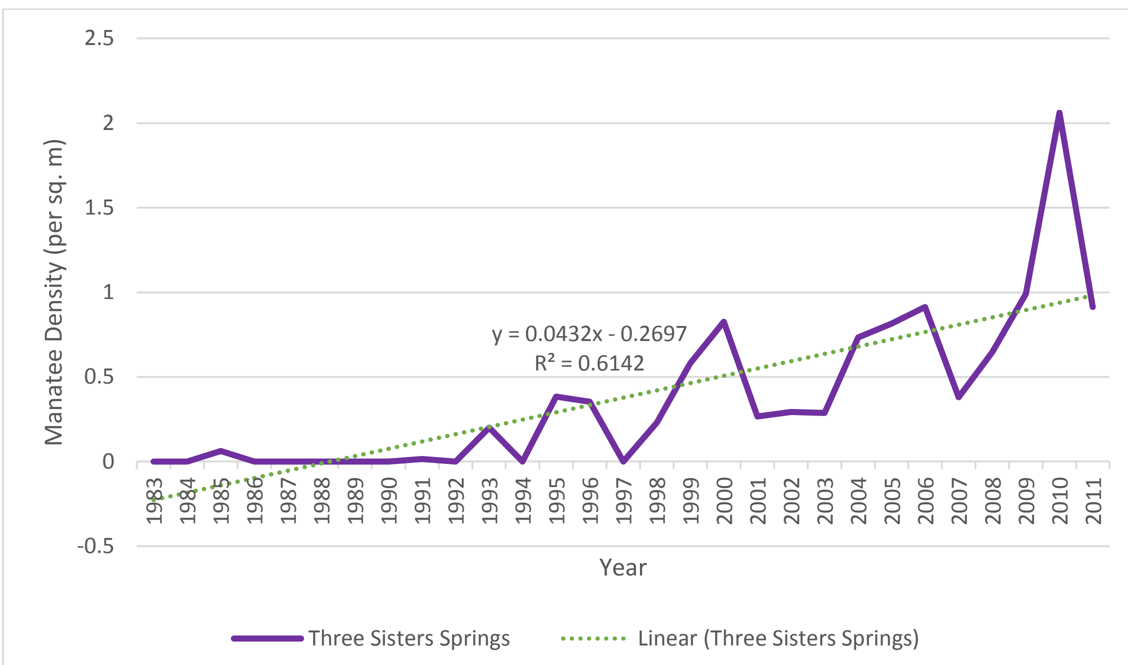

Figure 11d. Manatee densities within the Three Sisters Springs sanctuaries from 1983 – 2012.

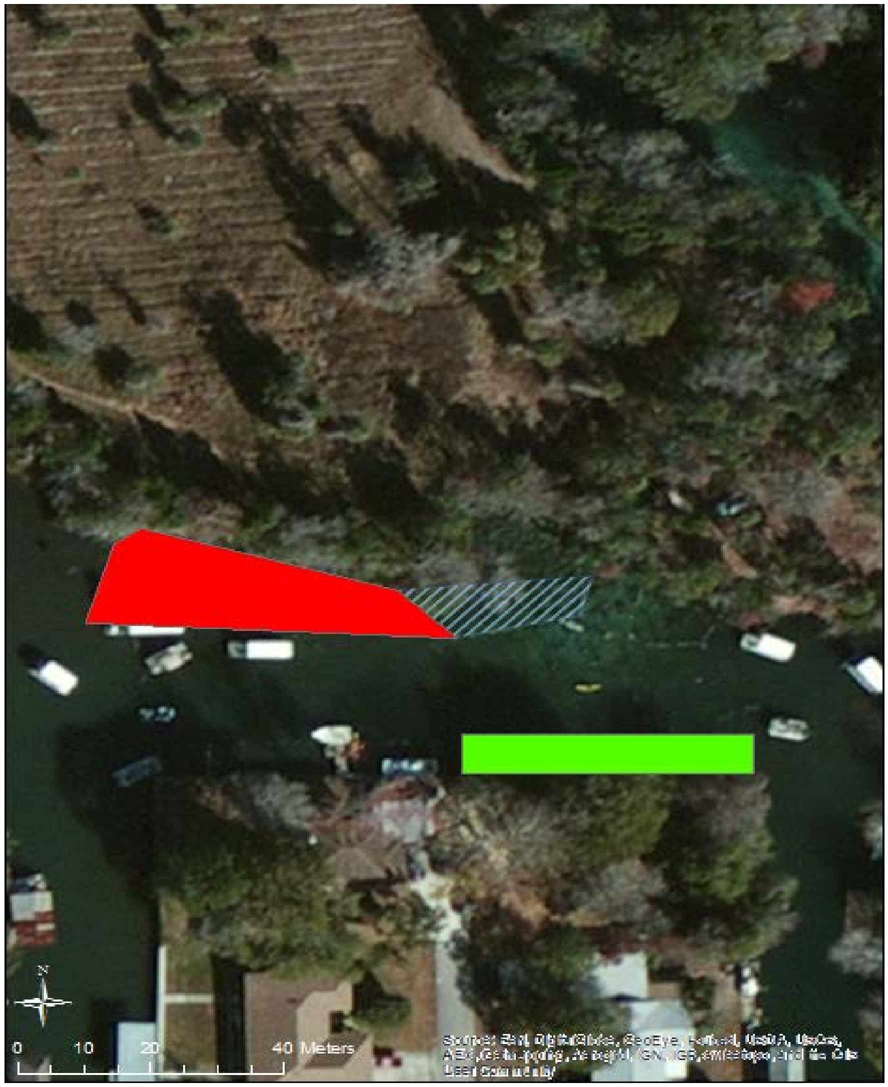

Figure 13. Location of the proposed addition to the Three Sisters Springs sanctuary.

