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Physiological Constraints on Warm-Water Habitat Site Selection and Utilization by the Florida Manatee (Trichechus manatus latirostris) in East Central Florida

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PHYSIOLOGICAL CONSTRAINTS ON WARM-WATER HABITAT SITE SELECTION AND UTILIZATION BY THE FLORIDA MANATEE (TRICHECHUS MANATUS LATIROSTRIS) IN EAST CENTRAL FLORIDA

by

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ABSTRACT

Living at the northern limits of its geographic range, the Florida manatee is particularly susceptible to cold stress-related mortality during the winter months, with most deaths occurring in the lower two-thirds of the state. Contributing to this cold stress susceptibility is the manatee's limited physiological and behavioral responses available when thermally stressed. While capable of migrating south in response to falling water temperatures, manatees must still find warm water when ambient river temperature drops below 20°C for more than a few days. This is in part due to the species low metabolic rate, limited capacity for thermogenesis, and limited ability to raise its metabolic rate. Prolonged exposure to cold temperatures may result in cold stress syndrome, which involves a number of potentially life-threatening, if not fatal physiological changes. Survival during the winter months is therefore, dependent upon the manatee's ability to balance basic physiological needs, primarily the need to forage and to obtain fresh water with the need to stay warm.

When identifying which animals are most susceptible and where, analyses of statewide manatee mortality records from 1996 through 2011 (n = 823) indicated that, size and location matter. Medium to large-sized calves accounted for the majority of documented death from cold stress (46.6%), while subadults and small calves were the least represented size classes (14.3 % and 9.5%, respectively). Adults slightly outnumbered subadults (15.8%). Males outnumbered females in all size classes but gender differences were not statistically significant. With regards to location, two areas of the state, the southwest and central east coasts showed the highest incidents of cold stress-related mortality. Both are regions with no primary, natural warm-water springs and whose principal warm-water refugia are power plant effluents. Brevard County on the central east coast is the area most at risk during cold weather events accounting for more than 25% of all cold stress deaths statewide. Warm-water sites within this region are few and relatively underrepresented in the literature in an area well-studied in terms of manatee abundance and distribution relative to the operational power plant. Results from cold stress data analyses emphasize the importance of identifying and characterizing the physical attributes of both known and suspected secondary warm-sites used by manatees in this region for both long and short term protection of the species, and its critical habitat.

Three locations within Brevard County identified as passive thermal basins (PTBs), and classified as secondary warm-water sites, have been documented supporting in excess of 100 manatees on numerous occasions, and during winters of varying severity. Unique in physical appearance, distance to forage, hydrology including thermal profiles, and when it was used by manatees, each site challenged the accepted definitions and criteria of what constitutes an acceptable and appropriate warm-water site.

Through analyses of photo-identification records, site fidelity at two of these warm-water sites, the Berkeley Canal and the Desoto Canal, was established for a minimum of 20 highly identifiable animals, 15 of which used adjacent sites within the same year, and 6 that used both sites but during different years. Observations of daily use patterns within the sites supported optimization of thermoregulation through adjustments in both vertical and horizontal movement, the latter of which seemed to follow the path of the sun. Manatees using the sites also made use of bottom sediment presumably to stay warm at all three locations. Temperature data indicated that water temperatures monitored in the sediment at secondary sites were some of the highest in the county. The predictable movements during all but the coldest weather fronts indicated that manatees utilized these sites during the early morning and afternoon hours when ambient river temperatures were coldest, gradually returning to the river to feed as ambient temperatures began to rise later in the afternoon.

The availability of PTBs in proximity to primary warm-water sites within the region may provide an important component needed for manatees to successfully balance the need to forage with the need to stay warm by providing a network that allows for more efficient foraging while reducing exposure to sub-critical ambient river temperatures. The challenge of balancing the need to forage and to maintain homeostasis in the face of thermal stress is complex. This complexity was best approached and better understood through use of a manatee energetics model. The model was designed to facilitate simulation of an unlimited number of different case scenarios involving the exposure of virtually created manatees to a variety of winter conditions as might be experienced by real manatees in a natural system. Sixty-four different simulations were run using six virtual manatees of differing ages, gender, physical parameters, and knowledge of warm-water sites. Simulations were conducted using actual winter water temperature data from Brevard secondary sites and the ambient river from both a mild and a severe winter season. Outcomes, measured as changes in physical parameters indicative of body condition (i.e. mass, percent body fat, blubber depth, girths, etc.), showed that all else being equal, calves in the 2 year-old range fared poorly in all scenarios when compared to individuals of larger size. Subadults fared better than larger adults. This outcome illustrates the complex relationship between size, energy requirements and the synergistic effects of body mass, body fat and blubber thickness on SA:V ratio. Model outcomes agree closely with manatee cold stress mortality analyses predicting that medium to large-sized calves are most susceptible to CS, followed by adults, then subadults.

Because all models are simplifications of complex systems, the manatee energetics model is not without its flaws and limitations. The current version of the model could not predict the point at which cold stress mortality would occur. However, a cold stress warning system incorporated into the design alerts the user if potential CSS is likely based on changing physical parameters. Another limitation was the inability of the model to account for the behavioral plasticity of individual subjects since virtual manatees respond to water temperatures based on the user defined rules. A number of additional limitations related to gaps in existing manatee data the gaps were identified and defined. Despite these gaps, the model is designed to allow for incorporation of additional interactions, feedback loops and relevant data as it becomes available and as additional physiological interactions and energy requirements are more clearly defined.

Sensitivity analyses, a feature of the model that allowed for modifications in a number of physical as well as environmental parameters, provided an otherwise unlikely opportunity to see how incremental changes in input values, specifically the starting values for mass, percent body fat and blubber depth affected the model's outcome. Ultimately the goal of the model was to facilitate a better understanding of complex relationships by challenging our preconceived understanding of the manatee and its environment.

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Dedicated

To my parents, Eva and James,

For giving me roots and wings.

I miss you beyond all words.

And to Nelio,

An uncommonly decent human being.

For his guidance, moral support, and friendship.

How I wish you could have stayed here longer.

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INTRODUCTION

Many species live at the limits of their geographical ranges, imposing upon them numerous physiological and environmental challenges that threaten their survival. In response to these challenges living organisms may possess adaptations, or “malleable features of physiology that when modified in relation to changes in the physical or biological characteristics of the environment, contribute to increased reproduction of the species or inclusive fitness” (McNab 2002).

Adaptations are responses to natural selection that can be categorized as either behavioral or physiological. Throughout the animal kingdom examples of behavioral adaptations are numerous and include responses such as seasonal migrations to warmer latitudes (Corkeron and Conner 1999), use of microclimate to thermoregulate (Adolph 1990), feigning death or ”playing possum” when threatened (Francq 1969) and hibernation (Watts *et al*. 1981) to name a few. Examples of physiological adaptations are likewise numerous and include the ability to acclimate or acclimatize with respect to changing environmental conditions for example, by altering blood chemistry with respect to changes in altitude (Moore and Regensteiner 1983), increasing pelage thickness in response to changes in ambient temperature (Hart *et al* 1965), adjusting metabolic rates in response to reduced food intake (Rosen and Trites 1998), and accelerating the rate of development in response to dwindling resources (Pfennig 1990).

While an adaptation may facilitate an individual’s ability to maintain a constant internal environment, (homeostasis), almost all responses to environmental challenges involve secondary consequences or costs (Slobodkin 1964). Responses are rarely the result of a singular adaptation, and responses may have both behavioral and physiological components.

Of the four extant species of the order Sirenia, the Florida manatee (*Trichechus manatus latirostris*) lives at the extreme northern limits of the species' distribution. During the winter months Florida manatees may experience thermal stress when water temperatures fall below 20°C for two to three days (Bossart 2001). In response to declining water temperatures during winter months, Florida manatees may undergo seasonal migration to warmer latitudes and/or seek refuge in a network of warm-water refugia. Despite the manatees' tendency to migrate or seek out warm water, physiological limitations related to their low metabolic rate place them in a precarious position when trying to meet their metabolic needs, particularly during the winter months.

Fossil evidence suggests that at least 35 species of Sirenians have existed over the past 50 million years (Domning 2001, Reep and Bonde 2006). Currently, only four extant species from two families remain- all of which are considered endangered throughout their range. The three species in the family Trichechidae include the West Indian manatee (*Trichechus manatus*), found in the tropical and subtropical coastal regions of the southeastern United States and the Caribbean; the West African manatee (*Trichechus senegalensis*), found in both fresh and salt water habitats along coastal tropical West Africa; and the Amazonian manatee (*Trichechus inunguis*), found only in the fresh waters of the Amazon River. The fourth extant species, the dugong (*Dugon* *dugong*), is the only living member of the Family Dugongidae. Its range includes tropical and subtropical coastal waters in the Indian and Pacific Ocean (Lefebvre *et al* 1989) and is the only member of the order found exclusively in salt water.

The West Indian manatee is further divided into two subspecies: the Antillean manatee (*Trichechus manatus manatus*) and the Florida manatee (*Trichechus manatus latirostris*). The Antillean manatee can be found throughout the West Indies, the Caribbean, the coastal waters and rivers of Mexico (Lefebvre *et al.* 1989), and the northern and northeastern coast of South America in either fresh or salt water. The Florida manatee can be found year-round in the shallow rivers, estuaries and coastal waters of the Florida peninsula with a few individuals dispersing as far west as Texas and as far north as Massachusetts during the summer months (Fertl *et al*. 2005, C. Beck, Pers. Com.). During the winter, manatee distribution is largely restricted to Florida due to the manatee's intolerance of cold water, limited capacity for thermogenesis, and low metabolic rate (Irvine 1983, Scholander and Irving 1943). From December through March manatees can be found in large aggregations around warm water sources, both natural and artificial, in both fresh and brackish water.

The Florida manatee (*Trichechus manatus latirostris*) is listed as endangered under the Federal Endangered Species Act of 1973, and as a marine mammal, is further afforded protection by the Marine Mammal Protection Act of 1972. At the State level the manatee is also listed as endangered, and is protected under the Florida Endangered and Threatened Species Act of 1977 and the Florida Manatee Sanctuary Act of 1978.

Despite decades of legal protection, the manatee faces numerous threats to its long-term survival including collisions with watercraft, being crushed by water control structures including gates and locks, entanglement in fishing gear, loss of suitable habitat, exposure to cold temperatures during the winter months, red tide toxicity, threats due to global climate change and threats from other human-related activities.

Weighing only 30 kg and measuring 120 cm on average at birth, the Florida manatee can grow to lengths of 3.9 m and weigh over 1,500 kg, with females tending to be larger and heavier than males at maturity (Odell 1982). Manatees are believed to reach sexual maturity at the age of 6 to 10 years (Reynolds and Odell 1991). Gestation lasts 12-13 months and females are capable of giving birth generally to a single calf, every 2 to 5 years (Reynolds and Odell 1991). While twinning does occur, it is relatively uncommon. Calving can occur during any month but peaks during the spring and early summer from April through July. Calves tend to stay with their mothers 1.5 to 2 years on average, during which time they learn feeding behaviors and migratory patterns including location and use of warm-water refugia. The manatee lifespan is believed to be in excess of 50 years (Marmontel 1995) with the oldest manatee born and raised in captivity recently reaching 65 years of age (South Florida Museum, http://www.mckenzienewsservice.com).

Manatees are semi-social (Hartman 1979). The only true pair-bonds are temporary and occur between mother and calf during the first two years of the calf's life. Manatees can be seen aggregating in mating herds consisting of one female and several males during the breeding season with peak mating season occurring between

April and October. Manatees can also be seen in aggregations around sources of warm water in an effort to thermoregulate when water temperatures fall below 20ºC (Irvine 1983).

Although typically found in fresh and brackish waters, manatees may occasionally use inshore coastal waters of the Atlantic Ocean during breeding activities, in search of food, and during fall and spring migrations. Manatees appear to be well adapted to a wide range of salinities (Bossart 2001). Although manatees may get some of their dietary fresh water requirement from digesting plant matter (i.e. pre-formed water) and metabolizing body fat (i.e. metabolic water), they appear to require regular access to freshwater (Hartman 1974, 1979, Maluf 1989, Ortiz *et al*. 1998, Ortiz *et al*. 1999). Irvine *et al*. (1980) speculated that manatees may consume sea water. While the anatomy of the manatee kidney supports potentially the drinking of salt water, water turnover studies by Ortiz *et al*. (1999) indicated that manatees do not voluntarily consume it. Ortiz *et al*. (1998) showed that manatees housed in both fresh and salt water can regulate blood electrolyte levels despite exposure to changes in salinity.

Sirenians are the only truly herbivorous marine mammal. West Indian manatees are considered to be generalists with respect to feeding habits because they will consume a wide variety (over 60 species) of fresh, brackish, and saltwater submerged and surface-floating vegetation (Reep and Bonde 2006, Reynolds and Odell 1991). Fresh water favorites include hydrilla (*Hydrilla verticillata*) and water hyacinth (*Eichhornia crassipes*). Among the seagrasses consumed manatees prefer manatee grass (*Syringodium filiforme);* turtle grass *(Thalassia testudinum)* and shoal grass

(Halodule wrightii). Manatees have also been known to consume salt and fresh water algae, mangrove leaves, grass clippings, oak leaves and even acorns (O'Shea 1986, Reynolds and Odell 1991). Once thought to have ingested other organisms incidental to grazing, field observations by Courbis and Worthy (2003), further supported by stomach content analyses by O'Shea *et al.* (1991), indicate that manatees may opportunistically consume organisms such as tunicates and invertebrates. In captivity they can be sustained on romaine, iceberg and leaf lettuce, carrots, beets and other types of vegetation.

In autumn, manatees begin a southern migration to warmer latitudes in response to falling temperatures. On the west coast, the naturally warm waters of the Crystal River and Homosassa Springs area provide winter refuge for animals primarily from the northwest Big Bend region (Powell and Rathbun 1984) (Figure 1). Artificial sources of warm water in the form of industrial outflows on the central west coast provide refuge for manatees in the Tampa Bay area. A single power plant outflow provides refuge for hundreds of manatees in the Ft. Myers region, while other manatees migrate further south into the Florida Everglades and Whitewater Bay (Reynolds and Wilcox 1986; Reynolds 2011). Manatees on the east coast of Florida typically migrate south. Lacking any substantial natural sources of warm water, several hundred manatees have consistently been documented using the warm water effluents of the two power plants in Brevard County (Shane 1984, Reynolds 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2009, 2010, 2011).

Large winter aggregations of several hundred individuals have been documented at additional power plants further south in Fort Lauderdale and Riviera Beach (Reynolds and Wilcox 1986, 1994, Reynolds 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2009, 2010, 2011).

(Map: FWC)

Figure 1 Available known warm-water sites

Manatees living in the St. Johns River typically migrate south into the Upper St. Johns River, where they can utilize the naturally warm waters of Blue Spring, while some Individuals in the northern portion of the St. Johns River likely migrate to the coast and then south with other manatees of the Atlantic Coast sub-population into the waters of the Halifax River, Mosquito Lagoon, and the Indian River Lagoon (Deutsch *et al* 2003).

Prior to the introduction of coastal power plants in the 1950's, anecdotal accounts indicated that the winter distribution of the manatee on the east coast was limited to waters of the St. Sebastian River and south (Moore 1951). Bangs (1895) documented two cases of manatee mortality in the winter of 1894-1895 in the St. Sebastian River, near its confluence with the Indian River Lagoon. Both manatees appear to have died due a sudden "freeze". Historically, the St. Sebastian River was considered to be the northern most limit of the manatee's winter range. It has been suggested that the introduction of electric power plants to the Indian River Lagoon in Brevard County and along the St. Johns River in Duval County in the late 1950's and early 1960's artificially expanded the winter range of the manatee some 340km northward (Bell 2000). These power plants, or industrial thermal refugia, attract manatees during periods of cold weather by expelling water into the surrounding lagoon that is several degrees warmer than ambient river water. Manatees have become habituated to these areas, and over the years mothers have "passed on" this migratory information to subsequent generations. This notion of being entrained to certain sites is supported by the observed site fidelity that has been documented by photo-identification and telemetry studies of individual manatees in both natural and artificial warm-water refugia (Beck and Reid

1995, Beck 2000, Deutsch *et al*. 2003). This potentially makes subadults, that may have been weaned early or separated from their mothers, raised in captivity, or which potentially did not experience a cold winter during their time with their mothers more susceptible to cold exposure due to their naivety with regards to the location of warm-water sites.

Many of the current industrial warm-water sites used by manatees are nearing the end of their planned operating life-span. Based on winter aerial surveys conducted yearly since 1977, two plants, Florida Power and Light-Cape Canaveral Plant (FPL-CC) and the Orlando Utilities Commission-Indian River Plant (OUC) (formerly Reliant Energy) located in Brevard County and the surrounding waters have consistently provided critical winter habitat for an increasing number of manatees (McGehee 1982, Rose and McCutcheon 1980, Shane 1984, Raymond 1981, Reynolds 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2009, 2010, 2011, Reynolds and Wilcox 1985, 1986, 1994).

According to recent winter aerial surveys by Reynolds (2011), the FPL-CC effluents supported a minimum of 560 and 301 animals during the 2009-2010 and 2010-2011 winter seasons, respectively. Synoptic surveys conducted on 14 January 2014 reported a total of the 5,077 manatees statewide. Slightly more than 21% (n = 1087) of the animals counted were located in Brevard County. Eighty-eight percent (n = 957) of the manatees in Brevard County were located at the FPL-CC site. The remaining 12% (n = 108) sought refuge at alternative locations (FWC, Unpublished data). According to the National weather Service, the 2009-2010 winter season was the coldest winter on record for the east central Florida region since 1981 (National Weather Service, http://www.srh.noaa.gov). FPL-CC and the surrounding region delineate the current northern limit of the manatee's winter range along the east coast. In September of 2010 the FPL-CC facility stopped operations. The plant was demolished, rebuilt and converted to a natural gas plant with construction completed in 2013 (Winifred Perkins, FPL, Pers. Com.). During the reconstruction an interim heating system was created and implemented at the plant for the sole purpose of supporting manatees that normally use the discharge plume of the power plant during the winter months. Nearby OUC's operations were suspended in late October 2010. Without intervention of some kind or alternative sources of warm water within which to take refuge, changes in the operations of these older plants may have drastic if not catastrophic consequences for those animals habituated to these artificial warm-water effluents. Potential loss of these artificial warm-water sites creates a critical need to identify alternate warm-water sites within the region, to document manatee use of these sites, to document each site's characteristics, and to ultimately better understand the physiological and behavioral constraints that determine which sites may be attractive to manatees and capable of sustaining them during the winter months.

Aggregation sites with at least one winter count of 50 or more manatees that are capable of sustaining manatees during prolonged periods of cold weather have been defined as primary warm-water sites (Laist and Reynolds 2005). These warm-water refuges are usually the result of outflow from natural springs and industrial discharge (Laist *et al*. 2013). Sites that support large numbers of manatees during brief, relatively mild cold spells but not throughout the colder winters have been defined as secondary warm-water sites. These sites may be the result of isolated areas of shallow or deep water subject to solar warming and minimal flushing or disturbance and are often referred to as passive thermal basins (PTB's) (Laist *et al*. 2013). Additional features that make PTB's attractive include the availability of fresh water and close proximity to foraging grounds. Secondary sites or PTB's are generally not considered sufficiently warm enough to sustain manatees during periods of extremely low or prolonged cold temperatures. They may be used intermittently along with primary sites to allow manatees access to distant feeding grounds while minimizing exposure to cold water. Few passive secondary sites have be investigated or quantified and little is known of manatee usage in these areas.

In the absence of warm-water refugia, manatees are susceptible to cold stress-related symptoms when exposed to water temperatures below 20ºC for more than a few days (Bossart 2001, Bossart *et al.* 2002). Although robust in appearance, manatees are limited in their ability to respond metabolically to low water temperatures (Worthy and Worthy *in prep*). Unlike other marine mammals of similar size, manatees have a limited capacity for thermogenesis, exhibit high thermal conductance and have a relatively low basal metabolic rate (Kleiber 1932, Irvine 1983, Miculka and Worthy 1995, Worthy *et al*. 2000, Worthy and Worthy *in prep*). The relatively high surface area-to-volume ratio of late juveniles and subadults (176-275 cm in length [O'Shea *et al*. 1985]) and apparent inability to elevate metabolic rate (Miculka and Worthy, 1995, Worthy *et al*. 2000; Worthy *and* Worthy *in prep*) coupled with potential inexperience in locating warm water sites makes them particularly susceptible to cold stress-related illness, metabolic shut-down and death. In large mammals, juvenile survival probabilities in general are more sensitive to variation in environmental conditions than are adult survival rates (Benton and Grant 1996).

Externally, cold stress syndrome (CSS) may be characterized by visible lesions of the epidermis and dermis (Figure 2). These lesions generally begin on the manatee's muzzle, the leading edges of the pectoral flippers and around the perimeter of the tail paddle (referred to as a halo) before progressing in more extreme cases to the rest of the body.

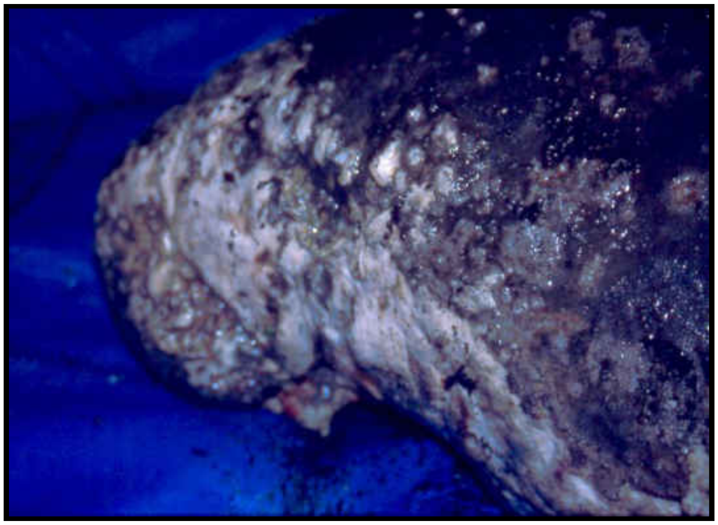

Photo: FWC: Permit No.MA770191

Figure 2 A rescued manatee exhibiting extensive cold stress lesions on the head

Tissue death in these areas often follows, resulting in sloughing of layers of epidermis and underlying tissue and often opportunistic secondary infection. Prolonged exposure to cold temperatures leads to a decline and eventually a halt in feeding (anorexia) and subsequent, often drastic, weight loss (cachexia) along the spine and ventrum. The ventrum may appear flattened or concave or may exhibit longitudinal folds due to weight loss. Manatees exposed for several days at a time may become lethargic and often seek shallow water. They may eventually become dehydrated and can develop enteritis. The lining of the intestines may slough. Dehydration may result in dry, hard, pelletized fecal matter resulting in constipation. There may be depleted fat stores (serous atrophy) around the heart and intestines (Worthy *et al*. 2000, Bossart *et al*. 2002). If environmental conditions do not change favorably and manatees suffering from cold stress cannot find warm water or if they are not rescued and treated appropriately, death may follow. In contrast, short term exposure to extreme drops in water temperature can result in rapid death from acute hypothermia, a condition that shows few if any external signs.

Manatees on the central east coast may be particularly at risk if prolonged cold temperatures prevail, given the tenuous nature of the future of aging power plants and the absence of warm water springs The two power plants in Brevard County belonging to FPL and OUC have undergone significant changes in the past five years, including the “mothballing” of the OUC Plant and the repowering of FPL-CC to a natural gas plant. Given the habitual nature of manatees, winter site fidelity, and the number of manatees utilizing these industrial effluents, the consequences of an FPL-CC shut-down could be catastrophic. According to photo-identification studies conducted by Beck (2000), approximately 24% of manatees using these two sites were not seen elsewhere (i.e. at other known warm water sites) during the winter months. Even in the presence of working power plants or other industrial outflows, winters with extremely low temperatures or acute cold snaps can result in the deaths of dozens of susceptible individuals. During the 1997-98 winter season, the closure of the Jackson-Smurfit Corporation's Pulp Mill in Fernandina Beach, Florida resulted in the deaths of several manatees and the need to rescue and relocate or rehabilitate several others (FWC, Manatee Mortality Database, Manatee Rescue Database, Deutsch *et al*. 2000). Juveniles and subadult manatees are not the only ones at risk in such cases. Any manatee caught far enough away from warm water sources, regardless of size, could fall into this category. In the 1989-90 winter season such an event resulted in the loss of 30 individuals in Brevard County over a period of 26 days, three of these were of adult size (>275cm) (FWC, State Manatee Mortality Database). In the event of a severe cold snap, even manatees seeking refuge at the power plants may be at risk if power plant effluents are incapable of maintaining water temperatures in the appropriate range, or if access to food sources requires prolonged exposure the sub-critical water temperatures.

While numerous short-term research projects have addressed the manatees' seasonal use of specific resources and locations of interest within Brevard County (Teidemann 1980, 1983, Hicks 1990, Heyman 1990), the majority of long-term studies have centered around manatee distribution, abundance, and aggregations at artificial refugia (Shane 1978, 1983, 1984, Reynolds 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003,2004, 2005, 2006, 2007, 2009, 2010, 2011) and in the Upper Banana River within the restricted zone of the Kennedy Space Center, and the Merritt Island National Wildlife Refuge (Irvine *et al*. 1978, Provancha and Provancha 1988, Provancha and Hall 1991), concentrating on locations primarily within the northern end of the county. Recent research by Provancha *et al*. (2012) looked at carrying capacity with regards to warm water and forage in 11 warm-water sites around the state including two known secondary sites in Brevard County. Numerous questions still remain as to the relative significance and use of potential secondary warm-water sites in Brevard County, the characteristics of those sites that make them attractive to manatees from a physiological as well as a behavioral perspective, and how these sites might complement known primary sites. The importance, future availability, and protection of these sites is also unknown and possibly in jeopardy. With an increase in the growth of Florida’s human population each year, intensive coastal development and subsequent taxing of natural resources, identification of existing and potential warm water sites is of critical importance to the persistence of these populations.

To address the issue of manatees and warm water, the Warm Water Task Force (WWTF) was created in 2000 under the direction of the U.S. Fish and Wildlife Service, as part of the Florida Manatee Recovery Plan (FMRP) (2001). The WWTF was delegated the task of identifying, evaluating, and monitoring manatee warm-water habitats, both natural and industrial, and to investigate suitable alternatives. Section

3.2.2.1 of the FMRP outlines the need for research focused on filling in gaps in available data regarding manatees, their warm water requirements and associated behavior. Efforts are needed to research manatee tolerances to low air and water temperature as well as their use of both warm-water refuges and surrounding habitat with respect to water temperature and the need for access to fresh water. Section 3.2.4.1 states the need to identify potential natural refuge sites near industrial warm water facilities used by manatees, and determine if enhancement of these sites is warranted. Reynolds (2000) proposed a list of several criteria to use when assessing the suitability of warm-water sites (Table 1). The criteria were developed to take into consideration both the “human factor” as well as the physiological needs of manatees.

Identification of additional secondary warm-water sites or PTBs with access to fresh water and feeding grounds can be utilized by management to implement the development of a network of appropriate warm-water refuges. This network, if capable of supporting animals displaced from the industrial sites, will be of critical importance if the species physiological requirements are to be met in what may be the limits of its current winter range.

Table 1 Assessment criteria for evaluating warm-water site suitability as suggested in Reynolds (2000)

Warm Water Site Criteria
Abundant local sea grass or appropriate forage
Access to available local fresh water
High proximity to migration routes
High proximity to summer habitat
Bathymetry- easy to reach deep water
High water quality and favorable future trends
Low Human population density and growth
Low levels of human-related noise and disturbance by boats
Low levels of local human-related mortality
Availability of undeveloped land and wetlands
Local protected areas
Easy creation of education and outreach facilities
Proximity to non-sensitive property
Local protected areas
Future land use
Located well south of historical winter distribution limit

The objectives of this study are four-fold. Chapter One investigates cold stress-related mortality in the Florida manatee through analyses of state manatee mortality records from 1996 through 2011. The goal was to uncover any trends in cold stress related mortality that might shed light on which individual are physiologically at the most risk and under what conditions, and use cold stress mortality data to identify regions in the state most affected and in need of additional study.

Chapter Two addresses the characterization of the hydrographic, thermal and physical properties of three important secondary warm-water sites or PTB's in Brevard County, an area of state where data indicates manatees are most at risk for cold stress-related mortality. Identified and potential threats to the use and sustainability of these sites are defined and discussed. Each warm-water site is evaluated against Reynolds list of criteria for the creation of warm-water sites (Reynolds 2000). A literature review of previous manatee research conducted in the region is presented.

Chapter Three addresses establishing the history and patterns of manatee use and site fidelity at the three secondary warm-water sites in Brevard County through monitoring of those sites during the winter months, analyses of historical and recent synoptic survey data showing manatee counts and distribution following cold fronts.

Chapter Four explores the delicate balancing act manatee face in order to maintain thermal homeostasis in a winter environment. This is facilitated through the use of a bioenergetics computer model designed to simulate the exposure of individual manatees to a variety of winter scenarios using both realistic manatee physical metrics, knowledge of warm-water refugia and realistic thermal regimes. Sixty four simulations were performed using virtual manatees of different sizes and ages interacting with their environment during the winter months using the modeling software STELLA©. Simulated results, measured as changes in physical parameters (e.g. mass, blubber thickness, or percent body fat) are presented and discussed.

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CHAPTER ONE: ANALYSES OF COLD STRESS-RELATED MORTALITY

Introduction

When water temperatures fall below the lower limit of the Florida manatees' thermoneutral zone (TNZ), 20°C, manatees must undertake seasonal migration to habitats in lower latitudes or choose to overwinter in a warm-water site. Failure to do so may lead to acute hypothermia or chronic cold stress syndrome (CSS), both of which can result in the death of the manatee. This is largely due to the manatees' relatively low metabolic rate when compared to other mammals of similar size (Irvine 1983, Kleiber 1932).

While manatees of all ages and size classes are known to suffer from CSS, it has long been promoted in the existing literature that late juveniles and subadults are at the highest risk. In earlier studies, late juvenile and subadult manatees were defined as nutritionally independent, sexually immature individuals, measuring between 176 and 275 cm in length (O'Shea *et al*. 1985). It is important to point out that based on these straight-length measurements, some of the smaller individuals within this size class may in reality still be dependent calves while some subadults may actually be small adults capable of reproducing.

Adjustments were eventually made to previously accepted size classes presented by O'Shea *et al*. (1985) to account for these observations. These adjustments are based on extensive photo-identification studies and field observations

(Beck and Reid 1995), age determination research, size-specific reproduction data, population biology studies (Marmontel 1993), and a better understanding of life history traits (O'Shea and Reep 1990). Photo-identification and aging study-base size class ranges and definitions vary slightly with respect to the adult category from the ranges employed by the Florida Fish and Wildlife Conservation Commission's (FWC) Manatee Rescue and Salvage Program (C. Deutsch, FWC, Pers. Com.; B. Bassett, FWC, Pers. Com.). Size class ranges employed by the FWC are defined in Table 2. These are the size classes delineations used throughout this study unless otherwise indicated.

Table 2 Breakdown of manatee size classes

Size Class	Total length (cm)
Perinatals	≤150
Calves	151 – 235
Subadults	236 – 265
Adults	>265

The subadult category is now recognized as individuals ranging from 236-265 cm, and individuals measuring greater than 265 cm are classified as adults. The calf size class may be broken down further into four subcategories as defined by the U. S. Geological Survey (USGS)-Sirenia Project's Manatee Individual Photo-identification System (MIPS) in Table 3 (C. Beck, USGS, Pers. Com.) The MIPS-defined perinatal or newborn range of 80 -160 cm includes slightly larger calves than the FWC range, but carcasses recovered by the FWC in excess of 150cm in length exhibiting newborn traits (e.g. remnants of an umbilical skirt or presence of fetal folds) validate the observation that a small number of calves exceed the 150 cm size limit at birth (B. Bassett, FWC, Pers. Com.).

Table 3 Breakdown of the manatee calf size classes

Size Class	Total length (cm)
Newborn	80 - 160
Small Calf	161 - 175
Medium Calf	176 - 205
Large Calf	206 - 235

It has long been widely accepted that the knowledge of where to find warm water is a learned behavior passed from mother to calf (Deutsch *et al*. 2003), and that naïve juveniles and subadults may fail to find refuges once fully independent. This may occur for a number of reasons. Calves born in early spring may experience only a single winter with their mothers at thermal refuge or may fail to imprint on a site, particularly during mild winters. Limited metabolic studies by Worthy *et al*. (2000) also showed that nutritionally independent manatees weighing 300 kg or less lack the ability to increase their metabolic rate to accommodate for the loss of body heat to the environment when water temperatures fall below 20°C. Newly Independent calves or late juveniles may suffer more from cold stress issues than either adults or dependent calves due to the combination of high surface area-to-volume ratio (SA:V) and the new-found reality of having to fend for themselves without the advantage of calorie-dense, nutrient-rich milk once provided by their mothers. Even if late juveniles and subadults are successful in finding adequate warm water, the need to feed on aquatic vegetation located outside of the thermal refuge may expose them to subcritical and potentially lethal water temperatures.

While CS related deaths seem more likely to affect manatees within a particular age class and size range, certain regions within the state appear to be at greater risk for CS mortality as well. Recent extreme cold weather events affecting the entire Florida peninsula have added greatly to the number of documented CS-related deaths. These unprecedented events provided valuable data that can be used to redefine our understanding of the individuals most affected and also the areas the state at most risk, further supporting the need to prioritize the identification and protection of critical warm-water sites where it is needed the most.

The objectives of this chapter are to quantify statewide CS-related manatee mortality in Florida from 1996-2011; to identify any trends in CS-related mortality either spatially and/or temporally, with respect to size and gender, and in relation to known warm water refugia; to calculate and compare the differences in relative SA:V with respect to recognized size classes, and to identify areas around the state where the magnitude of CS-related mortalities supports the need for the identification, creation, or restoration of warm-water refugia.

Methods

Cold Stress Mortality Analyses

Statewide manatee mortality records were queried for all causes of death from January 1996 through December 2011.Resulting records were queried again for all CS-related deaths that occurred within the same time frame (FWC, Manatee Mortality Database, Unpublished data). Complete mortality reports were downloaded and reviewed. For each mortality, total straight length (TL) was recorded. For each CS-related death additional metrics were collected from each report including: Field ID, the date the mortality was reported, gender, and carcass recovery location including county and coordinates.

CS mortality data were sorted with respect to gender and recognized size class. A Chi-square test was conducted to determine if the number of males differed significantly from the number of females affected by CS in any of the size classes. Additionally, a 2 way ANOVA was run to test for significant differences in mean TL as it relates to gender within each size class.

Using TL measurements, multiple size frequency distribution graphs were generated using Sigma Plot 11.0. The sizes of individual affected by CS deaths were compared to sizes affected by all causes of death to determine if CS mortality affected individuals of a particular size. Lines were added to each graph delineating the different recognized size classes previously defined in Table 2.

Recovery location coordinates from each CS mortality report were mapped using ArcGIS 10. 2 .1 to illustrate statewide CS-related mortality density distribution using point density analysis

The frequency of CS-related mortalities were tabulated by month and year (January through December), as well as by winter season (defined as 01 December through 31 March) to identify years and winters within which recognizable cold-related mortality events occurred. Four winters of varying severity ranging from mild to severe were identified: Winter 2007-2008 was classified as mild, 2008-2009 as moderate, 2010-2011 as strong, and 2009-2010 as severe, having been the coldest year on record since 1981 (National Weather Service, http://www.srh.noaa.gov). CS deaths were sorted by winter season. The mean total length for CS-related deaths was calculated for each of these four winters, and then graphed for comparison using a box plot with standard error bars using Sigma Plot 11.0, to illustrate the mean and range of sizes affected by winters of different intensities. A Kruskal-Wallis ANOVA on Ranks was conducted to determine if winter severity had a significant effect on the mean TL affected by CS.

Surface Area -to-Volume Ratio Calculations

Calculation of Surface Area

Live manatee, pre-release health assessments records from three Florida manatee rehabilitation facilities (Sea World, Miami Seaquarium and Lowry Park Zoo) from December 2003 through July 2013, as well as health assessment records from research-related manatee captures conducted by the FWC and USGS- Sirenia Project from December 2009 through 2012 (FWC, Unpublished Data), and post-release health assessment records from the Manatee Rehabilitation Partnership (MRP) (M. Ross,S2S, Pers. Com), were reviewed for manatee body length and girth measurements. These measurements were used to calculate the surface area (SA) and volume of healthy manatees, and subsequent calculations of SA:V for 165 individuals. SA was calculated in a manner similar to that described by McCully (2004), but using modified datasheets reflective of the limited number of measurements usually available on health assessment forms (APPENDIX A).

In addition to the TL measurement (i.e. tip of snout to distal tip of tail), 207 records contained the following straight length measurements: snout to axilla (STX) (axilla defined as the posterior insertion point of the pectoral flipper), snout to umbilicus (STU), snout to anus (STA), and snout to peduncle (STP). STX measurements were recorded for only 24 individuals as this is not a measurement regularly recorded. To augment the sample size with respect to the STX measurement, calculations were performed on the 207 sets of metrics from individual live manatees ranging from 144 cm to 351 cm to determine if predictable relationships exist between total straight length measurements and STU, STA, and STP measurements, and from the 24 records where the STX measurements were recorded. Each measurement was graphed against respective TL to determine if predictable values existed and were maintained across size classes. Once predictable relationships were established for each segment, a regression was established for STX using Sigma Plot 11, and then used to calculate the missing STX values. These estimated values were used in both the SA and V calculations for a subset of 165 live individual manatees for which both sufficient straight length measurements (or estimates in the case of STX) *and* a full set of actual girth measurements were available.

The following four girth measurements were collected: girth at axilla (GAX), girth at umbilicus (GAU), girth at anus (GAA) and girth at peduncle (GAP). Only girths recorded indicated as *actual* (i.e. obtained by wrapping a measuring tape around entire circumference at a given location) on the data sheets were used. Girths that were determined by doubling half girth measurements were not used in the calculations. Only manatees with a body score rating of good or better (or a 3 or high on a scale of 1-5) as assessed by an experienced veterinarian or biologist, and in good health were used in the calculations. Manatees known or suspected to be pregnant, or manatees with a flattened ventrum indicative of being under weight were also excluded from SA:V calculations.

The SA:V of each manatee was calculated using two separate approaches. The first approach treated each manatee as an array of three separate but adjacent truncated cones or frustums, the sizes of which were determined by each individual animal's respective girths and straight-length measurements taken from health assessment records. The frustum array was topped by a circular cone at the anterior end representing the manatee's head (Figure 3).

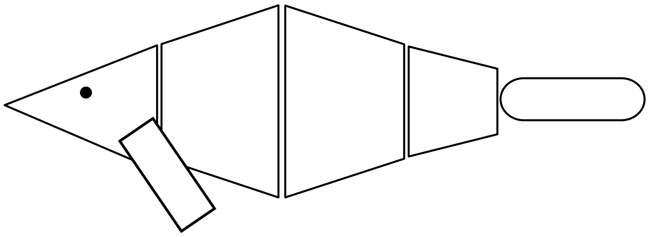

Figure 3 Manatee figure illustrating breakdown into geometric shapes used to calculate surface area-to-volume ratio

The lateral surface area of each truncated cone ($SA_{Frustum}$) was calculated using Equation 1, where *h* represents the height of the truncated cone, and *R* and *r* represent the radius of the corresponding girths (circumferences) at the top and bottom of each truncated cone, respectively (Figure 4).

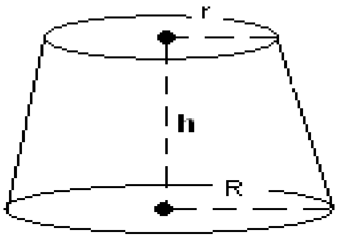

Figure 4 A truncated cone or frustum

$$SA_{Frustum} = \pi(R+r)((R+r)^2h^2)^{0.5} \tag{1}$$

The lateral SA of the cone, (SA_{Cone}), was calculated using Equation 2, where *h* represents the height of the cone, and *r* represent the radius of the girth at the bottom of the cone (i.e. GAU) (Figure 5).

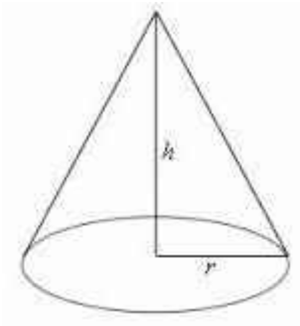

Figure 5 A right angled cone

$$SA_{cone} = \pi r\sqrt{(r^2 + h^2)} \quad (2)$$

Estimates of flipper and tail paddle SA were calculated for inclusion in the total SA for each individual. Since measurements of the flippers and the tail paddle were not typically taken during live animal health assessments, flipper and tail SA estimates were calculated using measurements taken from mortality records of freshly dead manatees. The assumption was made that in freshly dead carcasses flipper and tail measurements are unaffected by decomposition and closely represent accurate flipper and paddle dimensions of living manatees of the same size. Using mortality records for fresh carcasses collected from 1996 through 2002 (FWC, Unpublished data, http://research.myfwc.com/manatees/research) in which total straight length, flipper length and width, and tail paddle length and width (cm) were recorded (n = 242), SA was calculated for the appendages and tail by treating the flippers as rectangles and tail paddle as a ellipses and calculating SA using Equations 3 and 4.

$$SA_{flipper} = lw \tag{3}$$

$$SA_{paddle} = \pi \frac{1}{2} lw \tag{4}$$

The total SA for both pectoral flippers was obtained by multiplying the calculated SA of one side of a flipper by four to account for the back and front of each flipper. Likewise the total SA of the tail paddle was obtained by multiplying the SA of one side of the paddle by two to account for both the dorsal and ventral aspects. Manatee mortality records that indicated the presence of injuries that affected the measurements of either the tail or *both* flippers were excluded from the calculations. Flipper and tail paddle SA were plotted against TL and a regression was established using Sigma Plot 11. The total SA of each manatee was determined by adding the lateral SA of all three truncated cones to the lateral SA of the circular cone, then adding in the total SA of the appropriately-sized flippers and tail paddle as provided by the regression.

Calculation of Volume

The volume of each of each truncated cone or frustum ($V_{Frustum}$) was calculated using Equation 5, where h represents the height, r equals the radius of the top, and R equals the radius of the bottom of each truncated cone.

$$V_{Frustum} = \frac{\pi}{3}(R^2 + Rr + r^2)h \tag{5}$$

The volume of the circular cone (V_{Cone}) was calculated using Equation 6, where h represents the height of the cone and r equals the radius of the bottom of the cone.

$$V_{Cone} = \pi r^2 \frac{h}{3} \tag{6}$$

Total volume was determined by adding the volumes of the three truncated cones to the volume of the circular cone. Volume calculations were not performed for the pectoral flippers or the tail paddles based on the assumption that these two relatively thin areas do not contribute significantly to the total body volume.

Only manatees deemed in good health were used in the calculations. Manatees known or suspected to be pregnant or manatees with a flattened ventrum, indicative of less than ideal weight, were also excluded from SA:V calculations. SA:V were graphed against total straight length and delineated by size class for comparison. A second set of SA:V values were also graphed but without the addition of the SA contributed by the flippers and paddle to illustrate the effects of peripheral vasoconstriction on SA:V and the extent to which this adaptation reduces heat loss to the environment

An alternative and simpler approach was also used to calculate manatee SA:V not only for comparison but also for use in the bioenergetics model in Chapter 4. In this approach the manatee profile was reduced to the shape of an ellipsoid, and SA and volume were calculated for the axial region of the body only, excluding the appendages and tail (Figure 6). This approach resulted in reduced SA:V that more closely reflects a manatee employing the physiological adaptation of peripheral vasoconstriction

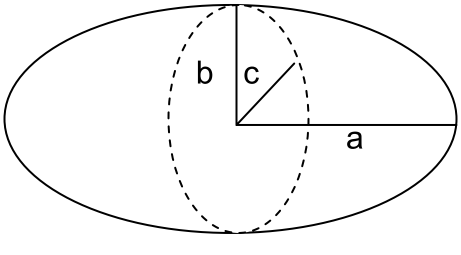

Figure 6 An ellipsoid

Calculation of both SA and volume of the manatee as an ellipsoid required a minimum of two measurements: STP and GAU. The volume of an ellipsoid ($V_{ellipsoid}$) was calculated using Equation 5, where *a* equals 1/2 STP and *b* and *c* both equal the radius at the umbilicus.

$$V_{ellipsoid} = \frac{4}{3}\pi abc \tag{5}$$

The SA of an ellipsoid was calculated using Equation 6 and was accomplished through the use of an online volume calculator [(http://Keisan.casio.com)](http://Keisan.casio.com)

$$SA_{ellipsoid} = 2\pi\left(c^2 + abx\,E(x,k) + \frac{bc^2}{ax}\,F(x,k)\right) \tag{6}$$

$$x = \sqrt{1 - \frac{c^2}{a^2}},\;\; k = \frac{\sqrt{1-\frac{c^2}{b^2}}}{x},\;\; a \geq b \geq c$$

F(x,k) 1st incomplete elliptical integral

E(x,k) 2nd incomplete elliptical integral

Results from this approach to SA:V were graphed against total length and compared to SA:V calculations using the frustum approach. The ellipsoid approach to manatee SA:V calculations and the corresponding equations were incorporated into the manatee energetics model presented in Chapter 4.

Results

Cold Stress Mortality Analyses

A total of 5,831 manatee mortalities were documented by the FWC from January 1996 through December 2011. Post mortem examination attributed 823 (14%) of the deaths to either chronic or acute CS. For the purpose of this study these numbers included 78 CS individuals measuring ≤150 cm in TL that are normally included exclusively in the perinatal category of mortality, regardless of the actual cause of death.

