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

Danielle C. Sattelberger[1], Joyce M. Kleen[2], Aarin-Conrad Allen[1], and Richard O. Flamm[3]
[1]Nova Southeastern University, Halmos College of Natural Sciences and Oceanography, 8000 N. Ocean Drive, Dania Beach, FL 33004, USA, ds1715@nova.edu, aa1429@nova.edu
[2]U.S. Fish and Wildlife Service, Crystal River National Wildlife Refuge, 1502 SE Kings Bay Drive, Crystal River, FL, 34429, USA, joyce_kleen@fws.gov
[3]University of South Florida – St. Petersburg, Kate Tidemann College of Business, 140 7th Avenue S., St. Petersburg, FL 33701, USA, Richard.Flamm@MyFWC.com

Abstract

The largest Florida manatee (*Trichechus manatus latirostris*) aggregation at a natural warm-water site occurs in Kings Bay, Crystal River, FL. Since 1983, manatee protection areas within Kings Bay have been created by the U.S. Fish and Wildlife Service and the State of Florida 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 suggested 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. Spatially explicit models using Geographic Information System (GIS) analysis revealed a strong correlation between high manatee density and artesian springs in Kings Bay during the winter seasons. Highest abundances were identified at three locations: King Spring, Three Sisters Springs, and Magnolia Springs, which coincide with pre-existing sanctuary designations; however, additional coverage is advocated to support the overflow of manatees outside of sanctuary boundaries. Manatees continued to use Kings Bay in the summer seasons, but no significant changes in average or peak manatee abundance were detected ($p = 0.71$ and $p = 0.45$ respectively). Average manatee counts increased by only 0.109 animals per year over the summer periods. As density patterns were not uniform across summer periods, a consideration of additional boat speed regulations is recommended. Within a habitat type, the Magnolia Springs, Banana Island, and Three Sisters Springs sanctuaries exhibited higher densities, suggesting differences in quality among sanctuaries. Years coinciding with extreme cold weather events also generated greater numbers of manatees.

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

INTRODUCTION

The Florida manatee is a federally- and state-listed endangered species that inhabits the shallow, slow-moving bodies of water including coastal bays, estuaries, and rivers, and can be found in fresh, salt, or brackish waters within the southeastern United States (Irvine and Campbell 1978; Lefebvre *et al.* 1989). Natural and anthropogenic mortalities, including harmful algal blooms (HABs), cold-induced stress, and particularly watercraft strikes and loss of warm-water refuges (Runge *et al*. 2015), continue to threaten the long-term viability of the Florida manatee population. Florida manatees reach sexual maturity between three to seven years of age and give birth to one calf every three years after a gestation period of twelve to thirteen months (Marmontel 1995; Odell *et al.* 1995; O'Shea and Hartley 1995; Rathbun *et al.* 1995; Reid *et al.* 1995; Anderson 2002). This life-history strategy of maturing slowly and investing a great deal of time and energy into the development of offspring requires stable adult survival rates to prevent the loss of species to extinction (MacArthur and Wilson 1967; O'Shea and Hartley 1995; O'Shea and Langtimm 1995; Marmontel *et al.* 1997; Langtimm *et al.* 1998).

Reliance on Warm-Water Refugia

The ability of Florida manatees to thermoregulate in cold waters is limited by their low metabolic rate and high thermal conductance (Irvine 1983; Bossart 1999; FWC 2007; Halvorsen and Keith 2008). Manatees in Florida are susceptible to cold stress syndrome, a condition characterized by hypothermia, frostbite, pneumonia, immune system suppression or a combination of all these factors (O'Shea *et al.* 1985; Bossart *et al.* 2003; Walsh *et al.* 2005; Halvorsen and Keith 2008) that can be fatal after long-term exposure to water temperatures below 20 degrees Celsius (Laist and Reynolds 2005a, 2005b). A seasonal migration to thermal refuges at 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) result from changing water temperatures (USFWS 1999). Severe or extended winters may also cause manatees to remain in the springs longer (Reep and Bonde 2006). Many manatees exhibit site fidelity, utilizing the same warm-water sources annually (Shane 1983a; Reid *et al.* 1991; Deutsch *et al.* 2003). After weaning, calves often follow the same migration routes as their mothers (Marmontel 1995). Mortality rates caused by cold stress syndrome have shown to have a significant impact on the manatee population (O'Shea *et al.* 1985; Ackerman *et al.* 1995; Laist and Reynolds 2005a, 2005b). A substantial number of manatee mortalities related to cold stress syndrome were documented in the winters of 2009 and 2010, years that produced unusually cold and record low temperatures in Florida. An additional 275 manatees with undetermined causes of death were recorded those years (FWC 2015), many of which could have been cold stress induced.