The Warden Key, North Banana Island, and Buzzard Island sanctuaries are not utilized to the same densities as the other sanctuaries, and their existence is subject to reevaluation. In 1994, these three sanctuaries became established in the bay. The number of manatees in the area had doubled since 1980 at that time while inadequate shelter for manatees provided by existing sanctuaries, a substantial increase in the number of visitors, and reports of increasing manatee harassment had been cited (USFWS 2014). The results of this study, nonetheless, suggest that the usage and quality of the Warden Key, North Banana Island and Buzzard Island sanctuaries may have changed over time. All three sanctuaries exhibited significantly lower densities over time since they were created (-0.00002, -0.00008, and -0.00003 manatees per sq. meter per year respectively) (Figures 11e, 11f, and 11g). A possible explanation for this observation is that they do not contain any springs within their boundaries that provide thermal refuge to wintering manatees. An additional factor may be the change in distribution of resources utilized by manatees, encouraging manatees to relocate to newer sanctuaries. This shift, for example, may be due to an increase in salinity causing manatees to move to fresher waters or higher quality food sources. Food resources within Kings Bay have likely shifted in their abundance, variety, and distribution due to increases in salinity (Hoyer *et al.* 2001; Frazer *et al.* 2006). Significant reductions in plant biomass may result from an increase of salinity by only two to three practical salinity units (psu) (Hoyer *et al.* 2001). An average bottom salinity of 2.1 psu was documented by Frazer *et al.* (2001) in Kings Bay within one year of monitoring, causing changes in the vegetation from fresh water tolerant plants to sale tolerant plants (Frazer *et al.* 2001; 2006). This change in vegetation may be affecting the distribution and abundance of manatees within Kings Bay, and as a result, affecting the value of sanctuaries established to provide food resources (Kleen and Breland 2014). Manatees have been reported leaving the warmth of springs to colder waters temporarily to feed (Kochman *et al.* 1985), but during extreme cold fronts, manatees may remain close to warm-water sources and thus not feed for days (Reynolds 2000). Human disturbance is another likely factor, as manatee responses to people and boats have been documented within Kings Bay (Sorice *et al.* 2003). Observations made associated with increasing numbers of people and boats include increased swimming, milling, and cavorting behaviors and decreases in resting, feeding, and nursing behaviors of manatees (Abernathy 1995; Wooding 1997; King and Heinen 2004).

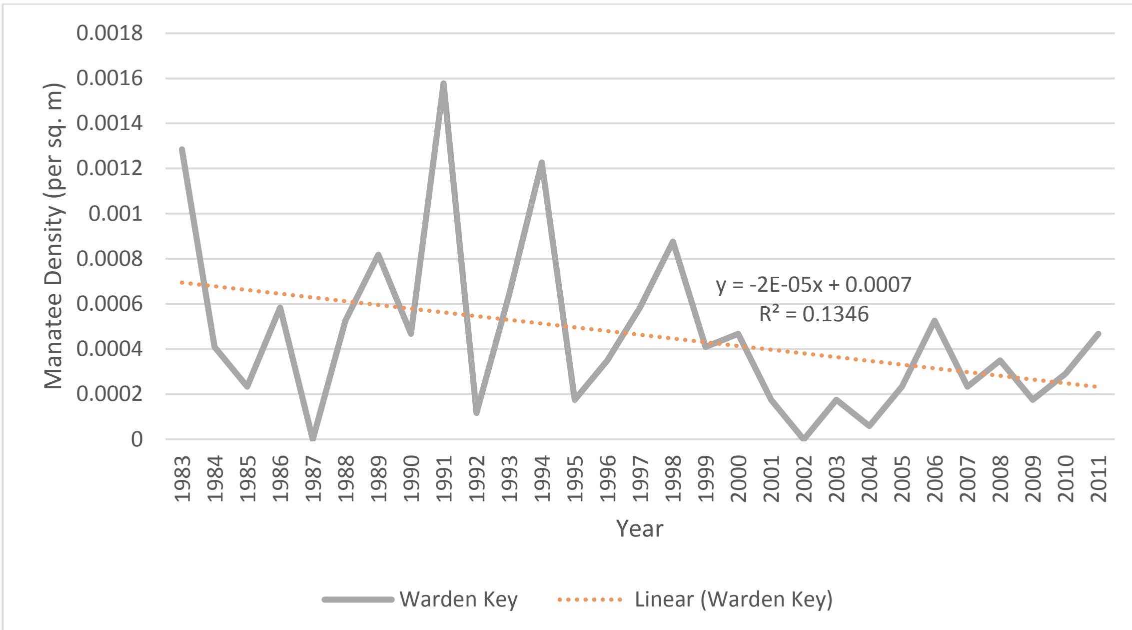

Figure 11e. Manatee densities within the Warden Key sanctuary from 1983 – 2012.