Gender and TL were documented in all 823 cases. With respect to TL, 13 measurements were estimates provided by experienced FWC staff and therefore, included in the analyses. Four hundred and forty-four individuals were male (54%) 379 (46%) were female, with males outnumbering females in all size classes (Table 4). X^2 analyses, however, found no significant difference between the number of males and females overall or within the different size classes ($X^2 = 4.824$, df = 4, $P = 0.306$, $\alpha = 0.05$). Results did show significant differences in CS mortality distribution between the size classes, specifically between the calf size class and all other size classes. Results from the two-way ANOVA indicated that there was no significant difference in means TL of each size class with respect to gender ($P = 0.071$, $\alpha = 0.05$).

Table 4 Cold stress mortality by size class and gender: 1996-2011

Size Class	TL (cm)	Total	Males	Females
All	--	823	441	379
Adult	>265	130	79	51
Subadult	236-265	118	69	49
Calf	151-235	497	256	241
Perinatal	≤150	78	40	38

Based on the recognized size class categories defined by FWC in Table 2, 60% (n = 497) of the CS-related mortalities were classified as calves. Subadults, accounted for only 14% (n = 118), while adult manatees and perinatals accounted for approximately 16% (n = 130) and 9% (n = 78) of CS-related mortality, respectively

Table 5 shows that closer analyses of the calf category indicated that medium and large sizes calves collectively account for 46.6% (n = 384) of all CS-related deaths, and 22.2% (n = 183) and 24.4% (n = 201) individually, while smaller calves account for only 9.5% (n = 78). Using the MIPS calf definitions, newborns or perinatals with a TL ≤ 160 cm, account for 13.7% (n = 113).

Table 5 Breakdown of calf cold stress mortality

Calf Type	TL (cm)	n	% of CS Deaths
Newborn	80-160	113	13.7
Small calf	161-175	78	9.5
Medium calf	176-205	183	22.2
Large calf	206-235	201	24.4

For all causes of death, 5831 manatee carcasses were documented from 1996 through 2011. TL measurements were recorded on all but 72 of the 5831 records. The mean TL of all carcasses recovered from 1996 through 2011 for all causes of death where TL was recorded (including those that died from CS, n = 5759) was 228 cm (s .d. = 70.2, median = 235 cm) (Figure 7). Removing CS-related deaths from all causes of death (n = 4936) resulted in a shift of the mean TL to 231 cm (s. d. = 72.9, median = 242 cm. The TL of carcasses recovered for CS-related mortality (n = 823) ranged from a minimum of 118 cm to a maximum of 368 cm, with a mean TL of 213 cm (s. d. = 48.3, median = 209 cm).

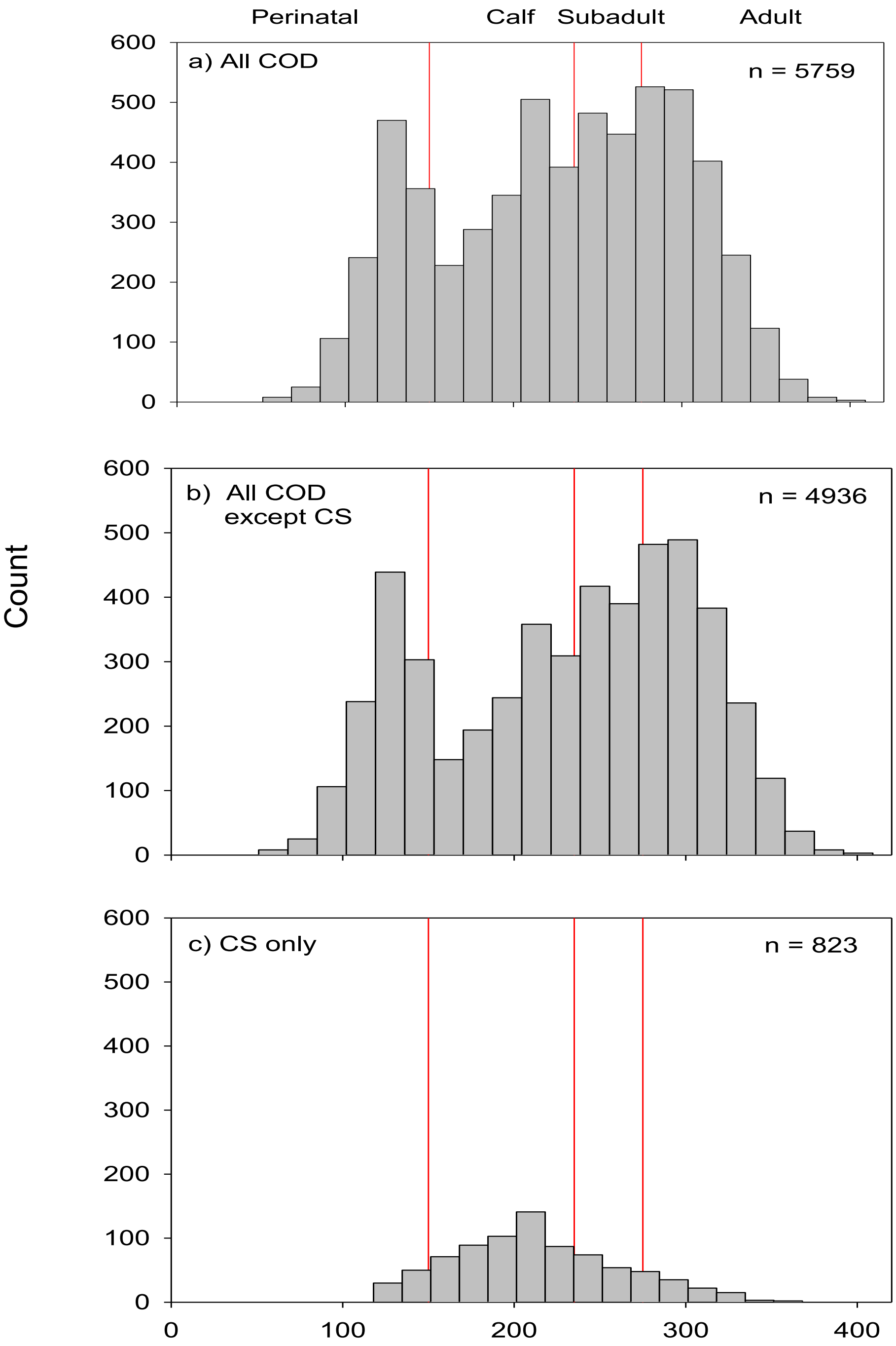

Figure 7 Comparison of manatee mortality size distribution: 1996-2011
a) all causes of death, b) all causes of death excluding cold stress,
c) cold stress deaths only

The effect of winter severity on CS mortality size class distribution shows that smaller individuals appear to be affected during even mild winters (Figure 8). The mean TL of CS-related mortalities in the 2007-2008 season, a mild winter, was 195 cm (s. d. =33.4) and manatees that died under those conditions ranged from 119 to 263 cm in length. During a moderate winter, 2008-2009, the mean TL was similar to that in a mild winter, 195 cm (s. d. = 42.3) but the range of sizes affected increased by more than 30 cm to include individuals ranging 121 to 295 cm in length. The mean TL during 2009-2010, one of the coldest winters on record, was 227cm (s. d. = 47.2). Manatees that died from cold CS during that winter included individuals ranging from 118 to 362 cm in length (Table 6). During moderate to severe winters there is a shift in the mean TL towards larger animals indicating that all sizes classes are at risk during severe winters.

Analyses using a Kruskal-Wallis One Way ANOVA on Ranks indicated significant differences in median TL of CS deaths when paired with winters of varying severity (H = 30.569, df = 3, P = <0.001). An all pairwise multiple comparison procedure (Dunn's Method) showed significant differences between the severe winter of 2009-2010 and all other winters with the exception of the 2010-2011 winter (P= <0.05). There was no significant difference in median TL between the 2007-2008 and 2008-2009 winters or between the 2007-2008 and 2010-2011 winters. The latter results were likely due to a small sample size (n = 21), representative of the level of CS mortality during the warmer 2007-2008 winter rather than the effect of winter severity.

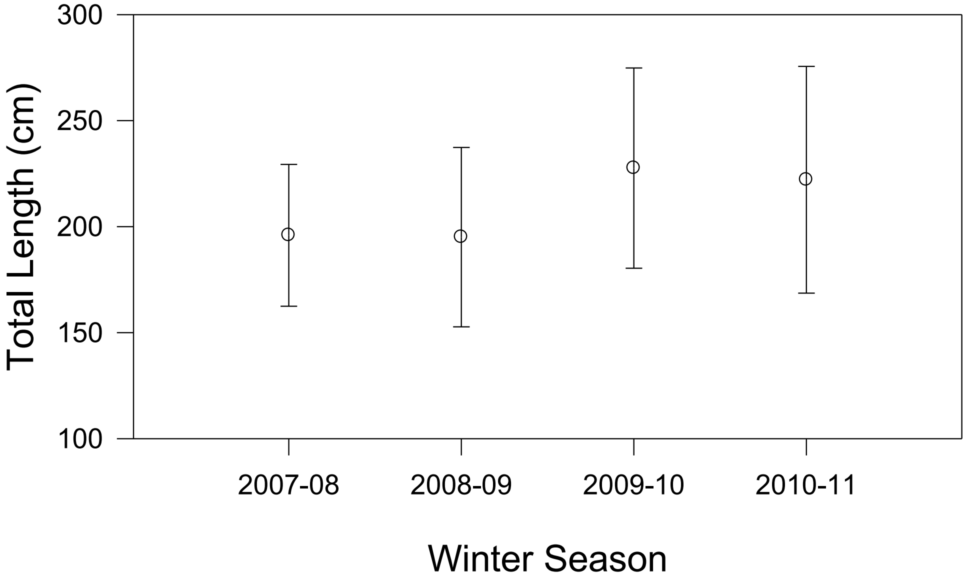

Figure 8 The effect of four winters of varying severity on mean total length and size range of cold stress-related deaths
(mild = 2007-2008, moderate = 2008-2009, extreme = 2009-2010, severe = 2010-2011

Table 6 Comparison of size ranges affected by cold stress-related mortality during four winters of varying severity

Winter	Type	n	Median	S.D	Range	Max	Min	Median
2007-08	Mild	21	195.9	33.4	144	263	119	194
2008-09	Moderate	74	195.0	42.3	174	295	121	195.5
2009-10	Severe	261	227.6	47.2	234	352	118	224
2010-11	Strong	166	222.1	53.5	249	368	119	219

A density distribution map of statewide CS mortality recovery locations illustrates that CS mortality is highest in Brevard County, on the central east coast (Figure 9). High CS-related mortality was also evident, although to a lesser extent, on the southwest coast in Lee County. Table 7 shows the breakdown of CS-related mortality for the top 20 Florida Counties for the same time frame. From 1996-2011, CS-related deaths occurred in 37 (55%) of the state's 67 counties. More than 56% of all CS-related deaths occurred in only four counties: Brevard and Indian River Counties on the central east coast, and Lee and Collier Counties on the southwest coast. Brevard County accounted for more than 25% (n = 207) of all CS-related deaths statewide, followed by Lee County with 12.8% (n = 106), Collier County with 10.2% (n = 84) and Indian River County with 7.9% (n = 65). Less than one percent of the CS-related mortalities occurred in each of the remaining counties: Miami-Dade, Flagler, Escambia, Hendry, Franklin, Glades, Gulf, Pasco, Bay, Desoto, Levy, Okeechobee, Dixie, Hernando, Santa Rosa, Taylor and Walton.

While 25% of all documented deaths attributed to CS from 1996-2011occurred in Brevard County, only 19.4% off all documented mortalities overall occurred in the same county during that time frame.

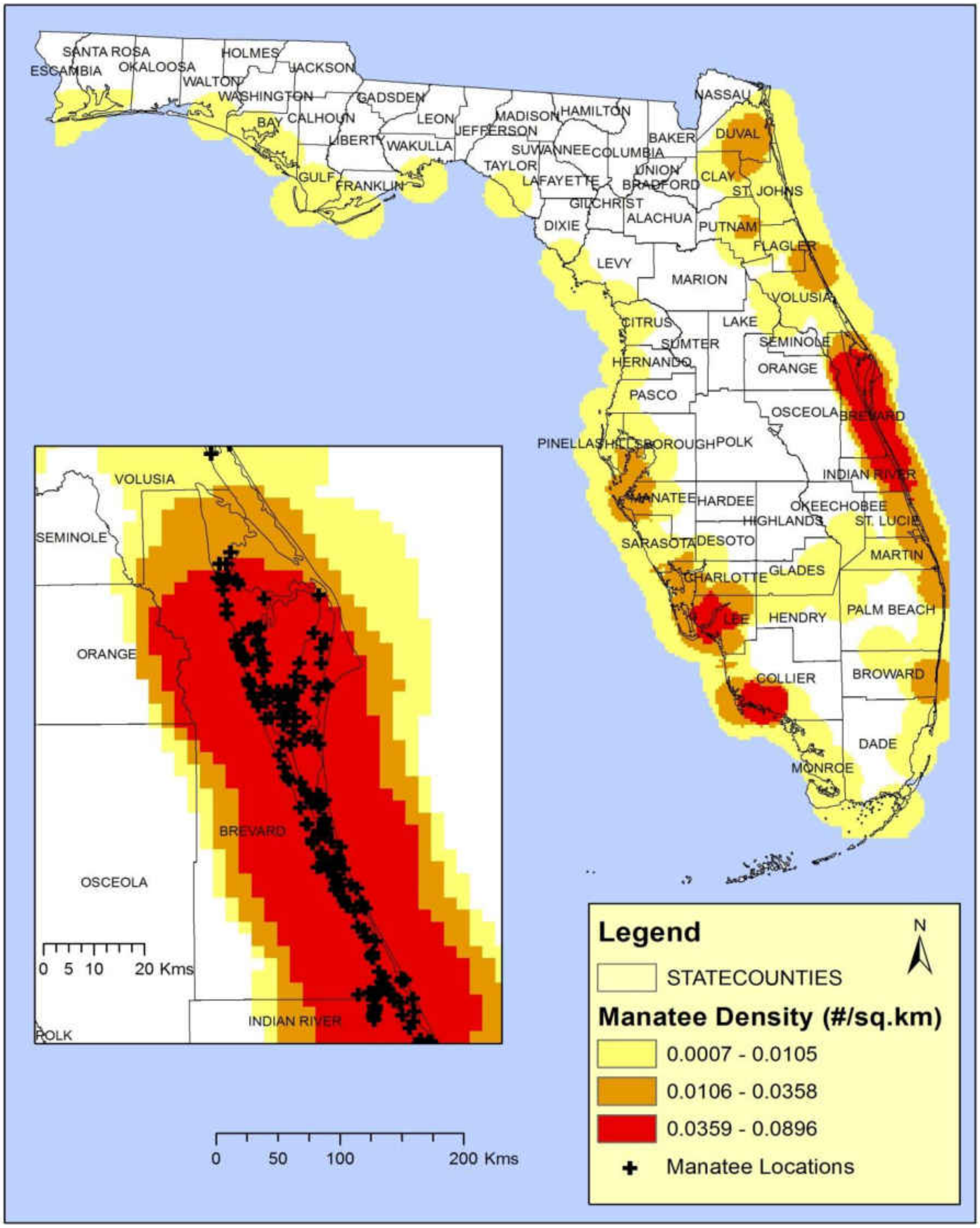

Figure 9 Cold stress mortality density distribution: 1996-2011

Table 7 Cold stress mortality in the top 20 Florida counties: 1996-2011

Rank	County(s)	N	% of total
1	Brevard	207	25.1
2	Lee	106	12.8
3	Collier	84	10.2
4	Indian River	65	7.9
5	Volusia	36	4.3
6	St. Lucie	30	3.6
7	Palm Beach	26	3.1
8	Duval	25	3.0
9	Martin, Monroe	24	2.9
11	Manatee	23	2.7
12	Broward	22	2.6
13	Charlotte	16	1.9
14	Putnam, St. Johns	15	1.8
16	Sarasota	14	1.7
17	Hillsborough, Pinellas	12	1.4
19	Clay	11	1.3
20	Citrus	10	1.2

East coast counties combined accounted for 54.1% (n = 445) of all CS-related mortalities with 46.4% (n=207) of those deaths occurring in Brevard alone, while counties on the west coast and along the St. Johns River account for 39% (n = 321) and 6.9% (n = 57) of the statewide total, respectively (Table 8).

Table 8 Cold stress mortality by coast: 1996-2011

Coast	**n**	**%**
East	445	54.1
West	321	39.0
Central	57	6.9

When broken down into management units (formerly subpopulations) as defined in the USFWS 2012 Draft Florida Manatee Stock Assessment Report (http://www.fws.gov/northflorida/manatee/SARS/20130328_FR1149-Draft_Revised_Manatee_SAR_FL_Stock.pdf), the two most affected management units are the Atlantic (60.8%) and the Southwest (33.5%) (Table 9).

Table 9 Cold stress mortality by management unit: 1996-2011

Unit	n	**%**
Atlantic	500	60.8
Southwest	276	33.5
Northwest	30	3.9
USJR	15	1.8

Temporally, CS-related deaths were documented during all but five months of the year with carcasses being recovered from November through May. Cumulatively, CS-related carcasses were most frequently recovered during the month of January (n = 358, 43.5%), followed by February (n = 205, 25.0 %), December (n = 124, 15.1%), and March (n = 101, 12.3%). A small number of carcasses exhibiting CS were recovered in April (n = 22, 2.7%) May (n = 9, 1.2%) and November (n = 4, 0.5%) (Figure 10). This pattern was not necessarily consistent across all years.

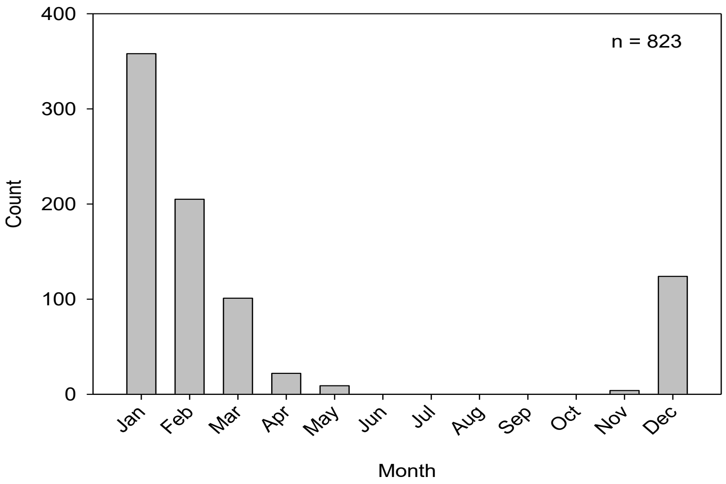

Figure 10 Cold stress mortality by month: 1996-2011

The number of CS-related manatee carcasses recovered yearly from 1996-2011 ranged from a low of four in 1997 to a high of 306 in 2010, with a *yearly* average (January-December) of 51.4 individuals (s. d. = 74.3) (Table 10). The yearly average was exceeded in 2004 (n= 52), 2009 (n = 63), 2010 (n = 306), and 2011 (n = 122).

Table 10 Cold stress mortality by year: 1996-2011

Year	CS	All COD	% CS
1996	17	415	4.1
1997	4	242	1.7
1998	10	232	4.3
1999	6	269	2.2
2000	15	272	5.5
2001	34	325	10.5
2002	18	305	5.9
2003	48	380	12.6
2004	52	276	18.8
2005	43	396	10.9
2006	30	417	7.3
2007	21	317	6.6
2008	34	337	10.1
2009	63	429	14.7
2010	306	766	39.9
2011	122	453	26.9
TOTAL	823	5831	14.1

The number of CS-related carcasses recovered per *winter season* (November-May, for the purposes of this calculation only) ranged from a low of three during the 1996-1997 winter to a high of 261 during the 2009-2010 winter. The *winter* average was 51.8 individuals (s. d. = 67.8).Table 11 shows that only three winter seasons exceeded the winter average: 2008-2009 (n = 74), 2010-2011 (n = 261), and 2009-2010 (n = 164).

Table 11 Cold stress mortality by winter season

Winter	CS Deaths	Rank
09-10	261	1
10-11	166	2
08-09	74	3
03-04	48	4
04-05	47	5
02-03	40	6
05-06	35	7
00-01	33	8
06-07	26	9
07-08	21	10
01-02	18	11
95-96	26	12
99-00	14	13
97-98	13	14
98-99	5	15
96-97	3	16

Surface Area -to-Volume Ratio Comparison

The calculation of SA and volume using health assessment records required that each record used contained both a specific set of straight length measurements and four corresponding actual girth measurements. With the exception of the STX measurement, 207 records contained sufficient straight length measurements but only 165 of those records contained both straight length measurements *and* the girth data necessary to calculate SA and volume. The STX straight length measurement was recorded in only 24 of the initial 207 records and in only 9 of the subsequent 165 records used to calculate SA:V, as this was not a measurement regularly taken. Calculations performed on 207 sets of metrics from individual live manatees ranging from 144 cm to 341 cm confirmed that predictable relationships exist between TL and specific body landmarks (e.g. snout to axilla). These results agree with similar unpublished length relationship calculations performed on manatee carcasses classified as badly decomposed (A. Costidis, FWC, Unpublished data) (Figure 11).

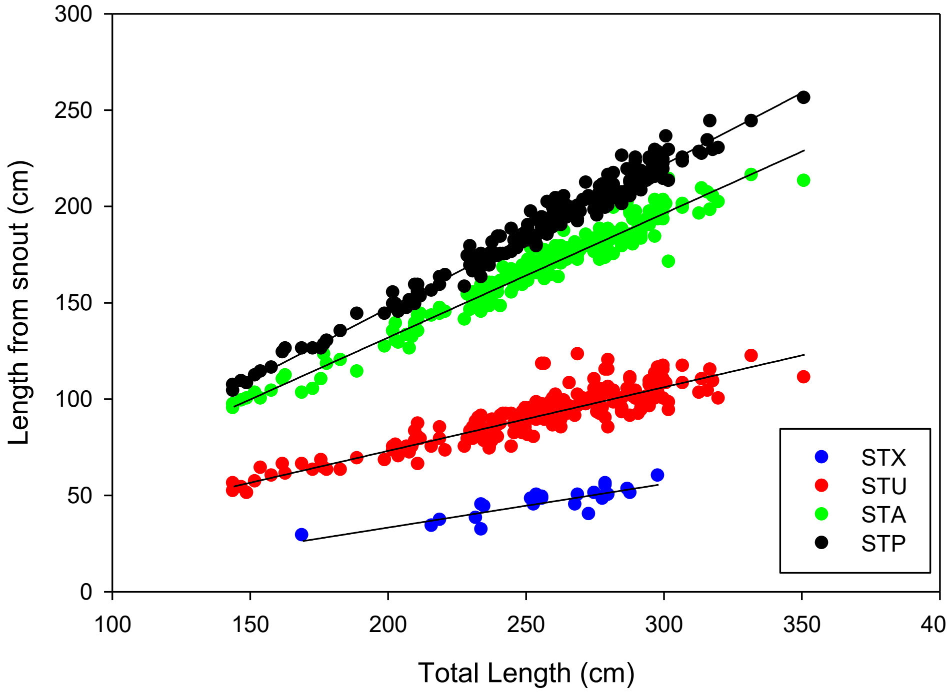

Figure 11 The relationship between anatomical landmarks and total length

The limited number of recorded STX measurements likewise showed a consistent relationship with respect to total straight length despite the small sample size (n = 24) (Table 12), providing a regression equation that was used to calculate STX values and augment those records where the data was not recorded. This allowed for the calculation of individual surface area to SA:V.

Table 12 The relationship between the locations of anatomical landmarks and total straight length in healthy Florida manatees

Measurement	Mean Proportion of TL	Std. Dev.	n	r^2	Regression Equation
Snout to Axilla	0.17	0.01	24	0.74	y = -12.002 + 0.227 * TL
Snout to Umbilicus	0.35	0.02	207	0.79	y = 6.995 + 0.331 * TL
Snout to Anus	0.65	0.02	207	0.95	y = 3.243 + 0.644 * TL
Snout to Peduncle	0.73	0.01	207	0.97	y = -1.938 + 0.745 * TL

Regression analyses of the SA of the tail and flippers they as relate to TL generated the equations used to calculate these same values to fill in the gaps in health assessment data (Figure 12and Figure 13, respectively). These values were added to the SA of the axial body for each of the 165 individuals based on their TL and used in the calculation of SA:V (Figure 14). The effect of PVC on SA:V is dramatic, resulting in a decrease of more than 50% in SA:V for all of the size classes. Mean SA:V values calculated for each size class showed that calves have a SA:V approximately 1.5 times greater than that of an adult (Table 13).

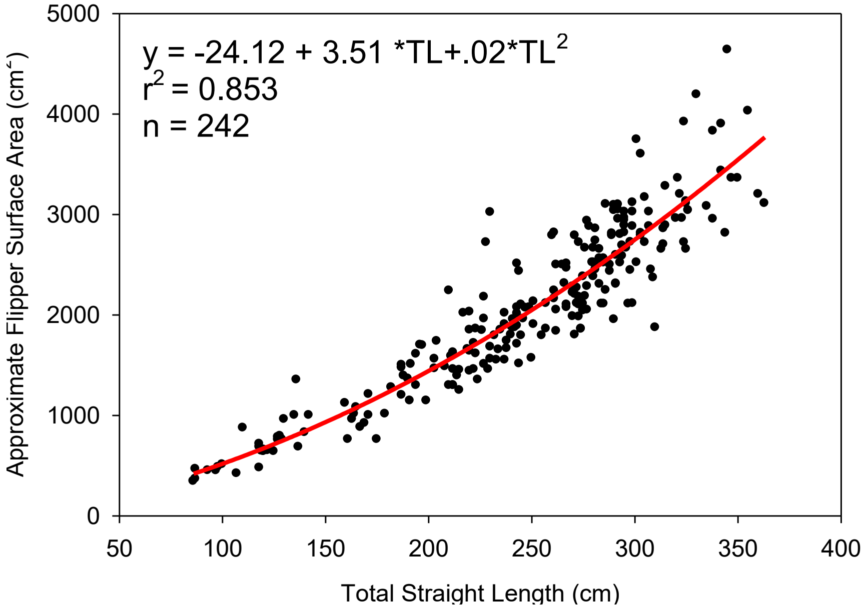

Figure 12 The relationship between total flipper surface area and total length

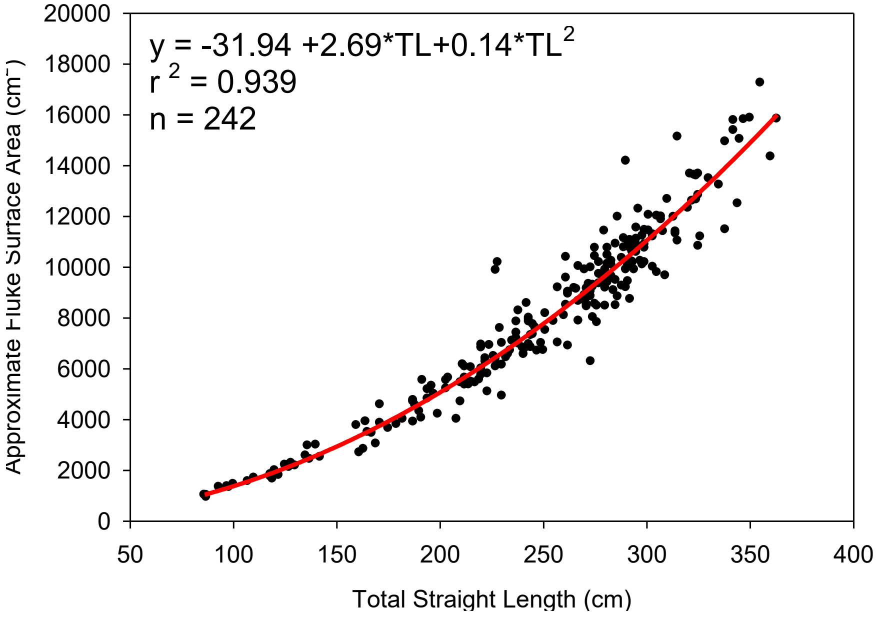

Figure 13 The relationship between total fluke surface area and total length

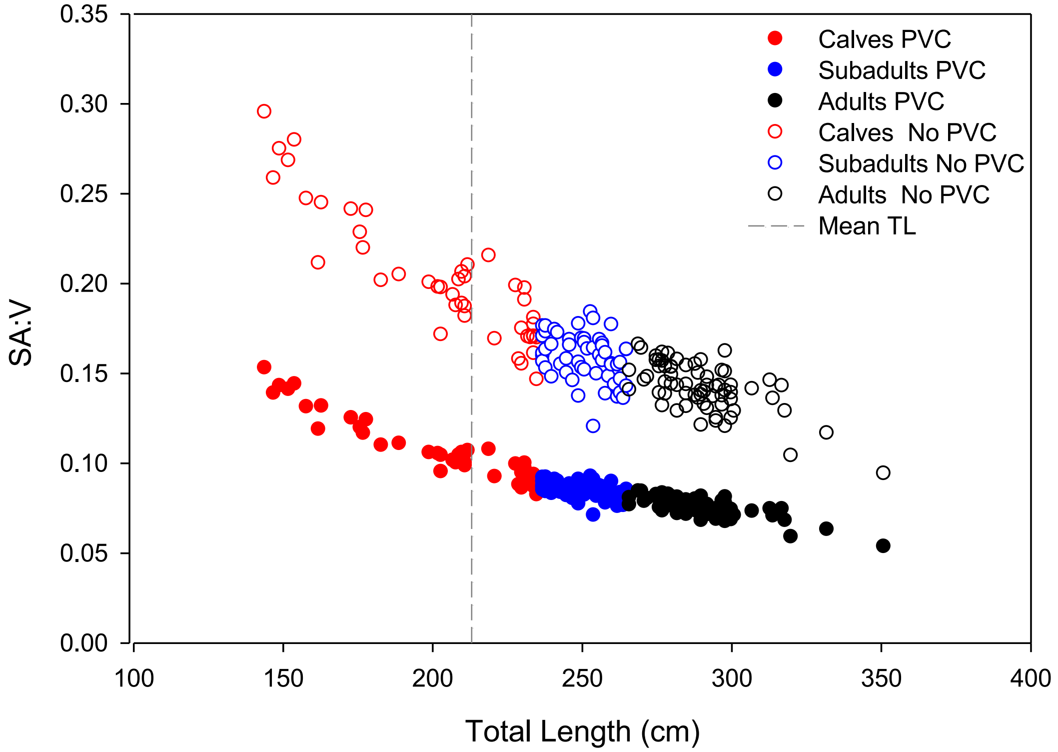

Figure 14 The effect of peripheral vasoconstriction on the surface area-to-volume ratio in healthy manatees

Table 13 Mean SA:V with respect to size class

Size Class	n	Mean TL	Std. Dev.	Mean SA:V	SA:V Std. Dev.
Calves	44	202.8	29.5	0.20	0.03
Calves PVC	44	202.8	29.5	0.10	0.01
Subadults	54	251.2	9.1	0.15	0.01
Subadults PVC	54	251.2	9.1	0.08.	0.00
Adults	67	290.2	15.5	0.14	0.01
Adults PVC	67	290.2	15.5	0.07	0.00

A side by side graphical comparison of the frustum approach to SA: V calculation and the ellipsoid approach indicate that both yield almost identical results (Figure 15).

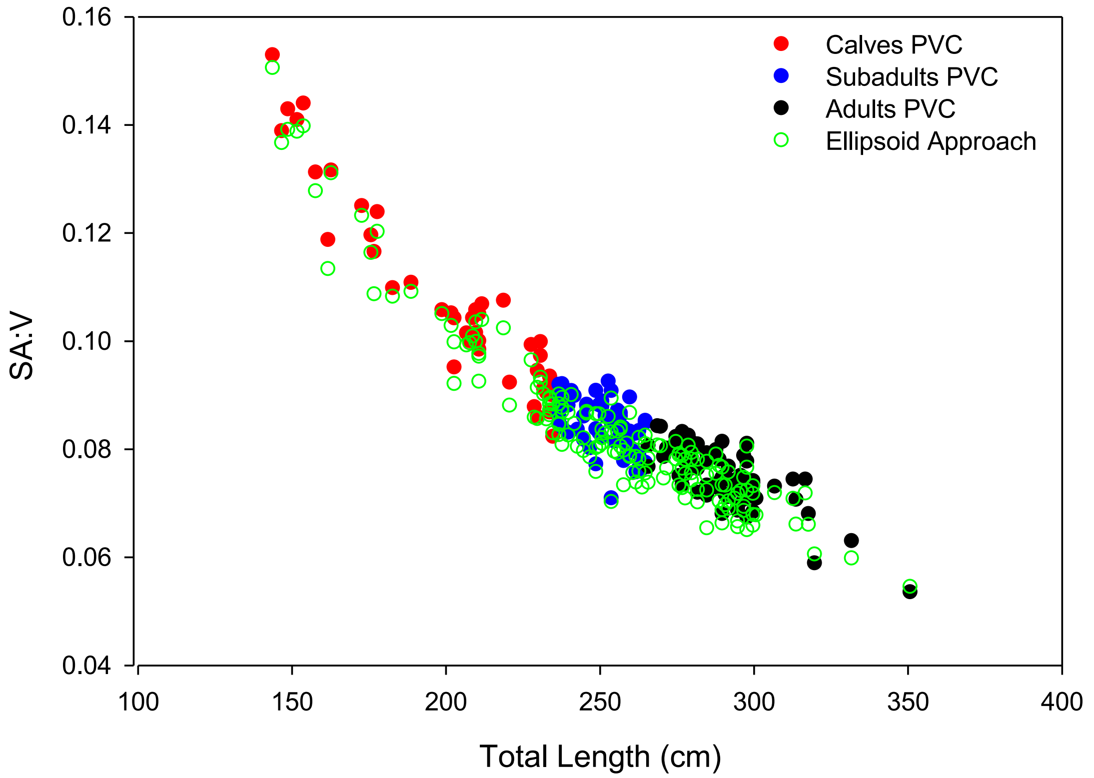

Figure 15 Comparison on of surface area-to-volume ratio using two different approaches

Discussion

Although-CS related mortality affects manatees of all ages and size classes, calves appear to be most at risk, with individuals measuring between 151 and 235 cm, accounting for more than 60% of all CS related deaths documented from 1996 through 2011. This range encompasses both dependent and independent calves. The average TL for CS related mortality was 213 cm, the equivalent of an approximately 2 year old calf (C. Beck, USGS, Pers. Com.).

Subadults, thought to be most at risk due to a combination of limited physiological as well as poor behavioral responses (i.e. naïve to the location of warm water sites), account for only 14% of CS-related deaths during that same time frame. It has long been recognized that young manatees are most susceptible to the physiological cascade of symptoms attributed to cold water exposure due in part to their high SA:V, high thermal conductance, low metabolic rate and low calorie diet. Additionally, many of these individuals at the upper end of the calf size range may be recently weaned or are no longer benefitting from the nutrient -rich milk provided by their mothers (Laist and Reynolds 2005). Calves in the lower half of the size range, while still nursing, may be exposed to lethal temperatures while migrating with their mothers from higher latitudes, and at even higher risk during severe prolonged cold spells when accompanying their mothers to feeding sites would mean certain death.

A metabolic study by Worthy *et al*. (*in prep*) showed that individuals weighing ≤300kg lack the ability to elevate their metabolism to compensate for heat loss to the environment when exposed to water temperatures below 20°C for short periods of time.

Based on manatee pre-release health assessment records a manatee weighing 300kg or less loosely corresponds to an individual with a total length of approximately 235 cm or less. There are currently no data available on metabolic response to prolonged cold exposure.

Two separate yet comparable approaches to estimating manatee SA:V are in agreement that calves, both dependent and independent (TL = 151 to235cm) have a SA:V ranging from 0.14 to 0.28 (mean = 0.20), while subadults and adult manatees benefit from lower SA:V ranging from 0.12 to 0.18 (mean = 0.15), and 0.09 to 0.16 (mean = 0.14), respectively. The high SA:V of newly weaned, independent calves or juvenile manatees make them particularly susceptible to CSS in the winter months since it corresponds to of a high rate of thermal conductance. Manatees like other marine mammals have the ability to reduce blood flow to the periphery, redirecting it to their core through peripheral vasoconstriction. This has a positive effect on SA:V by reducing the amount of surface area contributed by the flippers and tail paddle. This can result in a greater than 50% reduction in SA:V for calves (52.9%), and in similar reductions for subadults (53.4%) and adults (53.1%). Along with a possession of counter current heat exchange system that affectively recycles body heat, these physiological adaptations are critical during the winter months but may not be enough to maintain small calves of proportionally smaller mass and higher metabolic rates characteristic of growing adolescents.

A behavioral option available to independent larger calves is to remain in the warm water refuge, to forego feeding and to metabolize visceral fat and blubber reserves when ambient river temperatures fall below critical levels. By choosing this option however there is a trade off. Individuals in this size class will start metabolizing muscle tissue for energy, followed by lipids, including both visceral fat stores and blubber (Worthy 2001), thereby decreasing not only their insulating layer but their volume as well, while SA values remain constant. This in turn further increases the SA:V promoting additional heat loss to the environment. If water temperatures do not increase sufficiently to allow for foraging, the synergistic effects of the decrease in insulation, lack of forage and exposure to cold water can lead to a downward spiral. If ambient water temperatures increase only marginally, individuals with depleted blubber stores may be unable to maintain core temperatures if they leave the refuge, given the inability to elevate their metabolism (Worthy and Worthy, in *prep*). This will limit the amount of time individuals can leave the refuge to forage. Manatees in this situation will likely take in less energy than they spend.

CS mortality size class data likewise indicate a bias towards smaller individuals. The average total length for individuals documented as having died from CS is 213 cm, well below the size of a subadult (236 to 266cm), and the mean TL of 228cm for all causes of death. Many Individuals within this size range are likely newly independent calves (i.e. recently weaned). It is possible that calves weaned after only one winter season (i.e. born in early spring and weaned during their second fall season), or who experienced only mild winters in the first two years of life may be naïve to the location of critical warm-water sites having had to visit them infrequently or not at all. Even those calves that successfully imprinted on warm water locations during their formative years may find themselves in trouble during particularly cold winters like 2009-2010 and 2010-2011. This may be the result of failure or inability to balance the need for sufficient food and water with the need to stay warm which could in turn be the result of limited food resources located within tolerable distances of a warm-water site or resources located well beyond of their ability to travel without succumbing to thermal stress. It is likely that individuals of this size, despite the ability to find warm water and food are just physically unable to survive under such severe and prolonged conditions.

Males that died from CS outnumbered females over all, as well as in all size classes, although these differences were not statistically significant. The actions of females with calves may influence the differences seen in at least the adult mortality numbers in that nursing females may seek out warm water sooner than independent males to accommodate the physical limits of their dependent calves. This may likewise limit their foraging time and exposure to ambient river temperatures. Males without these constraints may spend more time outside of the refuge. Females are also known to have a higher percentage of body fat than males (Ward-Geiger 1995). This difference may give them a slight advantage when the need to fast arises.

Mortality records revealed CS-related deaths occur throughout the winter months. Most were documented during January and February with a small number as late as April and May and as early as November. CS-related deaths in the spring are likely the result of individuals failing to recover from chronic cold stress and gradually deteriorating physically for several weeks before succumbing. On occasion some of these individuals may be found lingering at warm-water sites in late winter when temperatures rise and the other manatees have left the area. Close monitoring of warm-water sites not only during cold fronts, but well after animals leave the site may allow for rescue and medical intervention for such individuals in time to prevent mortality.

Mortalities that occur in November may be the result of individuals encountering colder temperature at higher latitudes and failing to migrate south in a timely manner. These individuals have been documented at both primary and secondary sites within Brevard County amongst other manatees that show no signs of comparable CS. CS mortalities documented in December may occur for the same reason or may be the result of an early winter cold snap like the cold front that occurred in December of 2010.

Catastrophic cold-related events that occurred during the 2009-2010 and 2010-2011 winters hit the state particularly hard. While smaller manatees are more likely to suffer from CS-related mortality during mild to moderately cold winters, during extremely cold winters, even individuals in the largest size class were affected by both acute and CCS mortality

While CS mortality has been documented to some extent in all areas of Florida, deaths occurred primarily in the lower two-thirds of the state. Two areas within this range stand out, the southwest and east central Florida coast. From a subpopulation or management unit standpoint this means that both the Southwest and Atlantic units are most at risk. Despite the considerably higher mortality numbers affecting the Atlantic population, CS is of particular concern for the Southwest population which is already affected by high red tide and watercraft-related mortality. Along the east coast, one area is most at risk, specifically Brevard County. Home to manatees year-round and a destination for hundreds of manatees either passing through during fall and spring migrations or overwintering at the lone power plant, the resources of the Indian River Lagoon (IRL) attract manatees to Brevard year-round. Counts obtained from statewide synoptic surveys and aerial surveys of manatee aggregations at select power plant effluents stress the importance of Brevard County to a large number of manatees during the winter months. The disproportionate loss of manatees in the county when compared to other regions is nothing new. Following a severe and prolonged drop in temperature in December of 1989, 54 manatees died from CS statewide during the months of December and January. The majority of these occurred in the northeastern part of the state. Twenty seven deaths occurred in Brevard County alone while only seven occurred in southwest Florida (Ackerman *et al* 1995). Recent catastrophic CS events show similar CS mortality distribution with Brevard County experiencing much higher losses than other regions in the state. With so many manatees centrally located just north of their historic winter range during the cold season, the absence of any natural primary warm water sites, and currently only one operational power plant within that same region, the CS mortality events of February 2009, and the 2009-2010 and 2010-2011 winters were inevitable, and are likely to occur again under similar circumstances. How well the animals in the region fare will depend on many factors both within, and beyond our control.

Surveying Brevard County for manatee aggregations during the winter months may uncover additional existing and potential warm-water sites worthy of investigation. A number of locations have been identified, but not yet thoroughly characterized.

Characterizing the physical, hydrological and thermal features of those sites as well as understanding when and how the sites are used and under what conditions can provide important information when implementing measures to enhance those sites and protect the animals that use them.

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CHAPTER TWO: SECONDARY SITE CHARACTERIZATION

Introduction

Designated as an Estuary of National Significance in April of 1990, the 251 km (156 mile) long Indian River Lagoon (IRL) is recognized as one of the most biologically diverse estuarine ecosystem in North America, supporting over 4300 species of plants and animals, including 35 species that are either endangered or threatened (Smithsonian Marine Station, http:// www.sms.si.edu). Financially, the lagoon contributes in excess of $700 million to the local economy (Brevard County, http://www.brevardcounty.us), and $3.7 billion annually to the national economy through recreational fishing, agriculture, boating, ecotourism and water sports (St. Johns Water Management District, http://www.sjwmd.com/itsyourlagoon).

Comprised of the Indian River, the Banana River, Mosquito Lagoon and numerous tributaries, the IRL is an estuary situated between the Florida mainland and the longest barrier island complex in the United States (Smithsonian Marine Station, http://www.sms.si.edu). It is connected to the Atlantic Ocean by way of six inlets including Ponce Inlet in Volusia County; Port Canaveral and Sebastian Inlets in Brevard County; Fort Pierce Inlet in St. Lucie County; and Jupiter Inlet in Palm Beach County (Woodward 1994).

Situated between approximately 27° and 29°N (Woodward 1994), the lagoon spans six coastal counties and encompasses approximately 915 m^2 (353 square miles) of surface water. The lagoon's location is influenced by a subtropical climate. Shallow in nature, the IRL has an average depth of 1.22 m (4 ft). Average rainfall is approximately 128 cm (50 inches) in the IRL Basin annually (St. Johns Water Management District, http://www.sjwmd.com/itsyourlagoon). Its shallow depths along with year-round sunshine, and low-nutrient, brackish waters with salinity values in excess of 20 parts per thousand (ppt) make the IRL waters favorable for the growth of extensive seagrass beds, providing prime habitat for larval fish, marine invertebrates, juvenile sea turtles, alligators, bottlenose dolphins, sea birds and the Florida manatee. Seagrasses may be considered one of the sentinels of the lagoon's overall health and resilience. Of the 52 known species of seagrasses worldwide, seven grow in the IRL, including Johnson's seagrass (*Halophila johnsonii*) found only from Sebastian Inlet to northern Biscayne Bay. The diverse life found in the lagoon supports complex aquatic and terrestrial food webs.

Located on the central east coast of the Florida peninsula, Brevard County lies between 27.3° and 28.3°N latitude and -80.2° and -80.5W longitude. Brevard County encompasses approximately 46% (by length) of the IRL and provides critical manatee foraging, breeding, and calving grounds, as well as winter warm water aggregation sites despite the lack of any natural warm water springs in the region. With the introduction of two power plants in the northern part of the county in the late 1950's/early 1960's, it has been suggested that there was an expansion of the manatees' winter range on the east coast. With this expansion came a regular challenge of thermoregulation when water temperatures fell below the 18-20°C thresholds. Dealing with this thermal insufficiency requires the knowledge and use of existing industrial warm water refugia and/or the use of passive thermal sites if individual animals are to survive cold winters.

Identifying and studying winter aggregations of manatees in passive thermal basins located in the southern and central parts of Brevard County is critical to understanding their use of the region as well as their dependence upon certain locations to survive during the winter months. A review of the available literature shows that as early as 1895, Bangs published observations of manatees in the Indian River Lagoon. Specifically, Bangs recounted the death of two manatees in the St Sebastian River due to a “freeze” in the winter of 1894-1895. Recounts of a local resident indicated that manatees were known to use the St. Sebastian River and that they were particularly susceptible to “changes in temperature.” Bangs also indicated that “the region from Sebastian to St. Lucie has, for a number of years been the only part of the Indian River where manatees were seen.” This would seem to support the observation that the St. Sebastian River served as the northern most boundary of the winter range of the manatee in Florida (Moore 1951).

While a large part of the east coast manatee population may migrate in the fall to warmer waters and power plants in southeast Florida, annual power plant aerial surveys conducted by Reynolds from 1981 through 2011, along with year-round aerial surveys in the region in from September 1997 through September 1999 (FWC, Unpublished data) indicate that a large number of manatees reside in Brevard year-round, with many migrating into the region from farther north, seeking shelter in artificial warm-water refugia during the winter months. Manatees have been documented north of St.