Florida has many potential natural warm-water refuges for the manatee with more than 900 freshwater springs mostly located in the northern and central portions of the state (Florida Department of Environmental Protection 2012). These springs produce water temperatures at a constant ≥ 20°- 22°C year round, allowing manatees to thermoregulate during the colder months (Laist and Reynolds 2005a, 2005b; Kleen and Breland 2014). The springs are also heavily utilized by humans (Kochman *et al.* 1985; Buckingham *et al.* 1999; King and Heinen 2004; Sorice *et al.* 2006); public visitation (i.e., fishing, boating, swimming, and other in-water activities) has shown a steady increase over time in areas such as the Crystal River National Wildlife Refuge (CRNWR) (USFWS 2014).

This study assesses the current manatee protections in Kings Bay and makes

recommendations based on an analysis of 30 years of aerial survey data. Our specific objectives were; (1) to compare manatee distribution and abundance by season and over time, (2) to compare the distribution and abundance results with current manatee regulations and identify possible deficiencies in protection, and (3) present recommendations for enhancing manatee protection.

METHODS

Study Area

The natural springs and adjacent forage areas of Kings Bay, Crystal River located in Citrus County, Florida (Fig. 1) have historically provided manatees with warmth and sustenance (USFWS, unpublished report). Kings Bay is a designated manatee refuge; manatee protection areas within Kings Bay have been created since 1983 by the United States Fish and Wildlife Service (USFWS) and the State of Florida to allow manatees continued access to critical warm-water sites and quality foraging and resting areas (USFWS 2014). Waterborne activities, habitat degradation, and increasing boat traffic are of growing concern to the welfare of manatees (Buckingham 1990; Sorice *et al.* 2003). The year-round refuge designation restricts waterborne activities and boat speeds. During the winter season (November 15 – March 31), protection measures in the bay include State protection zones and seven Federal manatee sanctuaries. Sanctuaries have been established at manatee high-use sites in areas that manatees were already using, or trying to use, to give them a place to rest and thermoregulate undisturbed (USFWS 2014). 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. In order to determine whether restrictions are necessary in areas of regular or periodic manatee use, several factors are considered by USFWS, including but not

limited to the number of manatees and seasonal and/or year-round patterns of manatee use (FWC 2011).

Aerial Surveys and GIS

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. Data from 711 aerial surveys flown between 1983 and 2012 were obtained from U.S. Fish and Wildlife Service - Crystal River National Wildlife Refuge headquarters in Crystal River, Florida (Kleen and Breland 2014). A total of 18,793 points each representing one to many manatees were mapped. 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. Shapefiles for each survey were sorted into two periods to reflect seasonal shifts: winter (November 15 – March 31) when protection measures and sanctuaries are implemented, and summer (April 1 – November 14) when sanctuary protections are withdrawn. 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. 1). Using the Spatial Analyst extension, kernel density analysis was used to generate a surface representing areas of high manatee use for each season per year and all winters and summers between the years of 1983 and 2012. An output cell size of 2 meters 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.

Data Analysis

Average manatee counts were calculated for the winter and summer seasons. The peak count for each season was also identified 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

Kings Bay

Manatee relative densities for winter and summer are illustrated in Figures 2 and 4. Densities were higher and more spatially concentrated in winter than summer. Manatees were most densely clustered at King Spring, Three Sisters Springs, and Magnolia Springs, locations that overlap well with existing sanctuaries. However, the waters between Banana Island and Sunset Shores support a high density of manatees that surround King Spring, and this area extends outside sanctuary boundaries. The largest and densest aggregations (0.53 – 0.58 manatees per sq. meter) occurred at King Spring, the largest source of warm water within the bay (Buckingham 1990). The remaining three sanctuaries, Tarpon Springs, Warden Key, and Buzzard Island, did not support such high densities of manatees as compared to the other four

sanctuaries mentioned. The areas occupied by high densities of manatees display a consistent pattern of winter use across the 30-year time span (Fig. 3).