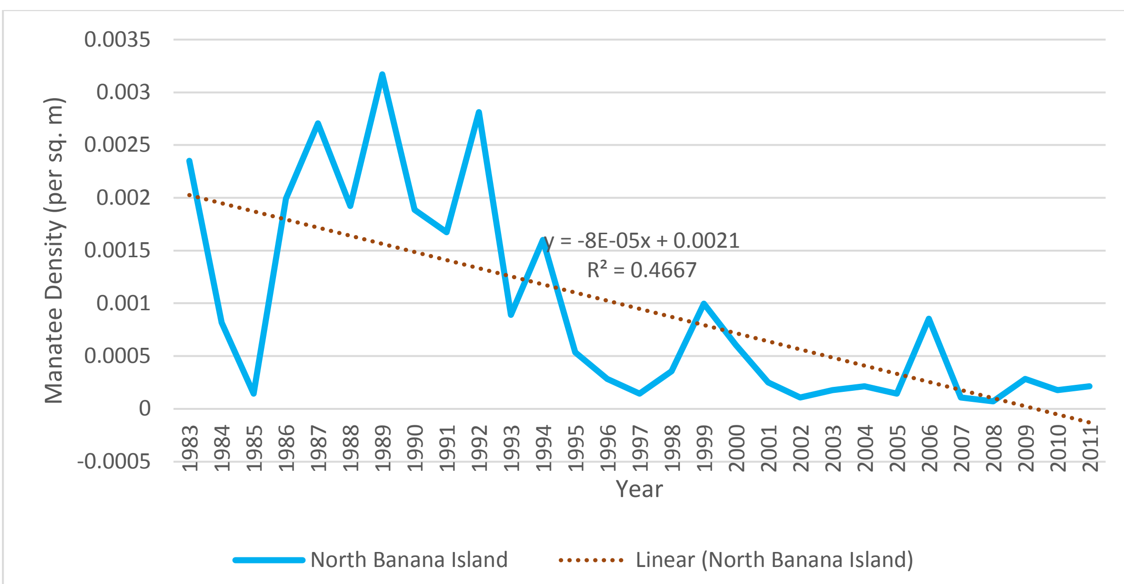

Figure 11f. Manatee densities within the North Banana Island sanctuary from 1983 – 2012.

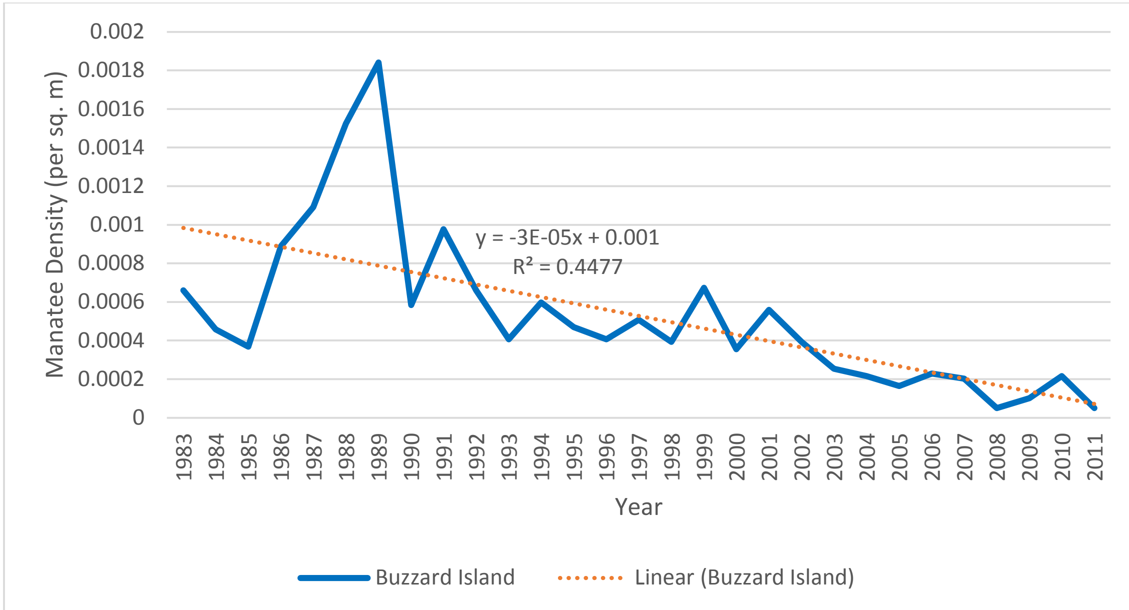

Figure 11g. Manatee densities within the Buzzard Island sanctuary from 1983 – 2012.

A reduction in the overall area of manatee protection sites by the elimination of current sanctuaries is not recommended, particularly when population numbers of both manatees and people utilizing Kings Bay continue to increase year round. However, if additional protection areas are designated within the bay as proposed in this study, it may allow for the elimination of others. Unfortunately, boat and other recreational access to waterways does not allow for optimum areas of protection to be created in locations where high densities of manatees are found. As a result, the newly suggested sanctuaries provide less coverage than the total area of the underutilized sanctuaries considered for reevaluation. Further analysis of the effects of altered habitat (i.e., salinity, vegetation, and protected areas) and human recreation (i.e., boating, swimming, etc.) is needed to better assess the abundance and distribution patterns of manatees within the bay (Kleen and Breland 2014) that will aid in the decision process regarding sanctuary relocations.

When the summer months approach and manatees are not limited by water temperatures, manatees disperse erratically outside of the bay in search of food and other resources that become depleted during the winter when the density of manatees increases (Hartman 1979; Kochman *et al.* 1985; Rathbun *et al.* 1990; King 2002). For this reason, it is difficult to distinguish which areas of Kings Bay are utilized most abundantly by manatees in the summer and which areas require the most protection. King's Spring continued to support a dense cluster of manatees during the summer months collectively throughout the 30 years (Fig. 4), possibly due to freshwater flow. Their required intake of water comes from actively drinking fresh water and from aquatic plant consumption (Ortiz *et al.* 1999; Ortiz and Worthy 2006). It is not definitively known what their fresh water requirements are, but, research suggests that the availability of fresh water may influence manatee distribution (Hartman 1974; Powell *et al.* 1981; Powell and Rathbun 1984; Butler *et al.* 2003). Early studies reported that relatively few manatees were observed during warmer months using wintering sites (Hartman 1979, Irvine and Campbell 1978). However, aerial survey counts reveal that manatees have been using Kings Bay year-round in increasing numbers. Peak counts recorded during the summer months have increased as well, reaching 235 animals within the bay. One hypothesis is that as water temperatures in the Gulf of Mexico rise above spring water temperatures from approximately March to October, the warm-water refuge in winter may become a cold water source in summer. (Irvine and Campbell 1978). It is also probable that the fresh water from the springs attracts the manatees (Richard Flamm, personal communication, 2013). The distribution of manatees throughout the bay, however, was shown to vary year to year over the summer seasons (Fig. 5). Due to the inconsistent pattern of seasonal use and distributions over time, it is challenging to provide protection from a management perspective through the use of sanctuaries during the summer months. Manatees are seen occupying all areas of the bay but at much lower densities compared to the winter months. Therefore, I believe a heavier reliance must be placed on boat speed zone regulations to prevent further manatee mortality in the course of a time when substantial recreational activity takes place.