Sebastian River in Brevard County since the 1970's (Irvine *et al*. 1979, Leatherwood 1979, Shane 1978). The effect of power plants on the manatee's East Coast winter distribution however, was not studied until a couple of decades after the introduction of the plants. It is not surprising then that while numerous manatee studies have been conducted in Brevard County, studies of aggregations around power plants at the northern end of the county seem to dominate the available literature (Shane 1978, 1981, 1983, 1984, Breen 1981, Rose 1981, Rose and McCutcheon 1980, Raymond 1981, McGehee 1982, Reynolds 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002a, 2002b, 2003, 2004, 2005, 2006, 2007, 2009, 2010, 2011, Reynolds and Wilcox 1985, 1986, 1988, 1994, Garrott *et al*. 1994, 1995; Beck and Reid 1995, Craig and Reynolds 2000). Both ground and aerial surveys of manatee abundance around two power plants in the Port St. John area are numerous.

In 1978 and 1979, two studies pertaining to manatees in Brevard County were published, one by Shane and the other by Leatherwood, respectively. Leatherwood's study was limited to opportunistic manatee counts incidental to dolphin aerial surveys and made no attempt to estimate the number of manatees, as this was not the primary goal of the research. There was no mention of distribution or abundance with respect to air or water temperature. These surveys were not specific to the power plants either. Shane's power plant study was the first of a multi-year research project that in subsequent years has been conducted by Rose, Reynolds, Wilcox and others under contract with the Florida Power and Light Company (FPL). The two power plants, one owned by FPL, FPL-Cape Canaveral (FPL-CC) and the other currently owned by the Orlando Utilities Commission (OUC), are located in the northern part of Brevard County and until recently both served as warm-water refugia in a county where substantial or primary natural warm-water sites are believed non-existent. The OUC plant went inactive in January of 2010. Its future operating status is unknown. FPL-CC was demolished in order to replace it with a natural gas plant in the fall of 2010. An interim heating system was added to the plant's intake canal in an effort to keep manatees warm during the winter until the plant's reopening in 2013. The repowering efforts were monitored closely for possible effects on current winter refugia use in the region (Deutsch and Barlas 2011, 2012, 2013).

In addition to power plant aggregations, Shane (1978) also discussed manatee distribution, behavior and abundance in the Indian and Banana Rivers throughout Brevard County in areas that included "likely manatee habitat as well as known areas of manatee concentration" (Shane 1984). Survey flights did not extend south of the Melbourne Causeway (SR192) (Figure 16). The areas surveyed included the grass flats across from the aforementioned power plants outside of the entrance to Rinker's Canal (now part of Pine Island Conservation Area), the Banana River Marine Services Marina Basin (a private residential marina located south of SR 520 off of the Banana River in Merritt Island), the Banana River just north of the NASA Causeway (SR405) and the SR520 Bridge (near what is now known as Kiwanis Park), the MSS (Mobile Service Structure) at Kennedy Space Center (KSC), Pad 39A Bay and Petersen's Point both in the NASA restricted area of the Banana River, the Mosquito Lagoon, the Port Canaveral

Lock area, the Trident Submarine Base at the Port, the Cape Canaveral Sewage Plant, Sykes Creek, the Cocoa Beach Sewage Plant, the Minuteman Causeway Cove in Cocoa Beach, the Grand Canal in Satellite Beach and Lake Shepard, a residential canal just south of Patrick Air Force Base connected to the Banana River by the Grand Canal. There is no mention in this work of manatees in Berkeley Canal, another residential canal just south of Patrick Air Force Base that in recent years has supported an increasing number of manatees during the winter months (A. Spellman, FWC, Pers. Obs.). Nor is there any mention of a similar canal off of the Desoto Parkway located approximately 4km south of the Berkeley Canal which starting in late 2009 began attracting upwards of 100 manatees. Manatee counts in Lake Shepard and the Grand Canal were not substantial during Shane's study (<20 individuals) in the winter months.

Manatee power plant aggregation studies subsequent to Shane (1979) focused primarily on the power plant aggregations identified in that study and not potential aggregation sites in the area. One exception was a brief mention of manatees aggregating in the Banana River Marine Services Marina Basin in a study of manatee aggregations at power plant effluents in south Florida (Rathbun *et al*. 1983). This latter study was not concentrating on the Brevard power plants but rather those power plants south of the county at Ft. Myers, Riviera and Port Everglades. The majority of photo-identification studies in Brevard County have also centered on the power plants and the Banana River Marine Services Marina basin (Beck and Reid 1995, Tyson 2000 Unpublished report). Turbid waters in most of Brevard County limit optimal photo-identification conditions in all but a few locations.

Working from north to south in the county, additional non-power plant-related manatee distribution and usage studies in the area include work by Irvine *et al.* (1979). In this study manatee abundance and distribution was documented by ground surveys at the MSS (KSC), Pad A39 Bay (KSC), AF Hanger Turning Basin, the Trident Sub Base (Port Canaveral), the Canaveral Sewage Plant, and the South Banana River Marine Services Marina Basin. Aerial surveys in this latter study however, included only the upper portion of the Banana River. Banana Creek was surveyed en route to the Banana River as manatees were sometimes documented in the creek next to the SR3 Bridge. The highest number of manatees counted during the study occurred during the month of November while the lowest counts occurred in January and February. Manatee abundance began to increase again in March and April suggesting that lower water temperatures experienced in the region during the winter months may be the cause of manatees migrating out of the area. Provancha and Provancha (1988) surveyed manatee abundance and distribution in the NASA restricted area of the northern Banana River. This study showed peak manatee numbers occurring in the spring months and with total numbers increasing from 56 individuals in 1978 to 297 in 1986. Abundance was lowest during the winter months.

Further south, Hicks (1990) conducted her Master's thesis research on manatee abundance in the Grand Canal, Satellite Beach. All surveys were boat-based and while Lake Shepard is mentioned, Berkeley Canal does not appear in her study. Hicks' study was conducted for a period of less than one year, encompassing the months of February through September. In her conclusion Hicks states that while manatees were rarely sighted in February, there was an increase in the number of manatees during the spring months, which appeared to be maintained during the summer months followed by a decrease again in September. As with other studies on manatee abundance, Hicks (1990) correlated this seasonal increase with rising water temperatures.

Tiedemann (1980, 1983) conducted his Master's thesis on manatee abundance in Turkey Creek, located south of Melbourne in Palm Bay. Surveys of the population were again boat-based only. Results of the one-year study indicate that manatees were absent from Turkey Creek from December to March of the study period in 1979. Only one winter season was sampled. Manatees were documented returning to the creek in early March when water temperatures exceeded 20°C. A total of 45 different manatees were identified in Turkey Creek during the study period.

A third Master's thesis by Heyman (1990) studied manatee abundance and distribution in the north fork of the St. Sebastian River (known as C-54) at the southern boundary of Brevard County. The C-54 spillway is a fresh water tributary to the north prong of the St. Sebastian River. Aerial surveys flown in 1987 by the U. S. Fish and Wildlife Service indicated consistent use of the north prong of the river by manatees. Heyman (1990) conducted her study over a period of eight months from November 1989 through June 1990. Census was from boats only, and the study did compare manatee usage to both air and water temperatures. The highest numbers of manatees were counted in November and December, while the lowest numbers of manatees were counted in May and June.

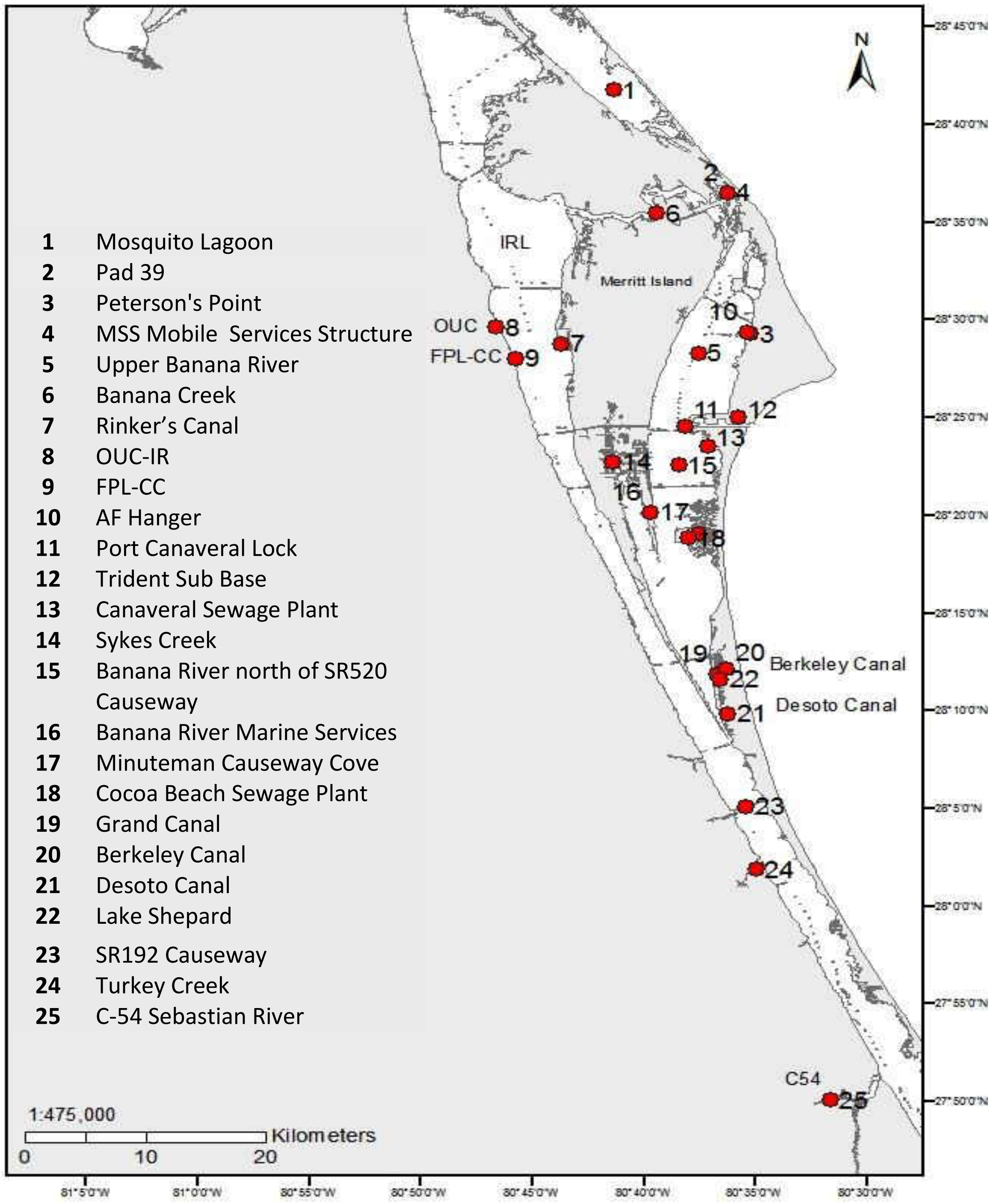

Figure 16 Location of areas of interest from manatee-related research within Brevard County, Florida

Two additional unpublished manatee studies conducted in Brevard County by Burke (1994) and Heckmann (1995) looked at critical habitat analysis outside of the winter months, and manatee abundance and distribution with respect to seasonality in the Banana River and at the two power plants, respectively. Neither study makes mention of warm water secondary sites.

Countywide manatee distribution aerial surveys were flown twice monthly by the FWC in Brevard County over a two-year period from September 1997 to September 1999. Results indicated that manatee numbers were "high during the winter months (December-January), peaked in March and then declined to relatively stable levels throughout the warmer months (April-October). Levels increased again in November" (Taylor and Ackerman, Unpublished manuscript). This particular study did cover the lower Banana River and results indicate that it is an important winter as well as summer habitat for large numbers of manatees. The largest aggregation of manatees documented during the winter months were at the power plants and C-54 Canal. However, manatees were documented in the Berkeley Canal at various times during the year with the highest counts documented in the months of January, February and March of 1999.

Additional surveys flown over known and suspected aggregation sites in seven contiguous east coast counties from November 2002 into April 2003 showed that Berkeley Canal and C-54 had the highest concentration of manatees outside of known thermal refugia during the winter months (Flamm 2003). Recent winter aerial surveys conducted twice monthly by Mote Marine Lab under contract with FPL during the FPL repowering project, show regular use of two passive thermal basins in Satellite Beach and the C-54 (K. Scolardi, Mote Marine Lab, Pers. Com.). A recent study by Laist *et al*. (2013) analyzed statewide winter manatee counts from the 1999 through 2011 synoptic surveys to determine the percentage of manatee using different types of winter refugia in an effort to show correlation between cold stress vulnerability and winter habitat preference.

Even with the most recent aerial surveys confirming the use of key secondary sites in the county and extensive documentation of manatees in Brevard County there is much that is still unknown about manatee warm-water and thermal refugia use, particularly at passive thermal basins (PTBs). The critical and precarious nature of the future of the two existing artificial warm-water sources in Brevard County, the threat of future power plant deregulation, and the potential for catastrophic events warrant a comprehensive, countywide study of critical winter habitat. While the power plant and Upper Banana River aerial surveys continue annually, continued and in-depth studies of the historically known aggregation sites (e.g. Banana River Marine Services Marina, Port Canaveral Locks, Lake Shepard, C-54 and Turkey Creek) as well as characterization of warm-water sites (e.g. the Berkeley and Desoto Canals) is needed. Ground counts during photo-identification trips as well as aerial survey results for the Berkeley Canal indicate a high number of manatees using this residential area off of the Grand Canal. In January 2004 more than 120 manatees were counted in Berkeley Canal during the winter synoptic survey (FWC, Unpublished data). Throughout the winter months of that same year manatee ground counts ranged between 60 and 90 individuals during colder days (FWC, Unpublished data.). An aerial survey conducted on 15 Feb 2011 reported a high of 140 manatees using the canal following the passing of a particularly strong cold front that affected the region (K. Scolardi, Mote Marine Lab., Pers. Com.). This was surpassed in 2014, when an aerial survey conducted on 02 February, counted 183 manatees in the canal (J. Reynolds, Mote Marine Lab, Pers. Com.). The question remains whether manatees were using this canal during the Shane and Hicks studies and were overlooked, or whether this canal has only become an aggregation site in recent years, and if so, when and under what conditions?

Provancha and Provancha (1988) and Shane (1978) proposed that manatees documented in the Banana River during the warmer months may migrate out of the county or leave the Banana River and congregate at the Brevard power plants in response to dropping air and water temperatures. The fact that manatees have been documented in the Berkeley Canal throughout the winter months in 2003, 2004 and 2005, and that they appear to show similar daily use patterns (A. Spellman, FWC, Per. Obs.) to manatees documented at the power plants (Deutsch 2000), (i.e. entering the canal in the early morning hours and leaving the canal during the late afternoon presumably to feed) suggests that this area may be another important warm-water site and as such warrants further study to determine its ability to support manatees during the winter months. Recent aerial survey counts indicate that use of these canals is quite substantial during the winter months (FWC, Unpublished data).

Although several telemetry studies have been conducted with manatees associated with east coast power plants during the winter months (Deutsch 2000) and along the Atlantic Coast of Florida (Deutsch 1996, Reid *et al*. 1995) absent in the literature are telemetry studies specific to manatee use of secondary warm-water sites. During the FPL-CC repowering project and for two years following its completion, a concurrent telemetry-based study is being conducted during the winter months by the Florida Fish and Wildlife Conservation Commission (FWC), to monitor and document the movements and habitat use by manatees believed to be dependent upon the power plant discharge. A small number of the animals caught during the first 5 years of this 6-year study appear to use at least one of the three secondary sites identified in this study (M. Barlas, FWC, Pers. Com., Deutsch and Barlas 2011, 2012, 2013). One of these manatees used the Satellite Beach sites exclusively throughout the winter after its initial capture close to the power plants (Deutsch and Barlas 2011).

Additional research in the region involved a study manatee use of seagrass beds conducted by Provancha and Hall (1991), to determine the impact of manatees on the health of seagrass beds in the restricted area of Kennedy Space Center.

Changes in Brevard County's coastal environment over the past twenty years have the potential to influence changes in manatee abundance and distribution in the region. These changes may be reflective of shoreline development, fresh water run-off leading to degradation or modification of critical habitat, increased recreational water use and subsequent disturbance, shifts in the manatee's range due to environmental and habitat changes in other areas of the state, global climate change and resulting sea level changes as well as resulting increases in annual temperatures, harmful algal blooms either directly or indirectly affecting the animals or their habitat and resources, and hydrologic changes in response to increased water needs of a rapidly increasing human population. In light of these developments, understanding what attributes make Brevard County such an important year-round habitat for manatees is important if that habitat is to be protected and available long-term. Winter habitat, specifically warm-water sites are especially important given the manatee's unique physiology and limited options for dealing with the cold.

In this chapter, three passive winter aggregation sites, or passive thermal basins located in central and southern Brevard will be defined or characterized in terms of their physical, thermal and hydrographic features. Sites will be compared with respect to their physical features, as well as their thermal profiles during winters of different severity, and relative to ambient river temperatures. Characterizations will also address each site's hydrographic features, availability of fresh water and proximity to the nearest forage. Each site will be evaluated against Reynolds' (2000) recommended criteria for assessing the suitability of existing and future warm water sites. Disturbances levels and potential threats to the sustainability of the PTB's will be identified and discussed. The critical need for increased protection efforts and the recommendation for seasonal protected areas or sanctuaries will also be addressed.

Methods

Site Descriptions

Site descriptions were compiled using existing county, city, and water management district charts, maps and records, interviews with local experts, temperature monitoring data, seagrass survey data and from hydrographic surveys conducted at each site. Incidental to photo-identification efforts sites were visited multiple times each winter to document any physical changes such as water depth, accessibility, disturbances, and availability of food. Each site was assessed using Reynolds (2000) criteria for assessing the suitability of warm water sites.

IRL seagrass distribution and abundance data sets were obtained from the St. Johns Water Management District (SJWMD) and used to generate seagrass distribution maps in relationship to the power plants and the three PTB's using ArcMAP 10.0. Maps were created using both 2009 and 2011 seagrass survey data to illustrate the changes that occurred to seagrass beds availability within proximity of the PTB's in the wake of an unprecedented algal super bloom that affected the region in the spring of 2011.

Temperature Monitoring

To generate thermal profiles for each of the three secondary sites, automated temperature data loggers (Hobo Pro 2V, Onset Computer Corporation) programmed to record temperature every 30 minutes were deployed prior to the start of the winter season (November). Probes were deployed at the three secondary sites at the Berkeley Canal, Desoto Canal and the C-54, as well as at the power plants, in the Indian River Lagoon and in other areas of interest throughout the county as outlined in Table 14 and illustrated in Figure 17.

Probes were named with a 2 to 3 letter field ID followed by a letter indicating where the probe was deployed with respect to depth (A = Air, S = surface, C= column, B = bottom, and Z = sediment). Generally, probes deployed within 0.5m of the surface were labeled as surface probes (e.g. BC_S = Berkeley Canal Surface Probe). Probes deployed within 0.5m of the bottom were labeled as bottom probes (e.g. BC_B = Berkeley Canal Bottom Probe). Probes deployed >0.5m from the surface or bottom were labeled as water column probes (e.g. BC_B = Berkeley Canal Column Probe). Probes in covered by sediment on the bottom were labeled as sediment probes (e.g. BC_Z = Berkeley Canal Sediment Probe).

Probes were initialized using Onset Computer programming software version Hoboware v. 3.2.1. To prevent bio-fouling the probes were encased in 1.5 inch PVC cases, drilled with numerous 3/16 inch holes, large enough to allow for movement of water into and out of the case but unfavorable for barnacle growth on the probes. In areas where cases exhibited moderate to high barnacle growth, knee-high nylon stockings were used to cover the PVC cases, effectively allowing for water to freely flow into the case while deterring barnacle growth that could limit water flow into and out of the case.

Table 14 Temperature probe deployment location and schedule

SITE	CODE	SITE TYPE	LOCATION	08/09	09/10	10/11	11/12
Indian River	IR_B	Ambient River	Titusville	X	X	X	*
Indian River	IRN_C	Ambient River	Port St. John	*	X	X	X
Indian River	IRS_C	Ambient River	Micco	*	X	X	X
Banana River	BR_C	Ambient River	Satellite Beach	X^{DL}	X	X	X
OUC Intake	RI_B	Ambient River	Port St. John	X	X	X	*
OUC Discharge	RD_C	Industrial WW	Port St. John	X	X	X	*
FPL Intake East	FI_C	Ambient River	Port St. John	X	X	*	*
FPL Intake East	FI_C	Interim WW	Port St. John	*	*	X	*
FPL Intake West	FIW_B	Interim WW	Port St. John	X	X	X	*
FPL Discharge-N	FD_B	Industrial WW	Port St. John	X	X	*	*
FPL Discharge-N	FD_B	Interim Ambient	Port St. John	*	*	X	*
FPL Discharge-S	FDS_B	Industrial WW	Port St. John	X	X	*	*
FPL Discharge-S	FDS_B	Interim Ambient	Port St. John	*	*	X	*
Berkeley Canal	BC_A	Ambient Air	Satellite Beach	X	X	X	X
Berkeley Canal	BC_S	PTB	Satellite Beach	X	X	X	X
Berkeley Canal	BC_C	PTB	Satellite Beach	X	X	X	X
Berkeley Canal	BC_Z	PTB	Satellite Beach	X	X	X	X
East Berkeley	BCE_Z	PTB	Satellite Beach	*	*	X	X
Central Berkeley	BCC_B	PTB	Satellite Beach	*	*	X	X
West Berkeley	BCW_B	Unclassified	Satellite Beach	*	*	X	X
Sleepy Lagoon	SL_B	Unclassified	Satellite Beach	X	X	*	*
Lake Shepard	LS_B	Unclassified	Satellite Beach	X	X	*	*
Desoto- Main	DC_B	Unclassified	Satellite Beach	X	X	X	X
Desoto- Ditch	DCN_B	PTB	Satellite Beach	*	*	X	X
Desoto- Ditch	DCS_Z	PTB	Satellite Beach	*	*	X	X
Grand Canal	GC_B	Unclassified	Satellite Beach	*	*	X	X
Melbourne-Tillman	MT_B	Unclassified	Palm Bay	*	X	X	*
C-54	SR_A	Ambient Air	Fellsmere	X	X	X	X
C-54	SR_S	PTB	Fellsmere	*	X	X	X
C-54	SR_C	PTB	Fellsmere	X	X	X	X
C-54	SR_B	PTB	Fellsmere	X	?	X	X
C-54	SR_Z	PTB	Fellsmere	*	X	X	X

(x = deployed, * = not deployed)

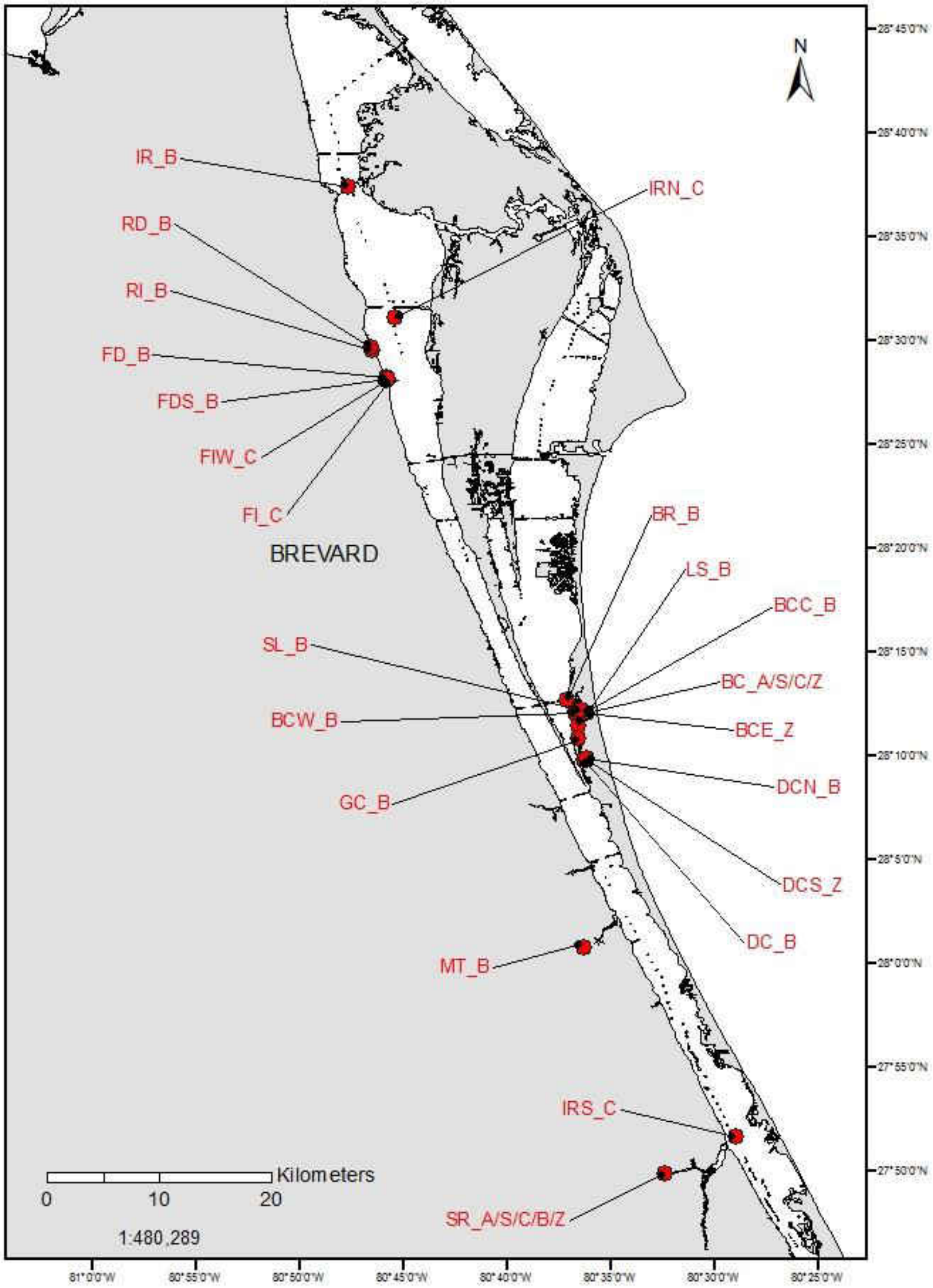

Figure 17 Temperature probe deployment locations in Brevard County

Probes were hung from private docks, fences, permanent structures and navigational pilings via 4.7mm, plastic-coated, metal cable. Due to lack of appropriate platforms to secure the probes in certain areas, probes at the Desoto Canal (DCN and DCS) were anchored to the bottom with steel tie-out stakes. Probes at the east end of Berkeley Canal (BCE_Z and BCE_B) were secured to a cinder block and submerged in an effort to prevent manatees from interacting with the equipment at that location and to prevent theft or vandalism.

Data from the probes were downloaded at varying intervals during the winter season depending on accessibility and time constraints. Probes deployed in the middle of aggregations were only downloaded at the end of each winter to avoid disturbing any manatees. Shortly after the end of each winter season (April) deployed probes were removed and a final downloads were performed. Downloads were exported to Excel using Hoboware 3.2.1. and raw data were archived as .hobo files then exported into .csv files for editing. Files were reviewed to identify any unusual temperature spikes or anomalies and to validate the data then saved as an edited Excel files. Multiple download files from the same site were then combined into a complete winter data set and then trimmed to include temperature data from December through March for each winter season monitored. In order to identify possible erroneous data points before analyses, the data set was graphed against local air temperature data (BC_A and SR_A) for each winter season using Sigma Plot 11.0. Suspect or questionable data points identified by exaggerated fluctuations in the graphs not consistent with fluctuations in local air temperatures or other probes located nearby were removed from analyses if further scrutiny of the data point(s) indicated that their validity was doubtful.

Descriptive statistics including the minimum, maximum and mean temperatures, standard deviation and range were calculated for each winter data set using Sigma Plot 11.0 statistical software. The daily and monthly maximum, minimum, and mean temperatures were also calculated for each data set using Microsoft Access (Windows Office 2007).Daily ranges were calculated by subtracting the daily minimum temperature from the daily maximum temperature. Daily temperature means were graphed for each probe location using Sigma Plot 11.0. When appropriate, graphic temperature profiles were generated for probes located at different depths within the same location to illustrate the thermal profile within a particular site of interest. Daily average temperature data from different locations were graphed alongside each other to show differences within and between warm-water sites, differences with respect to ambient river temperatures, and differences with respect to other areas of interest in the county.

The percentage of days that the daily mean temperature fell below the critical temperature of 20°C as well as a selected threshold temperature of 18°C were calculated for each warm water site in a manner similar to Loomis (2010) (Appendix D). Additional analyses included tabulation of the number of *consecutive* days water temperatures at each secondary site fell below these same thresholds within a given winter. These values were compared to those calculated for nearby and ambient sites as well.

To compare temperature differences within and among sites to ambient river temperatures over winters of varying severity (mild to severe), the mean winter delta-T (ΔT) values for each site with respect to ambient river temperatures (i.e. the temperature difference between ambient river and warm water sites) were calculated by subtracting the mean of the daily average temperature of ambient sites from the mean of the daily average temperature of warm water sites. The ΔT values were also calculated for other sites of interest in the area, and for additional ambient river sites. The ΔT values for each site were graphed against each ambient river site's winter mean temperature (IR_B, IRN_C, BR_B and IRS_C). Since the ambient river temperature was the one to which all others were compared, the average daily winter mean of the ambient site of interest was set at zero. Delta-T values were compared across four winters of varying severity from mild to severe to see how well warm-water sites maintained temperatures above ambient river using a box plot with standard error bars.

Hydrographic Surveys

Multiple locations within each of the three secondary sites were surveyed for temperature, salinity, and depth at the bottom of each sampling location using a YSI Model 600R Sonde. Activities were conducted under USFWS Permit# MA773494. Surveys were undertaken during a moderate cold front on either 13 February 2011 (C-54) or 14 February 2011 (Berkeley and Desoto Canals). Although colder fronts were experienced during the course of this study, all efforts were made to prevent the disturbance of manatees seeking refuge in the sites. Weather conditions the day of the survey were ideal due to mild winds (6-8mph), presence of a moderate cold front in the region (08 February through 15 February 2011), and no precipitation over a two day period. Surveys during critical cold fronts would likely have caused some manatees to leave the refuge and potentially subject them to lethal ambient water temperatures. This option was deemed unacceptable given the severity of the winter conditions, the physical stress on the animals, and an unusually high number of cold stress-related mortalities occurring in the region at the time.

Each survey was conducted in a manner appropriate the sites unique characteristics of depth, width and bottom composition as described below. To avoid damage to or fouling of the sensitive sensors of the YSI, the sampling probe (sonde) was mounted on a PVC pole high enough up to prevent it from interfacing with the sediment at each site during the sampling. Sediment readings were not taken during the surveys.

Berkeley Canal

The Berkeley Canal was surveyed 14 February 2011. The canal was divided into three equal transects: north, central, and south, each running parallel to the length of the canal. The north and south transect readings were measured 1.5 m off the seawalls while the central transect readings were measured midway between the seawalls in the center of the canal. YSI readings were taken from a paddle-propelled canoe in line with the east property boundary of each residence located along the canal, or every 24.2 m.

This allowed equidistant sampling locations and assured accurate positioning for subsequent readings on the different transect lines. Thirteen locations were sampled along each transect for a total 39 sample readings. Sampling was performed by slowly lowering the pole-mounted YSI sonde into the water until the pole hit the bottom. Each reading was labeled upon removal of the sonde using.

All efforts were made to avoid disturbing the manatees taking refuge in the canal. Weather conditions were optimal with little wind. Manatees were documented as present in the east end of the canal and were not significantly disturbed by the sampling.

Desoto Canal Drainage Ditch

Only one transect was conducted in the middle of the Desoto Canal due to its narrow width (7.5 m across) and shallow depth (maximum depth was 0.495 m in the center). The YSI data sonde was attached to a long PVC pole that spanned the width of the canal and was supported on each side by two observers. It was suspended from the middle of the pole and lowered into the water at the center point of the canal. Readings were taken every 10 m for a total of 12 readings. Manatees were documented as present in the canal when the measurements were taken but appeared to be unaffected by its presence.

Sebastian C-54 Canal

YSI readings were taken along three transect lines running west to east along the entire length of the C-54 canal. Readings were taken from a motorized watercraft (21ft, Key West) fitted with a bow-mounted, electric trolling motor, run at idle speed. Of the three sites, the C-54 was the only site affected by tidal flux and a current. At each sample site in the C-54, two anchors were deployed to minimize drifting during the readings. To facilitate the submersion of the probe and to prevent the immersion of the sonde head in the sediment, the probe was attached to a PVC pole approximately 25 cm from the end before being deployed into the water. For each of the three parallel transects ten reading were taken approximately 68 meters apart for a total of 30 sample readings. Manatees were documented as present during the sampling but appeared unaffected by sampling efforts.

Individual data files from all three sites surveyed were downloaded and exported as Excel files using the software EcoWatch® v. 9.0.1. For each individual file, the maximum depth and corresponding values for bottom temperature and salinity were identified and tabulate by sampling location. Additionally the site mean, standard deviation, range and maximum and minimum values for these characteristics were calculated to facilitate comparison between warm-water sites.

Results

Site Descriptions

Berkeley Canal Site

The Berkeley Canal is one of a number of residential canals located in Satellite Beach. It is located east of South Patrick Drive (County Road 513) between Arlington Street and Berkeley Street in unincorporated Satellite Beach, Brevard County, situated between latitudes 28.200829ºN and 28.200915ºN, and longitudes -080.603224ºW and -080.612332ºW (Figure 18). It has been recognized as winter aggregation site since the late 1990's and it is classified as a secondary warm-water site.

Berkeley Canal is a shallow (<2 meters), man-made canal built in the late 1950's on what were once dune swales running north to south along the barrier island just south of present day Patrick Air Force Base and State Road 404 (Brevard County Property Appraisers, http://www,bcpao.us/1943Book/t27/tr2737.htm) The canal measures approximately 303.6 m long and 22.5 m wide with a surface area of approximately 6831 meters^2. The canal dead ends at the east end. To the west its waters flow into to the Grand Canal after passing through two low-clearance, square openings in the concrete bridge overpasses at South Patrick Drive and Jolly Roger Blvd. The Grand Canal connects to the Banana River through several small cuts between a string of spoil islands, allowing manatees multiple paths into and out of the Grand Canal.

Salinity in the Berkeley Canal is low relative to the river ambient and is influenced by intrusion of fresh water from multiple sources. Fresh water enters the canal through two shallow storm water drainage ditches running north and south, and intersecting at the west end. YSI readings indicated that salinity is generally lowest along the north and south corners at west end. An additional source of fresh water enters through a corrugated metal storm water pipe located at the east end. Brackish water mixes with water in the canal from wind driven currents. Local anecdotal reports of the existence of an artesian spring at the east end on the north side of the canal could not be substantiated nor a specific point source located through hydrographic analyses during the course of this study. However, during an additional visit to the site on 22 April 2014, an YSI sonde was pulled behind a kayak along the east end to continuously monitor both salinity and water temperature. A sudden drop in salinity readings from 12 ppt to a reading of 4.1 ppt occurred at a location along the bottom of the canal, midway along the sea wall at the east end. During the visit several manatees were aggregated in the general vicinity of the location of the reading. Lower salinity levels in the canal than those found west of the bridges and in the Grand Canal would support the likelihood of substantial groundwater seepage at the east end particularly during the dry season (J. Fergus, City of Satellite Beach, Pers. Com.).

Developed for housing in the late 1950’s through the early 1960’s, 26 residential homes line the shore and no additional lots are available for development. The banks are armored by various forms of aging seawalls with only a few homes having docks. The bottom of the canal is sandy and covered by thick, muddy sediment of varying depth referred to as “muck”. The only vegetation in the canal appears to be growing over the sea walls of the surrounding residences and includes mangroves, Brazilian pepper, oak, and ficus trees.

The canal is relatively protected from meteorological as well as man-made disturbances due to the low clearance of the two concrete overpasses on South Patrick Dr. and Jolly Roger Dr. The low ceiling of these structures prevents access to all vessels with the exception of canoes, kayaks and small john boats. Additionally, private residences surrounding most of the perimeter limit access by the public, effectively reducing potential interaction with the animals. Despite this, disturbances affecting this site during the winter months include visitors to the site attempting to interact with (i.e.. touch and feed) the animals at the west end, limited fishing and cast netting into the site despite signs posted prohibiting such activities, and the occasional motorized and non-motorized small vessel entry. Currently no protective measurements are in place.

Seagrass distribution data from 2009 obtained from the St. Johns Water Management District (SJWMD), showed the presence of continuous seagrass beds, lining the east and west shorelines of the Banana River from the Pineda Causeway (SR 404) north extending to the Upper Banana River. The nearest continuous beds were located approximately 2.5km west of the Berkeley Canal. Additionally patchy seagrass beds lined the east shoreline of the lower Banana River south of SR 404 just outside of the Grand Canal system (Figure 19-left). Subsequent seagrass distribution surveys conducted in 2011 following an unprecedented algal super bloom in IRL showed marked loss of seagrass beds in these same locations (Figure 19-right).

The Berkeley Canal lies 34 km southeast of the nearest primary warm-water site at FPL–CC and 65 km northeast of the Vero Municipal Power Plant, in Indian River County. The Desoto Canal, located 4km south is the nearest secondary site, while the C-54 site lies 42 km to the southwest.

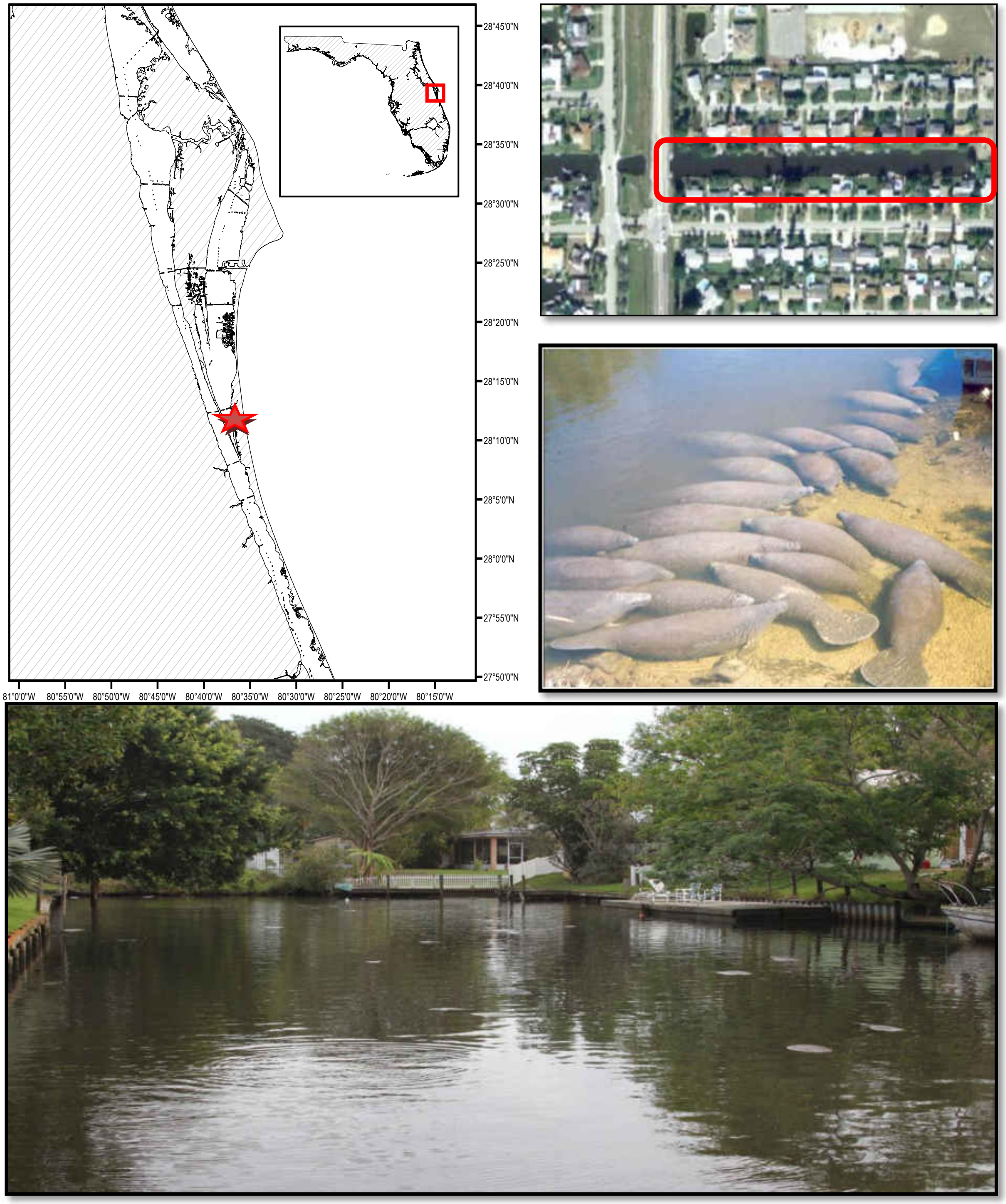

Figure 18 An overview of the Berkeley Canal Site in Satellite Beach, Brevard County.

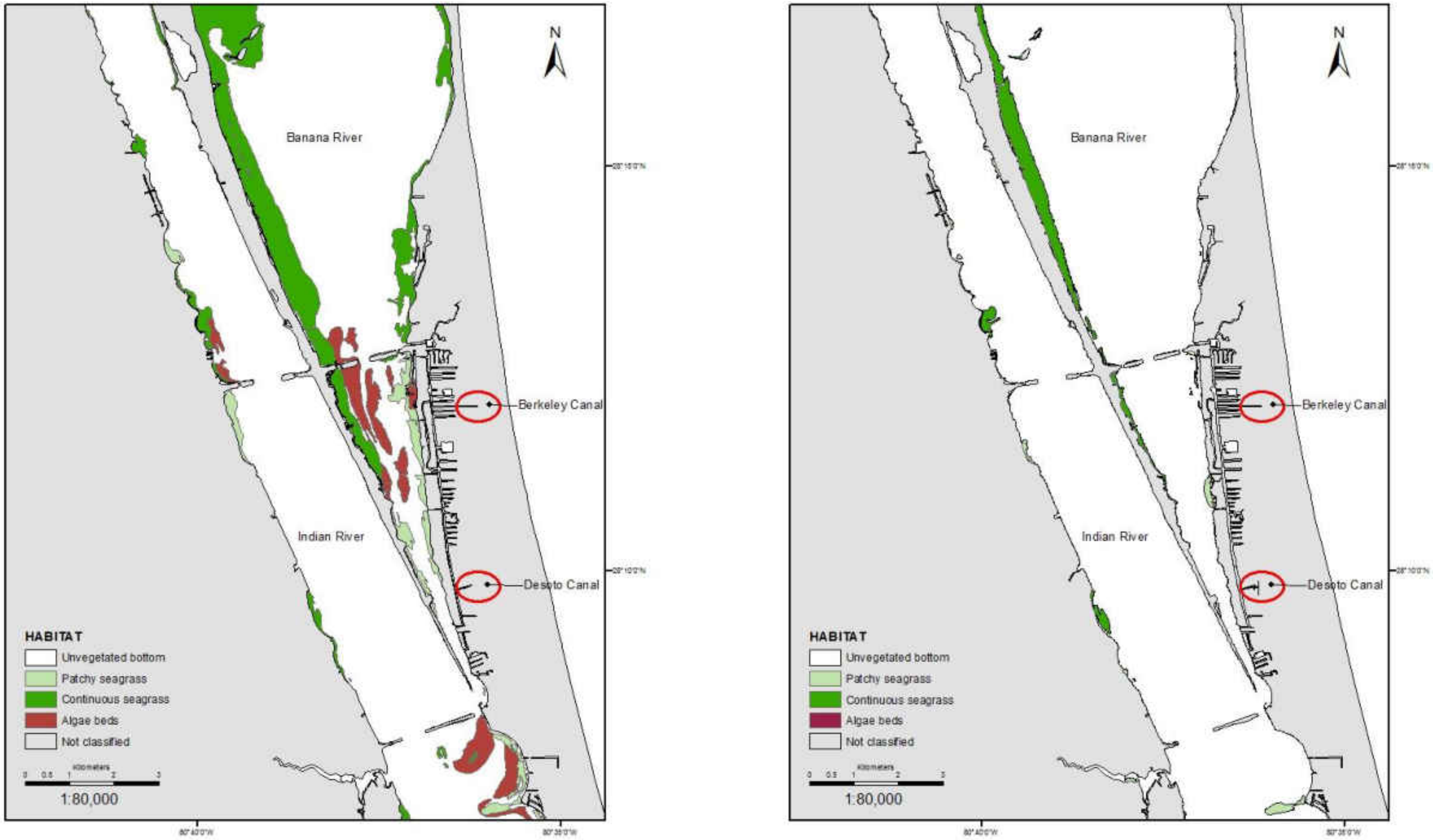

Figure 19 Paired maps comparing seagrass distribution and abundance in proximity to the Berkeley Canal and Desoto Canal in 2009, and after the occurrence of an algal super bloom in 2011 in the Indian River Lagoon 2009 (left), and 2011 (right).

Desoto Canal Site

The shallow, L-shaped Desoto Canal lies south of Desoto Parkway between Desoto Lane and Desoto Park, split down the middle by the town borders of Indian Harbour Beach to the west and Satellite Beach to the east, in Brevard County. The canal is situated between latitudes 28.164644 ºN and 28.163287°N and longitudes -080.603031ºW and -080.605547°W (Figure 20). The site consists of a man-made storm water drainage ditch installed in the 1960's (A. Potter, Satellite Beach Public Works, Pers. Com.), running in a north to south direction, and a main canal running from east to west. Prior to the fall of 2009, water levels in the Desoto ditch were negligible, (less than 10 cm) and manatees could not access that portion of the site.