A dramatic shift in distribution and density of manatees was observed during the summer months over the 30-year time span. Manatees were widely distributed throughout Kings Bay, yet a dense concentration of manatees (0.025 – 0.027 manatees per sq. meter) occupied King 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. 5). This reveals that manatees ranged far beyond the high density areas depicted in the kernel density analysis of all summers from 1983 to 2012.

A total of 58,535 manatee 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. Winter manatee counts within Kings Bay increased significantly between 1983 and 2012 (Fig. 6), 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. In later years, 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 weather event in winter. The annual average rate of increase of the total number of manatees occupying Kings Bay over the 30-year

time span (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. 6).

Kings Bay experienced no significant change in manatee counts during the summer months (Average: R = 0.05, $p = 0.76$; Peak: R = 0.24, $p = 0.19$) (Fig. 7). 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 summer manatee counts increased by an insignificant 0.109 animals per year. 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.

The results of the GLM revealed 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 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. Overall manatee densities in the Sunset Shores, Warden Key, Tarpon Springs, and Buzzard Island sanctuaries were much lower and displayed negative trends in manatee density over time (Figure 8). Years where there were significantly more manatees coincided with severe winters (Table 1).

DISCUSSION

CRNWR staff have conducted aerial surveys since 1983 when the refuge was established for the protection of the West Indian manatee. Accurate manatee counts from aerial surveys may be construed due to availability bias (the probability of an animal being seen from the surface) and visibility bias (the probability of an animal being detected by the observer) (Packard *et al.* 1987; Edwards *et al.* 2007). Visibility bias is exacerbated by factors such as environmental

conditions (i.e., bad weather conditions and dense vegetation), behavior of the manatees, and observer fatigue (Pollock and Kendall 1987; Wright *et al.* 2002). However, there were several properties of the Crystal River aerial surveys that reduced the influence of bias on the observations. To standardize potential observer bias, the same flight path was flown on every survey with the same observer used for almost all of the surveys between 1983 and 2012. Water clarity ranked at a 2.38 ± 10 (fair to good) on a scale of 1 (poor) to 5 (excellent) without any significant changes over the 30 years of surveying (Kleen and Breland 2014). This study was not designed to determine exact population numbers of manatees but rather to determine spatial and temporal changes in distribution and relative abundance within critical habitat to deliver an effective management strategy for this endangered species.

Kings Bay

The abundance and 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 (Hartman 1979; Kochman *et al.* 1985; Rathbun *et al.* 1990), altered behavior (Hartman 1979; Kochman *et al.* 1985), the availability and condition of warm-water refuges (Powell and Rathbun 1984; Kochman *et al.* 1985), and increased injury and mortality (Odell and Reynolds 1979; O'Shea *et al.* 1985). Manatee abundance has increased over the last 30 years as well as in locations where manatees congregate. One constant over the year is that with the onset of colder weather, manatees concentrate in the eastern and southern portions of the bay, aggregating near major springs to keep warm. Recommendations along with their justification are presented below.

Banana Island and Sunset Shores

The waters situated between the Banana Island and Sunset Shores sanctuaries encompassing King Spring support a very dense cluster of manatees during the winter that do not lie within sanctuary boundaries. Therefore, we recommend that between November 15 and March 31 the southern portion of the Banana Island sanctuary be expanded to allow for greater protection (Fig. 9), while still allowing boaters to navigate between the two sanctuaries. The 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 USFWS 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 Banana Island sanctuary have steadily increased. Sunset Shores had an increasing trend in manatee numbers until 1994 when the Buzzard Island, Warden Key, and Tarpon Springs sanctuaries were designated, suggesting a shift in usage. It is possible that manatees place a heavier reliance on the Banana Island sanctuary and surrounding areas of King Spring for warmth.