FUTURE RECOMMENDATIONS AND CONCLUSION

Future Recommendations

Protecting manatees in their natural habitat is crucial to the recovery of the species. In winter, Kings Bay is home to the largest natural concentration of Florida manatees. As illustrated by the results of this study, additional shelter through the use of a sanctuary network is necessary to provide enhanced protection to the high density populations occupying these areas. It is recommended that the in-water restrictions also need to apply on a year-round basis to protect an ever increasing number of manatees from harassment. Furthermore, additional efforts in both enforcement of policies and public education are needed.

The continuation of aerial manatee surveys will be critical in monitoring the effectiveness of sanctuaries within Kings Bay and improving conservation efforts. Further analysis of the effects of altered habitat and human activity is also recommended to guide the conservation of this endangered species.

Conclusion

Kings Bay provides critical habitat and serves as an important warm-water refuge site for the endangered Florida manatee. Since surveys began in 1983, the number of manatees actively using Kings Bay year-round has steadily increased. Aerial survey data illustrated seasonal changes in distributions, discovering significant increases in winter manatee counts over time. With manatee habitat often coinciding with recreational areas, manatee sanctuaries and refuges have been established within the area as a protection measure for the species. Kernel density analysis highlighted areas where manatees were most densely clustered and encouraged additional no-entry protection areas surrounding important major springs within the bay that provide manatees with essential resources necessary for survival. This information is extremely valuable for implementing additional conservation measures in Kings Bay and provides managers with information to make sound decisions when evaluating new or existing areas that offer critical resources and habitat to manatees. Future research should examine the effectiveness of boat speed zones to guarantee adequate protection to the endangered Florida manatee during summer months when their distribution is scattered throughout the bay.

Crystal River remains a setting where protection of an endangered species meets economic gain from tourism. As the number of visitors and demand for ecotourism increases, directing a plan that minimizes adverse impacts and focuses to protect this imperiled species while simultaneously allowing some freedom for recreation and tourism is essential. The efforts made in this study hope to aid in the enhancement of both awareness and manatee presence and protection.

LIST OF REFERENCES

Abernathy, J. 1995. Time-activity budgets and displacement rates in Florida manatees (*Trichechus manatus*) in the absence and presence of humans. Master's Thesis. Florida Atlantic University, Boca Raton, Florida. 27 pp.

Ackerman, B.B, S.D. Wright, R.K. Bonde, D.K. Odell, and D.J. Banowetz. 1995. Trends and patterns in mortality of manatees in Florida, 1974-1992, in: Population Biology of the Florida Manatee, U.S. Department of the Interior Information and Technology Report 1, August 1995.

Allen, A.C. 2013. The Manatees' Winter Vacation. Sources: The Journal of Underwater Education, First Quarter 25(1).

Allen, A.C., D.C. Sattelberger, and E.O. Keith. 2014. The People vs. the Florida manatee: A review of the laws protecting Florida's endangered marine mammal and need for application. Ocean and Coastal Management 102(A):1-7.

Allen, A.C. and E.O. Keith. 2015. Using the West-Indian manatee (*Trichechus manatus*) as a mechanism for invasive aquatic plant management in Florida. Journal of Aquatic Plant Management 53:95-104.

Anderson, Paul K. 2002. Habitat, Niche and Evolution of Sirenian Mating Systems. Journal of Mammalian Evolution 9:55-98.

Beck, C.A. and N.B. Barros. 1991. The Impact of Debris on the Florida Manatee. Marine Pollution Bulletin 22:508-510.

Beck, C.A. and J.P. Reid. 1995. An automated photo-identification catalog for studies of the life history of the Florida manatee. Pages 120-134 in T.J. O'Shea, B.B. Ackerman, and H.F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1. Washington, D.C. 289pp.

Bengtson, J.L. 1981. Ecology of manatees (*Trichechus manatus*) in the St. Johns River, Florida. Ph.D. Diss, Univ. Minnesota. 126pp.

Bengtson, J.L. 1983. Estimating food consumption of free-ranging manatees in Florida. Journal of Wildlife Management 47:1186-1192.

Best, R.C. 1981. Foods and feeding habits of wild and captive Sirenia. Mammal Review 11:3-29.

Blumstein, D.T. and E. Fernandez-Juricic. 2010. A Primer of Conservation Behavior. Sunderland, MA: Sinauer Associates, Inc.

Bossart, G. D. 1999. The Florida manatee: On the verge of extinction? Journal of the American Veterinary Medical Association. 214:1178-1182.

Bossart, G.D., R.A. Meisner, S.A. Rommel, Shin-je Ghim, and A. Bennett Jenson. 2003. Pathological features of the Florida manatee cold stress syndrome. Aquatic Mammals 29:9–17.

Buckingham, C.A. 1990. An Evaluation of Manatee Distribution Patterns in Response to Public Use Activities in Kings Bay, Crystal River, Florida. Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville. 49pp.

Buergelt, C.D., R.K. Bonde, C.A. Beck, and T.J. O'Shea. 1984. Pathologic findings in manatees in Florida. *Journal of the American Veterinary Medical Association.* 185:1331-1334.

Butler, S.M., J.P. Reid, and B.M. Stith. 2003. Detailed movements and habitat use patterns of radio tagged manatees in the western Everglades. Poster presentation at the 15th Biennial Conference on the Biology of Marine Mammals, 15-19 December 2003, Greensboro, North Carolina. Available from http://cars.er.usgs.gov/posters/index.html#manatee (accessed March 2015).