A mixture of storm water, water used for local residential irrigation, and warm, fresh water suspected to be of artesian aquifer origins enters the drainage portion of the canal through two 70 cm concrete storm water pipes, located at the northeast end. Fresh water flowing from each pipe, year-round, keeps salinity low relative to ambient river values. Multiple, old water-to-air, artesian well-based air conditioning system condensation pipes provide a constant stream of fresh water along the west shore of the drainage canal from which manatees regularly drink. One such pipe allows water to bubble up through a spot on the north bank of the main canal. The pipe and surrounding ground s covered with a thick sulfur residue characteristic of artesian well water. Water entering the drainage ditch through the two storm water pipes is consistently well-above nearby ambient river temperature (23 - 24°C), and was maintained above the critical temperature of 18°C throughout even the coldest winter (2009-2010). There is a constant and noticeable flow of fresh water out of these pipes year round. The drainage ditch portion of the canal is relatively shallow, measuring less than 1 m at the deepest section

Hydrographic Surveys

Hydrographic survey results for the Desoto site confirm the persistence of high temperatures throughout the small refuge despite the extremely shallow nature of the canal. Water temperatures were highest at the north end where water flows in to the site. Of the three sites surveyed, the Desoto canal had the lowest salinity values ranging from 2 ppt at the north end, gradually increasing to 12.3 ppt moving south (Table 17), Temperature readings ranged from 19.3° at the southern end to 22.23°C adjacent to the storm water pipes.

Although the site is not subject to tidal fluctuation, daily changes in water depth are wind driven or influenced by precipitation and run-off. This generally results in lower water levels during the winter months (i.e. the dry season) and higher levels during the summer months (i.e. the rainy season). A marked seasonal drop in water level described by Woodward-Clyde Consulting (1994) is particularly evident at this shallow site, causing water levels to drop approximately 0.3 m during the month of December and is believed to be influenced by the astronomical events. The bottom is covered with a thick layer of sediment which negatively affects water clarity.

The main portion of the Desoto Canal runs in an east to west direction intersecting with a storm water collection ditch at the east end. The canal is bordered by townhomes built in late 1970’s- mid 1980’s on Desoto Lane to the north and by similar housing built in the late 1990’s- early 2000’s on McGuire Blvd at Manatee Reserve to the south. Though deeper than the north-to-south running drainage ditch, the main canal is shallow (<1. 5 m) with a thick layer of fine sediment covering the bottom over the entire length. The canal is not affected by tidal fluctuation but is influenced by wind driven intrusion of brackish water from the Grand Canal which it intersects to the west. Warm (24°C) fresh water (salinity = 0 ppt) from a water-to-air air conditioning condensation pipe bubbles up through the grass at edge of the north bank close to the east end of the main canal. Additional fresh water run-off enters the canal through precipitation and through two additional concrete storm water pipes located on the east end of the north bank and at the intersection of the ditch and main canal on the east side. There is little shoreline vegetation other than St. Augustine grass and some overhanging sea grapes. The main canal is armored with large coquina rock boulders while the ditch was recently armored with a cement slabs on the residential side in 2010. There are no boat docks and boat use is limited to canoes, kayaks and small aluminum boats.

Disturbances affecting the site during the winter months include visitors to the site attempting to interact with the animals, limited fishing and cast netting into the site, and the occasional non-motorized vessel entry (e.g. canoes, aluminum boats). In response to visitor interaction with manatees at the site, primarily feeding and attempts to touch the manatees, the City of Satellite Beach Department of Public Works routinely and proactively erects post and rope barriers just prior to the arrival of cold fronts to protect manatees within the site, and to protect the banks of the canal from collapse. These ropes also help to prevent trespassing on private property surrounding the site. The ropes stay in place until the end of winter and have been very effective in reducing harassment at this location.

Seagrass distribution data from 2009 obtained from the SJWMD show the presence of continuous seagrass beds lining the east and west shorelines of the Banana River from the Pineda Causeway (SR404) north into the upper Banana River (SJWMD, http://floridaswater.com/gisdevelopment/docs/themes.html).The nearest continuous seagrass beds are located within 3.5 km northeast of the Desoto Canal. As with the Berkeley Canal, the Desoto Canal lies in close proximity to patchy seagrass beds lining the east shoreline of the lower Banana River south of SR404, and just outside of the Grand Canal system (Figure 19-left). The Desoto Canal's proximity to the junction of the Banana and Indian Rivers allows easy access not only to seagrass beds located in the lower Banana River but to both seagrass and algae beds south of the Eau Gallie Causeway (SR518). Seagrass beds located within close proximity of the Desoto Canal suffered from the same algal super bloom in 2011 that affected the IRL throughout the entire county, showing marked loss of seagrass beds in all locations (Figure 19-right).The Desoto Canal is located approximately 4 km south of the Berkeley Canal, 38 km southeast of the FPL-CC Plant and 61 km north of the C54 site.

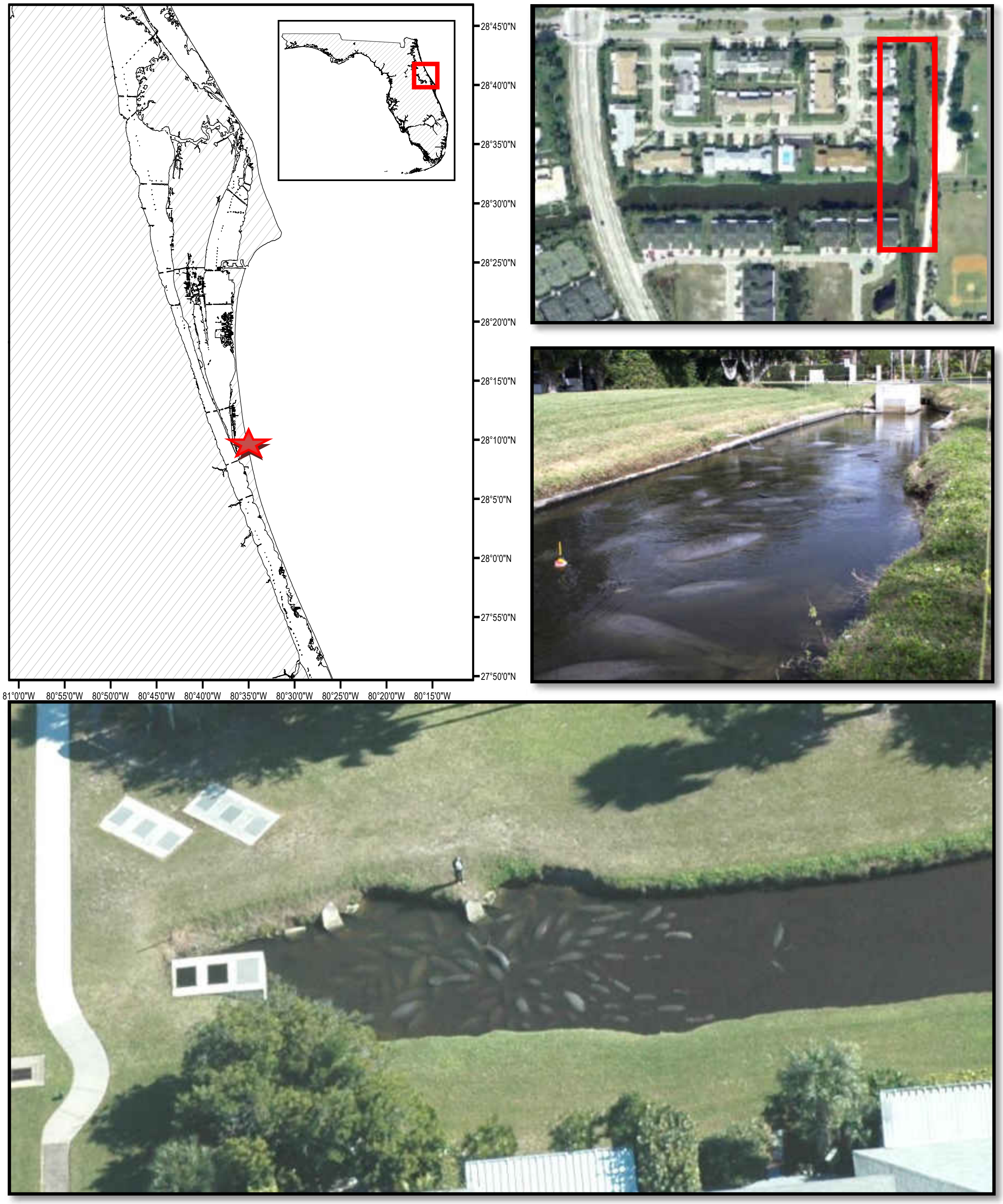

Photo: Courtesy of J. Provancha

Figure 20 An overview of the Desoto Canal Site in Satellite Beach, Brevard County

The C-54 Site

The C-54 is located in the north prong of the St. Sebastian River, in Brevard County situated between latitudes 27.830024ºN and 27.835422°N and longitudes -080.539212ºW and -080.519575°W (Figure 21). It is classified as a secondary warm-water site or PTB.

The C-54 was constructed in 1969 by the U.S. Army Corp of Engineers as part of the federal flood control project, and is currently under the authority of the St. John's Water Management District's. It lies on the border of Indian River and Brevard Counties and diverts fresh water from the upper St. Johns River into the western-most portion of the northern prong of the St. Sebastian River through a gated-spillway within the boundaries of the Sebastian River Buffer Preserve. On the east side of the spillway the canal measures approximately 2,041 m long and an average of 58 m wide with a surface area of approximately 118, 378 m^2

While characterized as brackish, salinity in the canal can vary widely due to the intrusion of fresh water flowing over the spillway and salt water intruding from both the Indian River Lagoon and the Sebastian Inlet. In addition to water entering through the spillway, fresh water runoff enters the canal through precipitation and through the Fells mere Canal spillway located approximately 635 meters down the canal along the south side. There is evidence of a halocline close to the spillway with salinity falling between 4 to14 ppt at surface to mid column depth, exceeding 20 ppt at the bottom (FWC, Unpublished data). Water depth at this site can exceed 4.5 m. Due to its close proximity to the Atlantic Ocean, the C54 experiences seasonal and monthly variations in tidal fluctuation, exhibiting a mean tidal change of approximately 0.5 ft (0.15 m) over a typical tidal cycle. Within the year, tides appear to be highest from October through November and lowest from February through April (Wicklein and Gain 1999).

While access to vegetation growing within the site is limited to the shoreline, manatees opportunistically graze on fresh water vegetation water hyacinth (*Eichhornia*) that flows over the spillway when winds blow out of the west (A. Spellman, FWC, Pers. Obs.). To obtain sufficient forage however, manatees must leave the St. Sebastian River to feed in the IRL. Prior to the algal super bloom in 2011, 2009 seagrass distribution data indicated continuous seagrass beds located both north and south of the St. Sebastian River in the IRL. Surveys conducted in 2011 show marked loss of seagrass beds in the same locations (Figure 22).

Disturbances at this site during the winter months include visitors to the site attempting to interact with the animals, a moderate level of fishing at the site, and the occasional motorized and non-motorized vessel entry (e.g. kayaks, canoes, small boats and boat-base ecotourism companies). The site is designated as an idle speed zone year-round and all vessels are prohibited within 45 m of the spillway.

The next nearest warm-water sites to the C-54 are the Vero Municipal Power Plant 23 km to the south, the secondary sites in Satellite Beach, located more than 38 km to the north, and the FPL- CC plant, 78 km to the north.

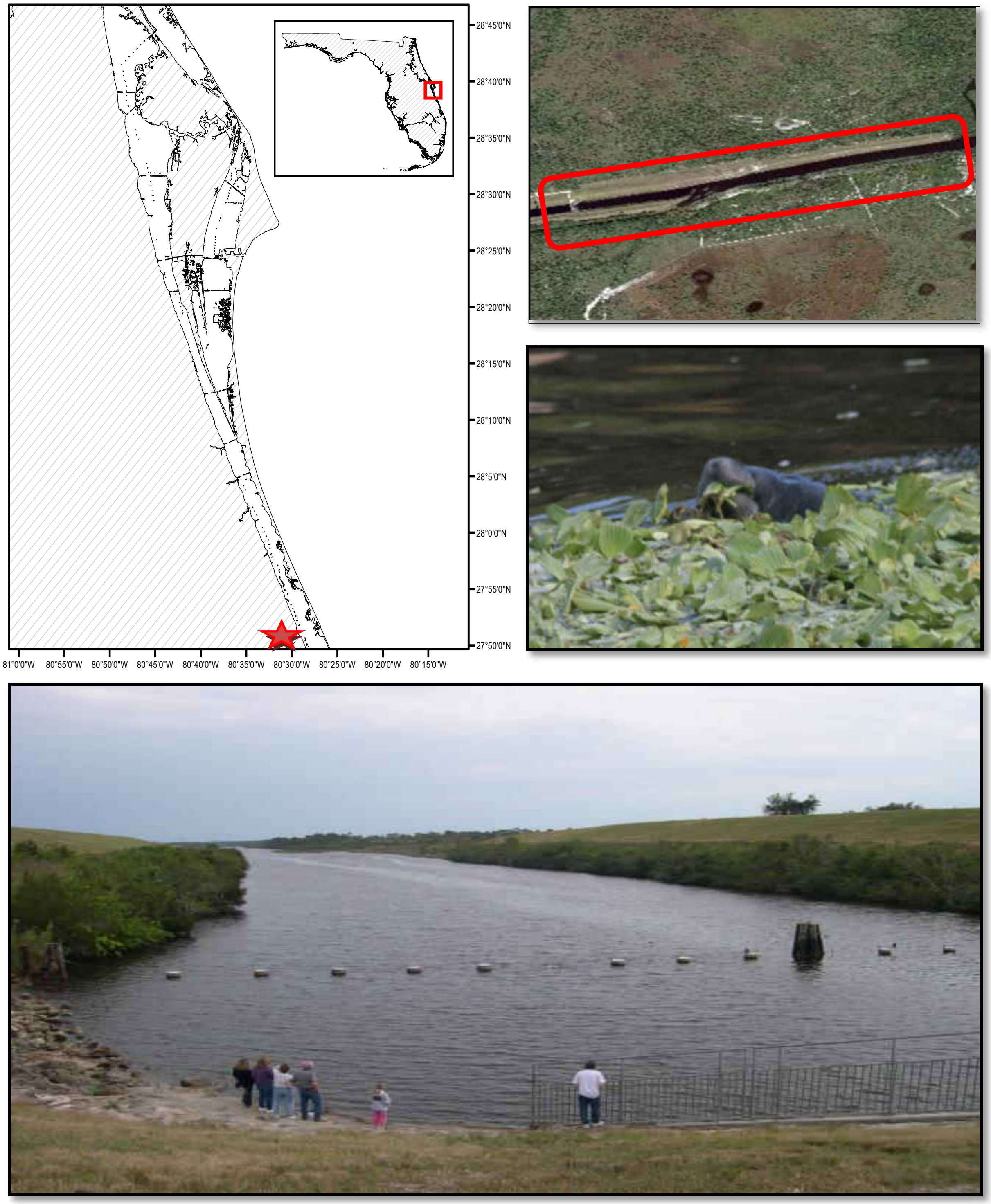

Figure 21 An overview of C-54 Site in the St. Sebastian River, Brevard County

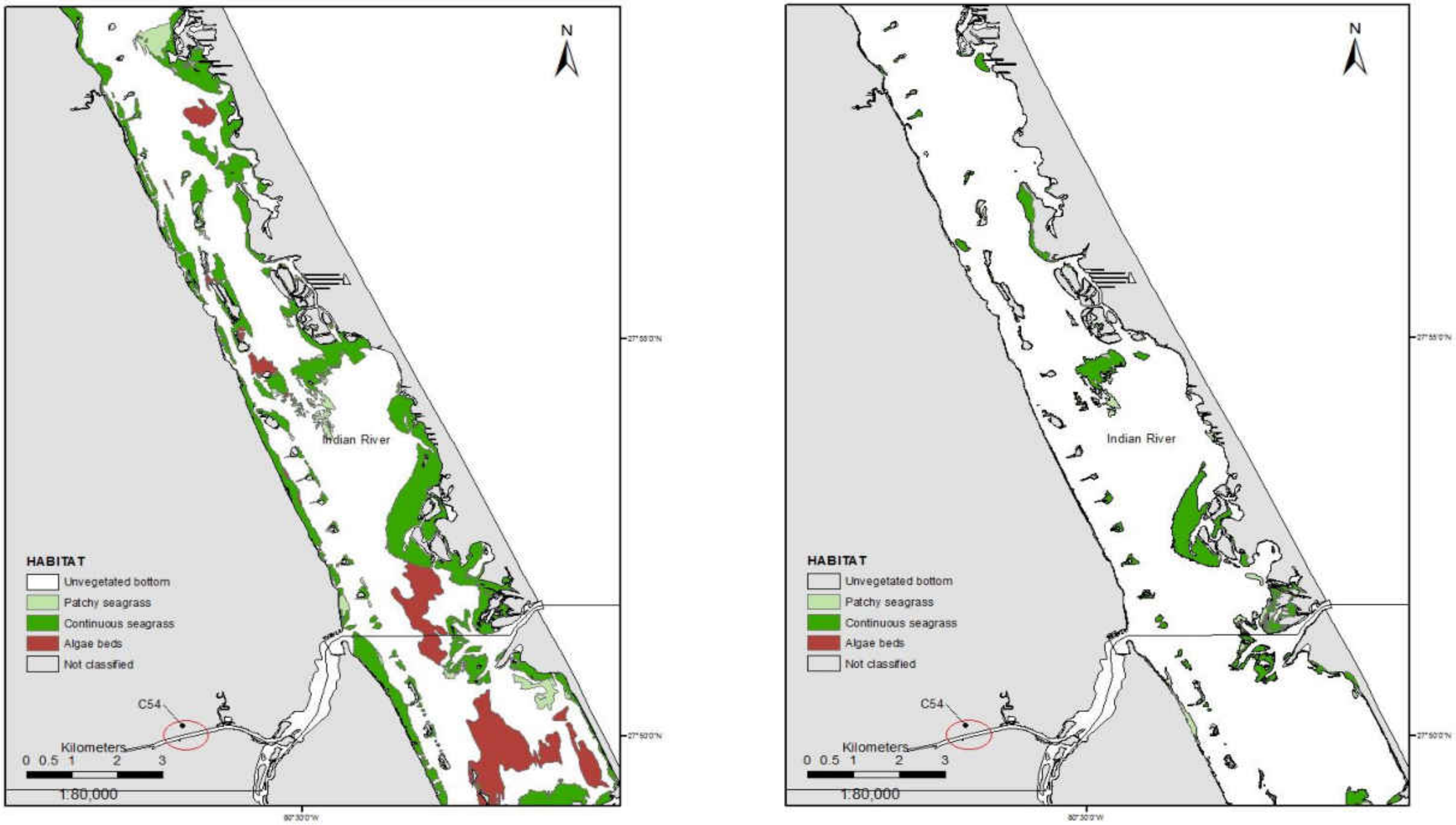

Figure 22 Paired maps comparing seagrass distribution and abundance in proximity to the C-54 site in 2009, and after the occurrence of an algal super bloom event in 2011 in the Indian River Lagoon
2009 (left), and 2011 (right)

Evaluation of the suitability of Brevard secondary sites according to criteria outlined by Reynolds (2000) indicates that all three secondary sites in Brevard fall short in a number of categories (Table 15). The assessment was made prior to the significant loss of seagrass beds in the IRL and therefore the assessment reflects abundant grasses in the proximity of each secondary site for that year. Of the 15 criteria, the top four represent the physiological needs of the manatee. These four criteria are satisfied in each secondary site. Sites fall short of suitability, however, when considering the “human factor”. Neither the Berkeley site nor the Desoto site offer access to deep water. All three sites are north of the desired historical winter range, and water quality, level of watercraft-related mortality, and high human pressure are issues at all three sites.

Table 15 Warm-water site suitability assessment for Brevard County secondary sites

Reynolds Warm Water Site Criteria	Berkeley Canal	Desoto Canal	C-54
Abundant local sea grass	YES	YES	YES
Available local fresh water	YES	YES	YES
Proximity to migration routes	YES	YES	YES
Proximity to summer habitats	YES	YES	YES
Bathymetry- easy to reach deep water	NO	NO	YES
Water quality & future trends	NEG	NEG	NEG
Human population density	HIGH	HIGH	LOW
Local human- related manatee mortality	HIGH	HIGH	LOW
Availability of undeveloped land/wetlands	NO	NO	HIGH
Local protected areas	NO	NO	YES
Easy creation education and outreach facilities	NO	NO	YES
Proximity to “non”-sensitive property	NO	NO	YES
Future land use Marinas/Ramps nearby	NO	NO	NO
Development pressure	LOW	LOW	LOW
South of historical winter distribution limit	NO	NO	NO

Temperature Monitoring

Daily mean water temperatures from sites around Brevard County show that ambient river water temperatures often fall below the critical minimum of 18-20°C even during mild winters (Figure 23-a, Figure 25-a, Figure 27-a, and Figure 29-a). The table in Appendix D shows the number of days in each winter season that daily mean water temperature at monitored sites met or exceeded 18°C and 20°C.threshold. During the 2008-2009 season daily mean water temperatures at the only ambient site monitored that year, IR_B, met or exceeded 18°C on 63 of the 121 day sample season or 53% of the time. During the very cold winter of 2010-2011, at that same site the number dropped to 47 days, or 39% of the time. Comparatively, during that same winter the daily mean temperature at the ambient site located in the IRL just east of the St. Sebastian River (IRS_C) met or exceeded the same threshold on 66 days or 55% of days during that same season. The number of days the daily mean temperature met or exceeded the 18°C threshold at the two remaining ambient sites, IRC_ C and BR_B during the 2010-2011 season, were 52 (43%) and 56 (44%), respectively.

While ambient temperature routinely fell below the critical minimum level throughout much of each of the four the winter seasons, two sites within the county, the C-54 and the Berkeley Canal (SR_Z and BC_Z) showed sediment temperatures within or above these values throughout most of the four winters. A third site within the Desoto canal, the shallow drainage ditch, shows temperatures exceeding the 18-20°C throughout all of the 2011-2012 winter. Due to equipment loss and malfunction at the Desoto Canal, data were available for only the last year of the study. During the winter of 2011-2012 mean daily water temperature at the site (DCN_B) and (DCS_Z) never fell below 2O°C. Spot checks with a handheld YSI during photo-identification trips showed temperatures exceeding 20°C during all three winters it was available to manatees.

The Berkeley Canal

Berkeley Canal daily winter mean temperatures were the highest of any site in the county across all four winters. This included the temperatures recorded at the FPL-CC site.

The Berkeley Canal sediment probe consistently recorded some of the highest water temperatures in the county regardless of winter severity (Figure 23-b, Figure 25-b, Figure 27-b, Figure 29-b). Comparisons to other probes deployed within the canal at different locations (BCC and BCW) indicate that warmer temperatures are primarily associated with the east end (Figure 30-b) with waters gradually cooling upon approaching the overpasses. Probes placed west of Jolly Roger Blvd show water temperatures approaching nearby ambient river values. Where multiple probes were deployed at the same location (BC_S, BC_C, and BC_Z) sediment values was not only consistently warmer but also showed less variation with respect to changes in air temperature (Figure 23-b, Figure 25-b, Figure 27-b, Figure 29-b). With the exception of the 2011-2012 winter, the BC_Z location had the highest mean winter and mean monthly temperatures in the county.

The C-54

The C-54 showed results similar to BC_Z with respect to sediment temperatures and stability over all four winters (Figure 23-c, Figure 25-c, Figure 27-c, Figure 29-c). Sediment temperatures within the site were the warmest recorded by the vertical array deployed next to the spillway. During the severe winter of 2009-2010, sediment temperatures at the C-54 appear to benefit from the site's depth, cooling slower than the sediment in the shallow waters of the Berkeley Canal. Conversely the sediment also warmed up more slowly when air temperature increased (Figure 25-d).

The Desoto Canal

The Desoto Canal site probes indicate that the main canal is not a warm-water site despite being warmer than ambient Banana and Indian River temperatures (Figure 23-d, Figure 26-a, Figure 28-a, Figure 30-a). Based on limited data, the ditch portion of the Desoto Canal is a warm-water site (Figure 30-a). The mean daily temperatures recorded during the 2011-2012 winter along with mean monthly and the mean winter temperature along with probe data and supplemental YSI readings taken during photo-identification trips show water temperatures that rival natural warm water springs. Water temperatures at the Desoto ditch site were among the most stable in the county despite the site's extremely shallow depth.

Other areas of interest

Temperature data from the Melbourne–Tillman Canal in Turkey Creek, and Sleepy Lagoon and Lake Shepard Canals in Satellite Beach indicted that these locations do not stay sufficiently warm enough during the winter months, falling below the 18° threshold in each winter season monitored a number of times (Figure 24-a and b, Figure 26-b, Figure 28–b, APPENDIX D). These three sites do however, show water temperatures higher than ambient river temperatures.

Comparisons between secondary sites

Comparisons between the three secondary sites consistently show slightly higher mean daily water temperatures in the Berkeley Canal sediment despite its shallow nature and regardless of winter severity. The C-54 sediments show values slightly lower than the Berkeley sediment values but responds slower to cold fronts both in cooling down and heating back up. The main portion of the Desoto Canal shows mean daily water temperatures inconsistent with the definition of a secondary warm water site, falling below the 18°C and 20°C threshold, often during each winter studied (APPENDIX D). However, the mean daily temperature of water entering the Desoto Canal storm water ditch during the 2011-2012 winter season exceeded sediment temperatures at the C-54 site and met or exceeded temperatures in the sediment at the Berkeley Canal. Additional winter profiles were unavailable for the ditch portion of the Desoto site due to loss of the monitoring equipment and improper initialization of gear prior to deployment resulting in loss of data during the 2010-2011 winter. While temperatures in the ditch do respond to changes in air temperature, these variations are minimal. Supplemental YSI readings taken at the site during photo-identification efforts in 2009-2010 and 2010-2011 indicate that the Desoto ditch maintains water temperatures that rival natural warm water springs regardless of winter severity and despite being extremely shallow.

Monthly mean temperature values from the FPL-CC northern discharge (FD_B) indicates that during the 2008-2009 and 2009-2010 winters, prior to the start of the repowering project Berkeley Canal sediment temperatures (BC_Z) exceeded discharge temperatures at the plant. Likewise BC_Z mean monthly temperatures exceeded the temperature in the interim warm water site at the FPL intake canal during the 2010-11 winter season with the exception of February (Appendix D).

Consecutive Days Below the18°C Temperature Threshold

The Berkeley Canal sediment mean daily temperature fell below 18°C for only 5 consecutive days during the 2009-2010 winter, the least amount of days for any monitored site with the exception of the northern discharge at the FPL_CC plant (Table 16). It too fell below the threshold for 5 days. In 2008-2009 however, the BC_Z site failed to fall below the 18° threshold at all while FPL-CC discharge temperature fell below the threshold for 4 consecutive days. Comparatively, the daily mean water temperature at theC-54 sediment site fell below this threshold for 16 consecutive days during the 2009-2010 winter.

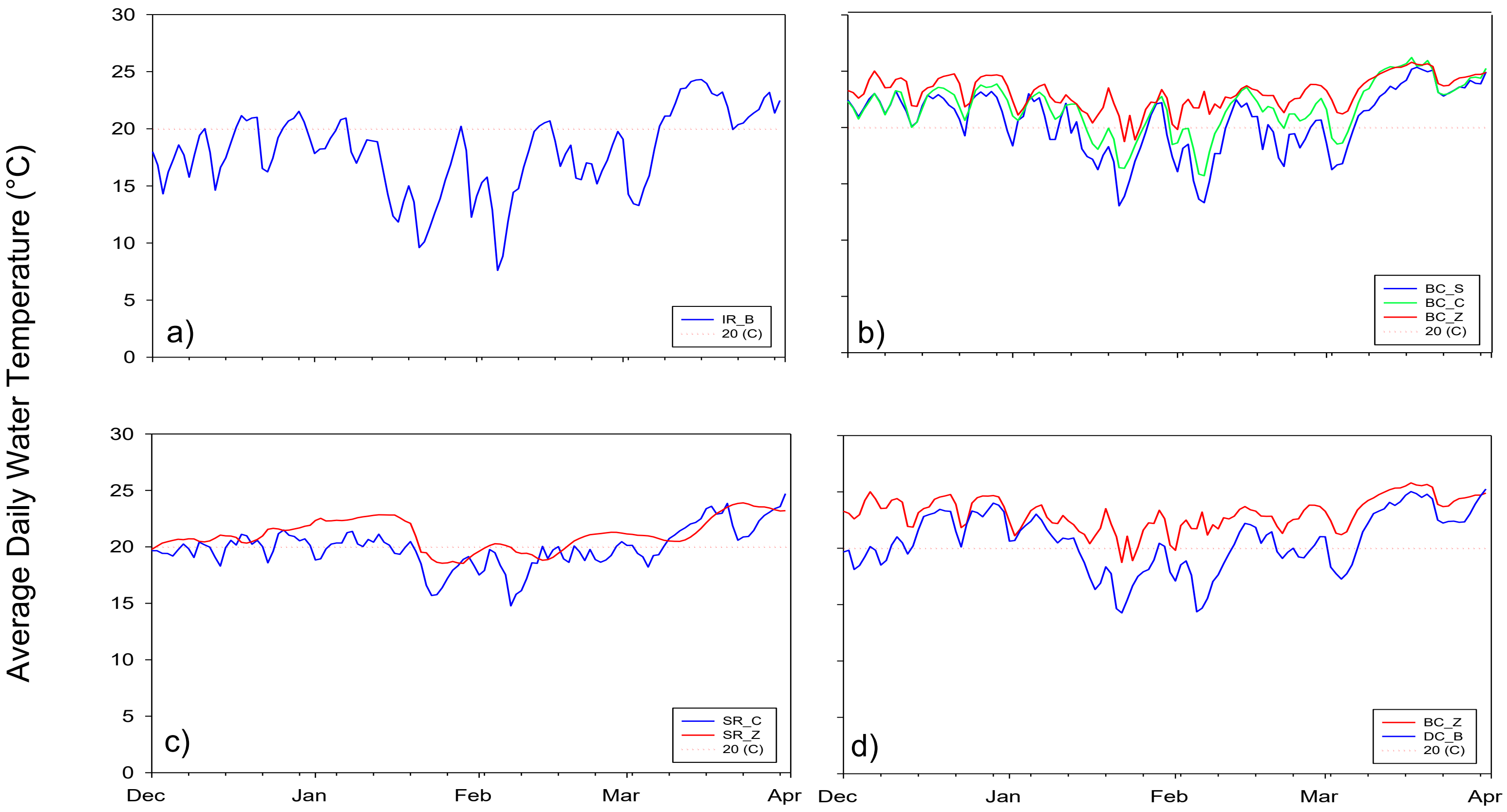

Figure 23 Winter 2008-2009 Daily average water temperatures for (a) IRL, (b) Berkeley Canal, (c) C-54, (d) Desoto Canal.

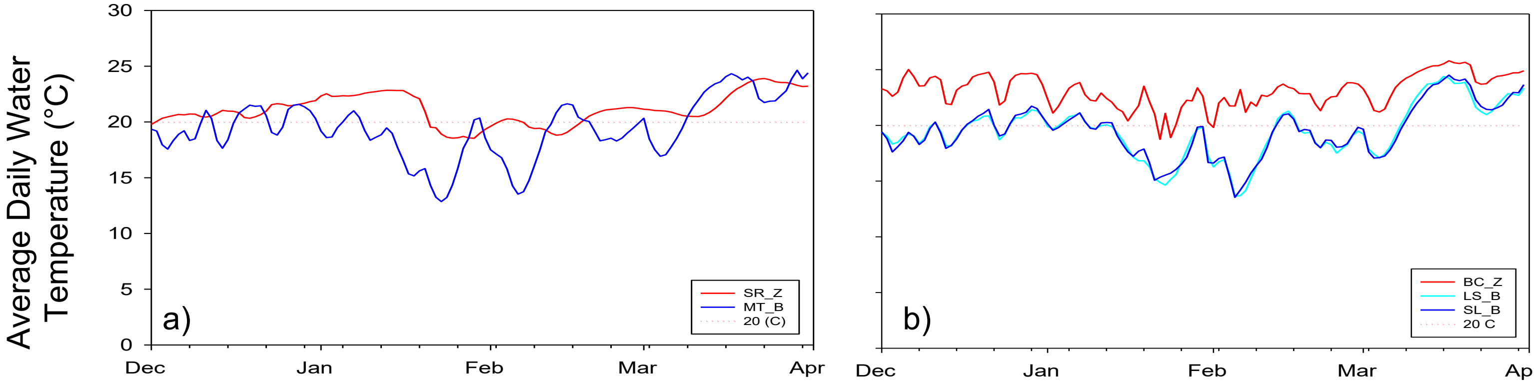

Figure 24 Winter 2008-2009 Daily average water temperature comparisons for
(a) C-54 and Melbourne-Tillman Canal at Turkey Creek, (b) Berkeley, Sleepy Lagoon and Lake Shepard Canals.

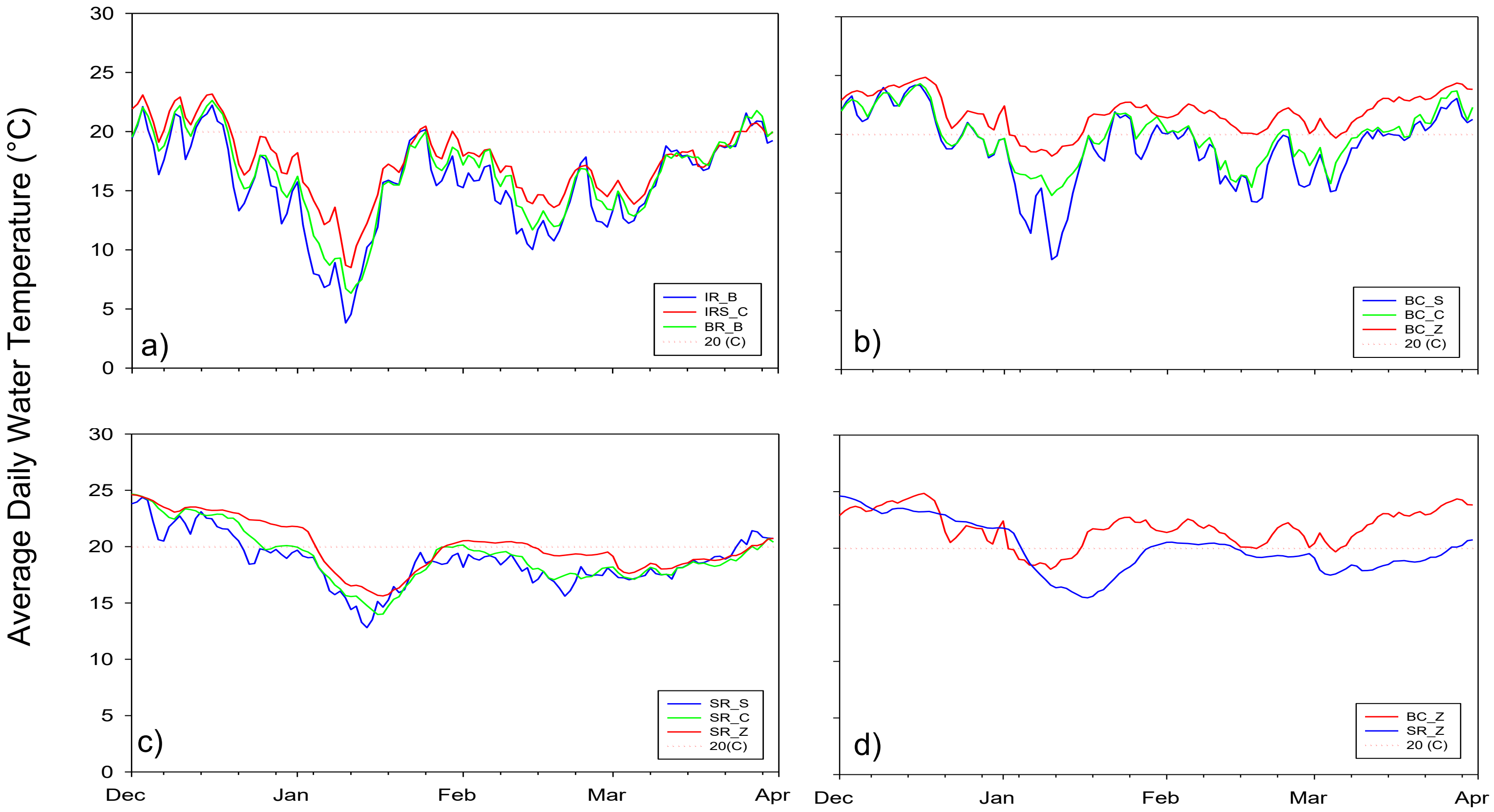

Figure 25 Winter 2009-2010 Daily average water temperature for
(a) IRL, (b) Berkeley Canal, (c) C-54 (d) Comparison of Berkeley Canal and C-54

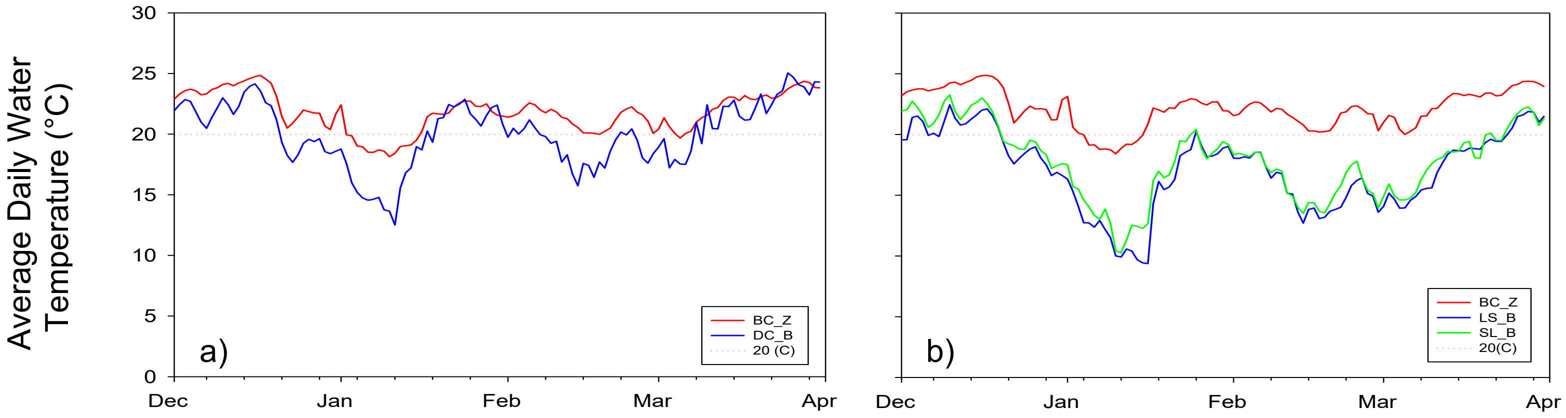

Figure 26 Winter 2009-2010 Daily average water temperature comparisons
(a) Berkeley and Desoto Canals, (b) Berkeley, Sleepy Lagoon and Lake Shepard Canals

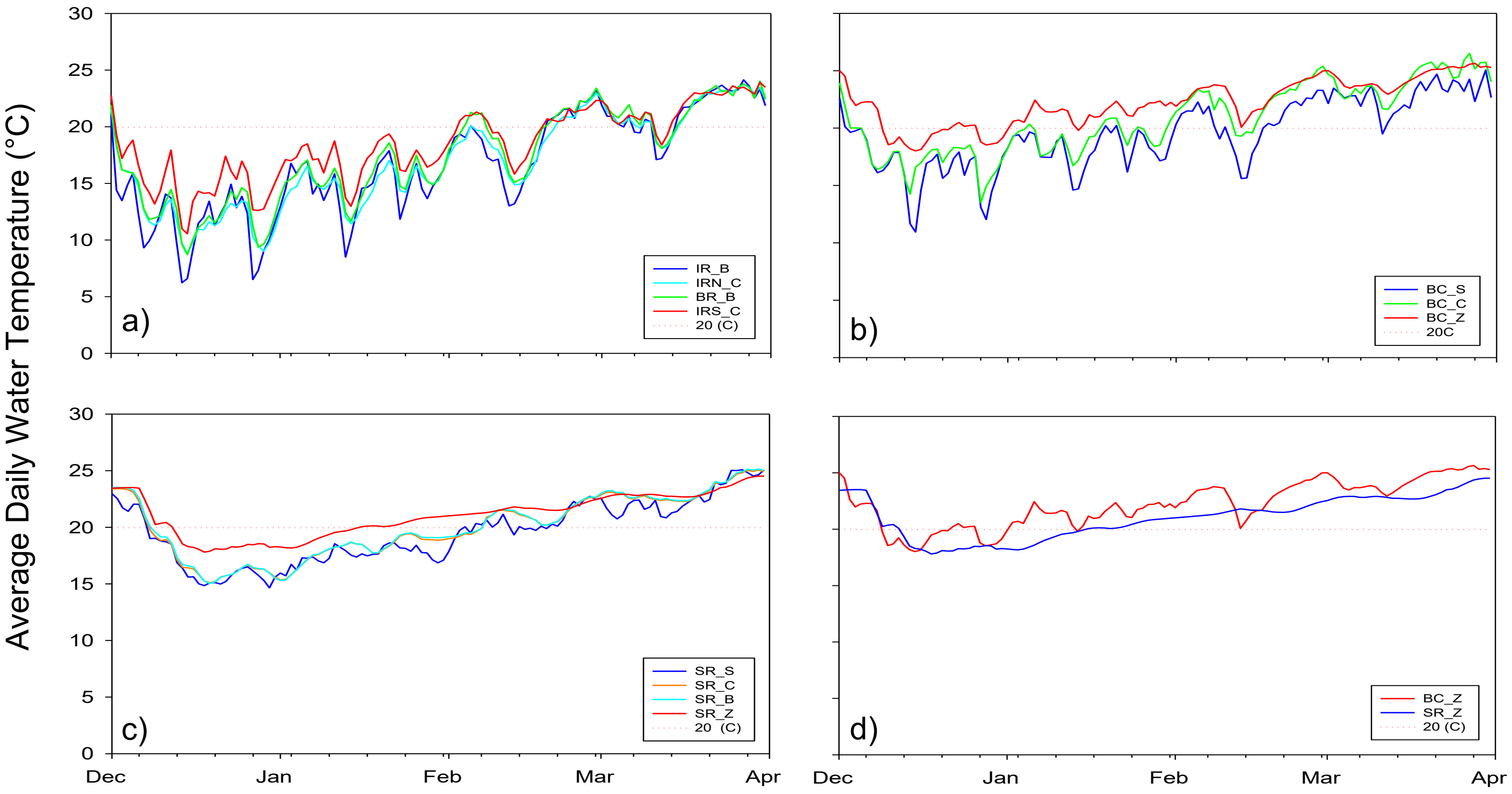

Figure 27 Winter 2010-2011 Daily average water temperature for
(a) IRL, (b) Berkeley Canal, (c) C-54, (d) Comparison of Berkeley Canal and C 54

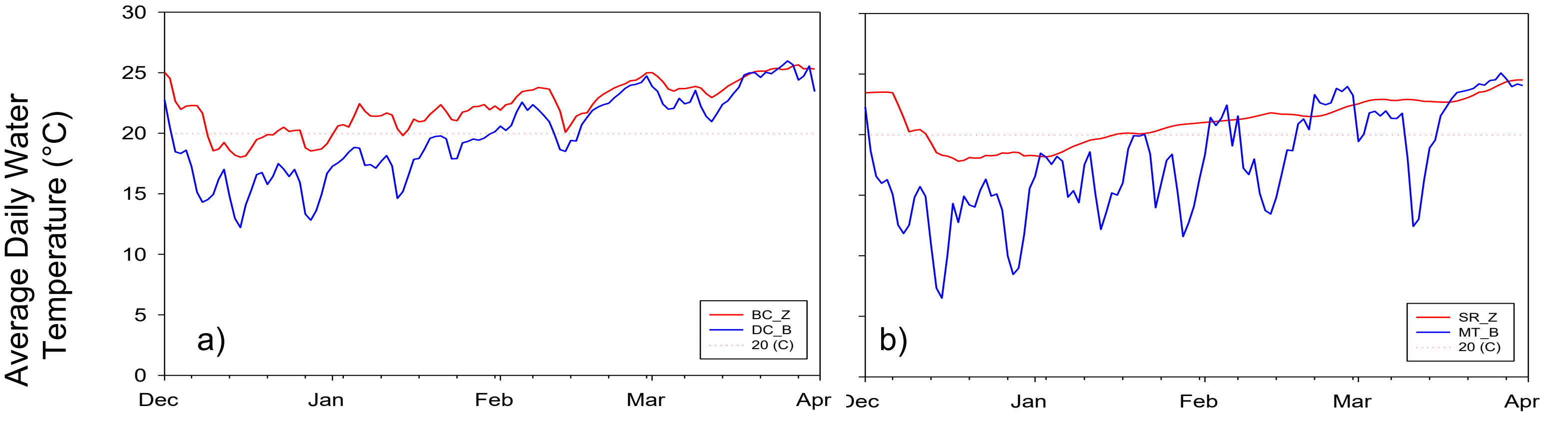

Figure 28 Winter 2010-2011 Daily average water temperature comparisons for (a) Berkeley and Desoto Canals, (b) C-54 and Melbourne Tillman Canal at Turkey Creek

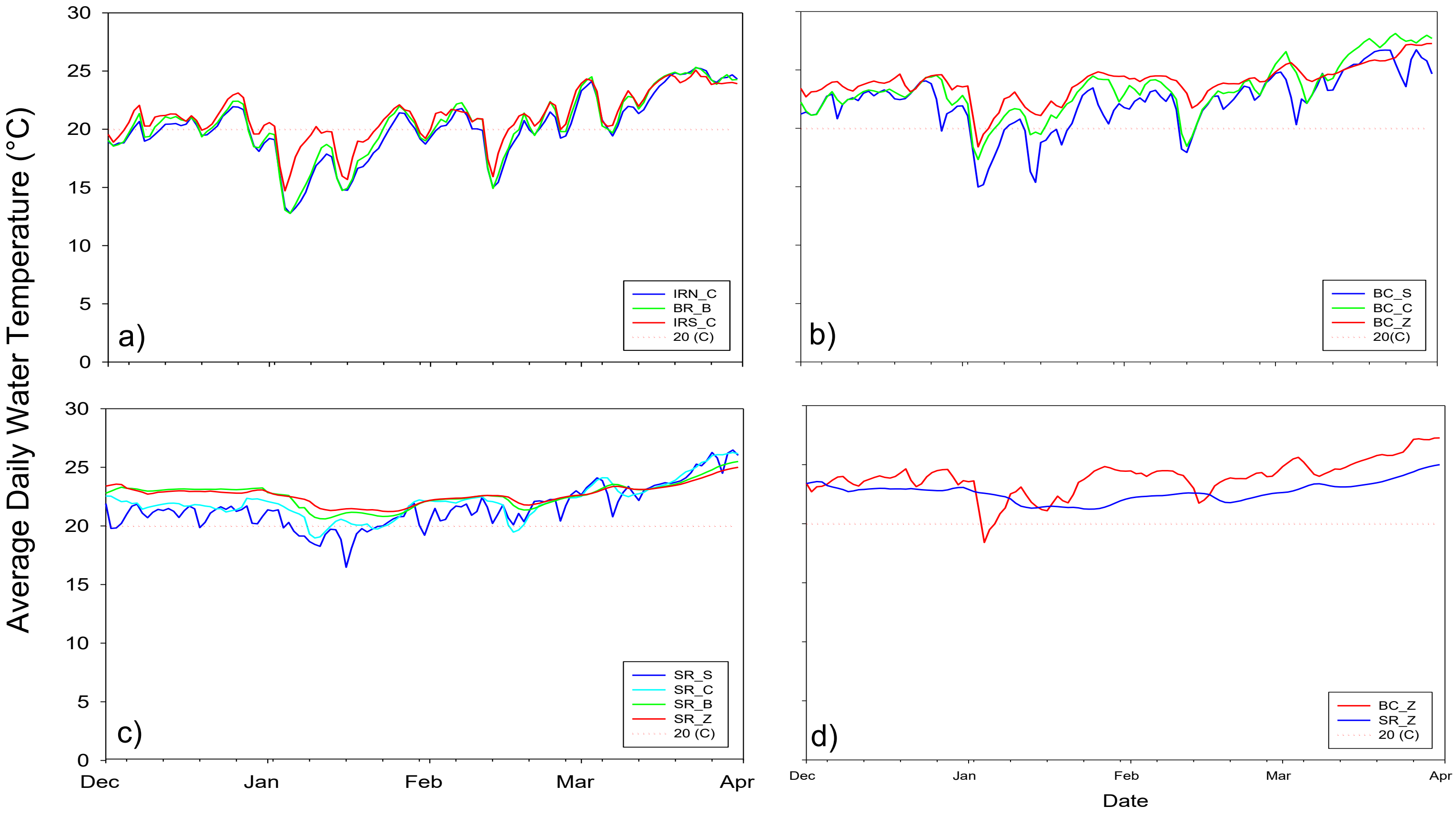

Figure 29 Winter 2011-2012 Daily average water temperature for (a) IRL, (b) Berkeley Canal, (c) C-54,(d) Comparison of Berkeley Canal and C-54.