Three Sisters Springs and Magnolia Springs

Three Sisters Springs and Magnolia Springs are also areas with pre-existing sanctuaries providing vital protection to manatees. However, based on the high usage of these areas by manatees, expansions of these two sanctuaries are recommended. An additional no entry area positioned at the southeast portion of the Magnolia Springs sanctuary should be considered (Fig. 9). Human disturbance at King Spring may be the source of groups developing at Magnolia Springs (Kochman *et al.* 1985). Other springs within the bay are less valuable to manatees due to unfavorable conditions such as smaller size, limited discharge, or narrow passes (Hartman 1979). Three Sisters Springs attracts thousands of visitors each year and is heavily regulated (Allen *et*

al. 2014; USFWS 2014). 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, which comprises of three warm-water spring heads, was a common resting spot for manatees, and restrictions were proposed to allow sufficient space for manatees to rest free from harassment (USFWS 2014). 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 expansion of two no-public entry areas by closing the eastern and western lobes of Three Sisters Springs (USFWS 2015). The Service's recommendation is consistent with the map of manatee distribution and abundance reported here (Fig. 2), suggesting 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. 9). Another sanctuary designation is proposed across the waterway from the existing Three Sisters Spring sanctuary.

Warden Key, Tarpon Springs, and Buzzard Island

The Warden Key, Tarpon Springs, and Buzzard Island sanctuaries, established in 1994, are not used by manatees to the same extent as the other sanctuaries within Kings Bay and are therefore subject to reevaluation. The results of this study suggest that the usage and quality of the Warden Key, Tarpon Springs, and Buzzard Island sanctuaries may have changed over time. A possible explanation for this observation may be the change in distribution of resources utilized by manatees, encouraging manatees to relocate to newer sanctuaries. This apparent shift

may be due to an increase in salinity causing manatees to move to waters of lower salinity or higher quality food sources (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 salt tolerant plants. 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) like Warden Key and Buzzard Island. An additional factor is that these sanctuaries do not supply as much warmth as other sites within the bay to provide thermal refuge to wintering manatees. 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 (Van Meter 2001; Flamm *et al.* 2013). Human disturbance is another likely factor, as manatee responses to people and boats have been well documented within Kings Bay (Sorice *et al.* 2003). Observations made associated with increasing numbers of people and boats include increases in swimming, milling, and cavorting behaviors and decreases in resting, feeding, and nursing behaviors of manatees (Abernathy 1995; Wooding 1997; King and Heinen 2004).

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. 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 (Kleen and Breland 2014)

to better assess the abundance and distribution patterns of manatees within the bay and to aid in the decision process regarding sanctuary relocations.

During the warm seasons, manatees are not limited by water temperatures and they will leave the warm-water refuges (Hartman 1979; Kochman *et al.* 1985; Rathbun *et al.* 1990; King 2002). Some of these sites remain aggregation areas for manatees for accessing fresh water, not for warm temperatures (Hartman 1974; Powell *et al.* 1981; Powell and Rathbun 1984; Ortiz *et al.* 1999; Butler *et al.* 2003; Ortiz and Worthy 2006). In this regard, manatees are still found in Kings Bay, often clustering around King Spring. Early studies reported that relatively few manatees were observed during warmer months using wintering sites (Irvine and Campbell 1978; Hartman 1979). 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. Females with young calves also tend to stay in the summer months and do not migrate as readily. 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 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, a heavier reliance must be placed on boat speed zone regulations to minimize manatee injury or death during a time when substantial recreational activity takes place.

Concluding Remarks

Crystal River wildlife managers currently face the challenge of enhancing manatee protection while providing visitors opportunities to encounter the endangered marine mammal in the wild. As the number of visitors and demand for ecotourism increases, directing a plan that protects the target species from adverse impacts while improving the visitor experience is necessary. The efforts made in this study hope to aid in the enhancement of both awareness and manatee presence and protection.

As illustrated by the results of this study, extending portions of sanctuary boundaries are recommended to provide necessary protection for manatees using Kings Bay. Additional efforts in both enforcement of policies and public education are needed as well. The continuation of aerial manatee surveys will be critical in monitoring the effectiveness of the sanctuaries within Kings Bay. Further analysis of the effects of altered habitat and human activity is also recommended to guide the conservation of this endangered species. Finally, 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.