Calambokidis, J. and J. Barlow. 2004. Abundance of blue and humpback whales in the eastern North Pacific estimated by capture-recapture and line-transect methods. Marine Mammal Science 20:63-85.

Deutsch, C.J., R.K. Bonde, and J.P. Reid. 1998. Radio-tracking manatees from land and space: tag design, implementation, and lessons learned from long-term study. Mar. Technol. Soc. J. 32:18-29.

Deutsch, C.J., J.P. Reid, R.K. Bonde, D.E. Easton, H.I. Kochman, and T.J. O’Shea. 2003. Seasonal Movements, Migratory Behavior, and Site Fidelity of West Indian Manatees along the Atlantic Coast of the United States. Wildlife Monographs 151:1-77.

Edwards, H.H., K.H. Pollock, B.B. Ackerman, J.E. Reynolds III, and J.A. Powell. 1997. Estimation of Detection Probability in Manatee Aerial Surveys at a Winter Aggregation Site. The Journal of Wildlife Management 71:2052-2060.

Etheridge, K., G.B. Rathbun, J.A. Powell & H.I. Kochman. (1985). Consumption of Aquatic Plants by the West Indian Manatee. Journal of Aquatic Plant Management 23:21-25.

Flamm, R.O., J.E. Reynolds III and C. Harmak. 2013. Improving Conservation of Florida Manatees (*Trichechus manatus latirostris*): Conceptualization and Contributions Toward a Regional Warm-Water Network Management Strategy for Sustainable Winter Habitat. Environmental Management 51:154-166.

Florida Department of Environmental Protection. 2012. Florida Springs. Retrieved on 26 December 2013 from <http://www.dep.state.fl.us/springs/faq.htm>.

Florida Fish and Wildlife Conservation Commission (FWC). Manatee Mortality Statistics. My FWC Florida Fish and Wildlife Commission. Yearly Manatee Mortality. Accessed 8 January 2013. <http://myfwc.com/research/manatee/rescue-mortality-response/mortality-statistics/>.

Florida Fish and Wildlife Conservation Commission (FWC). 2007. Florida Manatee Management Plan (*Trichechus manatus latirostris*). Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida. 281 pages.

Florida Fish and Wildlife Conservation Commission (FWC). 2010. Boating Accidents Statistical Report. Accessed 12 January 2014. <http://myfwc.com/media/1398421/2010_boating_statbook_introduction.pdf>.

Florida Fish and Wildlife Conservation Commission (FWC). 2011a. The Economic Impact of Saltwater Fishing in Florida. Accessed 15 January 2014. <http://www.myfwc.com/conservation/value/saltwater-fishing/>.

Florida Fish and Wildlife Conservation Commission (FWC). 2011b. Florida Manatee Sanctuary Act. Florida Administration Code Chapter 68C-22. Fla.Stat.Ann.§370.12subd.(2)

Florida Fish and Wildlife Conservation Commission (FWC). 2013a. The Economic Impact of Freshwater Fishing in Florida. Accessed 15 January 2014.

Florida Fish and Wildlife Conservation Commission (FWC). 2013b. Manatee Data Review and Summary for Western Pinellas County. Accessed 22 January 2015.

Frazer, T.K., S.K. Notestein, C.A. Jacoby, C.J. Littles, S.R. Keller, and R.A. Swett. 2006. Effects of storm-induced salinity changes in submersed aquatic vegetation in Kings Bay, Florida. Estuaries and Coasts 29:943-953. <http://www.myfwc.com/conservation/value/freshwater-fishing/>.

Garrott, R.A., B.B. Ackerman, J.R. Cary, D.M. Heisey, J.E. Reynolds, III, P.M. Rose, and J.R. Wilcox. 1994. Trends in counts of manatees at winter aggregation sites. Journal of Wildlife Management 58:642-654.

Garrott, R.A., B.B. Ackerman, J.R. Cary, D.M. Heisey, J.E. Reynolds, III, and J.R. Wilcox. 1995. Assessment of trends in sizes of manatee populations at several Florida aggregation sites. Pages 34-55 in T. J. O'Shea, B. B. Ackerman, and H. F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1, Washington, D.C., USA.

Guillory, V., A. McMillen Jackson, L. Hartman, H. Perry, T. Floyd, T. Wagner and G.

Graham. 2001. Blue Crab Derelict Traps and Trap Removal Programs. Gulf States Marine Fisheries Commission, Ocean Springs, Mississippi.

Halvorsen, K.M. and E.O. Keith. 2008. Immunosuppression Cascade in the Florida Manatee (*Trichechus manatus latirostris*). Aquatic Mammals 34:412-419.

Hartman, D.S. 1971. Behavior and ecology of the Florida manatee (*Trichechus manatus latirostris*) at Crystal River, Citrus County. PhD Dissertation, Cornell University, Ithaca, New York.

Hartman, D.S. 1974. Distribution, status, and conservation of the manatee in the United States. Natl. Tech. Inf. Ser., PB81-140725, Springfield, Va. 246pp.

Hartman, D.S. 1979. Ecology and Behavior of the Manatee (*Trichechus manatus)* in Florida. The American Society of Mammalogists, Special Publication 5.

Hooge, P.N., W.M. Eichenlaub, E.K. Solomon. 2001. Using GIS to Analyze animal movements in the marine environment. In: Kruse GH, Bez N, Booth A, Dorn MW, Hills S, Lipcius RN, Pelletier D, Roy C, Smith SJ, Witherell D (eds) 2001 spatial processes and management of marine populations. Alaska Sea Grant College Program, Anchorage, pp. 37–51.