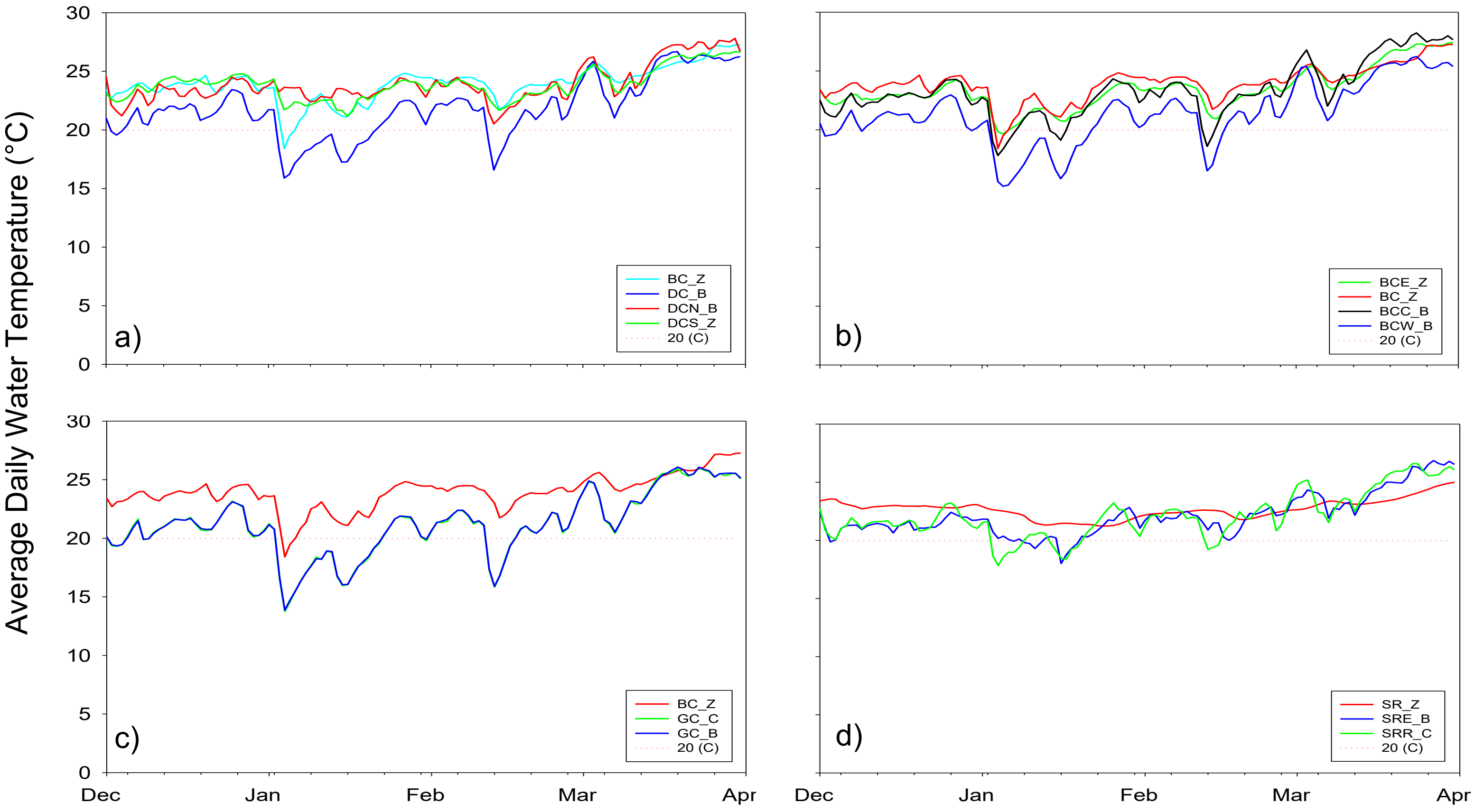

Figure 30 Winter 2011-2012 Daily average water temperature comparisons
a) Berkeley and Desoto Canals, (b) Berkeley Canal, (c)Berkeley and Grand Canal,
(d) C-54 and St. Sebastian River

Table 16 Number of consecutive days water temperature fell below 18° and 20°C at ambient sites, warm-water sites and other sites of interest

	2008-09 Consecutive Days		2009-10 Consecutive Days		2010-11 Consecutive Days		2011-12 Consecutive Days	
Site Code	<18°C	<20°C	<18°C	s <20°C	<18°C	<20°C	<18°C	<20°C
BC_S	6	13	14	33	28	44	4	9
BC_C	3	11	14	25	5	30	1	5
BC_Z	0	1	0	14	0	13	0	2
BCE_Z	*	*	*	*	5	30	0	2
BCC_B	*	*	*	*	*	*	1	5
BCW_B	*	*	*	*	48	62	7	19
GC_B	*	*	*	*	48	63	7	20
DC_B	7	15	15	41	29	59	4	19
DCN_B	*	*	*	*	*	*	0	0
DCS_Z	*	*	*	*	*	*	0	0
SR_S	*	*	17	93	29	58	1	16
SR_C	6	24	55	19	19	53	0	4
SR_B	*	*	*	*	27	61	0	0
SR_Z	0	13	16	40	2	36	0	0
MT_B	13	20	23	53	30	49	*	*
SL_B	12	30	33	53	*	*	*	*
LS_B	11	31	34	57	*	*	*	*
IR_B	14	21	44	58	48	63	*	*
IRN_C	*	*	*	*	62	65	18	26
IRS_C	*	*	33	57	31	63	4	11
BR_B	*	*	32	58	49	64	8	26
RI_C	12	37	43	58	61	66	*	*
RD_C	6	17	31	58	61	65	*	*
FD_B	4	5	5	31	33	59	*	*
FDS_B	*	*	7	19	*	*	*	*
FI_C	11	36	26	58	7	8	*	*
FIW_B	11	36	26	57	1	7	*	*

* no temperature probe deployed

Delta T Values

Box plot graphs shown in Figure 31 – 41 depict differences between the mean daily winter temperatures at monitored sites and those at ambient river site during all four winters. This difference is known as a ΔT. The BC_Z site shows the highest mean ΔT over ambient temperatures in each graph regardless of winter severity or ambient site. Standard error bars are indicative of the range in ΔT's at each site over a given winter. BC_Z shows positive ΔT values for all winters. During the 2009-2010 winter season, the mean winter ΔT for the BC_Z was approximately 6°C above ambient river temperature (IR_B), while the FPL mean winter ΔT of the FPL discharge (DSN_B) was approximately 4°C.

Delta T's calculated for ambient river sites indicate that the IRS_C site is consistently warmer than the other ambient sites and that the BR_B site is warmer than both IR_B and IRN_C sites across all winter season, by a slight margin.

A shift in the mean winter ΔT's is apparent during the severe winter of 2009-2010 when differences in temperature at monitored sites and ambient sites were smallest. When compared to ambient river temperatures in the northern IRL (IRN_C) most sites showed positive ΔT values. Half of these same sites however, showed negative ΔT values when compare to ambient temperatures in the southern portion of the county (IRS_C), indicating that the ambient river temperature was more favorable at the southern end of the county than temperatures recorded in sites to the north.

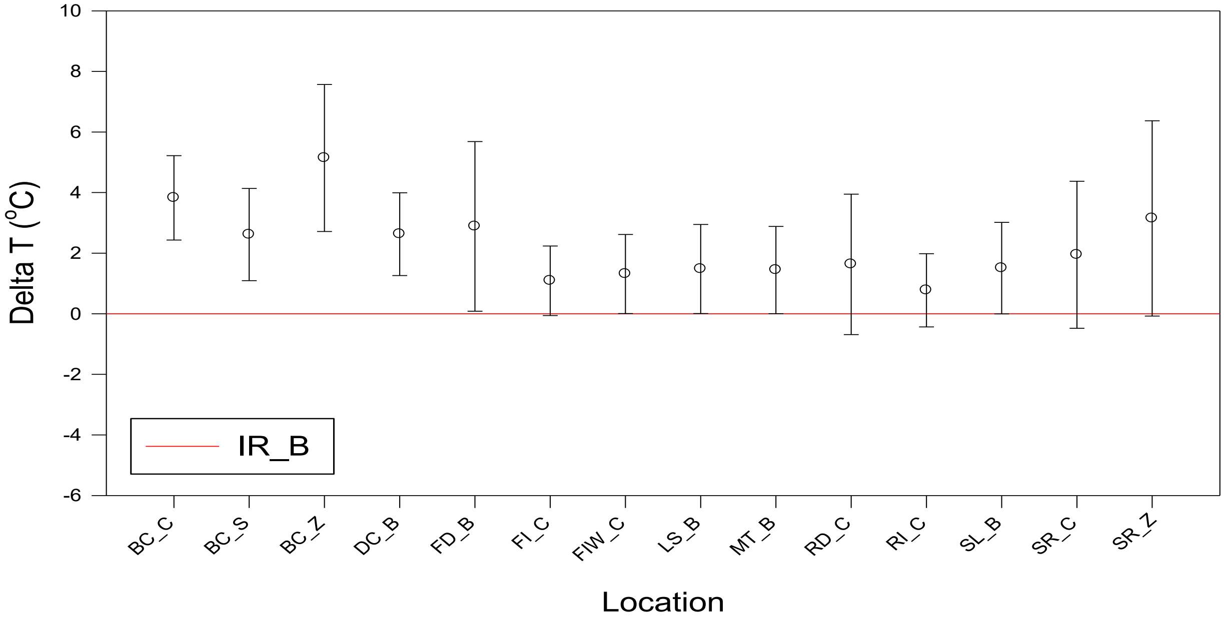

Figure 31 Mean ΔT's Winter 2008-2009 Relative to IR_B

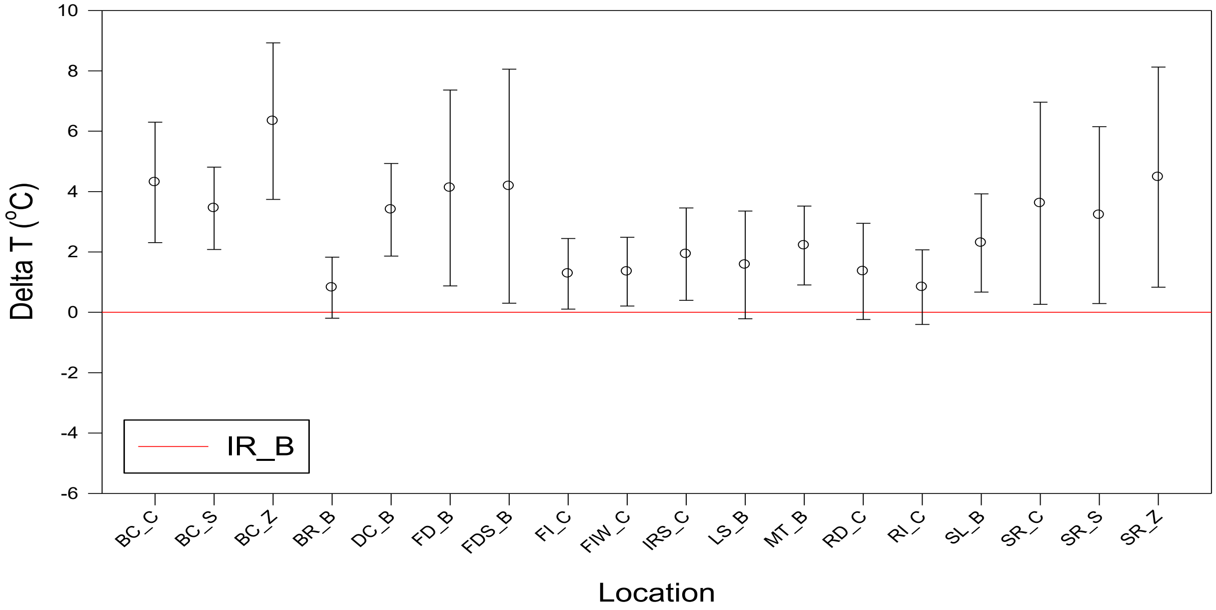

Figure 32 Mean ΔT's Winter 2009-2010 Relative to IR_B

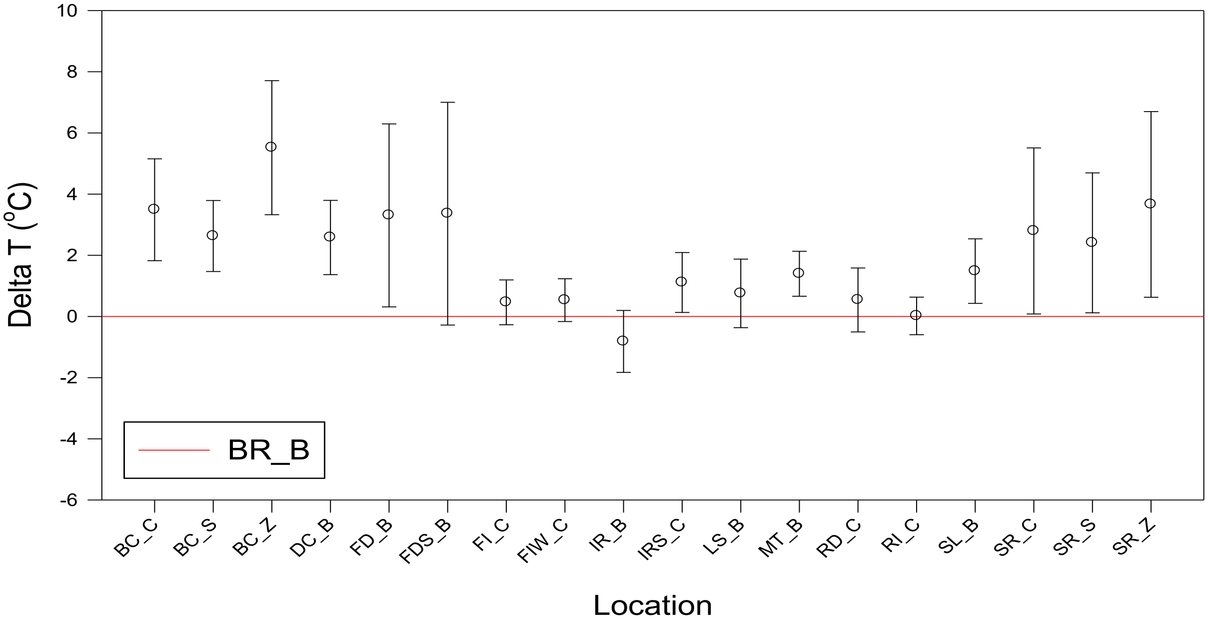

Figure 33 Mean ΔT's Winter 2009-2010 Relative to BR_B

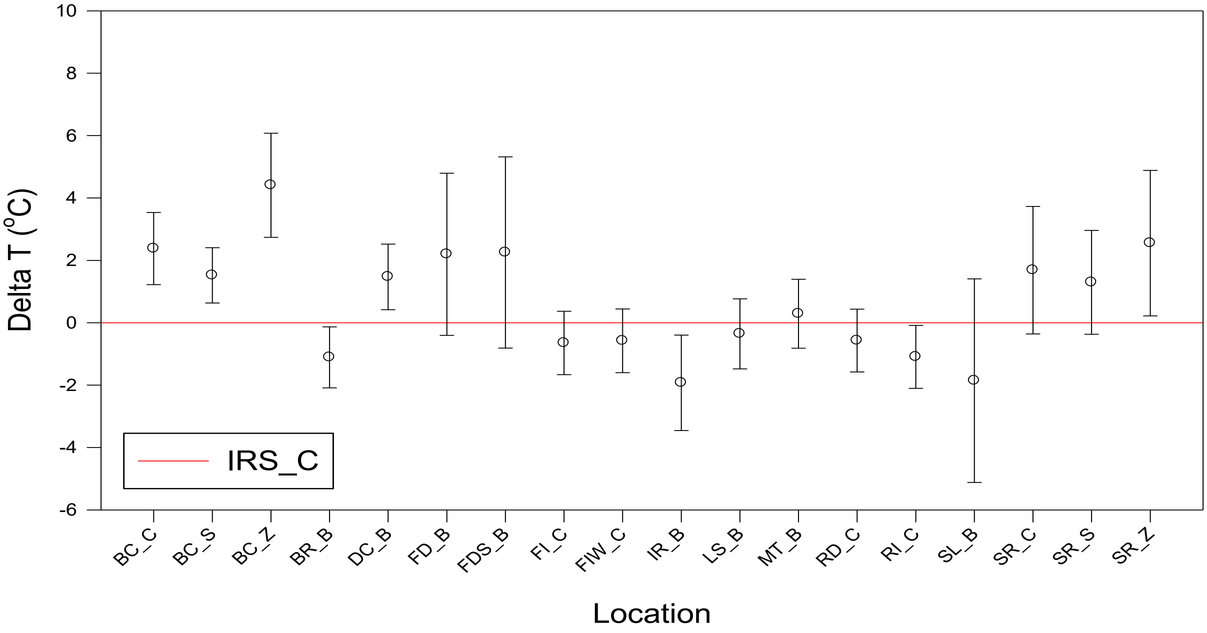

Figure 34 Mean ΔT's Winter 2009-2010 Relative to IRS_C

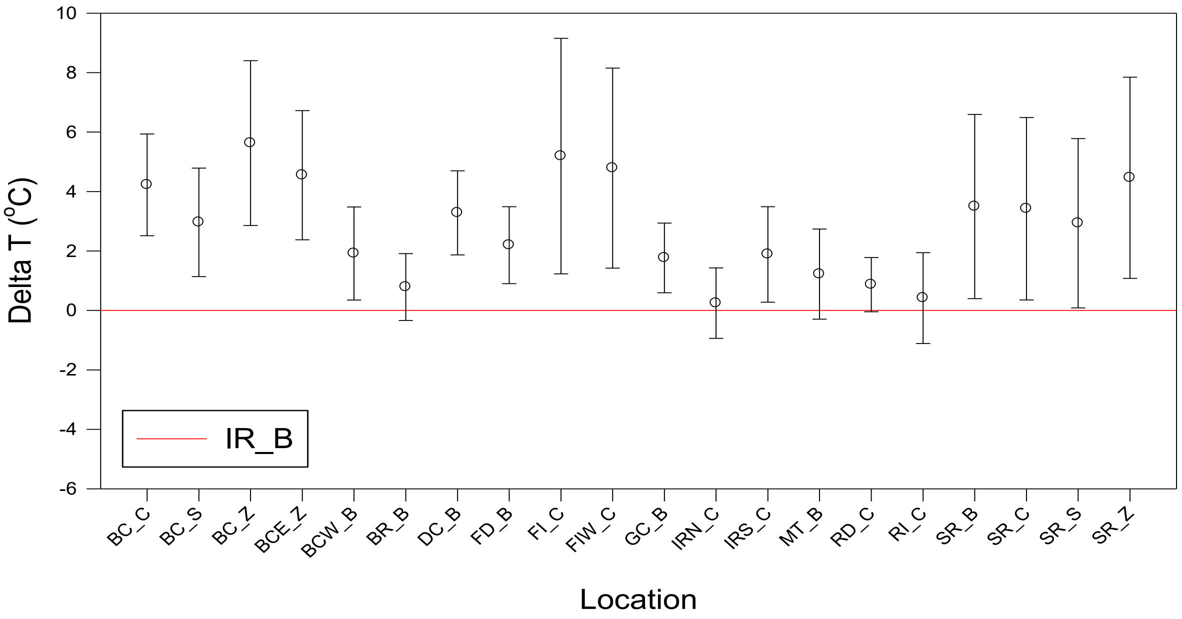

Figure 35 Mean ΔT's Winter 2010-2011 Relative to IR_B

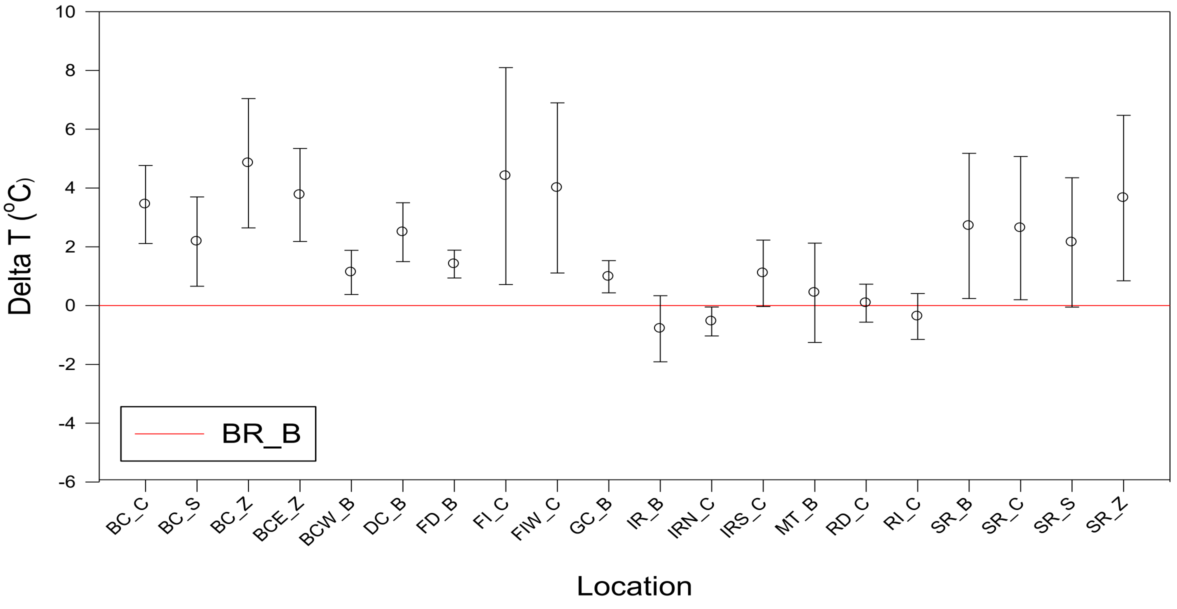

Figure 36 Mean ΔT's Winter 2010-2011 Relative to BR_B

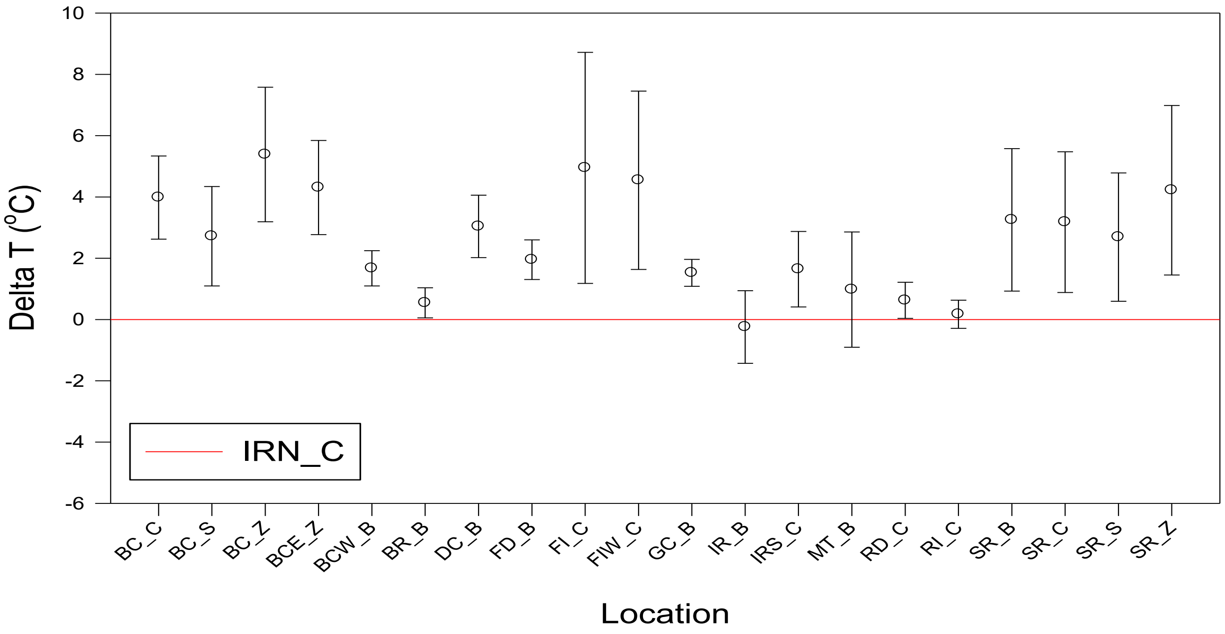

Figure 37 Mean ΔT's Winter 2010-2011 Relative to IRN_C

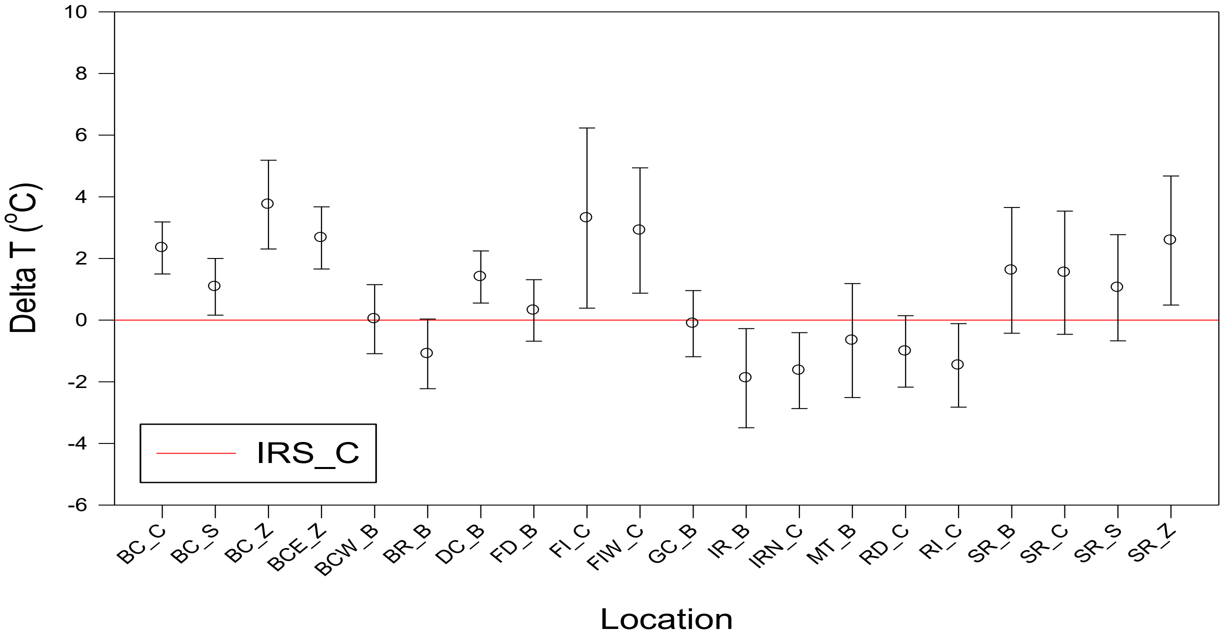

Figure 38 Mean ΔT's Winter 2010-2011 Relative to IRS_C

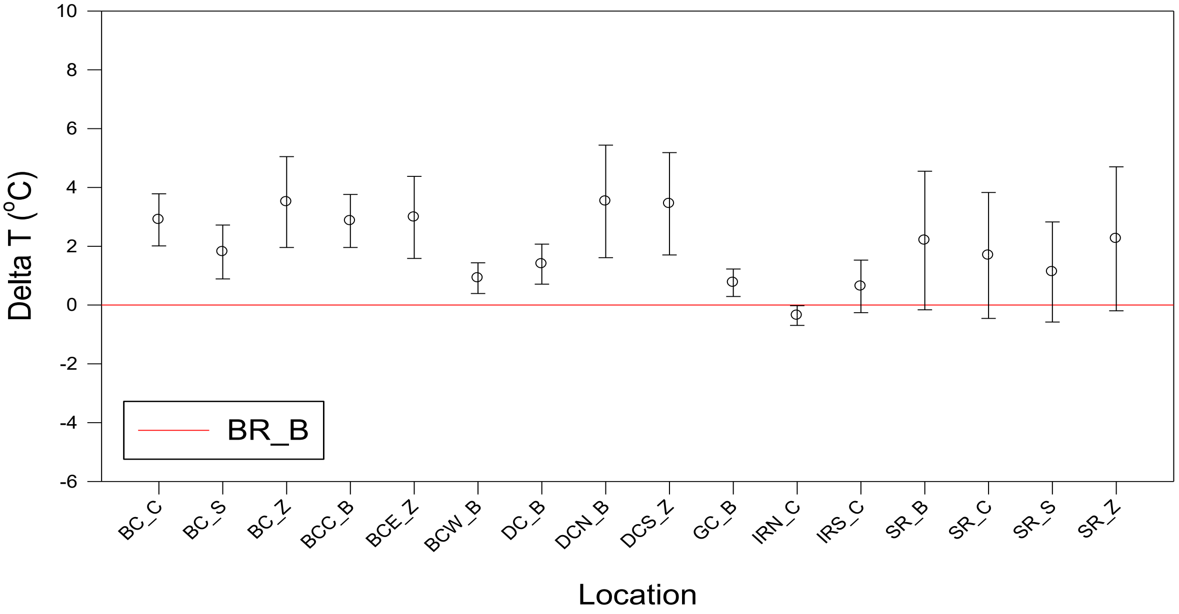

Figure 39 Mean ΔT's Winter 2011-2012 Relative to BR_B

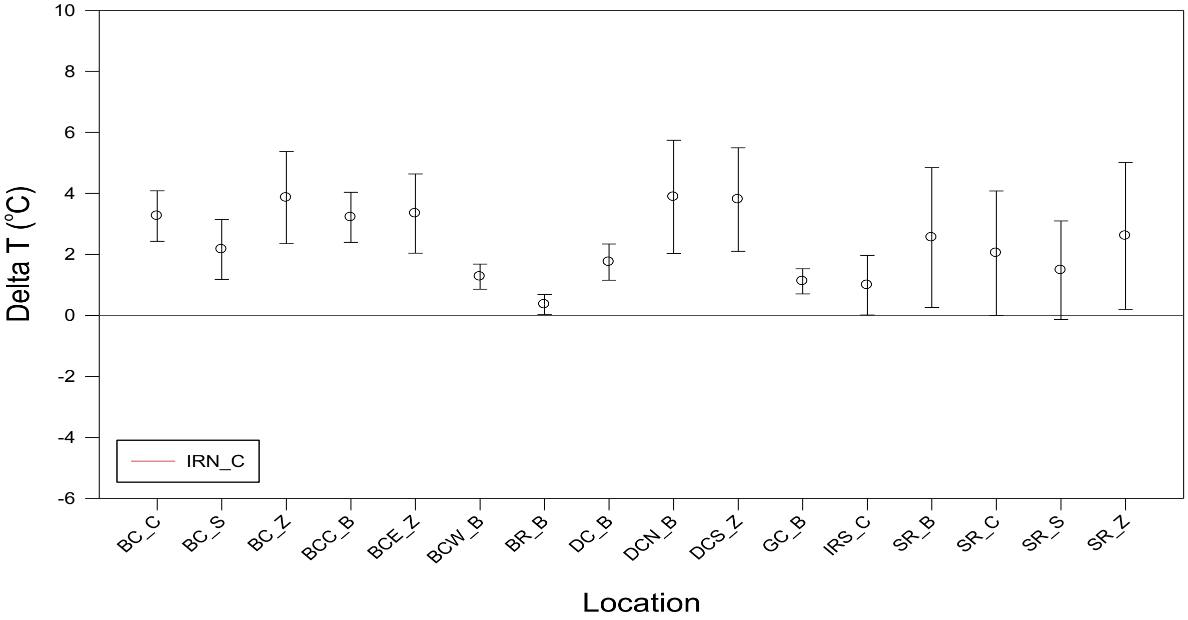

Figure 40 Mean ΔT's Winter 2011-2012 Relative to IRN_C

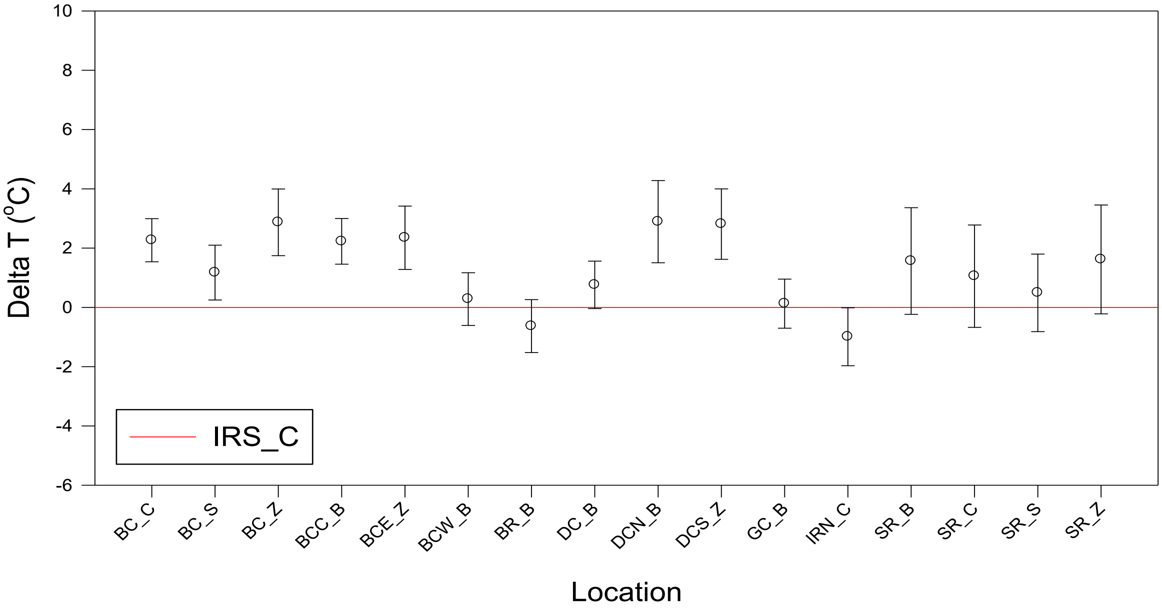

Figure 41 Mean ΔT's Winter 2011-2012 Relative to IRS_C

Hydrographic Surveys

Hydrographic survey results for the Desoto site confirm the persistence of high temperatures throughout the small refuge despite the extremely shallow nature of the canal. Water temperatures were highest at the north end where water flows in to the site. Of the three sites surveyed, the Desoto canal had the lowest salinity values ranging from 2 ppt at the north end, gradually increasing to 12.3 ppt moving south (Table 17). Temperature readings ranged from 19.3° at the southern end to 22.23°C adjacent to the storm water pipes.

Table 17 Hydrographic survey values for maximum depth, bottom temperature and salinity at the Desoto Canal on 14 February 2011

STATION NO. (N →S)	MAXIMUM DEPTH (m)	TEMPERATURE (°C)	SALINITY (ppt)
1	0.495	22.09	2.00
2	0.125	22.13	2.63
3	0.112	22.23	2.70
4	0.200	21.19	6.06
5	0.250	20.99	6.19
6	0.322	20.57	10.38
7	0.254	20.39	10.08
8	0.325	20.16	10.72
9	0.320	21.10	11.98
10	0.287	20.09	12.32
11	0.210	20.05	7.79
12	0.263	19.23	11.19

Results from the hydrographic survey conducted at the Berkeley Canal site confirm shallow but variable depths throughout the refuge. Most depth readings were less than a meter deep, with an average depth of only 0.598 m. Bottom water temperatures in the canal ranged from 18 to 19.7°C, slightly lower than both the Desoto Canal and C-54 on that day, yet still within the manatees' thermal neutral zone (TNZ). Salinity levels were higher than those at Desoto ranging between 12.2

and 15.4 ppt (Table 18 and Table 20). Survey results for the C-54 indicate warm bottom temperatures along the entire length of the canal. Salinity levels were comparatively high, ranging from 20.9 to 29.6 ppt, gradually increasing from west to east. Deeper than the other two sites, average water depth at C-54 was 2.9 m, but exceeded 4.8 m in some locations (Table 19 and Table 20).

Table 18 Hydrographic survey values for maximum depth, bottom temperature and salinity at the Berkeley Canal on 14 February 2011

STATION NO. (E→W)	DEPTH (m) TEMPERATURE (°C) SALINITY (ppt)		
	NORTH	CENTRAL	SOUTH
1	0.10	0.87	0.27
	19.56	19.01	19.13
	13.21	12.32	12.23
2	0.53	0.74	0.38
	19.13	19.70	19.00
	14.00	14.05	13.40
3	0.18	0.83	0.27
	18.89	19.47	18.82
	14.45	13.91	13.91
4	0.12	0.95	0.43
	18.74	19.28	18.74
	13.95	14.41	14.44
5	0.36	0.31	1.17
	18.58	18.70	19.26
	14.94	14.02	14.52
6	0.50	1.30	0.22
	18.62	19.29	19.00
	15.09	14.80	14.27
7	0.43	1.33	0.10
	18.70	19.15	18.88
	14.98	14.98	14.27
8	0.53	1.12	0.82
	18.85	18.91	18.68
	14.87	15.30	15.34
9	0.63	1.59	0.68
	18.64	18.93	18.74
	14.97	15.22	14.82
10	0.45	1.20	0.30
	18.96	18.92	18.92
	15.22	15.42	14.55
11	0.24	1.10	0.26
	19.17	19.08	18.91
	14.42	15.36	14.90
12	0.26	1.23	0.40
	19.21	19.06	18.59
	13.31	15.43	14.06
13	0.40	0.56	0.15
	18.53	19.14	18.00
	14.41	15.32	14.06

Table 19 Hydrographic survey values for maximum depth, bottom temperature and salinity at the C-54 on 13 February 2011

STATION NO. (W→E)	DEPTH (m) TEMPERATURE (°C) SALINITY (ppt)		
	NORTH	CENTRAL	SOUTH
1	4.86	4.74	4.46
	21.35	21.44	21.36
	23.59	22.16	23.58
2	3.06	2.43	2.41
	21.29	21.29	21.23
	23.51	23.28	22.85
3	2.36	2.80	1.95
	21.22	21.29	20.97
	23.46	24.20	22.01
4	2.18	*	2.07
	21.13	*	21.06
	23.21	*	23.55
5	2.83	3.18	1.94
	21.18	21.16	22.07
	23.51	25.12	20.85
6	2.06	1.59	2.15
	21.16	21.01	21.13
	22.69	22.18	24.11
7	1.85	2.76	2.56
	21.03	21.17	21.08
	23.14	27.71	24.27
8	4.09	4.27	2.35
	21.15	21.15	21.07
	29.24	29.34	23.26
9	3.66	4.81	3.56
	21.12	21.14	21.14
	29.27	29.49	29.25
10	2.04	4.72	2.31
	21.15	20.84	21.11
	23.36	29.38	24.42

*data download failure at this location

Table 20 Comparison of depth, bottom temperature and salinity values for Brevard County secondary warm-water sites from hydrographic surveys conducted in February 2011

	DEPTH			TEMPERATURE			SALINITY		
	Desoto	Berkeley	C-54	Desoto	Berkeley	C-54	Desoto	Berkeley	C-54
Mean	0.264	0.598	2.967	20.9	18.9	21.2	7.8	14.4	24.7
Std. Dev.	0.10	0.41	1.04	0.10	0.32	0.21	3.84	0.79	2.69
Range	0.383	1.492	3.27	3.0	1.7	1.2	10.3	3.2	8.7
Max	0.495	1.590	4.856	22.2	19.7	22.1	12.3	15.4	29.6
Min	0.112	0.098	1.590	19.2	18.0	20.8	2.0	12.2	20.9

Discussion

The task of identifying and characterizing warm-water sites within an area of the state identified in the previous chapter as the most at risk for cold stress-related mortality is challenging. It has quickly become a high priority task in response to the prolonged, record-breaking cold fronts experienced across the Florida peninsula in recent winters. Coupled with recent, unprecedented seagrass losses in the same region, identification and protection of these sites may be crucial in supporting large numbers of manatees outside of the lone power plant's influence, and in facilitating access to more distant food sources while reducing the manatee's exposure to potentially lethal water temperatures.

Sufficient space, appropriate water depth and water temperatures capable of sustaining manatees during cold spells, as well as the availability of fresh water and proximity to adequate forage are all important considerations from a physiological standpoint. Often it is an aggregation of manatees that first attracts attention to such locations, already having located a warm water site long before it has been characterized. Characterization of such sites is critical if appropriate actions are to be implemented by resource managers to enhance or protect these areas and the aggregations that use them, in both the long and short term.

Important characteristics to define include but are not limited to thermal profiles, bathymetry (depth), salinity, sediment type, site boundaries, distances to the closest forage and known migratory routes, and disturbance levels. Quantifying water temperature is arguably the most logical place to start site characterization as this appears to be the limiting factor for use of a site.

Temperature profiles obtained for several locations in Brevard County and compared to ambient river temperature over four winter seasons confirmed the existence of at least three important warm-water sites within the county borders in addition to the heavily used FPL-CC site. Daily mean water temperature values measured at various locations around Brevard County indicate that ambient water temperatures in the IRL frequently fall below the minimum critical temperature (18-20°C) needed to sustain manatees even during mild winters. Temperature data also confirm the presence of at least two PTB's within county borders. Furthermore, and not surprisingly, data indicate that water temperatures not only vary from ambient to secondary sites, but that they also vary latitudinally with respect to ambient river temperatures.

Given the importance of this one power plant as a warm-water site to a significant number of manatees in the region during the winter months, identification and protection of available, nearby warm-water sites is essential in the event of a catastrophic power plant failure. It is also important in the design and creation of a warm-water network capable of supporting those same animals in the future, if managers are to be successful in the long term goal of weaning manatees off of the power plant discharge.

Water and air temperature monitoring in sites of interest around Brevard County over four winter seasons from 2009 through 2012 allowed for comparison of thermal conditions not only within a given site but also among sites across winter conditions ranging from mild to severe. While not all suspected warm-water sites within the county were monitored, three areas known to attract manatees during cold fronts were chosen for the study. Only one of these sites, the C-54, had been investigated in the past but only for a period of less than one winter (Heyman 1990).

The three sites of interest in this study include the deep waters of the C-54, located at the southern border of Brevard County in the north prong of the St. Sebastian River, and two shallow water sites at the Berkeley Canal and the ditch portion of the Desoto Canal, both located in residential neighborhoods of Satellite Beach. The latter of these two sites has a relatively short history of manatee use having only become accessible during the span of this study, yet it has quickly become a very important aggregation site, particularly during severe cold weather. While each of the sites share similar characteristics and are recognized as winter manatee aggregation sites, each has features unique unto themselves, and are used under different circumstances relative to, and strongly influenced by environmental conditions, as well as the limits of manatee physiology.