ACKNOWLEDGEMENTS

This research was conducted as part of a Master of Science thesis project for DCS at Nova Southeastern University. DCS thanks committee members Dr. Richard Flamm, Dr. Curtis M. Burney, and Dr. Patrick Hardigan for their support and constructive remarks, the late Dr. Edward O. Keith for his encouragement and inspiration, Aarin-Conrad Allen who assisted with data analysis and provided further insight on manatees and GIS technical support for this project, and Joyce M. Kleen for providing the aerial survey data used in this study. Additional thanks to

Amber D. Breland of the United States Fish and Wildlife Service, North Mississippi National Wildlife Refuge. This work was supported by the U.S. Fish and Wildlife Service - Crystal River National Wildlife Refuge headquarters in Crystal River, Florida. This research was conducted under the authority of special use permit no. 13005.

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., 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.

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

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

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.

Buckingham, C.A., L.W. Lefebvre, J.M. Schaefer, and H.I. Kochman. 1999. Manatee Response to Boating Activity in a Thermal Refuge. Wildlife Society Bulletin 27:514-522.

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).

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, and J.A. Powell. 2007. Estimation

of Detection Probability in Manatee Aerial Surveys at a Winter Aggregation Site. The Journal of Wildlife Management 71:2052-2060.

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. Accessed 26 December 2013. <http://www.dep.state.fl.us/springs/faq.htm>.

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). 2011. Florida Manatee Sanctuary Act. Florida Administration Code Chapter 68C-22. Fla.Stat.Ann.x370.12subd.(2).

Florida Fish and Wildlife Conservation Commission (FWC). 2015. 2015 Manatee Mortalities. Accessed 28 March 2015. < http://www.myfwc.com/research/manatee/rescue-mortality-response/mortality-statistics/2015/>.

Frazer, T.K., S.K. Notestein, M.V. Hoyer, J.A. Hale, and D.E. Canfield, Jr. 2001. Frequency and duration of pulsed salinity events in Kings Bay. Final report submitted to the Southwest Florida Water Management District (SWFWMD Contract No. 98CON000041). Gainesville: University of Florida.

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.

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. 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.

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.

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. 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.

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.

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.

Marmontel, M., S.R. Humphrey, and T.J. O'Shea. 1997. Population Viability Analysis of the Florida Manatee (*Trichechus manatus latirostris*), 1976-1991. Conservation Biology 11:467-481.

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

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 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.).

Packard, J.M., R.C. Summers, and L.B. Barnes. 1987. Variation of Visibility Bias during Aerial Surveys of Manatees. The Journal of Wildlife Management 49:347-351.

Pollock, K.H. and W.L. Kendall. 1987. Visibility Bias in Aerial Surveys: A Review of Estimation Procedures. The Journal of Wildlife Management 51:502-510.

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.

Runge, M.C., C.A. Langtimm, J. Martin, and C.J. Fonnesbeck. 2015. Status and threats analysis for the Florida manatee (Trichechus manatus latirostris), 2012. U.S Geological Survey Open-File Report 2015-1083.

Sattelberger, D.C. 2015. Seasonal Warm-Water Refuge and Sanctuary Usage by the Florida Manatee *(Trichechus manatus latirostris)* in Kings Bay, Citrus County, Florida. Master's thesis. Nova Southeastern University. Retrieved from NSUWorks, Oceanographic Center. (43) <http://nsuworks.nova.edu/occ_stuetd/43>.

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.

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.

Sorice, M.G., C.S. Shafer, and R.B. Ditton. 2006. Managing Endangered Species Within the Use-Preservation Paradox: The Florida Manatee (*Trichechus manatus latirostris*) as a Tourism Attraction. Environmental Management 37:69-83.

U.S. Fish and Wildlife Service (USFWS). 1999. Multi-Species Recovery Plan for South Florida. Accessed 28 August 2015. <http://www.fws.gov/verobeach/MSRPPDFs/WestIndianManatee.pdf>.

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.

U.S. Fish and Wildlife Service (USFWS). 2015. U.S. Fish and Wildlife Service to Enact Additional Manatee Protection Measures at Three Sisters Springs (February 2015). 4pp.

Van Meter, V.B. 2001. The Florida manatee. Florida Power & Light Company, Miami, Florida.

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.