Hoyer, M.V., T.K. Frazer, D.E. Canfield, Jr., and J.M. Lamb. 2001. Vegetation evaluation in Kings Bay/Crystal River (Final report submitted to the Southwest Florida Water Management District). Gainesville: University of Florida, Institute of Food and Agricultural Sciences.

Hurst, L.A., & C.A. Beck. 1988. Microhistological characteristics of selected aquatic plants of Florida with techniques for the study of manatee food habits. U.S. Fish and Wildlife Service. Biological Report No. 88. pp. 145.

Irvine, A B, and H W. Campbell. 1978. Aerial census of the West Indian manatee (*Trichechus manatus*) in the southeastern United States. Journal of Mammalogy 59:613-630.

Irvine, A.B., J.E. Caffin, and H.I. Kochman. 1982. Aerial surveys for manatees and dolphins in western peninsular Florida Fish. Bull. 80:621-630.

Irvine, A.B. 1983. Manatee metabolism and its influence on distribution in Florida. Biological Conservation 25:315-334.

King, J. M. 2002. An assessment of manatee behavior as affected by human interactions at two sites in Crystal River, Florida (Unpublished Master’s thesis). Florida International University, Miami.

King, J.M. and J.T. Heinen. 2004. An assessment of the behaviors of overwintering manatees as influenced by interactions with tourists at two sites in central Florida. Biological Conservation 117:227–234.

Kleen, J.M. and A.D. Breland. 2014. Increases in Seasonal Manatee (*Trichechus manatus latirostris*) Abundance Within Citrus County, Florida. Aquatic Mammals 40:69-80.

Kochman, H.E., G.B. Rathbun, and J.A. Powell. 1985. Temporal and spatial distribution of manatees in Kings Bay, Crystal River, Florida. Journal of Wildlife Management. 49:921-924.

Laist, D.W. and J.E. Reynolds, III. 2005a. Influence of power plants and other warm-water refuges on Florida manatees. Marine Mammal Science 21:739-764.

Laist, D.W. and J.E. Reynolds, III. 2005b. Florida manatees, warm-water refuges, and an uncertain future. Coastal Management 33:279-295.

Langtimm, C.A., T.J. O'Shea, R. Pradel and C.A. Beck. 1998. Estimates of annual survival probabilities for adult Florida manatees (*Trichechus manatus latirostris*). Ecology 79:981-997.

Ledder, D.A. 1986. Food habits of the West Indian Manatee, *Trichechus manatus latirostris*, in south Florida. M.S. Thesis. Univ. of Miami, Coral Gables, FL. pp. 114.

Lefevbvre, L.W., T.J. O'Shea, G.B. Rathbun and R.C. Best. 1989. Distribution, status, and biogeography of the West Indian manatee. Pages 567-609 in C.A. Woods (ed.), Biogeography of the West Indies: past present and future. Sandhill Crane Press, Gainesville, FL.

Lefebvre, L.W. and H.I. Kochman. 1991. An evaluation of aerial survey, replicates count methodology to determine trends in manatee abundance. Wildlife Society Bulletin 19:298-309.

Lefebvre, L.W., M. Marmontel, J.P. Reid, G.B. Rathbun and D.P. Domning. 2001. Status and biogeography of the West Indian manatee. Pages 425-474 in C.A. Woods, F.E. Sergi (eds.), Biogeography of the West Indies, patterns and perspectives, 2nd ed. CRW Press, Boca Raton, FL.

MacArthur, R.H. and E.O. Wilson. 1967. The theory of island biogeography. Princeton University Press. Princeton, NJ.

Marmontel, M. 1995. Age and reproduction in female Florida manatees. Pp. 98-119 in T.J. O'Shea, B.B. Ackerman, and H.F. Percival, eds., Population Biology of the Florida Manatee (*Trichechus manatus latirostris*). National Biological Service, Information and Technology Report 1. 289 pp.

McCullagh, P. and J.A. Nelder. 1989. Generalized Linear Models. Chapman & Hall, London.

Meigs-Friend, Gaia. 2003. Manatee Winter Distribution in Kings Bay, Crystal River, FL and its Application to the Design of Manatee Speed Zones and Sanctuaries in the Bay. Master's Thesis, Duke University. 32 pp.

Moore, J.C. 1951. The range of the Florida manatee. Quart. Jour. Florida Acad. Sci. 14: 1-19. National Marine Manufacturers Association. 2013. 2012 Recreational Boating Statistical Abstract. National Marine Manufacturers Association.

National Marine Manufacturers Association. 2013. 2012 Recreational Boating Statistical Abstract. National Marine Manufacturers Association.

Odell, D.K. and J.E. Reynolds III. 1979. Observations on manatee mortality in South Florida. Journal of Wildlife Management 43:572-577.

Odell, D.K., G.D. Bossart, M.T. Lowe, and T.D. Hopkins. 1995. Reproduction of the West Indian manatee in captivity. Pages 192-193 in T.J. O'Shea, B.B. Ackerman, and H.F. Percival, (eds.), Population Biology of the Florida Manatee. National Biological Service Information and Technology Report 1. Washington, D.C. 289 pp. (Abstract).

Ortiz, R.M., G.A.J. Worthy, and F.M. Byers. 1999. Estimation of Water Turnover Rates of Captive West Indian Manatees (*Trichechus manatus*) Held in Fresh and Salt Water. The Journal of Experimental Biology 202:33-38.

Ortiz, R.M. and G.A.J. Worthy. 2006. Body Composition and Water Turnover Rates of Bottle-Fed West Indian Manatee (*Trichechus manatus*) Calves. Aquatic Mammals 32:41-45.

O'Shea, T.J., C.A. Beck, R.K. Bonde, H.I. Kochman, and D.K. Odell. 1985. An analysis of manatee mortality patterns in Florida, 1976-81. Journal of Wildlife Management 49:1-11.