Bangs (1895) commented on the deaths of two manatees in the St. Sebastian River following a sudden “freeze” in the winter of 1894 -1895 stating that “the only chance for manatees to escape certain death lay in their being able to reach deep water before they were overcome by the cold”. While that may have been true, during the course of this study two relatively shallow warm-water sites have shown that depth, while certainly advantageous, is not necessarily a limiting factor in warm-water site selection by manatees.

The Berkeley Canal, though relatively shallow (< 2meters), benefits from a thick layer of organic sediment also found in the Desoto Canal, the C-54, and surrounding waterways. Temperatures recorded in the sediment were consistently some of the highest recorded at any site within in the county, offering manatees an additional source of thermal support. The canal's temperature profile shows that it regularly exceeds the minimum water temperature necessary to support manatees throughout mild to moderate winters, possibly even severe winters, making it an important secondary warm-water site, The canal's location also offers quick access to nearby seagrass beds, however depleted in recent years, and its low salinity which would indicate that fresh water is likely available at the site. Little else about it however, satisfies Reynolds (2000) proposed criteria for a suitable warm-water site. The close proximity of the Berkeley site to the next nearest site, the Desoto Canal may enhance its appeal to thermally challenged individuals or females with dependent calves. Despite its shortcomings, the Berkeley Canal has become an important refuge with winter counts exceeding 100 individuals when ambient river temperatures fall below 18°C.

In comparison, the small drainage ditch that defines the newly available Desoto Canal site is so shallow that it is not uncommon to see the dorsal surface of larger manatees exposed to the air while resting on the bottom. Despite its shallow nature, the thermal profile documented in the storm water ditch at the Desoto site rivals water temperatures of natural warm water springs throughout the winter, regardless of severity (W. Hartley, Blue Springs State Park, Unpublished data). It seems equally as attractive to manatees as any primary site and under similar conditions. Its shallow depth however, requires careful monitoring due to the occurrence of a documented seasonal water level drop that occurs in the IRL early each winter (Woodward-Clyde 1994) and a shifting layer of thick ”muck”. Such an event occurred in early January 2010 when water levels dropped so low that large manatees exhibited difficulty navigating into and out of the to the canal (A. Spellman, FWC, Pers. Obs.). To avoid a potentially dangerous entrapment situation involving in excess of 100 manatees within the site, intervention was deemed necessary. After carefully studying the situation, the FWC, in a joint effort with the City of Satellite Beach and Brevard County Road and Bridge officials, conducted limited emergency dredging in the constricted portion of the canal, freeing up passage into and out of the site. While the “muck’ has the potential to restrict access to shallow sites, it appears to have an important role in thermoregulation as manatees often surfaced covered in the sediment,

Despite the limited temperature data available for the site, preliminary temperature monitoring conducted with a handheld YSI Model 30, during site visits as part of photo-identification survey efforts in the winter of 2009-2010 consistently revealed water temperatures well above ambient river temperatures. Following even the coldest days of that same winter, water temperature readings taken at the site registered between 19 to 23°C. This site successfully supported in excess of 140 manatees throughout the entire record-breaking winters of 2009-2010 and 2010-2011.

The presence of a small number of old water-to-air air conditioning systems in the adjacent housing provided a constant flow of fresh warm water to the site through a number of 1-inch diameter PVC pipes year round. Manatees regularly drink from these pipes despite the low salinity and availability of the fresh water throughout the ditch portion of the canal. The PVC pipe located west of the elbow turn on the main canal, shows a persistent build up of sulfur residue where it bubbles up from under the ground. The sulfur residue coupled with a constant positive flow would indicate that the well systems upon which the air conditioning system depends is artesian (J. Fergus, City of Satellite Beach, Pers. Com.). While these pipes do not contribute significant amounts of water to account for the volume of warm water found in this site, they offer insight into how the previously non-existent site may have become available seemingly overnight in the fall of 2009.

The consistently high temperature, low salinity and year-round flow of water entering through the storm water pipes even in the dry season would indicate that this site likely benefits from the intrusion of artesian-based well water possibly coming from nearby neighborhoods. Artesian wells are confined, fresh water aquifers maintained under pressure. Historically, during the development of Satellite Beach, wells were typically drilled one for every 2 residential lots and were used primarily in lawn irrigation. Many of these wells had been capped in recent years. It is believed that some of the well shafts have likely deteriorated allowing water under pressure from the underlying aquifer to bubble up through the soil (J. Fergus, City of Satellite Beach, Pers. Com.). Despite a 2008 water diversion project meant to limit run off into the ditch, ground water, well water, and storm water all flow into the canal to some extent. The constant flow and warm temperatures make the intrusion of artesian aquifer water highly likely as a source.

Prior to 2009 the drainage ditch portion of the canal was almost completely occluded by sediment (A. Spellman, FWC, Pers. Obs.). No dredging or maintenance occurred in the canal that would account for the scouring of sediment that would had to have taken place sometime prior to the winter of 2009-2010 (A. Potter, Satellite Beach Public Works, Pers. Com). Given that the water table would had to have risen by approximately 1m lagoon-wide to account for water levels at the Desoto site documented in late 2009, it is more likely that a strong meteorological event involving large amounts of water forced the sediment out of the canal allowing water to collect in the ditch (J. Fergus, City of Satellite Beach, Pers. Com.) In the summer of 2008, Brevard County was hit particularly hard by Tropical storm Faye. Unprecedented rain fall followed the 36 hour stationary storm causing severe flooding throughout much of the county. The amount of rain flowing out if the storm water pipes entering the Desoto Canal may have been of sufficient force to purge the sediment, effectively scouring out the ditch and freeing up the site for use by manatees already familiar with the main canal by making it accessible for the first time. Water temperature and salinity readings are consistent with the presence of some type of fresh water intrusion. While lawn irrigation and precipitation may account for some of the flow, it cannot account for the constant rate of flow observed at the site.

Freshwater input at the Berkeley Canal may likewise be the result of collapsed or leaky wells, artesian aquifer intrusion through the porous overlying Hawthorne layer, or possible groundwater seepage. Whatever the source, salinity readings in the canal differ from those in the ambient river indicating freshwater input of some kind. Additional hydrographic surveys are necessary but the quick rate of mixing that occurs in the canal may hinder discovery of the fresh water's source. It is highly likely there is more than one. During removal of the 2013-14 winter temperature monitoring probes from the canal, it was observed that the location of a small manatee aggregation at the east end, midway along the east bank corresponded to YSI bottom readings of 4.1 ppt with salinity values increasing to more than 19 ppt as the probe was pulled to the surface. This observation lends support to anecdotal information from local residents who hold the belief that an artesian spring contributes to the canals attractiveness to manatees.

The C-54 site is large and deep in comparison to the two previously discussed sites. It also has a thick sediment layer covering the bottom, but its stark landscape and expansive profile leaves the site unprotected and exposed to environmental conditions. It is also subject to tidal fluctuation from the nearby Sebastian Inlet, salt water intrusion from the IRL, and the mixing of large amounts of fresh, and potentially colder waters flowing in from the St. Johns River via the spillway.

While conventional wisdom dictates that certain characteristics make some locations more attractive as winter aggregation sites than others, features viewed as marginal or irrelevant may actually be what is attracting manatees to the site because they provide a physiological advantage often overlooked. For example, while deeper sites are often associated with warmer, more stable water temperatures, temperature data from the shallow waters of the Berkeley Canal, specifically at the BC_Z location, taken at 1.2 m, indicate that it is one of the warmest locations in Brevard County despite its shallow depth. Bottom temperatures at the Berkeley site rival those recorded at the C-54 SR_Z site taken at 4.3 m. This observation was consistent over the course of this study, including the bitterly cold winter of 2009-2010. While temperatures at both sites benefit positively from thick layers of bottom sediment in which manatees are regularly documented wallowing, water temperature at the C-54 site has the potential to be negatively influenced by water diverted from the Upper St. Johns River, which during the colder months may contribute cooler waters that sink to, and influence the bottom depths of the refuge. This maybe particularly evident following increased overflow at the spillway caused by precipitation affecting the Upper St. Johns River Basin.

While warm bottom temperatures favor manatees, in order to breathe manatees have little choice but to pass through the overlying, often cooler water layers. The water column in deep water sites may take longer to heat up than those in shallow sites when weather conditions turn more favorable, forcing manatees to traverse through the colder water layers to access the surface. While shallow water generally cools more quickly in response to cold fronts, it also warms up more quickly when weather conditions improve allowing manatees in shallow water sites access to the surface through layers of water that have warmed up more rapidly than at the deeper sites. While this may seem inconsequential to the large animals, for smaller animals using deep water sites, this repeated exposure to cooler water while addressing the need to breathe may further add to thermal stress. Shallow water conditions like those at the Desoto Canal site may provide more favorable conditions for smaller individuals by allowing for them to stay warm in the sediment while almost simultaneously accessing the surface through water of equally warm temperature. Sites with intermediate water depths and little to no supplemental warm water intrusion such as the Berkeley Canal site appear to be used within a specific range of temperatures possibly reflective of the rate at which the site warms up and cools down.

While the proximity of nearby seagrass beds to these secondary sites certainly adds to the sites' attractiveness from a physiological standpoint, use of these sites may also serve to alleviate foraging stress on the heavily used seagrass beds closer to the power plant by allowing manatees to venture farther to forage while providing thermal refuge within physically tolerable travel distances. This may be particularly important to subadults, independent calves and females with nursing calves.

The short and long terms effects of the catastrophic loss of seagrass beds in the IRL following the documented algal super bloom of 2011 have yet to be determined, but the loss of seagrass beds in Brevard County was extensive and severe. It is estimated that 60% or 47, 000 acres of Brevard's seagrass beds have been lost since 2007 and recovery has been slow at best (T. Rice, SJWMD, Pers. Com.) It is not unreasonable to assume that manatees will be affected by this loss and will find it necessary to adjust and adapt behaviorally with respect to how they use the existing warm-water network and surrounding resources. Once lined with plentiful, healthy seagrass beds, the area of the Banana River just north of the Berkeley and Desoto canal sites shows marked reduction from surveys conducted in 2009 and again on 2011. Loss of seagrass beds however, is only one of a number of threats to this network. It is nonetheless one of the more pressing and timely issues currently affecting this particularly at-risk area of the state.

There are additional threats that may negatively affect these key secondary sites, either immediately or in the near future. Recently, an unprecedented loss of manatees occurred in the IRL almost exclusively within the borders of Brevard County. The cause or causes have yet to be determined. Declared an unusual mortality event (UME), the event has resulted in the deaths of 123 manatees from July 2012 through Jan 2014, including several cases recovered from each the three secondary sites (FWC, Unpublished data). Large numbers of manatees in close proximity to each other have always been cause for concern among managers and researchers in the event that a specific region is particularly hard hit by stochastic and potentially catastrophic event such as has happened in Brevard County in recent years (i.e. cold events, UME).

While thermal sites are continuously shaped and altered by natural processes, human pressures can be equally formidable. Dredging and muck removal to facilitate navigation could alter the depths and thermal profiles of all three sites. Conversely, unmitigated build up of muck could preclude manatee entry into the sites as it almost did in 2009 at the Berkeley site and again in January of 2010 at the Desoto Canal. Storm water diversion projects may alter fresh water availability as well as change water depths and could be particularly devastating to shallow sites such as the Desoto Canal. Likewise capping or plugging the wells currently suspected of providing warm water to the Desoto site would likely lead to the end of the site altogether.

While having manatees in locations readily accessible to the public may seem like a desirable situation from both and educational and economic perspective, as the sites and manatees become more popular among residents and visitors alike, the level of disturbance and harassment will likely increase as well. Both the Berkeley Canal and C54 sites attract varying levels of recreational fishing activities, as well as predominantly kayak and paddleboard-based recreation and ecotourism. These latter activities are relatively unregulated and their effect on site usage by manatees is unknown. The result of fishing into aggregations will likely increase the likelihood of entanglement. Observations of manatee reactions to kayak encounters within the secondary sites often result in a negative reaction by the manatees which often leave the site in rapid fashion.

Long-term threats to the secondary sites include the potential adverse effects of sea level rise and increases in water temperatures due to climate change, The effects of climate change as it pertains to the future of manatees and critical winter habitat are complex. The implications of climate change as it pertains to ecosystems in lower latitudes are addressed at length in a recent paper by Edwards (2013), using the manatee as an example. While warmer temperatures in Central Florida during the winter would seem to favor manatees from a thermal standpoint, the consequences of sea level rise would likely have dire affects on seagrass distribution, productivity and abundance. Likewise changes in depth, hydrology and available resources in the IRL would undoubtedly affect the suitability of existing warm-water sites.

Desoto Canal site is the shallowest of the three sites in this study. As such, it is particularly susceptible to any drops in water level; build up of sediment or dredging to remove sediment, and shoreline armoring to mitigate shoreline collapse. The longevity of the canal’s seemingly constant flow of warm water, presumed to be coming from old residential wells, is uncertain, and a refuge that seemingly appeared over night may disappear just as quickly if its thermal source is not protected.

The persistence and longevity of secondary sites depends not only an understanding of shared traits among sites that make them attractive to manatees, but also an understanding of traits unique to each site. One of the outcomes of characterizing PTB’s is an increased understanding of what constitutes a functional secondary site or PTB. This understanding in turn increases the chances of discovering other promising sites within the region. By focusing research efforts on locating and identifying sites with similar characteristics in the areas where cold stress-related mortality is highest, managing agencies will have greater success in designing a warm-water network in Brevard County and the surrounding areas.

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CHAPTER THREE: SECONDARY SITE USAGE AND SITE FIDELITY

Introduction

Living at the northern limits of their winter range, Florida manatees have little choice but to seek out warmer water sites or thermal refugia when ambient water temperatures fall below 18-20°C. Much of the population makes predictable migrations to points located south of their summer distribution. Manatees that choose not to migrate to more southern latitudes as well as those passing through a given region on their way southward may make use of existing warm-water sites where they form aggregations that can exceed several hundred individuals. These sites are classified as either primary or secondary warm-water refuges and can be of natural as well as industrial origin. Warm-water sites with at least one winter count comprised of 50 or more manatees and that are capable of sustaining manatees during prolonged periods of cold weather are defined as primary warm-water sites (Laist and Reynolds 2005). This definition generally encompasses natural, first order magnitude warm water springs such as Crystal River and Blue Spring, and industrial outflows such as those found at coastal power plants.

Sites that support large numbers of manatees during brief, relatively mild cold spells but not throughout the colder winters are defined as secondary warm-water sites. Secondary warm-water sites may be the result of isolated areas of shallow or deep water subject to solar warming, groundwater seepage and minimal flushing or disturbance and are generally referred to as passive thermal basins

(PTB's) (Laist *et al*. 2013). Fresh water availability may also play a role in the attraction to secondary warm-water sites, as might the availability of, or access to local foraging grounds. Secondary sites are not considered sufficiently warm enough to sustain manatees during periods of extremely low or prolonged cold temperatures. The physical and hydrographic characteristics of known winter secondary sites vary from site to site however, as does the extent of their use by manatees. Sites may be shallow or deep, passive or spring-fed, natural or man-made, ranging from fresh water to brackish, and of varying distance to or from primary warm-water sites, migratory paths and foraging areas.

The conditions under which secondary warm-water sites are utilized on the central east coast of Florida is relatively under-documented, as is extent of individual manatee fidelity to those sites. The high number of manatees documented during the winter months in Brevard County (FWC, Unpublished data, Reynolds 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002a, 2002b, 2003, 2004, 2005, 2006, 2007, 2009, 2010, 2011, K. Scolardi, Mote Marine Lab, Pers. Com.) makes this particular area of study critical to the protection of manatees and to an understanding of the strengths and weaknesses of the existing warm-water network.

The ability of manatees to adapt to modifications at existing sites, or respond to potential catastrophic loss of known primary sites has always been of serious concern among researchers. Telemetry and established photo-identification studies support the observation that manatees show strong winter site fidelity (Deutsch *et al*. 2003, Reid *et al*. 1991). Manatees familiar with only one winter site would likely be at greater risk during stochastic events such as power plant failures, extremely cold winters, or catastrophic loss of seagrass beds, than those animals familiar with multiple sites. Knowledge of the location of warm-water sites is believed to be taught by nursing females to their calves during the first two years of the calf's life. For this reason calves that are born in captivity or orphaned prior to their first winter are believed to be at a disadvantage when released into the wild and are viewed as naïve (M. Ross, Sea2Shore Alliance, Pers. Com.). These naïve individuals are generally monitored using telemetry gear for a period of at least one year after release back into the wild to assure that they have successfully survived release or reintroduction. This monitoring, while necessary to determine survival success, is both time consuming and expensive. Wild calves that experience mild winters during the first two years of life may likewise be naïve with respect to warm-water sites once weaned and at risk during their first winter as independent juveniles. Coupled with their high SA:V and limited ability to increase their metabolic rate (Irvine 1983, Worthy *et al*., 2000, Worthy and Worthy, *In prep*.) these individuals may be more likely to suffer from cold stress syndrome than those who familiar with both primary and secondary sites. Given these constraints and physiological limitations, juveniles are particularly vulnerable to cold temperatures, and the availability of secondary sites may play a critical role in their ability to successfully forage, find warmth and ultimately survive the winter in a given region.

While most winter aggregation studies in the east-central region of the state have addressed primary industrial sites such as the power plant effluents at the FPL-CC site and OUC (Refer to literature review in Chapter Two), few if any in-depth studies have attempted to characterize the site itself or address the use of multiple secondary sites in the region during the winter. Secondary sites may serve not only as migratory way points or “stop-over’s” where manatees can temporarily leave the cold temperatures of main rivers and estuaries, but they may also serve as overwintering sites particularly in mild to moderately cold winters, possibly even during severe winters.

Secondary sites may offer the advantage of being closer to critical foraging areas than primary warm-water sites, limiting the time that individuals are exposed to sub-critical temperatures traveling to and from the seagrass beds to forage. This may be of particular importance to adult females with dependent calves that cannot survive prolonged exposure to cold. Additionally, manatees using secondary sites may alleviate competition for heavily grazed foraging resources closer to primary sites. While a handful of secondary sites have been identified in Brevard County, characterization of these sites and an understanding of their role in the warm water network are lacking. Identification of additional, perhaps marginal sites that may be available for use with some enhancement or modification is also needed. In addition to locating and characterizing existing sites, disturbances and threats to the suitability of the sites need to be identified. Once this is accomplished protective measures can be implemented so as to preserve the integrity and availability of the sites from year to year.

The objectives of this chapter were to document manatee use of the three secondary sites in Brevard County during the winter months through manatee counts obtained during repeated site visits and photo-identification efforts; to determine if manatees using the site show fidelity over subsequent winters; to describe any daily site usage patterns and the conditions under which these are observed; to determine the environmental conditions under which manatees use each site; to assess the ability of a site to support manatees over winters of varying severity; to contribute manatee sighting and scar pattern photos and data to the USGS Sirenia Project's Manatee Individual Photo-identification System (MIPS), and to initiate and maintain long-term manatee attendance and identification records for each site.

Methods

During the winters of 2008-2009 through 2011-2012, three manatee warm-water aggregations sites, the Berkeley Canal, the Desoto Canal and the C-54, were regularly visited as part of routine winter monitoring and regional winter photo-identification efforts by the FWC. Data collected during these visits by the FWC and trained volunteers were used to gain a better understanding of manatee use of the three secondary sites and to address the question of site fidelity in this study. Due to the unique challenges relative to each site, the methods used to determine site usage and site fidelity were tailored to maximize data acquisition at each location, and as so are described by individual site when appropriate.

Site Fidelity and Use

Site usage and fidelity were partly addressed for two of the three sites through use of established photo-identification procedures developed by the Florida Fish and Wildlife Conservation Commission Manatee Photoidentification Project and the US. Geological Survey's Sirenia Project Manatee Individual Photoidentification System (MIPS) (Beck and Reid 1995). Site configuration at the C-54 was not conducive to photo-documentation due to the lack of an appropriate vantage point from which to take photos. Individual site fidelity and use were not addressed for this site. Photo-identification was conducted at the Berkeley Canal and Desoto Canal sites only. It is important to note that the Desoto Canal site only became available for study during the 2009-2010 winter season and thereafter. Poor photo-identification conditions plagued the Berkeley Canal Site for most of the 2010-2011 and 2011-2012 winters. During that time photo-identification efforts were increased at the Desoto Canal. For this reason 2007-2008 winter photoidentification records from the Berkeley site were reviewed and used to help address the question of site fidelity.

Visits to each warm water site were part of the FWC's ongoing photo-identification efforts in the region and were conducted under USFWS Permit No. MA7734949. At the beginning of each visit environmental site conditions were recorded on standardized environmental data sheets as per FWC photo-identification protocol. Manatees already present at the start of each visit were counted at least twice then noted on the data sheet. Counts were taken at all visits but photo-documentation efforts took place only when conditions were favorable.

During visits to both the Berkeley and Desoto Canals individual manatees were photographed using either a Canon D50, or a Canon D50 EOS Digital SLR camera, equipped with a 28–135 mm, or a 70-300 mm lens and a circular polarizer used to reduce glare. Standardized manatee scar sketch sheets were used to draw and record each manatee's scar pattern and any corresponding photograph exposure numbers. Additional information recorded for each animal included size class, gender when known, the presence of a dependent calf, and any additional comments or observations. All photographs, sketches and environmental data sheets were submitted to the USGS Sirenia Project for inclusion in the MIPS database and archived with the FWC Manatee Photoidentification Project.

Berkeley Canal

During the 2008-2009 through 2010-2011 winter season, manatees were counted and photographed as they passed through the shallow waters of a small basin located between two cement overpasses at the entrance to the Berkeley Canal. The number and duration of site visits and the timing of the counts varied. Visits were dictated by environmental conditions, the presence or absence and movement of manatees, as well as staff and volunteer availability. Efforts were made to visit the site as often as possible to count the number of manatees present, to maximize the number of individuals documented, and to determine if manatees exhibited daily site usage patterns by recording arrival or departure times for individual animals over the course of the day. The general arrival and departure patterns of manatees determined during the 2007-2008 winter, as well as the timing of favorable lighting and photographic conditions, were used to plan subsequent visits around particular time frames to maximize photo-identification opportunities. When possible, the frequency of visits was increased during the passage of predicted cold fronts to document the presence or absence of manatees at the site and behavior with respect to temperature

Desoto Canal

Photo-identification and warm-water site monitoring efforts began in early January 2010 at the Desoto Canal site immediately following receipt of an aerial survey report documenting the presence of at least 100 manatees in a shallow storm water collection ditch located off of the Desoto Parkway (J. Provancha, Pers. Com.). During the 2009-2010, 2010-2011, and 2011-2012 winter seasons, manatees were counted and photographed as part of the state's ongoing photo-identification efforts. The number and duration of site visits and the timing of the counts varied. Visits were dictated by environmental conditions, the presence or absence and movement of manatees, as well as staff and volunteer availability. Efforts were made to visit the site as often as possible to count the number of manatees present, to maximize the number of individuals documented, and to determine if manatees exhibited daily site usage pattern. When possible, the frequency of visits was increased during the passage of predicted cold fronts to document the presence or absence of manatees at the site and behavior with respect to temperature. At the Desoto Canal site, manatees were photographed from the adjacent shoreline. Priority was given to photo-documenting the most obviously scarred individuals first since frequent movement within the canal stirred up the bottom sediment quickly diminishing visibility and photographic conditions.

C-54

Beginning in the winter of 1998-1999, volunteers with the Department of Environmental Protection at the Sebastian River Buffer Preserve were recruited and trained to count manatees located east of the spillway at the C-54, during the winter months. Counts have continued yearly from November 1st through March 31st. Volunteers were trained to conduct five 2-minute counts of manatees from a set location off of the spillway structure during each visit. Participants recorded the maximum number of manatees seen during each count, along with time of day and corresponding environmental conditions (e.g. approximate wind speed and direction, salinity, cloud coverage and water temperature) on standardized datasheets.

During the first two winters of this study, 2008-2009 and 2009-2010, counts were made by volunteers at varying times of the day and were subject to volunteer availability. In order to collect data that would help identify site attendance patterns, volunteers increased their survey efforts to three counts each day when possible during set time periods for the 2010-2011 and 2011-2012 winters.

Manatee counts conducted from December through March of the 2010-2011 and 2011-2012 winter data sets were tabulated then assigned to one of three observation periods. Observation periods separated counts into morning surveys which took place at or before 1000h; late morning/early afternoon surveys which took place after 1000h and up to 1400h, and late afternoon/early evening counts which took place after 1400h. The maximum number of manatees counted per day for each survey was used for all analyses. A 2 way ANOVA was performed to determine if the number of manatees counted during each survey period was significant differently with respect to the time of day and winter season, indicative of a daily use pattern that may be reflective of winter conditions.

Using data from the survey days during 2010-11 and 2011-12 winters when counts were conducted three times per day during each of three different sampling periods, the maximum daily counts for each of the three surveys were graphed against C-54 (SR_Z) and ambient river (IRS_C) and local air temperatures (SR_A) to determine if increases in manatee numbers not only correlated with falling temperatures but also showed predictable daily patterns of site use (i.e. higher in the morning, gradually decreasing during the day).

To address the question of site fidelity, photographs and scar sketch sheets from each site for each winter monitored were examined to determine if there had been repeated visits by any individuals to the same site during subsequent years; if any individuals visited the site over the course an entire winter season, specifically the 2010- 2011 winter season, and if any individuals were documented using both sites either during the same winter or during subsequent winters. Twenty different manatees were chosen for this exercise. Each manatee was chosen based on the presence of predominant, unique and persistent scars easily recognized and matched during the course of the study and that were likely to have been documented and recognized even in poor field conditions (i.e. poor water clarity). A table was created to summarize each individual animal's attendance with respect to site and winter season as confirmed through photoidentification. Individual names assigned to each manatee in the table are not official identifications as assigned in the MIPS database, but rather were used in the field to facilitate recognition during the study.

Manatee distribution in response to the passage of significant cold fronts during the study as it pertains to the three sites was addressed by reviewing yearly, winter synoptic surveys. Manatee counts and distribution data from statewide aerial synoptic surveys conducted under the coordination of the FWC and during the 2008-2009, 2009-2010, and 2010-2011 winters were imported into ArcMAP 10.0.and used to generate maps illustrating manatee distribution in Brevard County immediately following the arrival of a strong cold front (FWC, Unpublished data). Maps were created for each of the three secondary sites to compared manatee distribution as it pertains to use of PTB's and the affects of winters of varying severity on counts and distribution. Data were queried to determine how many individual manatees were represented by each data point. The total number of animals at each of the three secondary sites were tabulated and compared against the number of manatee counted statewide, and those at the FPL-CC plant.

Notable manatee behavioral observations documented in the secondary sites during the study were compiled from field notes for inclusion in the discussion as they pertain to adaptations to cold stress

Results

The inaccessibility of the Desoto Canal site during the first year of this study prevented the comparison of manatee counts with the Berkeley site for the 2008-2009 winter season. Ground counts in excess of 100 individuals regularly occurred at the Berkeley site during both the 2008-2009 and 2010-2011 winters (Table 21). This site would therefore seem to support a large number of manatees during mild to moderate winters and possibly for a limited time during more severe winters. Poor visibility and access at the Berkeley site however, make it difficult to accurately count the number of manatees present since animals at the east end of the canal tended to bottom rest in the thick sediment during colder periods. Counts at the Berkeley site were therefore, likely underestimates, further underscoring the importance of this site as a winter refuge.

Conditions at the Desoto site varied from season to season ranging from full visibility early on in its use to very poor visibility during subsequent winters as manatees in the canal competed for position in the sediment. At the Desoto site, ground counts exceeded 120 individual during both the 2009-2010 and 2010-2011 winters, with the highest counts occurring within 24 hours of a passing cold front. High counts at the Desoto site generally coincided with decreasing numbers in the Berkeley site as documented in response to a severe cold front early on in the season (Figure 42). This appeared to coincide with ambient river temperatures falling sharply despite Berkley sediment temperatures remaining well above 18°C. Column temperatures at the Berkeley site did however, fall below the critical level of 18 °C.

Low counts and reduced number of site visits were reflective of warmer conditions and absence of manatees at the sites during the 2011-2012 winter. Different survey conditions and the criteria that influence manatee use at each site (i.e. water clarity and temperature) must be taken into account when making comparisons. Counts at each site represent the minimum number of manatees present.

Table 21 Average manatee counts per site visit at the Berkeley and Desoto Canal sites.

Site	Winter	No. site visits	No. days manatees present	Total Count (Min.)	Visit Mean	Min	Max
Berkeley	2008-2009	51	51	1739	33.4	3	100
	2009-2010	22	22	489	22.2	1	63
	2010-2011	72	65	1532	21.2	0	100
Desoto	2009-2010	27	27	1337	49.5	4	144
	2010-2011	85	66	3538	41.6	0	120
	2011-2012	18	6	138	8.10	0	46

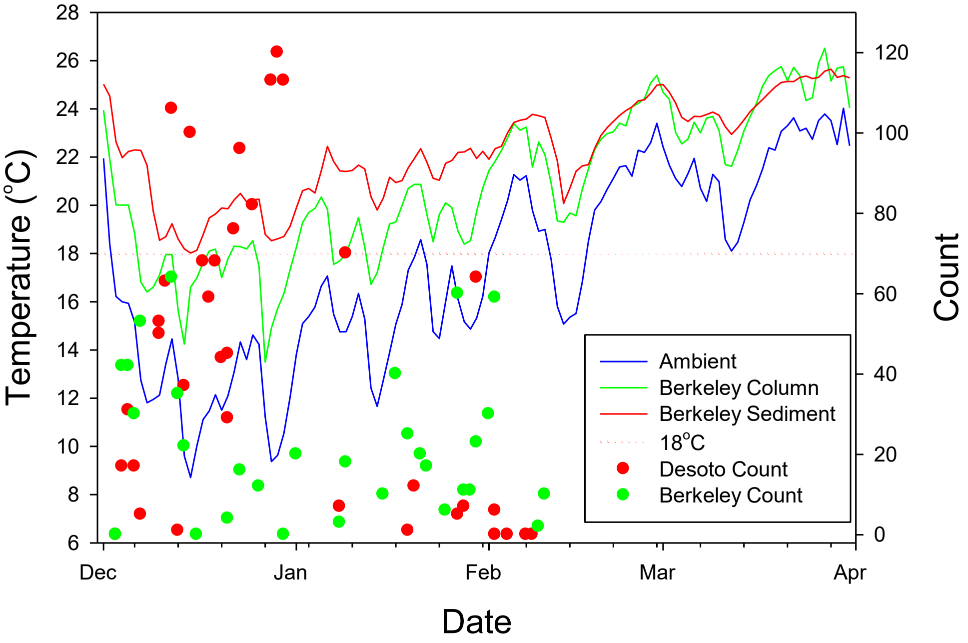

Figure 42 Manatee counts at the Berkeley Canal and the Desoto Canal during a prolonged cold front in early winter 2010-2011

Analyses of photo-identification records from the 2007-2008 through 2011-2012 winters indicate that at *minimum* of 20 different individuals have used at least one of the two Satellite Beach sites during at least two different winters (Table 22). Fifteen of the 20 individuals have been documented at both sites, six of these during the same winter. Three individuals were documented at least once during each winter season. Comparison of photos of individuals from both sites showed not only site fidelity but also use of both sites by some individuals (Figure 43).

Figure 43 Photo-documentation of an adult female manatee that overwinters in the Satellite Beach warm-water sites at Berkeley and Desoto Canals (clockwise from top left): Berkeley Canal on 11 Jan 2008; Desoto Canal on 08 Feb 2010; Desoto Canal on 07 Dec 2010; Desoto Canal on17 Jan 20

Table 22 Winter attendance records supporting site fidelity for 20 manatees using the Berkeley or Desoto Canal sites during the 2007-2008 through 2011-2012 winter seasons (X = present)

		MANATEE									
Winter	Site	Italics	Phoebe	Butterfly	Canada	Vancouver	Blip	Savage	Charms	Hash	Tri
2007 - 2008	Berkeley	X	X	X	X	X	X	X	X	X	
2008 - 2009	Berkeley	X	X	X		X	X	X	X	X	X
2009 - 2010	Berkeley					X				X	
	Desoto	X	X	X	X	X	X		X	X	
2010 -2011	Berkeley		X	X	X						
	Desoto	X	X	X	X				X	X	X
2011 - 2012	Berkeley				X						
	Desoto	X		X	X			X		X	

		Seven	Candace	Tripoli	Nantucket	Arrowhead	Archie	Picket	Argyle	Echo	Ribeye
2007 - 2008	Berkeley										
2008 - 2009	Berkeley	X	X	X	X						
2009 - 2010	Berkeley						X			X	
	Desoto		X	X	X	X	X	X	X		
2010 - 2011	Berkeley	X								X	
	Desoto		X		X	X	X	X	X	X	X
2011 - 2012	Berkeley	X									
	Desoto		X		X	X					X

Site visit attendance records collected and tabulated for the Desoto site during the 2010-2011 winter, indicate that a number of individuals did use the site throughout coldest part of the winter, despite the occurrence of strong and prolonged cold fronts early in the season and a colder than average winter overall. The graph in Figure 44 illustrates the daily mean temperature profiles of the ambient river sites in Brevard County while Table 23 represents attendance records for a select number of individually identifiable manatees documented at the Desoto site during that same time frame. By the end of January, ambient water temperatures in the lagoon had improved and the manatees effectively vacated the site for the remainder of the winter. Additional analyses of attendance records for the 2010-2011 winter produced similar result involving many of the same individuals during the coldest winter on record in 30 years.

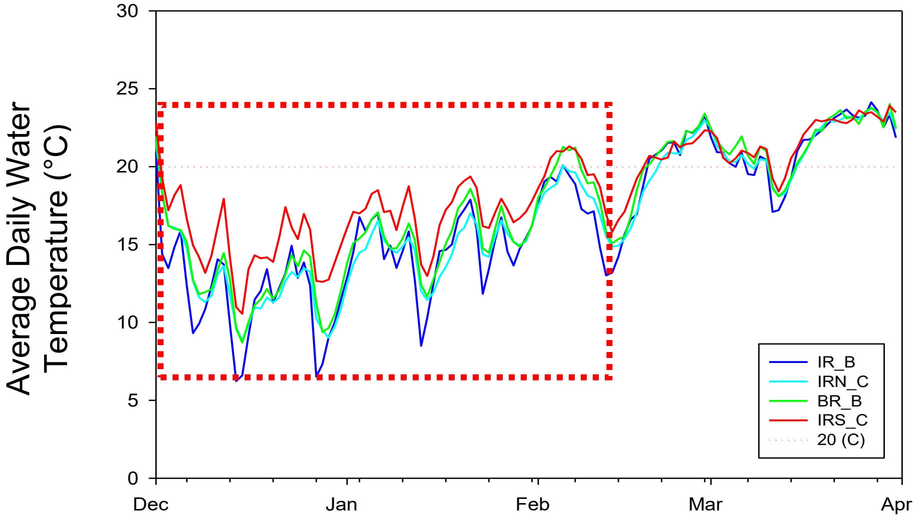

Figure 44 The affects of an early winter cold front on the daily mean water temperature at ambient river sites during a colder than average winter: 2010-2011.

Table 23 A sample of Individual manatee attendance records at the Desoto Canal site during the 2010-2011 winter season showing manatee use of the refuge throughout the winter despite a colder than average season

DATE	BUTTERFLY	TRI	DEMON	ECHO	MOTH	CANADA	HASH	ITALICS	RIBEYE
2-Dec-10	X							X	
3-Dec-10	X					X		X	
4-Dec-10						X			
7-Dec-10	X	X					X	X	X
8-Dec-10	X				X				
10-Dec-10	X	X				X	X		
12-Dec-10	X							X	
13-Dec-10	X	X				X	X	X	
14-Dec-10	X	X		X	X	X	X	X	
20-Dec-10	X	X		X		X		X	
22-Dec-10	X	X	X		X		X	X	
24-Dec-10	X	X	X	X				X	
25-Dec-10	X	X	X		X	X		X	
26-Dec-10									
27-Dec-10	X	X	X	X	X	X			
28-Dec-10	X			X	X	X			X
29-Dec-10	X	X	X			X	X	X	X
30-Dec-10	X	X		X	X	X	X	X	
31-Dec-10	X	X	X	X	X	X	X	X	
1-Jan-11		X	X		X		X	X	X
2-Jan-11	X		X						X
3-Jan-11	X		X					X	X
4-Jan-11	X		X					X	
5-Jan-11			X						X
7-Jan-11	X	X	X	X		X	X	X	
14-Jan-11	X	X	X	X		X	X	X	X
15-Jan-11	X		X	X	X		X	X	
17-Jan-11					X				
19-Jan-11			X						X
20-Jan-11				X					
23-Jan-11	X	X				X			X

DATE	BUTTERFLY	TRI	DEMON	ECHO	MOTH	CANADA	HASH	ITALICS	RIBEYE
25-Jan-11			X						
26-Jan-11			X		X				
27-Jan-11	X		X	X	X	X			X
28-Jan-11	X		X	X	X	X	X		X
30-Jan-11			X		X		X		X
31-Jan-11			X						
11-Feb-11	X								

Manatee surveys conducted three times per day at the C-54 predominantly show higher numbers of manatees in attendance during the morning sampling period than during subsequent mid-day and afternoon surveys for both the 2010-2011 and 2011-2012 winter (Table 24 and Table 25). Comparisons between the two winters showed that the mean counts during the morning hours for the 2010-2011 winter were more than double those of the 2010-2011 winter. Mean averages for late afternoon counts however, were more comparable (Table 26, Figure 45). The maximum number of manatees counted with respect to winter and survey period occurred during the 2010-2011 morning hours with a high count of 199 manatees.

Despite morning counts generally being higher than those at any other time period during the 2010-2011 winter, results of a 2 way ANOVA indicated that there was no significant difference between counts taken before 1000h and counts taken in the later parts of the day nor was there a significant difference when comparing affects of winter season on counts. This would suggest the lack of a daily use pattern at the site.

Regardless, graphical comparison of the data plotting survey counts by time period against ambient river and air temperature showed higher morning counts at the C54 consistent with drops in water temperature in the IRL, and noticeable decreases in counts occurring the late afternoon hours in the winter of 2010-2011 (Figure 46). Comparatively, counts from the milder 2011-2102 winter show less stratification with respect to the time of day the survey was conducted and fewer manatees.

Table 24 C-54 manatee counts: Winter 2010-2011

	Count		
Date	≤1000h	1000h -1400h	≥1400h
2-Dec-10	28	10	11
3-Dec-10	16	12	11
5-Dec-10	51	40	23
6-Dec-10	41	29	32
8-Dec-10	152	91	21
9-Dec-10	199	51	35
12-Dec-10	73	46	35
13-Dec-10	41	26	18
15-Dec-10	94	55	9
16-Dec-10	100	28	12
20-Dec-10	11	7	3
27-Dec-10	21	10	9
31-Dec-10	10	3	6
2-Jan-11	8	5	5
5-Jan-11	0	5	0
10-Jan-11	5	4	2
17-Jan-11	10	12	7
28-Jan-11	30	10	7
31-Jan-11	10	7	2
5-Feb-11	0	0	0
7-Feb-11	0	1	0
12-Feb-11	33	19	8
13-Feb-11	30	17	24
14-Feb-11	24	17	11
15-Feb-11	40	30	8
19-Feb-11	8	17	0
20-Feb-11	1	3	0
7-Mar-11	11	5	8
20-Mar-11	0	2	3
22-Mar-11	4	0	2
24-Mar-11	0	0	1
28-Mar-11	0	0	2
30-Mar-11	0	0	0

Table 25 C-54 manatee counts: Winter 2011-2012

>

	COUNT		
DATE	≤ 1000h	>1000≤1400h	>1400h
5-Dec-11	8	12	3
6-Dec-11	4	5	2
7-Dec-11	2	3	5
8-Dec-11	14	4	18
9-Dec-11	5	5	8
13-Dec-11	9	7	0
14-Dec-11	18	11	3
19-Dec-11	15	13	12
26-Dec-11	0	2	0
28-Dec-11	0	1	2
2-Jan-12	14	15	21
3-Jan-12	41	36	17
4-Jan-12	48	55	30
5-Jan-12	71	19	21
6-Jan-12	34	29	58
9-Jan-12	42	49	26
10-Jan-12	11	14	0
11-Jan-12	4	4	1
12-Jan-12	13	3	9
16-Jan-12	45	22	21
17-Jan-12	19	16	4
18-Jan-12	20	23	7
23-Jan-12	4	0	2
24-Jan-12	1	0	0
26-Jan-12	0	2	0
30-Jan-12	2	7	3
31-Jan-12	9	8	3
1-Feb-12	2	10	2
2-Feb-12	6	7	1
3-Feb-12	5	1	4
6-Feb-12	0	0	1
9-Feb-12	15	3	1
16-Feb-12	23	10	4
23-Feb-12	0	1	1

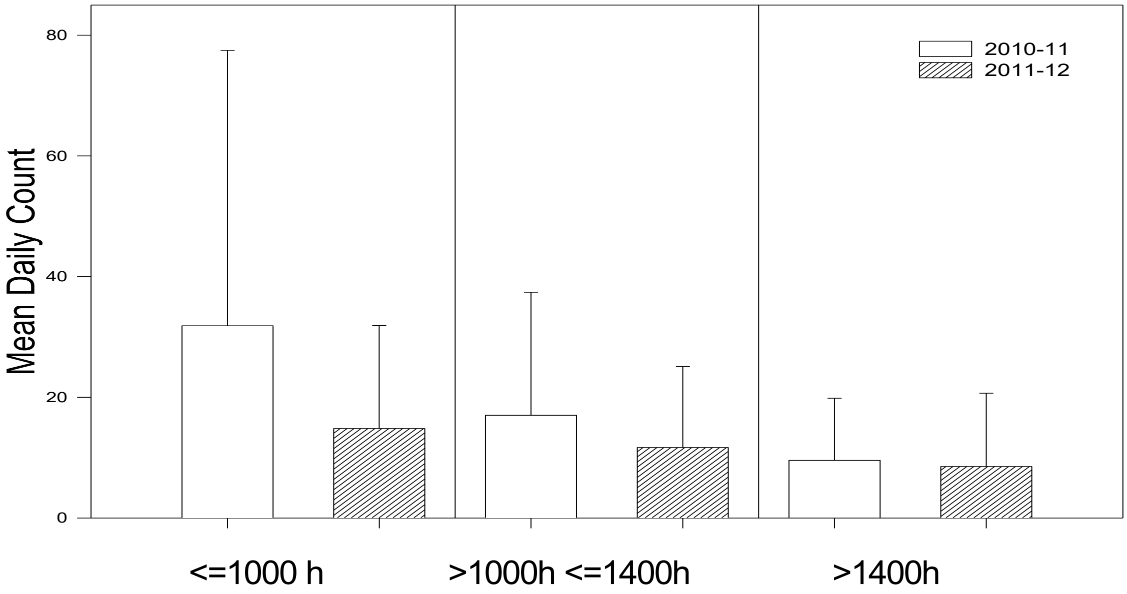

Figure 45 Comparison of manatee attendance patterns with respect to time of day at the C-54 during the 2010- 2011 and 2011-2012 winters

Table 26 The timing of manatee site attendance at the C-54 based on counts conducted three times daily during the 2010- 2011 and 2011-2012 winters

Winter (No. days)	Time Period	Mean Count	Std Dev	Range	Max	Min	25%	75%
2010-2011	≤1000h	31.8	45.6	199	199	0	3.3	40.3
(n = 33)	>1000h ≤1400h	17.0	20.3	91	91	0	3.0	26.5
	>1400h	9.5	10.2	35	35	0	2.0	11.3
2011-2012	≤1000h	14.8	17.0	71	71	0	2.0	19.0
(n = 34)	>1000h ≤1400h	11.7	13.4	55	55	0	3.0	15.0
	>1400h	8.5	12.1	58	58	0	1.0	12.0

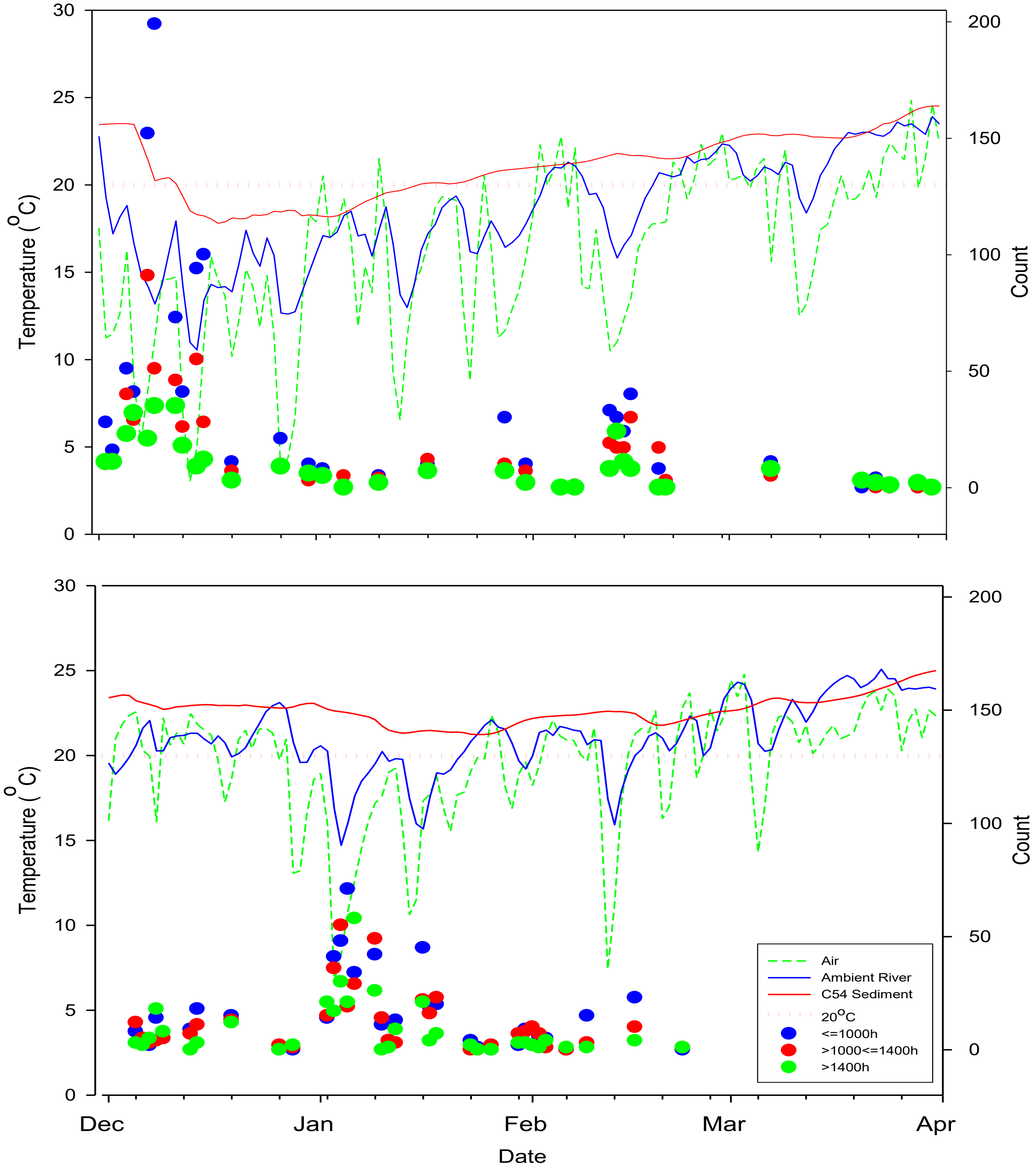

Figure 46 Manatee attendance at the C-54 as it correlates to time of day and ambient river temperature, during the 2010-2011 (top) and 2011-2012 (bottom) winters

Synoptic surveys conducted in all but one of the study winters showed that during the severely cold 2009-2010 winter season, manatees responded by aggregating primarily at the FPL site but also that a number of animals were documented at the Berkeley Canal, the Desoto Canal and the C-54.

Table 27 Manatee synoptic survey counts at Brevard warm water sites

	TOTAL	WEST	EAST	FPL-CC	Berkeley	Desoto	C-54
2009-10	3802	1654	2148	484	18	1	59
2010-11	5017	2297	2780	957	12	45	52
2011-12	4834	2402	2432	402	63	0	3

During the two milder winters, attendance at these sites was also confirmed with the exception of the Desoto Canal in 2011-2012. The distribution during the comparatively milder winters appeared less concentrated, with animals spreading out from the secondary sites yet still within close proximity, if not actually in the site itself (APPENDIX E, Figure 53, Figure 54, Figure 55, Figure 56, Figure 57, Figure 58, Figure 59, Figure 60, Figure 61).

Discussion

Manatee use and movement between warm water sites during the winter months is driven primarily by the need to maintain thermal balance. Individual cold tolerances among different animals further complicates our understanding of why some manatees use one site over another, and why some individuals survive prolonged cold events while others do not. By simultaneously monitoring water temperatures at both Satellite Beach sites and documenting site usage by individually identifiable animals, it was possible to show that many animals used both sites predictably with respect to temperature during the winter. When ambient river water temperatures fall blow 18°C, manatees started using the warmer waters of the Berkeley site. When water column temperatures within the Berkeley site fell below 18°C for more than a few days however, manatees using the site appeared to have either burrowed down in the sediment or began using the Desoto site as documented in the 2010-2011 winter. When both ambient river and Berkeley Canal water temperatures began to rise, the reverse pattern occurred and animals moved back to the Berkeley site.

Prior to the 2009-2010 winter, temperature monitoring efforts and visits to the Desoto Canal site indicated less than optimal water temperatures in the main canal, while prohibitively low water levels in the ditch precluded manatee use during the previous winters. Despite the unavailability of the site in prior to fall of 2009, manatees known to use the Berkeley Canal, including independent calves and subadult-sized individuals, began using the Desoto ditch as soon as it became available, showing surprising plasticity in behavior. If future manufactured warm-water sites are to succeed in attracting manatees, proximity to existing sites is one of the more important considerations in choice of the location and design.

Despite the shallow nature of the Berkeley and Desoto sites, both regularly supported large numbers of manatees during all, or at least part of the most severe winters on record. Movement patterns documented within the sites, presumed to optimize thermoregulation, including vertical as well as horizontal migration, immersion in the sediment, and sunbathing which were common to all three locations. During early morning hours and on overcast or colder windy days, manatee presence during counts was often underestimated specifically at the Berkeley and C-54 sites. This was the result of manatees using the warmer microclimate provided by the thick sediment covering the bottoms of all three sites. Mud-covered individuals were difficult to count accurately as only their noses breached the surface momentarily to take a breath. This likely leads underestimation of how many manatees the Berkeley site actually supported. Aerial surveys conducted during the FPL-CC repowering project confirmed this assumption on a number of occasions when comparison of land and aerial results obtained on the same day indicated substantial differences in numbers (K. Scolardi, Mote Marine Lab, Pers. Com.)

As if rising with the sun, manatees quietly resting on the bottom gradually emerge to take direct advantage of not only the sun’s rays but of small increases in surface water temperature as well. Tracking the path of the sun like a sundial, horizontal migration in the site resulted in a shift in the aggregation from the east end of the canal to the edge of its western boundary late in the afternoon. Beginning around noon, a gradually increasing number of manatees would begin to leave the canal, presumably to forage in the river. On extremely cold days movements out of the site were diminished, while entrance into the site increased noticeably. Larger groups of individuals were documented entering at the same time than on warmer days, and more animals overall would arrive following the passage of a cold spell. Some individuals were even documented entering the site at higher than usual speed.

Despite having one of the warmest temperature profiles, sediment temperature at the Berkeley site may not be the limiting factor for its use. Manatee counts taken at Berkeley and Desoto during a severe and prolonged cold spell in 2010-2011, then graphed against ambient river, Berkeley sediment and column temperatures, indicated that the shallower yet consistently warmer temperatures at the Desoto site were preferable to swimming through than the colder column temperatures at Berkeley.

Documentation of manatee use at the Desoto site was more easily monitored but challenging nonetheless. Despite its extremely shallow profile, a thick layer of sediment covering the bottom was easily stirred up in the water column as manatees wrestled for position in the deeper portion of the canal. Manatees were often so tightly packed together and covered in sediment that it gave the appearance of an aggregation approximately half its size. Disturbance of the group by another manatee often resulted in an eruption of manatees, revealing an actual number of animals well in excess of the original count. Arrival and departure of animals at the site often went unnoticed under the camouflage of thick sediment and dark water. Despite the continuous supply of fresh warm water maintained well above the manatee’s critical thermal threshold, manatees generally left the canal as soon as water temperatures at the Berkeley site increased. Vertical and horizontal migration patterns similar to those at Berkeley, but specific to the Desoto site, were observed. Likewise manatees appeared to arrive at the site sometime early in the morning as river temperatures cooled. Additional animals were usually documented entering during the late morning hours, while numbers seemed to decrease late in the afternoon. During severe and prolonged cold spells, many individuals did not appear to leave the site at all. This seemed to apply to animals of large calf size and smaller.

The remote nature of the deeper C-54 site limited the opportunity to observe of how individuals might have used the canal. Immersion in the sediment, sunbathing and both vertical and horizontal migration were observed. As with the Desoto and Berkeley sites, forage is usually absent at the C-54 site. On occasion, winds originating out of the west blow copious amounts of water lettuce backed up behind the structure over the spillway into the waters below. Manatees quickly dispatch the vegetation before the current has a chance to take it away. Manatee counts at the site show the highest numbers during the morning hours, gradually tapering off as the day progresses. This pattern is more obvious during colder periods of time despite the failure of statistical tests to demonstrate significant differences. As with the other site, higher counts correspond to passing cold fronts.

Examination of photoidentification data indicated that many of the same individuals used the Berkeley and Desoto sites during consecutive or subsequent winters. A subset of these used both sites. Site fidelity was determined for individuals all ages and size classes. During the extreme winter of 2009-2010 and 2010- 2011 upwards of 100 individuals used the Desoto site for the duration of the winter, and were present on a large number of survey days. Animals often thought to have left the site to forage, were later found that same day in the Berkeley canal.

Synoptic survey results further support the value of these secondary sites by showing manatee use of locations other than the power plant following the passage of notable cold fronts. Milder winters show slight dispersion around key warm winter sites, while severe cold spells such as the one that occurred in January 2010, show tight concentration around limited sites. Secondary sites may be of particular importance following the arrival of quickly changing severe weather, when travel to the power plant is not a viable option.

Behavioral Observations

While generally qualitative, sometimes anecdotal, and often impervious to statistical analyses, behavioral observations within aggregation sites may provide valuable insights into why manatees use one site over another.

A behavior repeatedly observed and described among manatee field biologists as “calf parking’ has been documented in well-protected locations including the

Berkeley Canal during the winter months (L. Keith and A. Spellman, FWC, Pers. Obs.) Documented again during the course of this study, “parking” is likely a behavioral adaptation that allows nursing adult females access to nearby forage while leaving dependent offspring in a safe and warm location. Calves that have been parked are usually several months old and appear to be capable of forgoing nursing for at least a few hours. Interestingly, very young calves are rarely seen “parked”, presumably because of the need to nurse frequently (on average every 60 minutes, ±12 minutes [Shapiro 1996]) dictating that smaller calves stay in close proximity to their mothers. This could be a problem during the more severe cold fronts.

During a particularly strong cold front in mid-December 2010, repeated efforts were made to match up a very small, dependent calf (estimated to have been no more than 3 months old) that appeared to be alone in the Desoto Canal, with its respective mother. The calf was very small (TL = approximately 1 m). During this time the calf appeared to stay healthy and robust, yet never appeared to leave the canal. Both the Berkeley and Desoto sites were used by numerous mother-calf pairs in addition to large numbers of subadults. The process of matching up mother-calf pairs usually took a number of visits to both sites each season. In the process of trying to match up the small calf with its mother another interesting observation related to “calf parking” was observed. On multiple occasions, the small calf along with several other dependent calves at the site were observed nursing opportunistically on different adult females in addition to their own mothers during this particularly cold period. Likewise a number of adult females were observed taking turns nursing multiple calves in addition to their own, a behavior that has also been documented with orphaned calves in captivity as well as in the wild (Shapiro 1996, W. Hartley, Blue Spring State Park, Pers. Com.). With repeated observations it became apparent that while some nursing females left the warmth of the canal alone, presumably to forage, other females with calves remaining at the site would nurse a number of calves in addition to their own, presumably freeing smaller calves from having to follow their mothers into ambient waters of lethal temperature. It is interesting to note that while each female appeared receptive to nursing her own calf, most appeared agitated when nursed on by calves that were not related. This occurred daily over the course of approximately three weeks while ambient water temperatures remained low (i.e. nearby ambient river temperature reached a low of 8 °C in the Banana River and 7.8°C in the Indian River on 15 December 2010) and exposure to ambient river temperatures would likely have been lethal for calves even for a short period of time. Once water column temperatures reached 18°C at the Berkeley site, nursing females with dependent calves would leave the Desoto system and often enter the Berkeley Canal together, allowing for confirmation of suspected mother-calf pairs. It was at this time that the smallest calf was finally paired with a surprisingly small (approximately 244cm), relatively indistinct, nursing female. This mother-calf pair relationship was maintained throughout the rest of the winter and documented on multiple occasions. Presumably this “wet nursing” behavior is a form of reciprocal altruism, a behavioral adaptation that provides females with dependent calves the ability to address their foraging needs while allowing the calves to receive adequate nutrition and to avoid thermal stress. The location of secondary sites in Satellite Beach, 34 km south of the nearest primary site, may facilitate access to distant seagrass beds while providing valuable “calf parking” locations for females with smaller, dependent calves.

On a number of occasions during the 2009-2010 and 2010-2011 winters, one of the secondary sites, the Desoto Canal, provided unique and timely opportunities to identify, assess and ultimately rescue a number of severely cold stressed and debilitated individuals. As previously mentioned when water column temperatures at the Berkeley Canal site reached approximately 18°C, almost all of the animals using the warmer Desoto Canal system left that site, many moving on to the Berkeley Canal site (as confirmed by photo-id) while others went out in the river presumably to feed and/or move amongst warm-water sites. In almost all cases, those individuals that stayed behind at the Desoto site were smaller in size, in poor physical condition, and in need of medical intervention. Such incidences resulted in the rescue of five manatees in 2010 and an additional four in 2011. No manatees were rescued from the Berkeley site during that time. All rescued manatees at Desoto site fell within the independent calf to subadult range (mean = 209 cm TL, range = 195 to 250 cm) and exhibited signs of moderate to severe cold stress (FWC, Unpublished data). These rescue situations illustrate the importance of monitoring warm-water sites during, as well as for a period of time after colder weather has passed. These sites may be of particular importance in the thermoregulation and survival of smaller, independent individuals.

As mentioned in Ch. 2, sediment found in thick layers covering the bottom of all three sites has the potential to obstruct entry into shallower sites and requires careful monitoring. This same sediment is actually beneficial in that it provides a warm layer within which manatees are often seen wallowing in an effort to better thermoregulate (Figure 47). Dredging of residential canals known to support manatees during the winter months should be approached cautiously as it has the potential to remove a valuable feature common to all of the chief secondary sites in the county. Failure to control the sediment however presents a real risk of sites like the Desoto canal becoming occluded and inaccessible once again.

Photo: FWC: Permit No.MA770191

Figure 47 Evidence of mud wallowing as a behavioral adaptation addressing thermal stress

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CHAPTER FOUR: MANATEE ENERGECTICS MODEL

Introduction

Manatee survival in Florida during the winter months is dependent upon the precarious balance of physiological needs and environmental stresses. These physiological needs include access to the appropriate critical habitat, particularly warm-water sites, and meeting metabolic requirements by obtaining adequate nutrition and fresh water. The main environmental stress is exposure to cold water. Equipped with limited physiological and behavioral adaptations to the cold, manatees generally address physiological needs and avoid thermal stress either by migrating to warmer latitudes and overwintering there until the spring or by utilizing a network of warm-water sites in the higher latitudes where food is available, accessible, and ideally abundant.

The manatee's low metabolic rate, high rate of thermal conductance, and subsistence on low energy vegetation makes them particularly susceptible to cold stress syndrome (CSS) when water temperatures fall below 20°C (Bossart 2001, Bossart *et al.* 2002). At no time during the year then is the delicate nature of this balance more apparent than during the cooler months. The suitability of a particular warm-water site as it pertains to the survivability of the manatee during the winter depends upon a number of variables both environmental and physiological.

As shown in Chapter One, one region of Florida, Brevard County is at particularly high risk for cold stress-related manatee mortality. This is due not only to its large winter population, but also to its location, and the lack of any primary natural warm-water sites such as natural springs.

Within Brevard County, located along the western shoreline of the Indian River Lagoon (IRL) are two commercial power plants: the Florida Power and Light-Cape Canaveral Plant (FPL-CC) and the Orlando Utilities Commission-Indian River Plant (OUC), both located in the northern Cocoa, approximately 2.8 km apart. Both plants have provided thermal refuge for an increasing number of manatees for more than 50 years, and are considered critical habitat for manatees in the region during the winter months. The OUC Plant recently suspended operation having been “mothballed” or retired in 2010, and its future plans to generate power are uncertain.

The FPL-CC plant recently completed demolition, rebuilding and repowering, changing from a plant fueled by coal and oil to a natural gas powered facility. It reopened in 2013. During repowering the FPL-CC plant continued to support several hundred manatees throughout the winter months with the implementation of an interim warm water heating system in the plant’s intake canal (Reynolds 2011). Manatees using the OUC Plant quickly moved over to the FPL Plant when OUC shut down unexpectedly in January of 2010 due to a boiler failure. This left the FPL Plant as the only primary warm-water site for more than 200 km in each direction for the remainder of the winter.

Since the completion of FPL-CC’ s repowering, manatees have returned to using the power plant’s discharge (J. Reynolds, Mote Marine Lab, Pers. Com). The interim heating systems remains as a back-up system in the event of a failure at the plant. The FPL-CC plant is of particular importance given the lack of any natural primary warm water refugia on the east coast. While manatees have been documented using these industrial sites since the 1970's (Shane 1978), high concentrations of manatees aggregating in this region have the potential to place unsustainable pressure on limited nearby food resources (i.e. seagrass beds).

A 2012 manatee carrying capacity report to the USFWS by Innovative Health Assessments, LLC (IHA) indicated that while key warm-water sites within the county have the capacity to support more manatees than are currently using the system (i.e. not yet at carrying capacity with regards to space), forage within reasonable distance to the sites studied is a limiting factor. Recent loss of seagrass beds within close proximity of the power plant following algal super bloom in the spring of 2011, coupled with high competition for limited resources, may require the use of alternative warm-water sites if manatees are to effectively expand their foraging range while balancing metabolic needs while minimizing thermal stress. Warm-water sites known as passive thermal basins (PTBs) may serve this purpose. How and when PTBs (also referred to as secondary sites), are used and what affect they have on manatee survival, have long been questions of high importance.

During the winter months, time spent traveling to and from available feeding sites as well as time spent grazing, add up to time spent in waters of sub-optimal temperature (i.e. <20°C). Exposure to these temperatures requires an increase in energy expenditure in response to loss of body heat to the environment. The ability to forage efficiently while maintaining thermal homeostasis is a function of the manatee's size, specifically its surface-area-to-volume ratio (SA:V), body condition, knowledge of local warm water sites and awareness of the surrounding habitat and resources. The ability to obtain sufficient food is a function of the distance to appropriate forage, the quality and abundance of available and accessible seagrass beds in the region, and individual thermal tolerance. Knowledge and use of alternative warm-water sites within the vicinity of distant forage may allow manatees to maximize grazing time while minimizing exposure time by providing short term warm-water sites or alternative thermal refuge.

In addition to the industrial sites, there are at least three known secondary warm-water aggregation sites in Brevard County. Two of these sites, the 54 in the north prong of the St. Sebastian River, and the Berkeley Canal in Satellite Beach located off of the southern end of the Banana River, have been documented as supporting considerable numbers of manatees for some time (Heyman 1990, DEP, Unpublished data, FWC, Unpublished data). The third site, a storm water drainage ditch off of Desoto Parkway, also located in Satellite Beach, was discovered during the time frame of this research. Since its discovery in late 2009, the Desoto Canal has provided winter habitat to a large number of manatees (>100) during even the most severe of winters. These three sites have been designated as secondary warm-water sites. Specifically, the C54 and Berkeley Canal are characterized as passive thermal basins (PTBs). The third site at Desoto Parkway is likely warmed not only by solar radiation, but also by the intrusion of warmer than ambient water from the subterranean artesian aquifer. This observation was supported by water temperatures recorded at the site that were comparable to temperatures at warm water springs. The site has maintained this temperature throughout the past four winter seasons regardless of severity.

Use of both primary and secondary warm-water sites within the county, and the need to satisfy nutritional requirements by seeking out forage outside of thermal refugia place manatees in a precarious position during the winter months. Failure to balance the need to stay warm and the need to forage can lead to acute hypothermia, chronic cold stress syndrome (CSS), starvation, and even death. As presented in Chapter1, analyses of documented cold stress-related mortality data indicates that late first year and second year calves (also referred to as juveniles) whose total length (TL) falls within the 175 to 235 cm range are at the greatest risk. This may be related to their high SA:V, coupled with the lack of knowledge, or potentially limited experience in finding food and warm water. Additionally, thermoregulatory studies conducted on captive manatees indicate that individuals under 300kg show little to no increase in metabolic rate when exposed to temperatures below 20°C for several hours (Worthy *et al*. 1999, Worthy and Worthy, *In prep*). A 300 kg manatee would closely match the weight of a robust second year calf with a TL of approximately 235cm based on prerelease health assessment records (FWC, Unpublished data)

The combination of the manatee's relatively large size, physiological requirements, elusive behavior and mobility, coupled with its aquatic lifestyle and endangered status make studying and understanding this balance a challenge that can be best addressed through the process of computer modeling. Modeling allows for the simplification of complex systems (Ford, 1999). The purpose of the model was not only to predict outcomes for different scenarios, but also to provide a way of manipulating variables within a complex system to increase our understanding of that system and to assist in guiding research. Ecological modeling provides researchers with a tool capable of simulating an infinite number of scenarios for both systems and subjects that may otherwise be too difficult or even impossible to address.

The objective of this chapter is to introduce, compare and discuss the outcome s generated by a computer model designed to simulate manatee energetics during the winter months. The desired outcome of the model is a better understanding of how manatees fare physically utilizing existing warm water sites, during winters of varying severity and with different levels of local knowledge, while balancing the need to maintain body temperature and forage.

Methods

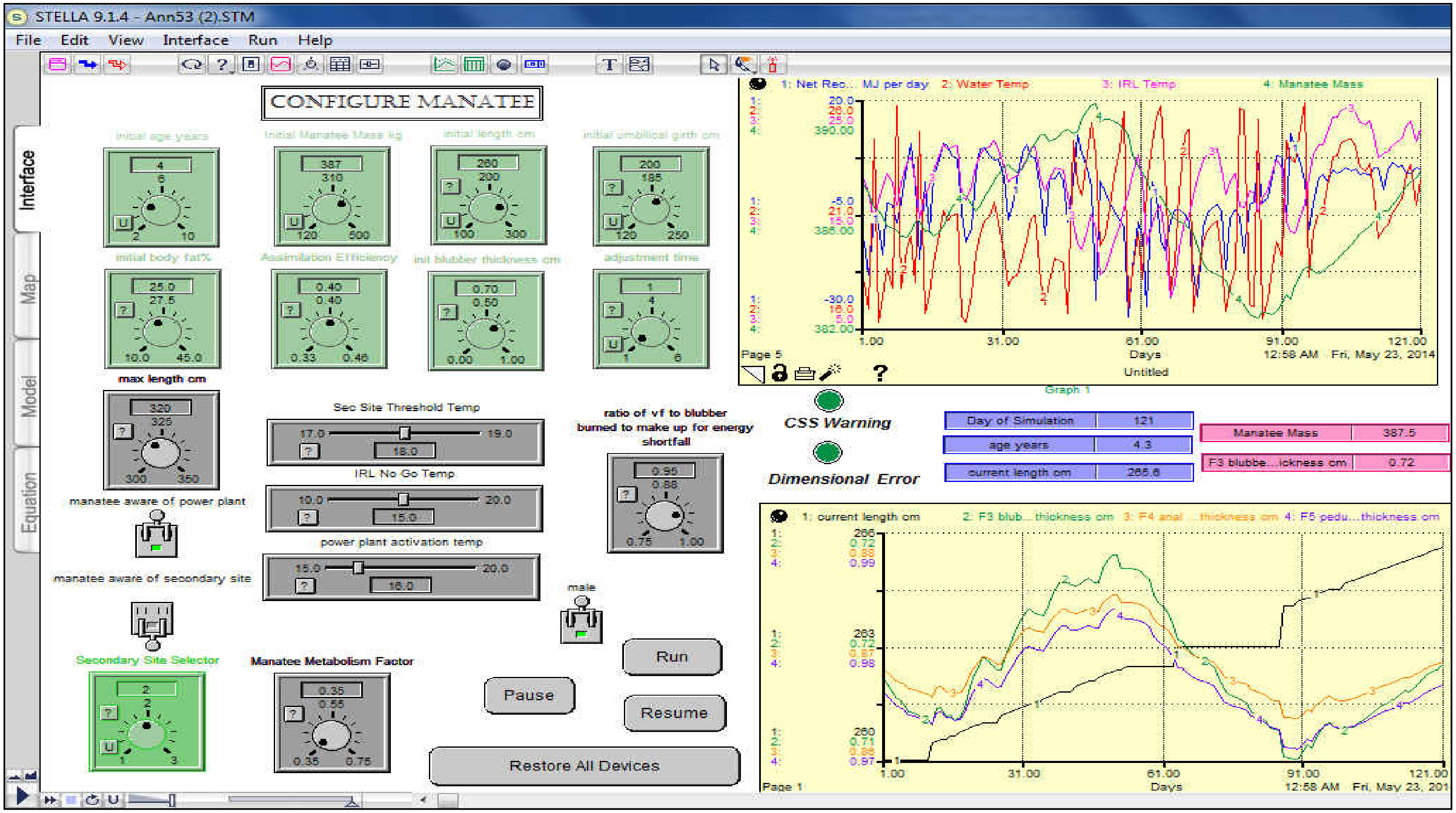
Development of a Manatee Energetics Model: Modifications and Additions to an Existing Model

To gain a better understanding of the complex physiological and thermal challenges manatees face while living at the northernmost limits of their winter range and how these challenges influences warm-water site selection, a manatee energetics model was developed in collaboration with an aerospace engineer/modeler using the computer modeling software STELLA version 9.1.4 (ISEE Systems). STELLA was chosen by the modeler because of its ease of use in modeling dynamic ecological systems. Through use of a combination of stocks, flows, converters and feedback loops, STELLA employs a system dynamics approach to simplifying and understanding multifaceted ecological relationships. Data incorporated into the design of the model were collected from a number of sources including available scientific literature, state manatee mortality and pre-release health assessment records, historical accounts of manatee life histories and the observations and input of numerous manatee experts. The model was designed to incorporate additional relationships, data, and feedback loops as these become available.

The version of the model developed for this study was built upon the existing framework of a basic manatee energetics model that looked at energy input via consumption versus energy expended via energetic processes, over a period of five years, using computer generated temperature data (S. Myers, Unpublished data). Criteria and data for the expansion of this model were provided to modify and expand the basic version to address the needs of this particular study. Modifications were made to the original model to accommodate the following additions ;

- the availability of secondary as well as primary warm water sites for manatee use
- adjustments to standard metabolic rate (SMR) to account for differences in growing individuals of varying ages and adult subjects
- expansion of the acceptable size class range to include not only healthy adult-sized manatees but also calves and subadults at least 2 years of age, and greater than or equal to 200cm total straight length,
- adjustments to initial body condition parameters to allow for the configuration of virtual subjects that closely reflect realistic manatees of varying initial body condition
- assignment of gender recognizing the differences in fat content values that exist between males and females (Ward-Geiger 1995)
- the ability to introduce individual manatees with varying degrees of local knowledge (i.e. knowledge of power plants or secondary sites)
- the effect of individual surface area-to-volume ratios (SA:V) as well as changes to SA:V on winter survival
- the ability to run simulations tailored to the shorter winter season of interest to this study and using actual field data from the Indian River Lagoon and Brevard County secondary sites

The model was designed to allow for the easy configuration and manipulation of an unlimited number of virtual manatee test subjects through use of a user friendly input interface screen (Figure 48).



initial age years 4 (2 – 10)

Initial Manatee Mass kg 387 (120 – 500)

initial length cm 260 (100 – 300)

initial umbilical girth cm 200 (120 – 250)

initial body fat% 25.0 (10.0 – 45.0)

Assimilation Efficiency 0.40 (0.33 – 0.46)

init blubber thickness cm 0.70 (0.00 – 1.00)

adjustment time 1 (1 – 6)

max length cm 320 (300 – 350)

Sec Site Threshold Temp 18.0 (17.0 – 19.0)

IRL No Go Temp 15.0 (10.0 – 20.0)

power plant activation temp 16.0 (15.0 – 20.0)

ratio of vf to blubber burned to make up for energy shortfall 0.95 (0.75 – 1.00)

manatee aware of power plant

manatee aware of secondary site

male

Secondary Site Selector 2 (1 – 3)

Manatee Metabolism Factor 0.35 (0.35 – 0.75)

Day of Simulation 121

age years 4.3

current length cm 265.6

Manatee Mass 387.5

F3 blubbe...ickness cm 0.72

\

Figure 48 Manatee energetics model interface with Simulation 1 input values and output data

To prevent the configuration of test subjects with unrealistic physical parameters, validation of each virtual manatee was regulated by a feature built into the model known as the dimensional error alarm. This visual warning system was created to alert the user that a manatee of given measurements would not fall within acceptable physical parameters of realistic manatees. Additionally, a cold stress (CS) warning feature was included on the interface to indicate whether or not the test subject would likely suffer from CS-related issues under the current simulation parameters. The extent of the exposure was defined by the display of one of three possible colors: green for no CS likely, yellow for mild to moderate CS, and red for severe CS likely to result in the death of the subject. The CS alarm was designed to provide a continuous visual output (i.e. blinking the appropriate color) during the simulation reflective of the manatee's body condition for each day.

The version of the model used in this study was designed to simulate the exposure of manatees of differing physical metrics (i.e. gender, mass, TL, etc.), and local warm water knowledge to a series of water temperature conditions reflective of the winter months in Brevard County. Manatee use of the surrounding environment was manipulated by a number of adjustable "if -then" temperature scenarios built into the design, that dictate the manatee's decision to feed or to seek refuge in a warm-water site. Other variables built into the model determined whether or not an individual possessed knowledge of the power plant and/ or existing secondary sites. Additionally, the model incorporated adjustable temperature threshold criteria setting guidelines for use of secondary sites, movement to and from the river, and the ambient river activation temperature used to triggered power plant operation (i.e. whether or not the power plant is running and providing warm water).

Configuration of Virtual Manatees

State manatee health assessment (HA) and release records from rehabilitated manatees use in Chapter 1 were use to provide realistic, body measurements for each virtual manatee used in the model (FWC, unpublished data). The metrics used included age (years), gender, mass (kg), TL (cm), and girth at umbilicus (cm).

Case Studies

Three manatees, each representing the different, recognized size classes of calf, subadult, and adult were chosen from pre-release HA records to create a total six virtual manatees, designated A through F. For each size class a male and female with identical metrics were created to allow for comparison of results taking into account to the possible effects of gender (Table 28).

Table 28 Individual virtual manatee configured for use in the manatee energetics model

Virtual Manatee	Age (Year)	Size class	Gender	TL (cm)	Mass (kg)	GAU (cm)
A	4	Subadult	Male	260	387	200
B	4	Subadult	Female	260	387	200
C	3	Calf	Male	232	292	177
D	3	Calf	Female	232	292	177
E	10	Adult	Male	297	448	206
F	10	Adult	Female	297	448	206

Additional data provided for each simulation included the manatee’s response or adjustment time to changes in water temperature (days), initial percent body fat (%), assimilation efficiency (AE), and initial average blubber thickness (cm) as defined in Table 29.

Table 29 Manatee energetics model virtual manatee input variable definitions and data sources

Manatee Input Variable	Definition	Source
Estimated or known age (years)	Recognized age/size class	C. Beck, USGS, Pers. Com.
Gender	Male or Female	****
Initial mass (kg)	Manatees weight	health assessment/rescue records
Initial total straight length (cm)	length from snout to trailing edge of fluke	health assessment/rescue records
Initial girth at umbilicus	Actual girth	health assessment/rescue records
Initial blubber thickness (cm)	Mean blubber thickness	(Ward- Geiger 1995)
Initial percent body fat	Visceral fat + blubber For manatee ≥2 years	(Worthy and Worthy *in prep*) (Ortiz and Worthy 2004)
Manatee metabolism factor	Factor needed to adjust SMR as predicted by Kleiber (1932) down to what is appropriate for manatees	(Worthy and Worthy *in Prep)*
Assimilation efficiency	Amount of ingested energy that is actually absorbed	(Worthy and Worthy 2014)
Adjustment Factor	No. days it takes manatee to react to temperature	****
Knowledge of power plant	Manatee familiar with a power plant	****
Knowledge of secondary site(s)	Manatee is familiar with a secondary site	****

Calculation of Winter Mean Daily Water Temperature Profiles

Mean daily winter water temperature profiles were compiled for the ambient river and for two of the three known secondary sites for the 2008-2009 and 2009-2010 winters as presented in Chapter 2. These profiles were imported into the model as Excel files along with corresponding caloric values for seagrasses reflective of seasonal variability (Dawes and Lawrence 1980). Specifically, mean daily water temperatures from an ambient Indian River site (IR_B), the Berkeley Canal (BC_B) and C54 (SR_Z) secondary sites were used in the model The power plant temperature regime was generated by the model and was directly influenced and determined by the supplied ambient river temperature values and the power plant activation temperature threshold of 16°C (61°F).

Environmental and decision-based variables used in the model are listed and defined in Table 30.

Table 30 Environmental and decision-based input variables used in the manatee energetic model

Model Input Variable	Definition
No Go IRL temperature	Temperature at which manatees will not leave a warm water site to feed or travel
Power plant activation temperature	Ambient river temperature value that triggers the power plant to produce warm water
Secondary threshold temperature	Temperature below which secondary site becomes too cold and manatees will leave for the power plant
Water temperatures for IRL and secondary site(s)	Mean daily water temperatures from December through March
Secondary site selection	Berkeley Canal or C54
Knowledge of power plant/ operational	Manatee aware of power plant or power plant available
Knowledge of secondary site/ available	Manatee aware of secondary site or secondary site available

Simulations

Thirty-two simulations involving 6 different virtual manatees were conducted as outlined in Table 31 using mean daily temperature data from the 2008-2009 winter season as calculated in Chapter 2. Identical simulations were run against the 2009-2010 winter temperature data to allow comparison of outcomes across winters of varying severity (Figure 49 and Figure 50). The 2008-2009 winter was considered to be representative of a moderate winter having been slightly colder than average, while 2009-2010 was recognized as one of the most severe on record for the region according to the National Weather Service (www.srh.noaa.gov).

For each winter, simulation runs 1 through 27 used virtual manatees of healthy weight and in good or better body condition as indicated in the health assessment records. These subjects were designated Virtual Manatees A through F and assigned physical metrics as defined in Table 28. For simulations 1 through 24, each individual was run through the same series of four different winter scenarios. With the exception of age, gender, total length (TL), girth at umbilicus (GAU) and mass, all model input variables were held constant except one- the manatee's knowledge or availability of warm-water sites in the form of a power plant and/or secondary site.

Scenario 1 provided warm water refuge in the form of the power plant but no knowledge of a secondary site

Scenario 2 provided warm water refuge in the form of both the power plant and knowledge of a specific secondary site- the Berkeley Canal.

Scenario 3 provided warm water refuge in the form of both the power plant and knowledge of a specific secondary site- the C54.

Scenario 4 provided no warm water refuge from either the power plant or secondary sites

Simulations 25 through 27 subjected the three male manatees of different size classes, corresponding to virtual manatees A, C, and E, to identical conditions as defined in scenario 2, to explore the effects of age and size on winter survival, including the effects of SA:V.

Simulations 28 through 32 used virtual manatee A, a subadult male with modifications made to its initial body condition. These modifications included gradually decreasing mass, percent body fat, and blubber thickness values over the course of five simulations, the purpose of which was to introduce individuals of less than optimal body condition into the model at the start of a given winter to evaluate the effects of reduced mass and fat stores on winter survival.

In simulations 1 through 27 the following variables were kept constant:

- Initial % body fat = 25%
- Initial assimilation efficiency (AE) = 0.40
- Initial mean blubber thickness = 0.70
- Adjustment time = 1 day
- No Go IRL temperature = 15°C
- Power plant activation temperature = 16°C
- Maximum length = 320 cm
- Secondary site use threshold temperature = 18°C
- Manatee metabolism factor = 0.35
- Ratio of visceral fat to blubber burned to make up for energy shortfall = 0.9

Table 31 Manatee energetics model simulations scenarios and input parameters

Sim. Run	Age (years)	Sex	Age Class	Mass (kg)	TL (cm)	GAU (cm)	% Fat	AE	Blubber (cm)	2°Temp (°C)	No Go IRL Temp (°C)	Adj. Time (day)	1° Site ?	2° Site ?	PP On Temp (°C)
1	4	M	SA	387	260	200	25	0.4	0.70	NA	15	1	Yes	No	16
2	4	M	SA	387	260	200	25	0.4	0.70	18	15	1	Yes	2	16
3	4	M	SA	387	260	200	25	0.4	0.70	18	15	1	Yes	3	16
4	4	M	SA	387	260	200	25	0.4	0.70	NA	NA	1	No	No	16
5	4	F	SA	387	260	200	25	0.4	0.70	NA	15	1	Yes	No	16
6	4	F	SA	387	260	200	25	0.4	0.70	18	15	1	Yes	2	16
7	4	F	SA	387	260	200	25	0.4	0.70	18	15	1	Yes	3	16
8	4	F	SA	387	260	200	25	0.4	0.70	NA	NA	1	No	No	16
9	3	M	CC	292	232	177	25	0.4	0.70	NA	15	1	Yes	No	16
10	3	M	CC	292	232	177	25	0.4	0.70	18	15	1	Yes	2	16
11	3	M	CC	292	232	177	25	0.4	0.70	18	15	1	Yes	3	16
12	3	M	CC	292	232	177	25	0.4	0.70	NA	NA	1	No	No	16
13	3	F	CC	292	232	177	25	0.4	0.70	NA	15	1	Yes	No	16
14	3	F	CC	292	232	177	25	0.4	0.70	18	15	1	Yes	2	16
15	3	F	CC	292	232	177	25	0.4	0.70	18	15	1	Yes	3	16
16	3	F	CC	292	232	177	25	0.4	0.70	NA	NA	1	No	No	16
17	10	M	AA	488	297	206	25	0.4	0.70	NA	15	1	Yes	No	16
18	10	M	AA	488	297	206	25	0.4	0.70	18	15	1	Yes	2	16
19	10	M	AA	488	297	206	25	0.4	0.70	18	15	1	Yes	3	16
20	10	M	AA	488	297	206	25	0.4	0.70	NA	NA	1	No	No	16
21	10	F	AA	488	297	206	25	0.4	0.70	NA	15	1	Yes	No	16
22	10	F	AA	488	297	206	25	0.4	0.70	18	15	1	Yes	2	16
23	10	F	AA	488	297	206	25	0.4	0.70	18	15	1	Yes	3	16
24	10	F	AA	488	297	206	25	0.4	0.70	NA	NA	1	No	No	16
25	4	M	SA	387	260	200	25	0.4	0.70	NA	15	1	Yes	2	16
26	3	M	CC	292	232	177	25	0.4	0.70	18	15	1	Yes	2	16
27	10	M	AA	448	297	206	25	0.4	0.70	18	15	1	Yes	2	16
28	4	M	SA	387	260	200	25	0.4	0.70	NA	NA	1	Yes	2	16
29	4	M	SA	365	260	192	20	0.4	0.65	NA	15	1	Yes	2	16
30	4	M	SA	350	260	184	15	0.4	0.60	18	15	1	Yes	2	16
31	4	M	SA	320	260	175	15	0.4	0.50	18	15	1	Yes	2	16
32	4	M	SA	300	260	170	10	0.4	0.35	NA	15	1	Yes	2	16

Each simulation generated final or end-of-winter values for mass (kg), age (years), TL (cm), and blubber thickness (cm). By subtracting final values from initial values, changes in mass (Δ mass) and blubber thickness (Δ blubber) were calculated. The percent change for each measurement was then calculated (%Δ. mass, %Δ blubber) by dividing the Δ value by the initial value and multiplying the results by 100.

For each simulation conducted, the model generated 22 different time series graphs tracking changes in the different metrics throughout the 121 day winter. The name and contents of each graph are listed in Table 32. Graphs that can only illustrate output relative to a single simulation are defined as individual graphs. Graphs capable of side by side comparisons of individual output values from different simulations but on the same graph were defined as comparative graphs. Graphs helpful in illustrating differences or similarities for a given simulation or series of simulations were copied from the model interface and included in results to facilitate comparisons between different individuals.

SA:V ratios were calculated for each manatee by the model using the initial TL and GAU measurements. The model calculated SA:V by viewing each manatee as an ellipsoid and using Equations 5 and 6 as presented in Chapter 1. This approach took into account the reduction in surface area across which heat is lost to the environment when an aquatic mammal responds to negative thermal stress (i.e. cold) by employing the physical adaptation of peripheral vasoconstriction (PVC). Start and end values extracted from the SA:V graphs were tabulated and used to calculate change in SA:V as well as the percent change in SA:V.

Table 32 Manatee energetics model graphical output options and contents

Graph	Variables tracked	Type
Energy Budget	Water Temperature experienced by the manatee, Energy Recovered per day (MJ), Heat Energy per day (MJ), Ingested Energy per gay (MJ)	Individual
Manatee Location	When in IRL, FPL, or Secondary site	Individual
Energy Expenditure	Heat Energy per day (MJ)Feeding SMR Energy, Rest Energy, Socialize Energy	Individual
Growth and Age Progression	Water Temperature experience by the manatee, Manatee Mass, Ideal Mass, Age (years)	Individual
Energy Investment	Net Recovered Energy per day (MJ),Water temperature experienced by the manatee, IRL Temperature, Manatee Mass	Individual
Mass	Mass	Comparative
Body Fat	Percent Body fat	Comparative
Blubber thickness	Blubber thickness at umbilicus, anus, peduncle	Comparative
Visceral Fat	Visceral fat mass	Comparative
Surface area to volume ratio	Surface Area to volume ratio	Individual
IRL Usage	Manatee In IRL, IRL Temperature	Individual
Secondary Site Usage	Manatee in secondary Site	Individual
Power Plant Usage	Manatee using power plant effluent	Individual
IRL and Warm water Profiles	Water Temperatures at WW sites and in IRL	Individual
Activities budget	Time spent feeding, resting, socializing, traveling	Individual
Percent body fat and girth	Changes in body fat and different girths values	Individual
Growth Factor	K, K mod, Feeding Factor	Individual
Feeding time	Total hours in a day the manatee spent on feeding	Individual
Ingested Energy	Energy ingested per day (MJ)	Comparative

Results

A total of 64 simulations were run through the manatee energetics model. Thirty-two simulations used temperature data collected during the 2008-2009 winter from sites within Brevard County including both ambient IRL temperature and known secondary sites at the Berkeley Canal and C54 (Figure 49). Mean daily ambient air temperature data collected from Satellite Beach were also included in each of the graphs to illustrate the timing and severity of cold fronts in each winter. An additional 32 identical simulations were run using temperature data collected from the same locations during the 2009-2010 winter season (Figure 50).

In each of the winter temperature profile graphs, the power plant discharge plot depicted the *actual* discharge temperatures collected during the 2008-2009 and 2009-2010 winters. The power plant discharge temperatures used in the simulations however, were actually created by the model, and were determined by both the actual ambient river temperature data provided, and the choice of a power plant activation temperature that dictated when the plant was running. Actual discharge temperatures were provided in these graphs for comparison with the simulated power plant temperature profiles. The resulting simulated power plant temperature profiles were influenced by an ambient river temperature trigger of 16°C (61°F) for both winters, reflective of the actual trigger temperature used during that time.

Model output data for the 2008-2009 winter simulations are listed in Table 33 and output data for the 2009-2010 winter simulations are listed in Table 34.