O'Shea, T.J. and H.I. Kochman. 1990. Florida manatees: distribution, geographically referenced data sets, and ecological and behavioral aspects of habitat use. In: J. E. Reynolds, III & K. D. Haddad (eds.), Report of the Workshop on Geographic Information Systems as an Aid to Managing Habitat for West Indian Manatees in Florida and Georgia. Florida Marine Research Publication 49:11-22.

O'Shea, T.J. 1995. Waterborne recreation and the Florida manatee. In: Knight, R.L., Gutzwiller, K.J. (Eds.), Wildlife and Recreationists. Island Press, Washington, DC, pp. 297-311.

O'Shea, T.J. and W.C. Hartley. 1995. Reproduction and early-age survival of manatees at

Blue Spring, Upper St. John's River, Florida. Pages 157-170 in T. J. O'Shea, B. B. Ackerman and H. F. Percival eds. Population Biology of the Florida Manatee, National Biological Service Information and Technology Report 1. Washington D. C.

O'Shea, T.J. and C.A. Langtimm. 1995. Estimation of survival of adult Florida manatees in the Crystal River, at Blue Spring, and on the Atlantic coast. In: T. J. O'Shea, B. B. Ackerman, & H. F. Percival (eds.), Population biology of the Florida manatee (q.v.).

O'Shea, T.J., L.W. Lefebvre, and C.A. Beck. 2001. Florida manatees: perspectives on populations, pain, and protection. Pages 31-43 in L.A. Dierauf and F.M.D. Gulland, eds. Handbook of Marine Mammal Medicine, 2nd edition. CRC Press, Boca Raton, FL.

Packard, J.M., R.C. Summers, and L.B. Barnes. 1985. Variation of visibility bias during aerial surveys of manatees. Journal of Wildlife Management 49:347-351.

Packard, J.M., D.B. Siniff, and J.A. Cornell. 1986. Use of replicate counts to improve indices of trends in manatee abundance. Wildlife Society Bulletin 14:265-275.

Packard, J.M., R.K. Frohlich, J.E. Reynolds, III, and J.R. Wilcox. 1989. Manatee response to interruption of a thermal effluent. Journal of Wildlife Management 53:692-700.

Powell, J.A. 1981. The manatee population in Crystal River, Citrus County, Florida. In: R. L. Brownell, Jr., & K. Ralls (eds.), The West Indian manatee in Florida. Proceedings of a workshop held in Orlando, Florida 27-29 March 1978 (q.v.).

Powell, J.A., D.W. Belitsky, and G.B. Rathbun. 1981. Status of the West Indian Manatee (*Trichechus manatus*) in Puerto Rico. Journal of Mammalogy 62:642-646.

Powell, J.A. and G.B. Rathbun. 1984. Distribution and abundance of manatees along the northern coast of the Gulf of Mexico. Northeast Gulf Sci. 7:1-28.

Rathbun, G.B., J.P. Reid, and G. Carowan. 1990. *Distribution and movement patterns of manatees* (Trichechus manatus) *in northwest peninsular Florida*. St. Petersburg: Florida Marine Research Institute. 48 pp.

Rathbun, G.B., J.P. Reid, R.K. Bonde, and J.A. Powell. 1995. Reproduction in free-ranging Florida manatees. Pages 135-156 in T.J. O'Shea, B.B. Ackerman, and H.F. Percival, editors. Population biology of the Florida manatee. National Biological Service Information and Technology Report 1. Washington, D.C. 289pp.

Reep, Roger L. and Robert K. Bonde. 2006. The Florida Manatee: Biology and

Conservation. University Press of Florida. Gainesville, FL.

Reid, J.P., G.B. Rathbun, and J.R. Wilcox. 1991. Distribution patterns of individually identifiable West Indian manatees (*Trichechus manatus*) in Florida. Mar. Mamm. Sci. 7:180-190.

Reid, J.P., R.K. Bonde, and T.J. O'Shea. 1995. Reproduction and mortality of radio-tagged and recognizable manatees on the Atlantic coast of Florida. Pages 171-191 in T. J. O'Shea, B. B. Ackerman and H. F. Percival eds. Population Biology of the Florida Manatee, National Biological Service Information and Technology Report 1. Washington D. C.

Reynolds, J.E., III and J.R. Wilcox. 1985. Abundance of West Indian manatees (*Trichechus manatus*) around selected Florida power plants following winter cold fronts, 1982-1983. Bull. Mar. Sci. 36:413-422.

Reynolds, J.E., III and J.R. Wilcox. 1986. Distribution and abundance of the West Indian manatee *Trichechus manatus* around selected Florida power plants following winter cold fronts: 1984-85. Biol. Conserv. 38:103-113.

Reynolds, J.E., III and J.R. Wilcox. 1987. People, power plants, and manatees. Sea Frontiers 33:263-269.

Reynolds, J.E., III and J.R. Wilcox. 1994. Observations of Florida manatees (*Trichechus manatus latirostris*) around selected power plants in winter. Mar. Mamm. Sci. 10:163-177.

Robbins, B.D. 1997. Quantifying temporal change in seagrass areal coverage: the use of GIS and low resolution aerial photography. Aquatic Botany 58:259-267.

Samek, K. 2004. Unknown Quantity: The Bottled Water Industry and Florida's Springs. Journal of Land Use 19:569-596.

Seaman, D.E. and R.A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77:2075-2085.

Shane, S.H. 1983a. Manatees and power plants. Sea Frontiers 29:40-44.

Shane, S.H. 1983b. Abundance, distribution and movement of manatees (*Trichechus manatus*) in Brevard County, Florida. Bull. Mar. Sci. 33:1-9.

Shane, S.H. 1984. Manatee use of power plant effluents in Brevard County, Florida. Florida Scientist 47:180-187.

Smith, K.N. 1993. Manatee habitat and human-related threats to seagrass in Florida: a review. Florida Dept. of Environmental Protection (vi + 38) Tallahassee, FL.

Sorice, M.G., C.S. Schafer, and D. Scott. 2003. Managing Endangered Species within the Use/Preservation Paradox: Understanding and Defining Harassment of the West Indian Manatee (*Trichechus manatus*). Coastal Management 31:319-338.

U.S. Census Bureau. 2013. State & county Quickfacts: Citrus County, FL. Retrieved on 15 March 2015 from http://quickfacts.census.gov.

U.S. Census Bureau. 2014. State & county Quickfacts: Florida. Retrieved on 01 March 2015 from http://quickfacts.census.gov.

U.S. Fish and Wildlife Service (USFWS). 1980. Habitat as a Basis for Environmental Assessment. ESM 101. 101 ESM, U.S. Fish and Wildlife Service/Division of Ecological Services, Washington, D.C.

U.S. Fish and Wildlife Service (USFWS). 2001. Florida Manatee Recovery Plan, (*Trichechus manatus latirostris*), Third Revision. U.S. Fish and Wildlife Service. Atlanta, Georgia. 144 pp.

U.S. Fish and Wildlife Service (USFWS). 2010. Endangered and Threatened Wildlife and Plants; Emergency Rule To Establish a Manatee Refuge in Kings Bay, Citrus County, FL. Federal Register 75 (09 November 2010):68719-68723.

U.S. Fish and Wildlife Service (USFWS). 2014. Draft Environmental Assessment: Manatee Wildlife Viewing on Crystal River National Wildlife Refuge Three Sisters Springs Citrus County, Florida (December 2014). 165 pp.

Walsh, C. J., C.A. Luer and D.R. Noyes. 2005. Effects of environmental stressors on lymphocyte proliferation in Florida manatees, *Trichechus manatus latirostris*. Veterinary Immunological Immunopathology 103:247-256.

Wooding, J. 1997. An assessment of manatee behavior relative to interactions with humans at Three Sisters Springs, Crystal, River, Florida. A report submitted to the U.S. Fish and Wildlife Service. Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, Florida. 68 pp.

Wright, I.E., J.E. Reynolds, III, B.B. Ackerman, L.I. Ward, B.L. Weigle, and W.A. Szelistowski. 2002. Trends in manatee (Trichechus manatus latirostris) counts and habitat use in Tampa Bay, 1987-1994: implications for conservation. Marine Mammal Science 18:259-274.

APPENDIX A

Descriptive statistics for the total number of manatees by season and year during the winter seasons.

Season	Year	N	Mean	Std. Dev	Min	Max
Winter	1983	19	73.79	26.57	18	120
Winter	1984	9	93.67	17.08	54	112
Winter	1985	23	65	27.57	7	112
Winter	1986	16	103	42.17	14	161
Winter	1987	16	118.19	40.26	16	162
Winter	1988	13	114.54	51.19	42	176
Winter	1989	16	131.06	67.46	16	248
Winter	1990	15	107.73	52.49	30	244
Winter	1991	15	140.8	59.98	28	212
Winter	1992	15	136.87	70.25	37	278
Winter	1993	16	119.94	69.38	5	226
Winter	1994	16	142.69	58.66	49	271
Winter	1995	14	156.79	59.76	23	248
Winter	1996	17	109.82	68.90	8	211
Winter	1997	15	155.87	67.98	67	284
Winter	1998	18	111.5	64.76	28	235
Winter	1999	19	159.84	56.42	59	250
Winter	2000	16	185.75	86.70	20	301
Winter	2001	15	123.87	79.95	37	257
Winter	2002	17	178.53	82.74	5	282
Winter	2003	9	169.56	52.47	96	255
Winter	2004	11	164.09	81.94	29	273
Winter	2005	12	175.92	96.61	52	310
Winter	2006	11	184.09	40.83	118	263
Winter	2007	9	135.33	75.36	39	230
Winter	2008	10	195.5	117.07	32	344
Winter	2009	11	276.36	168.75	16	566
Winter	2010	9	287.78	182.61	25	516
Winter	2011	11	191.64	163.41	13	543

APPENDIX B

Descriptive statistics for the total number of manatees by season and year during the summer seasons.

Season	Year	N	Mean	Std. Dev	Min	Max
Summer	1983	2	67.5	16.26	56	79
Summer	1984	8	11.13	6.64	2	20
Summer	1985	18	19.94	18.55	2	71
Summer	1986	5	26	27.18	2	71
Summer	1987	3	80.33	42.85	41	126
Summer	1988	8	40.25	43.03	4	121
Summer	1989	4	80.5	49.13	22	135
Summer	1990	4	32.5	17.99	19	57
Summer	1991	10	57	43.21	5	128
Summer	1992	21	38	39.52	7	154
Summer	1993	9	50	55.89	6	191
Summer	1994	10	59.8	49.60	6	165
Summer	1995	16	48	38.93	8	117
Summer	1996	6	58.33	27.70	16	88
Summer	1997	10	47.5	29.44	17	107
Summer	1998	6	32.67	17.00	9	57
Summer	1999	6	87.67	72.80	47	235
Summer	2000	10	58.3	26.99	19	105
Summer	2001	4	46	4.69	43	53
Summer	2002	5	47.4	22.79	30	84
Summer	2003	5	40.8	9.81	29	55
Summer	2004	15	38.53	19.39	13	81
Summer	2005	14	58.29	21.65	31	104
Summer	2006	14	55.71	22.93	17	108
Summer	2007	16	46.75	17.4	24	78
Summer	2008	11	56.82	43.62	16	170
Summer	2009	16	36.94	22.48	1	80
Summer	2010	15	42.6	37.35	11	166
Summer	2011	15	43.93	23.19	28	118
Summer	2012	15	45.2	49.09	13	213