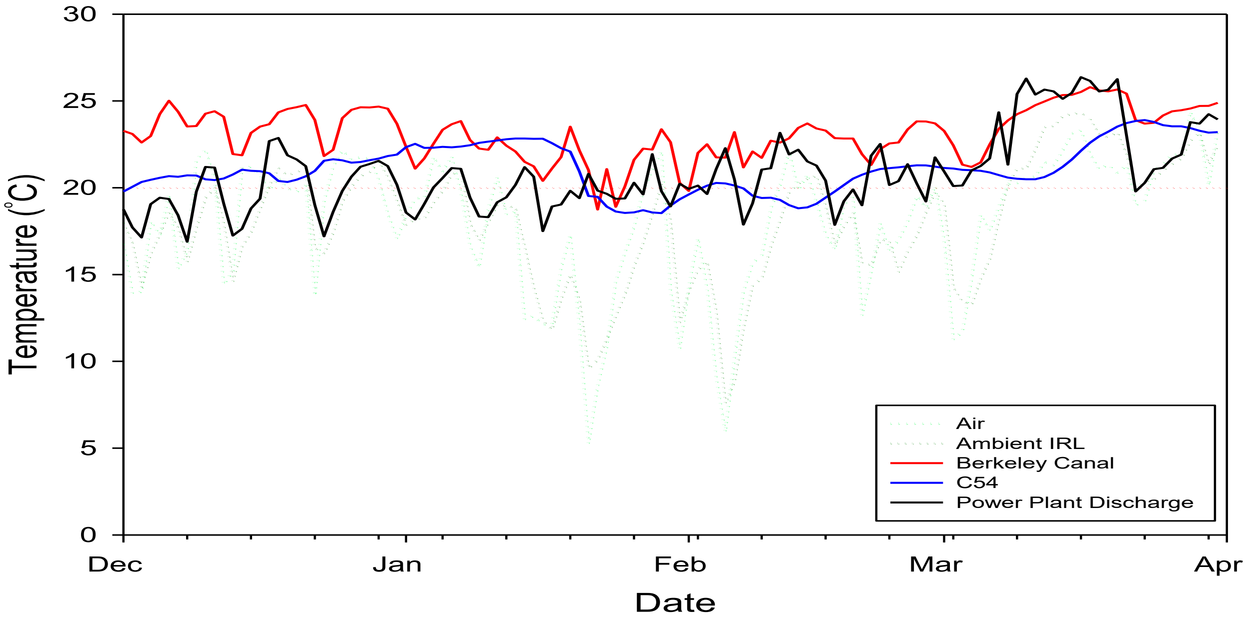


Figure 49 2008-2009 Winter mean daily temperatures at select locations used in model simulations

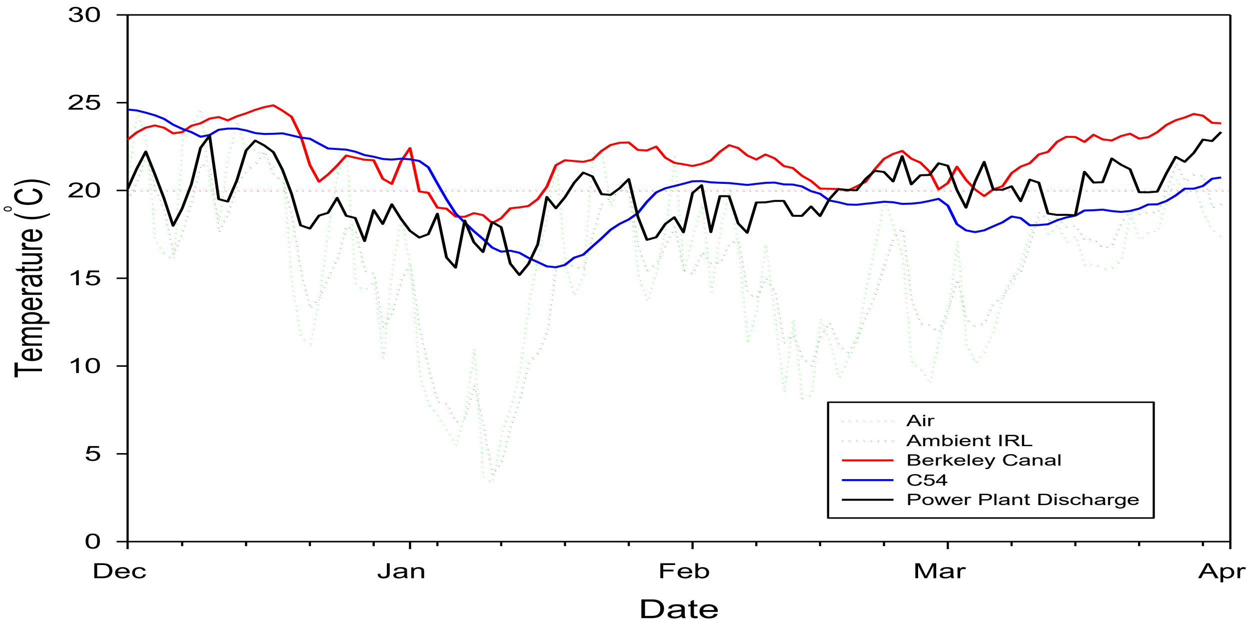


Figure 50 2009-2010 Winter mean daily temperatures at select locations used in model simulations

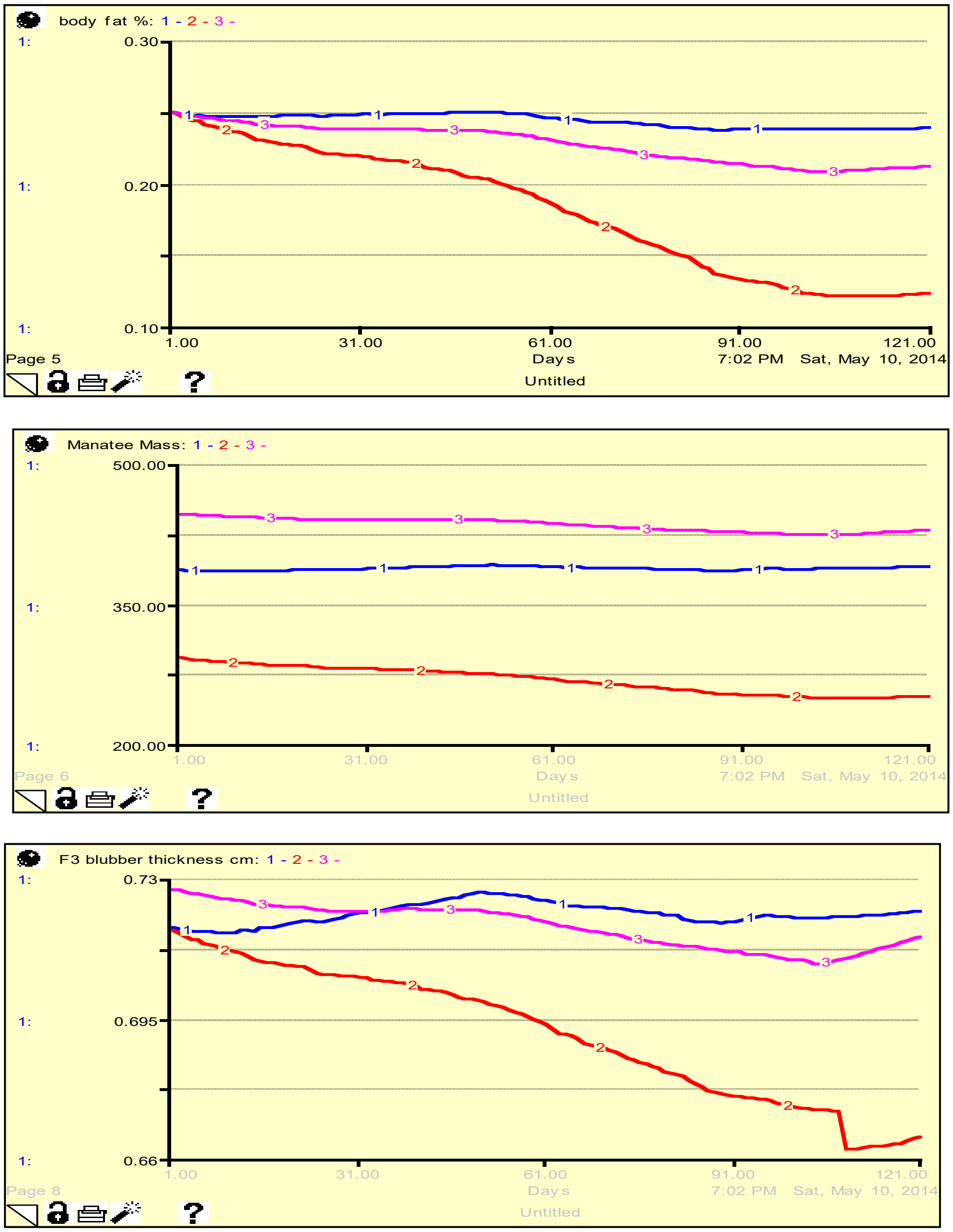
The temperature graphs for the 2008-2009 and 2009-2010 winters in Brevard County showed differences in the timing of major cold events as well as in the number of cold fronts, duration and severity. Cold front events in the 2009-2010 winter were more severe and of longer duration than those in 2008-2009. In 2008-2009 the first cold front of significance arrived in late January, followed by a second cold front event of similar duration and severity in early February. Mean daily ambient river temperatures however, never fell below 7.6°C during either front. The first cold front of any significance in 2010 was documented in early January. Compared to the cold fronts the previous winter, the front in 2010 was prolonged and severe forcing the mean daily ambient river temperature to fall below 4°C (3.8°C) on January 10th.

Output data for the 2008-2009 simulations 1 through 24 indicate that healthy individuals of subadult size fared best (simulations 1 through 8). Subadults showed increases in both TL and blubber depth values with female gaining slightly more than males (0.1 to 2.9% for males, 4.9 to 5.7 % for females). Subadults also exhibited the smallest increases in SA:V (0.69 to 1.98%) of all three size classes in all four scenarios. Subadults who had knowledge of secondary sites showed small increases in mass (0.10 to 0.7%), while those without secondary site knowledge showed slightly higher decreases in mass (0.28 to 1.73%).

Output data from simulations 9 through 16 indicate that calves fared the worst exhibiting the highest percent decrease in mass (13.7 to 16.7%), the highest percent decrease in blubber depth (4.3 to 5.7%), and the highest increase in SA:V (10.56 to 12.99%) in all 8 simulations and in all four scenarios. Percent change in blubber was similar for both males and females. Calves did show a small increase in TL. Each run involving calves resulted in a yellow CSS warning alert, indicating mild to moderate CS symptoms were likely.

End results for simulations 17 through 24 indicate that adults fared better than calves but not as well as subadults under the same conditions. The adults showed increases in TL, decreases in mass (12.5 to 13.9%) and a narrow range of changes in blubber depth, both positive and negative (-1.4 to 1.4%), depending on the scenario. Males with no knowledge of secondary sites showed a decrease in blubber depth while those aware of secondary sites maintained their initial blubber depth. Females showed an increased in blubber depth (1.4%) in all scenarios except Scenario 4. Adults with knowledge of a secondary site showed smaller losses in mass than those without. Increases in adult SA:V (2.36 to 3.30%) were higher than in subadults but lower than in calves.

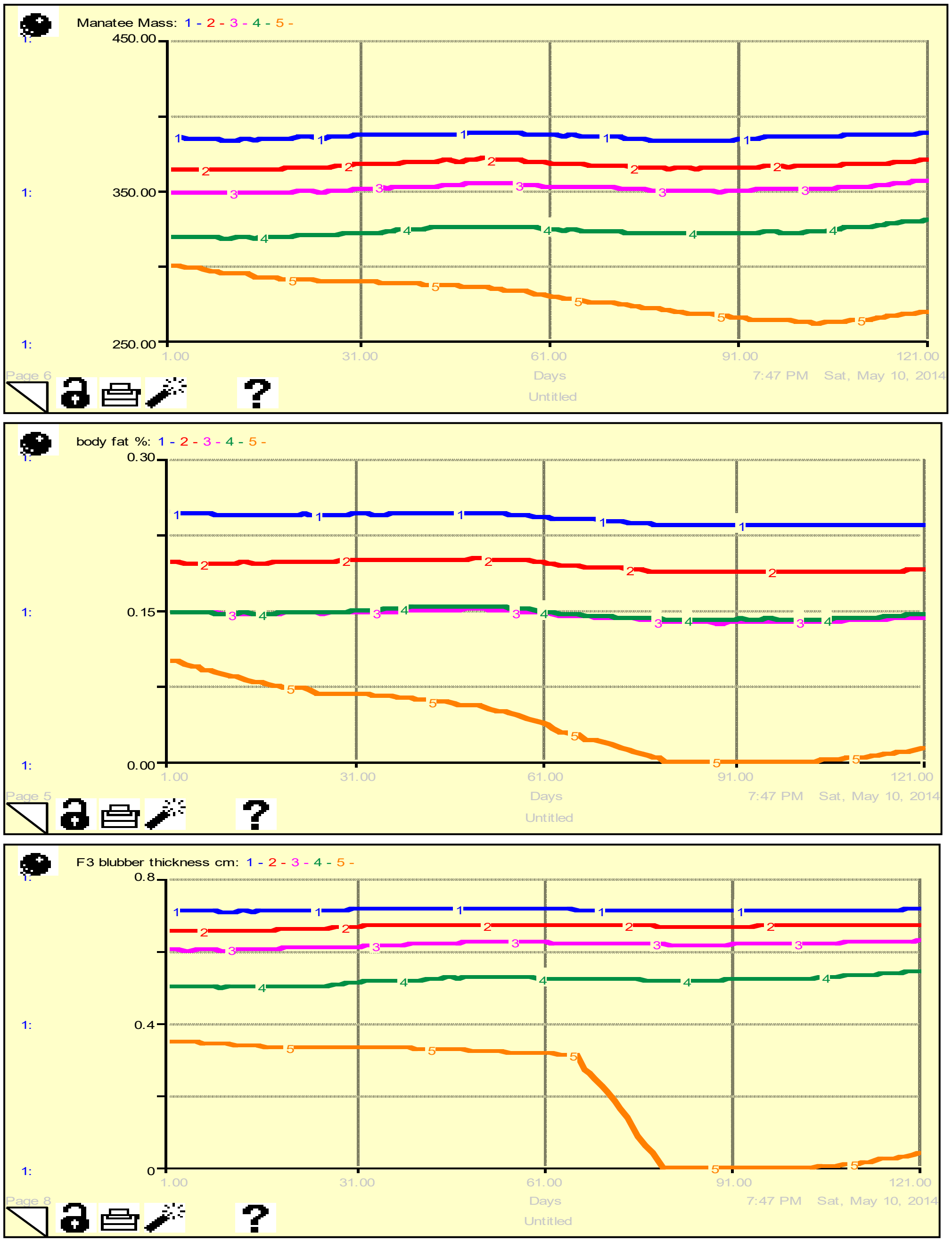
Time-series graphs depicting simulations 25 through 27, compare the effects of a winter of moderate severity on mass, percent body fat, and blubber thickness for manatees of different size classes (Figure 51). Despite higher initial values, adults showed a decrease in mass (3.97%) while subadults experienced a small increase (1.01%). Calves showed the greatest decrease in mass (14.1%).



(Plots 1 through 3 correspond to subadult, calf, and adult subjects in simulations 25 through 37, respectively)

Figure 51 Model-generated comparative time-series graphs illustrating changes in mass (top), percent body fat (middle), and blubber thickness at the umbilicus (bottom) for three males representing the three size classes during the 2009-2010 winter season

Simulations 28 through 32 indicated that small changes in mass, % body fat and blubber thickness generally resulted in unfavorable increases in SA:V (-0.56 to 5.7%). The subadult used in the in the simulation started showing the potential for cold stress when small changes were made in the initial mass, percent body fat and blubber depths representative of an individual in decline. Despite the knowledge of both the power plant and a secondary site, continuous decreases in initial starting values resulted in a yellow CSS warning light for simulations 28 through 31, and a red CSS warning light for simulation 32. Comparative time-series graphs illustrating changes in percent body fat, mass, and blubber depth indicated that simulation 32 likely ended with the death of the individual due to the excessive loss of body fat and blubber (Figure 52).



(Plots 1 through 5 correspond to simulations 28 through 32, respectively)

Figure 52 Model-generated comparative time series graphs illustrating changes in mass (top), percent body fat (middle), and blubber thickness at the umbilicus (bottom) for a 260 cm, subadult male manatee of varying initial body condition during the 2008-2009 winter season

Simulations using 2009-2010 temperature profiles also suggest that subadults fared better than either adult or calf-size subjects, despite the severe nature of the winter season. Decreases in mass occurred in all four scenarios and were higher than those in the 2008-2009 simulations (3.0 to 7.8%). Individuals with knowledge of a secondary site however, experienced smaller decreases in mass than those without. Percent increases in SA:V were higher than in the 2008-2009 simulations (2.67 to 5.44%). With the exception of Scenario 4 blubber depth values remained the same or showed small increases (0 to 2.9%), with females showing slightly higher values than males (1.4 to 2.9% and 0 to 1.4%, respectively).

Calves in all four scenarios showed significant decreases in mass (20.8 to 28.9%). Likewise decreases in blubber depth exceeded those in the 2008-2009 simulations. Calves unaware of the both the power plant and a secondary site showed a 100% reduction in blubber while those aware of the power plant experienced a decrease in blubber depth within the 17 to18% range. Knowledge of the secondary site at the Berkeley Canal in conjunction with knowledge of the power plant reduced the loss of blubber depth to 7.1%. Use of the C-54 site in conjunction with the power plant however, resulted in a greater loss of blubber (27.1 to 37.1%) than use of the power plant alone, with females losing more blubber than males. Increases in SA:V ratio values likewise exceeded 2008-2009 values ranging from 14.9% for calves using the power plant to 20.9% for those unaware of any water sites. All simulations involving calves resulted in the activation of the CSS warning light (CSW). Calves using any combination of warm water sites triggered a yellow alert. Those not aware of or failing to use warm water sites triggered a red CSS warning, indicating that under those circumstances the individuals would likely not survive.

Adults fared better than calves but not as well as subadults during the severe 2009-2010 winter simulations. Adults lost between 15.1 and 19.4% of their mass, with males losing more than females and individuals using the Berkeley Canal losing the least. Increases in SA:V ranged from 2.91 to 7.09%. With the exception of the manatees in Scenario 2 (knowledge and use of the power plant and the Berkeley site), all simulations resulted in the activation of a yellow CSS warning light.

Side by side comparisons of simulations 25 through 27 again resulted in the activation of the yellow CSS warning light for the calf, as well as the for adult manatee. No cold stress warning was activated for the subadult.

Simulation 28 through 32 involving the introduction of a subadult in varying body condition produced results comparable to those from the 2008-2009 simulations. Loss of mass, decrease in blubber depth and increase in SA:V all exceeded 2008-2009 values. Yellow CCS warnings were activated for simulations 29 through 31. Simulation 32 resulted in a red CSS warning.

Table 33 Model simulation results for 2008-2009 Winter

Case	End Mass (kg)	Δ Mass (kg)	% Δ Mass	End Blubber Depth (cm)	Δ Blubber (cm)	% Δ Blubber	TL (cm)	CSW?	Start SA:V	End SA:V	Δ SA:V	% Δ SA:V
1	385.9	-1.10	-0.28	0.72	0.02	2.9	265.6	No	0.082	0.083	0.001	1.27
2	389.7	2.70	0.70	0.72	0.02	2.9	265.6	No	0.082	0.082	0.001	0.69
3	387.4	0.40	0.10	0.72	0.02	2.9	265.6	No	0.082	0.082	0.001	0.70
4	382.3	-4.70	-1.21	0.71	0.01	1.4	265.6	No	0.082	0.083	0.001	1.76
5	385.1	-1.90	-0.49	0.73	0.03	4.3	265.6	No	0.082	0.083	0.001	1.33
6	389.4	2.40	0.62	0.74	0.04	5.7	265.6	No	0.082	0.082	0.001	0.75
7	385.8	-1.20	-0.31	0.74	0.04	5.7	265.6	No	0.082	0.083	0.001	1.23
8	380.3	-6.70	-1.73	0.73	0.03	4.3	265.6	No	0.082	0.083	0.002	1.98
9	248.2	-43.80	-15.00	0.66	-0.04	-5.7	239.5	Yellow	0.093	0.103	0.011	11.60
10	251.8	-40.20	-13.77	0.67	-0.03	-4.3	239.5	Yellow	0.093	0.102	0.010	10.56
11	250.2	-41.80	-14.32	0.66	-0.04	-5.7	239.5	Yellow	0.093	0.103	0.010	10.99
12	243.2	-48.80	-16.71	0.66	-0.04	-5.7	239.5	Yellow	0.093	0.105	0.012	12.97
13	248.7	-43.30	-14.83	0.67	-0.03	-4.3	239.5	Yellow	0.093	0.103	0.011	11.42
14	250.4	-41.60	-14.25	0.67	-0.03	-4.3	239.5	Yellow	0.093	0.103	0.010	10.93
15	250.8	-41.20	-14.11	0.67	-0.03	-4.3	239.5	Yellow	0.093	0.103	0.010	10.90
16	243.0	-49.00	-16.78	0.67	-0.03	-4.3	239.5	Yellow	0.093	0.105	0.012	12.99
17	427.0	-61.00	-12.50	0.69	-0.01	-1.4	298.7	No	0.079	0.081	0.002	2.58
18	429.7	-58.30	-11.95	0.70	0.00	0.0	298.6	No	0.079	0.081	0.002	2.56
19	431.1	-56.90	-11.66	0.70	0.00	0.0	298.6	No	0.079	0.081	0.002	2.36
20	422.2	-65.80	-13.48	0.69	-0.01	-1.4	298.7	No	0.079	0.081	0.003	3.25
21	426.1	-61.90	-12.68	0.71	0.01	1.4	298.6	No	0.079	0.081	0.002	2.83
22	429.4	-58.60	-12.01	0.71	0.01	1.4	298.6	No	0.079	0.081	0.002	2.60
23	427.2	-60.77	-12.45	0.71	0.01	1.4	298.6	No	0.079	0.081	0.002	2.36
24	420.0	-68.00	-13.93	0.69	-0.01	-1.4	298.6	No	0.079	0.081	0.003	3.30
25	390.9	3.90	1.01	0.72	0.02	2.9	265.6	No	0.082	0.082	0.001	0.67
26	251.1	-40.90	-14.01	0.67	-0.03	-4.3	239.5	Yellow	0.093	0.102	0.009	10.11
27	430.2	-17.80	-3.97	0.72	0.02	2.9	298.6	No	0.079	0.081	0.002	2.29
28	388.5	1.50	0.39	0.72	0.02	2.9	265.6	No	0.083	0.082	0.000	-0.33
29	376.2	11.20	3.07	0.68	0.03	4.6	265.6	Yellow	0.085	0.085	0.000	0.31
30	356.9	6.90	1.97	0.63	0.03	5.0	265.6	Yellow	0.089	0.089	0.000	0.14
31	330.9	10.90	3.41	0.55	0.05	10.0	265.6	Yellow	0.094	0.093	-0.001	-0.56
32	269.4	-30.60	-10.20	0.04	-0.31	-88.6	265.6	Red	0.097	0.102	0.006	5.71

Table 34 Model simulation results for 2009-2010 Winter

Case	End Mass (kg)	Δ Mass	% Δ Mass	End Blubber Depth (cm)	Δ Blubber	% Δ Blubber	TL (cm)	CSW?	START SA:V	ENDING SA:V	Δ SA:V	% Δ SA:V
1	372.0	-15.0	-3.88	0.70	0.00	0.0	265.6	No	0.082	0.084	0.002	3.05
2	375.4	-11.6	-3.00	0.71	0.01	1.4	265.6	No	0.082	0.084	0.002	2.66
3	371.4	-15.6	-4.03	0.70	0.00	0.0	265.6	No	0.082	0.084	0.003	3.25
4	357.7	-29.3	-7.57	0.69	-0.01	-1.4	265.6	No	0.082	0.086	0.004	5.03
5	374.0	-13.0	-3.36	0.72	0.02	2.9	265.6	No	0.082	0.084	0.002	2.86
6	375.3	-11.7	-3.02	0.72	0.02	2.9	265.6	No	0.082	0.084	0.002	2.67
7	370.4	-16.6	-4.29	0.71	0.01	1.4	265.6	No	0.082	0.084	0.003	3.37
8	356.7	-30.3	-7.83	0.69	-0.01	-1.4	265.6	No	0.082	0.086	0.004	5.44
9	229.5	-62.5	-21.40	0.58	-0.12	-17.1	232.0	Yellow	0.093	0.107	0.014	15.10
10	230.8	-61.2	-20.96	0.65	-0.05	-7.1	232.0	Yellow	0.093	0.106	0.014	14.64
11	228.2	-63.8	-21.85	0.51	-0.19	-27.1	232.0	Yellow	0.093	0.107	0.014	15.51
12	208.1	-83.9	-28.73	0.00	-0.70	-100.0	232.0	Red	0.093	0.112	0.019	20.93
13	229.3	-62.7	-21.47	0.57	-0.13	-18.6	232.0	Yellow	0.093	0.107	0.014	15.14
14	230.8	-61.2	-20.96	0.65	-0.05	-7.1	232.0	Yellow	0.093	0.106	0.014	14.65
15	227.7	-64.3	-22.02	0.48	-0.22	-31.4	232.0	Yellow	0.093	0.107	0.015	15.68
16	209.1	-82.9	-28.39	0.00	-0.70	-100.0	232.5	Red	0.093	0.112	0.019	20.88
17	407.6	-80.4	-16.48	0.67	-0.03	-4.3	298.6	Yellow	0.079	0.083	0.004	5.14
18	414.2	-73.8	-15.12	0.68	-0.02	-2.9	298.6	No	0.079	0.082	0.003	4.30
19	408.9	-79.1	-16.21	0.67	-0.03	-4.3	298.6	Yellow	0.079	0.083	0.004	4.98
20	393.0	-95.0	-19.47	0.66	-0.04	-5.7	298.6	Yellow	0.079	0.084	0.006	7.09
21	410.2	-77.8	-15.94	0.67	-0.03	-4.3	298.6	Yellow	0.079	0.082	0.004	4.80
22	411.3	-76.7	-15.72	0.68	-0.02	-2.9	298.6	No	0.079	0.082	0.004	4.67
23	408.5	-79.5	-16.29	0.67	-0.03	-4.3	298.6	Yellow	0.079	0.083	0.004	5.04
24	394.3	-93.7	-19.20	0.66	-0.04	-5.7	298.6	Yellow	0.079	0.084	0.005	6.91
25	373.6	-13.4	-3.46	0.70	0.00	0.0	265.6	No	0.082	0.084	0.002	2.91
26	233.6	-58.4	-20.00	0.65	-0.05	-7.1	232.0	Yellow	0.093	0.105	0.013	13.83
27	410.7	-37.3	-8.33	0.68	-0.02	-2.9	298.6	Yellow	0.079	0.082	0.004	4.72
28	374.3	-12.7	-3.28	0.70	0.00	0.0	265.6	Yellow	0.082	0.084	0.002	2.84
29	355.1	-9.9	-2.71	0.66	0.01	1.5	265.6	Yellow	0.085	0.087	0.002	2.59
30	340.9	-9.1	-2.60	0.61	0.01	1.7	265.6	Yellow	0.089	0.091	0.002	2.65
31	313.3	-6.7	-2.09	0.51	0.01	2.0	265.6	Yellow	0.094	0.096	0.002	2.42
32	244.7	-55.3	-18.43	0.00	-0.35	-100.0	265.6	Red	0.097	0.104	0.007	7.65

Discussion

Living at the northern limits of its geographic range, the Florida manatee faces the repeated challenge of maintaining its body temperature in the face of thermal stress. At no time during the year is this more apparent than during the winter months. Ill-equipped to handle water temperatures below 20°C for more than a few days at a time, manatees possesses limited physiological and behavioral adaptations in response to cold temperatures.

Available behavioral responses include migration to lower latitudes, retreat to warm-water sites, adjustments to daily habitat use patterns to minimize time spent in to sub-optimal temperatures, reduction of body surface area by positioning pectoral flippers close to the body, and reduction in activity levels to conserve energy. Physiological responses include redirection of blood from the periphery to vital organs through the process of peripheral vasoconstriction, and use of a countercurrent heat exchange system to minimize heat loss to the environment. Despite these adaptations, manatees are at a disadvantage when confronted with sub-optimal temperatures. This is due to the combined effects of the manatees' relatively low metabolism, the limited ability to elevate metabolic rate to compensate for heat lost to the environment, limited capacity for thermogenesis, and a diet of low calorie vegetation.

Smaller manatees are believed to be at greater risk of thermal stress due to their high SA:V, inexperience in finding forage, and potentially limited knowledge of warm-water locations. Given that SA:V decreases in manatees with an increase in size, it would be reasonable to assume that the larger the manatee, the lower the SA:V. This in turn results in less heat lost to the environment, giving larger manatees a thermal advantage when water temperatures drop.

Analyses of statewide manatee mortality records presented in Chapter 1 indicated that smaller manatees, specifically older calves account for the majority of documented CS-related deaths. The same analyses however, also indicated that documented adult mortalities attributed to cold stress outnumbered those in the subadult category despite subadults having a higher SA:V. Likewise the smaller, dependent calves accounted for the least number of documented CS-related mortalities, despite having the highest SA:V.

Results generated from the manatee energetics model presented in this chapter agree with the findings of the CS mortality analyses from Chapter 1. This would suggest that a combination of factors more complex than SA:V alone contributes to the manatees' susceptibility to CSS.

After configuring virtual manatees representative of the three recognized size classes and introducing them into the model, thermal regimes and warm water availability were manipulated through repeated simulations. Data were tabulated and compared. Results indicate that calves, specifically those around the 200 cm range showed the most measurable change in physical parameters in response to cold exposure. In each simulation involving virtual manatees of calf size a CSS warning alarm was activated. Two of the warnings issued were red in color indicating that the calf would in all likelihood have died from CSS before the end of that winter under those particular conditions. Both warnings occurred under conditions specified in Scenario 4 during simulations using the 2009-2010 winter temperature data. In both instances the calves lost virtually all of their blubber and visceral fat before the winter ended.

The decreases seen in initial mass, blubber depth and girth values in each simulation involving calves reinforces the belief that there is a high cost associated with maintaining thermal balance in light of a SA:V, and the higher metabolic rate and energy needs of a growing calf. At a TL of 200 cm, calves may be either recently weaned and on their own for the first winter, or still be in the company of their mothers and at least partially dependent upon them for nutrition. Calves face unique thermal challenges in each of these situations.

Once independent, calves no longer benefit from parental experience or from dietary supplementation of nutrient-dense, calorie-rich milk. During the winter months, recently weaned calves must locate both forage and warm water in a timely manner to meet dietary requirements while limiting exposure to potentially lethal temperatures.

The length of time a calf can forage outside a warm water site is dependent upon a number of factors in addition to the limits imposed by a high SA:V. One of these factors is the temperature gradient or the difference in temperature that exists between the manatee and the ambient river. During warmer winters, a smaller gradient means less heat lost to the environment allowing the calf to forage for a longer period of time. Conversely, during a cold winter, a large gradient means greater heat loss to the environment. This means less time spent foraging if the calf is to maintain thermal balance. Less time foraging may result in an energy deficit requiring the calf to metabolize stored visceral fats, muscle tissue and eventually blubber. Reductions in visceral fats, blubber and muscle results in a decrease in volume while surface area remains the same. This causes a corresponding increase in SA:V, further exacerbating the amount of heat lost to the environment. In the process of metabolizing blubber, critical insulation is reduced, further facilitating an even greater amount of heat lost to the environment. If environmental conditions do not change favorably for the calf, the synergistic effects of these physical changes will result in hypothermia, metabolic shut down and eventually death. Retreating to a warm-water site, while beneficial, will likely fail to allow recovery as the calf, unable to forage, will continue to metabolize already depleted fat and muscle stores.

Calves still dependent on their mothers on the other hand, may experience suboptimal temperatures during long foraging trips that could exceed the calf's tolerance limits, particularly if seagrass beds are located far from the power plant or use of nearby warm-water sites is not an option.

While the model did not allow for configuration of virtual manatee calves with a TL of less than 200 cm, the surprisingly low number of CS -related deaths documented for the smaller dependent calf category warrants discussion given the high SA:V. One explanation for the low level of CS-related mortality documented for this size class is the calorie-rich, nutrient-dense milk provided by their mothers. Ward-Geiger's (1995) comparative analysis of blubber content suggests that nursing calves have thicker blubber depth to offset the high SA:V. Based on work with captive calves observations of nursing behavior of dependent calves in captivity on surrogate females suggest that manatee calves feed in small bouts approximately every 60 minutes (Shapiro 1996).

The use of secondary sites by manatees, particularly females with dependent calves, coupled with the repeated observations described in Chapter 3 of “calf parking” and “wet nursing” at the Desoto Canal site during the 2009-2010 winter, suggest the use of two additional behavioral adaptations in response to thermal stress. These two adaptations would likely benefit the smaller, dependent calves and could explain, in part, the low percentage CS mortalities documented for that size class during the winter months.

The first of these adaptations, referred to as” calf parking,” appears to allows an adult female with a dependent calf the option of leaving the calf in a warm water site while freeing her up to forage alone, unencumbered and for a longer period of time. This behavior was observed during the winter on multiple occasions in secondary sites on both east and west coast in the mid to late 1990’s (L. Keith, Pers. and A. Spellman, FWC, Pers. Obs.). The second adaptation, “wet nursing”, previously described with regards to an orphaned calf, appears to allow females with a nursing calf the opportunity to forage while another nursing female remains behind at the warm water site to nurse a number of dependent calves in addition to her own. Upon returning from the foraging trip, the nursing females trade places, allowing both adults and dependent calves the opportunity to obtain adequate nutrition while limiting calf exposure to lethal water temperatures. Using this approach, calves are able to nurse frequently while lactating females take turns foraging. This can only benefit the females who require greater amounts of vegetation to support both their metabolic needs and the needs of the growing calves.

Additionally, the low number of CS related moralities assigned to the small calf subclass may be influenced by the timing of peak calving season which corresponds with the arrival of warm weather, effectively reducing the number of calves entering the winter measuring less than 175 cm. Fewer observations of mating activity during the winter months lend support to the suggestion that reproductive activities may also be suppressed when it is cold (Hernandez *et al*. 1995). With a gestation of 12 to 14 months this would result in more calves being born primarily under more favorable spring conditions.

Healthy subadults fared slightly better than adults in all scenarios challenging the widely held belief that during the colder months larger manatees benefit thermally from having a smaller SA:V and that subadults are most at risk. This paradox can be explained by comparing the amounts of food required to sustain manatees of different sizes and the associated forage time required to obtain it.

Manatees typically eat an amount vegetation equivalent to between 5 to 10% of their body weight daily, feeding for approximately 4 to 8 hours each day (Reep and Bonde 2006). This means larger individuals require more food. The 488kg adult manatee used in the simulations would require between 24 to 48 kg of seagrass daily, while the 397 kg subadult would require approximately 20 to 40 kg daily, and the independent calf of 292 kg would need to consume between 15 to 30 kg each day.

Assuming that manatees graze at the same rate regardless of age or size, adult manatees would need to spend more time feeding than either subadults or calves in order to consume the appropriate amount of vegetation. This would prolong the adults' exposure to sub-optimal ambient river temperatures. With prolonged exposure comes an increase in metabolic cost, specifically the need to adjust metabolic rate to offset the increase in heat lost to the environment. Increasing metabolic rate would require the input of additional energy which in turn would require the ingestion of additional vegetation making it necessary to spend more time foraging. Extending forage time may not be an option if the manatee is spending more energy than it is recovering. This may force adult manatees to limit forage time, and seek refuge in a warm water site until ambient conditions improve, resulting in failure to obtain sufficient forage

During periods of severe cold, when time spent feeding may be limited, adults would be at a disadvantage when compared to subadults and calves because of the need to support the metabolism of a larger animal. Failure to obtain enough forage would force adult manatees to eventually metabolize fat stores, followed by muscle tissue, and eventually blubber. As with calves, metabolism of visceral fat, muscle and blubber in adults would lead to an increase in SA:V, loss of insulation, and a decrease in mass. Healthy adults have the advantage over calves however, because adults typically possess greater fats stores that can be used sustain them during periods of fasting. The model accounts for these differences in fat stores by calculating the initial body fat values as a percentage of the manatee's initial mass.

Subadults appear to do better than both adults and calves under all condition, in mortality data analyses. There are number of possible reasons for this. Despite a higher

SA:V ratio which may impose limits on time spent foraging, subadults require less vegetation to meet their daily dietary intake than adults. This translates into less time foraging, less exposure to cold water, and more time to spend in a warm water site. While subadults possess proportionally fewer fat stores, they also benefit from having smaller mass, requiring less energy when fasting than adults.

Limitations of the Model

The use of a computer model to simplify relationships and manipulate variables within complex systems is not without its limitations. In the process of modeling complex systems it is not uncommon to oversimplify them by failing to recognize the existence of some relationships, or by misunderstanding the true nature of others. In many instances, while the interactions are obvious, the data needed to incorporate these relationships into the model design are lacking. For this reason and several others, all models should be view as inherently flawed or imperfect (Forrester 1961).

The model created for this study was developed by building upon the framework of an existing but more basic manatee energetics models. This was accomplished by identifying and incorporating additional interactions and relationships that addressed manatee energetics based actual behavior documented during the winter months into the design. Data and design elements essential to understanding these relationships and interactions, and critical to the operation of the model, were collected from available relevant published and unpublished research, federal and state manatee databases, extensive behavioral observations and data collected in the field, as well as known manatee life history parameters.

Despite best efforts with regards to its design, this model is not without its limitations. One such limitation is the inability of the model to recognize if the manatee died during the simulation and when. Losses in mass, depletion of fat stores, and reduction in blubber depth as well as increases in SA:V undoubtedly play important roles in the progression of CSS. Identifying critical thresholds for these variables would seem like a logical place to start, but analyses of mortality and rescue data fail to provide consistent lethal values for these metrics either within, or across size classes. In reality it is more likely that the process of CSS is more complex, involving the synergistic effects of changes in multiple variables, the relationship of which is yet to be determined.

Another limitation is that this version of the model is that it was not designed to be agent based. In an agent based model decisions are made at the level of the individual. For example, in an agent based energetics model the decision of what to do is determined by the individual manatee’s core temperature. The model in this study is based on the concept of system dynamics. How the manatees use the system is based on a number of ‘if-then” type variables and associated rules determined by the user. The rules apply equally to all individuals regardless of their configuration. For example, the temperature conditions under which a manatee may move into the IRL is determined by the user through sliding switches on the interface page (Figure 48). If the NoGo IRL temperature threshold is set at 15°C, the model tells the manatee that it will not leave the warm water site when IRL temperatures read ≤ 15°C. This decision is based on the cues from the system such as ambient river temperature, not the tolerance level of the individual in the simulation. The model does not take into consideration the plasticity of individual manatees.

When calculating foraging time the model certain values incorporated into the current design are not based on the actual distance to feeding grounds or associated travel time, or the effects these have on energy expenditure. Likewise, when comparing the benefits of different secondary site use, the model does not take into consideration the differences in distance to each location or the effects this has on travel time to and from the power plant or seagrass beds, or on energy expenditure.

The current design does not allow for the configuration of virtual manatees less than 200 cm, less than 2 years of age, or of adult females that are lactating or pregnant. This is because individuals under 200 cm are likely to be nursing calves. The effects of nursing, pregnancy and growth rates of calves under two years of age with respect metabolic rate are unknown.

The model is currently designed to allocate net recovered energy to growth. This allows the manatee to increase in length even if the conditions of the simulation deplete the manatee to the point where growth is unlikely. When conditions suggest that the manatee likely perished during the simulation, the model still allows the manatee to recover and return to foraging if environmental conditions improve.

Actual IRL and secondary site temperature date were collected every half hour from 01 December through 13 March for each winter. The data used in the model however, reflects calculations of the mean daily winter temperature. Actual maximum and minimum temperatures that the manatees experience are not used. Using the mean or average daily temperature may under represent the severity of actual cold fronts allowing virtual manatees to survive a winter when realistically they would not. Use of mean daily temperatures may also misrepresent water temperature ranges at secondary sites or in the IRL. The latter will affect the temperature regime for the power plant.

Despite the limitations of the current version of the manatee energetics model presented in this chapter, the output data generated from scenarios simulated for the purpose of this study closely support the findings of the CS-related mortality analyses presented in Chapter 1. Specifically, model output results challenge the perception that larger animals are less affected by CSS due to the advantages of having a lower SA:V. Conversely, smaller individuals would be more susceptible to CSS due to a high SA:V. What the model outputs indicated were that calves in the 200 cm range would indeed be affected more so than adults and that adults would fare better than calves under the same conditions. However, the model also indicates that subadults would actually fare better than individuals in the larger adult size class despite having a higher SA:V. These somewhat unexpected results encouraged a new way of thinking about manatee energetics, and fostered a better understanding by producing by challenging long-standing assumptions. In the opinion of modeling pioneer Jay Forrester, upon whose work the concept of System Dynamics was developed, “the most useful models are the ones that produce *counterintuitive* results, forcing manager to reexamine their *intuitive* understanding of the system “ (Ford 1999).

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SUMMARY

Manatee use of winter habitat requires a balance between physiological needs and environmental stressors. Limited in its physiological response to the cold, the Florida manatee must employ a number of behavioral responses in order to survive at the northernmost limits of its range. The ability to find warm water close to forage is paramount. With no natural warm water springs and only a single power plant on which to depend, manatees in the east central part of the state, benefit from knowledge of a small but available network of secondary sites known as passive thermal basins. Use of these sites however, does not come without costs. The long term management goal of freeing manatees from dependence upon power plant effluents requires an understanding of these costs if a suitable network is to be created and maintained for manatees in the future. The most effective design will require an understanding of manatee use of the current system and strive to address any weaknesses in what is currently available.

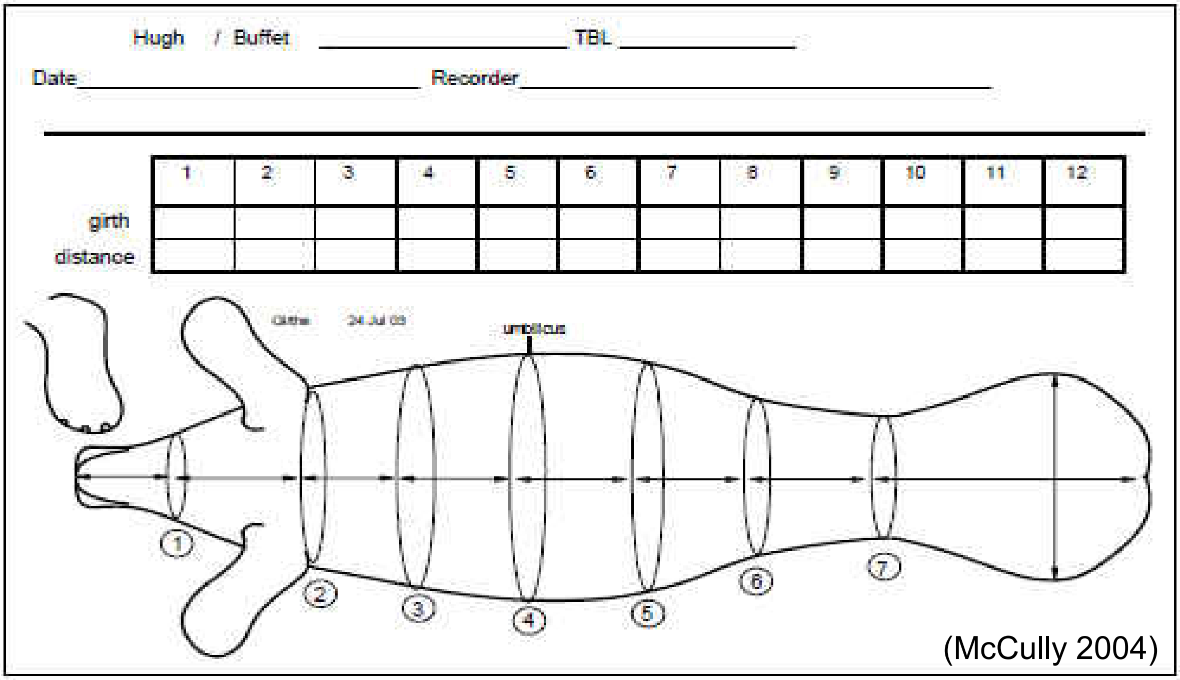
By identifying and characterizing secondary sites used by manatees, we increase our understanding of what constitutes a suitable site based on locations manatees are currently using. Some of these sites do not conform to definitions of suitable habitat but are of great importance nonetheless. Most of these sites remain unprotected from human disturbances, putting manatees at risk when they can afford it the least. Seasonal protection for these sites must rank high on the criteria list if manatees are to fully benefit from the network. Additional research is necessary with regards to defining

the limitations in manatee metabolism as it pertains to thermoregulation. While manatee use of warm water springs and power plant effluents are topics well-represented in the available literature, more focus is necessary on research that addresses alternative warm water options. The unprecedented winter seasons that affected the entire Florida peninsula in 2010 and 2011 will likely happen again. The importance of the three sites characterized in this study was evident during those events, providing thermal shelter to a large number of manatees while facilitating access to additional areas of forage.

The ability to model complex environmental systems will allow researchers and natural resource managers to manipulate key variables in the manatee's environment as well as its physiology to gain a better understanding of the challenges faced during the winter months. These models however, will only be as strong as their weakest link. Fortunately models like the one used in this study can be designed to allow for input of the most current data as it becomes available.

Much remains to be learned from the three PTB's located in Brevard County, and it is only a matter of time before another cold winter affects the area. Steps must be taken now and in the near future to assure that these sites will be available when that time comes.

APPENDIX A: MANATEE LENGTH AND GIRTH DATA SHEETS

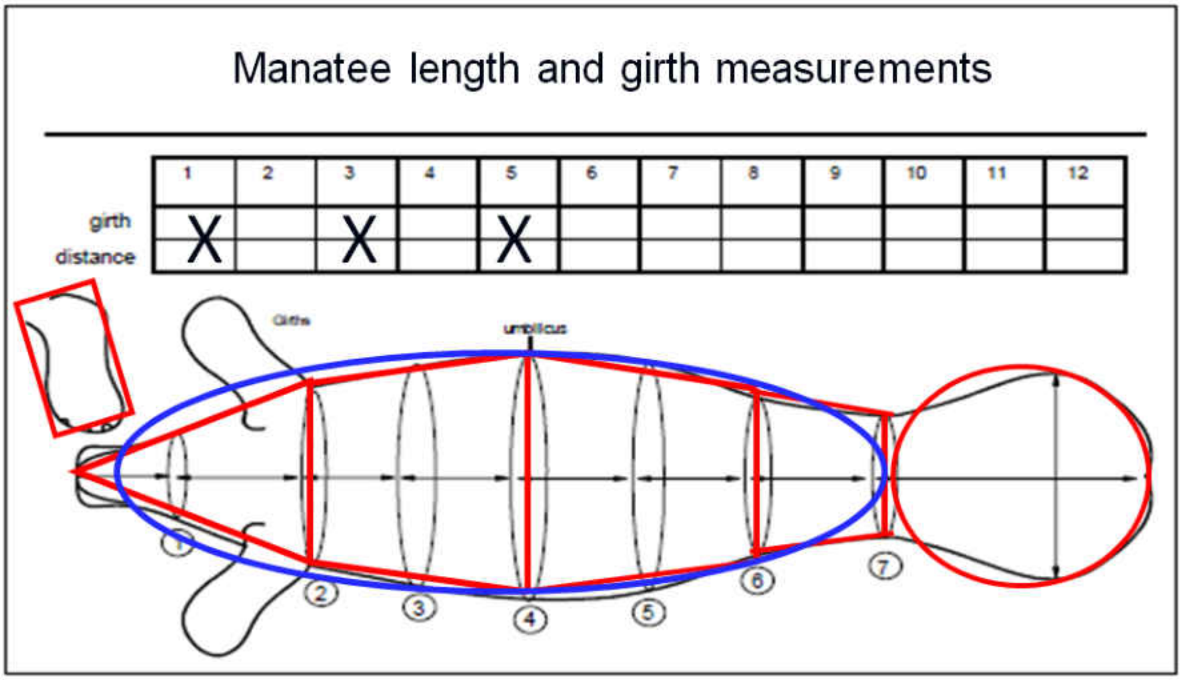


Hugh / Buffet ____________________ TBL ______________

Date____________________________ Recorder______________________________________

	1	2	3	4	5	6	7	8	9	10	11	12
girth												
distance												

(McCully 2004)



Manatee length and girth measurements

	1	2	3	4	5	6	7	8	9	10	11	12
girth	X		X		X							
distance												

APPENDIX B: MONTHLY MEAN WATER TEMPERATURE TABLES FOR AMBIENT RIVER AND SECONDARY WARM WATER SITES

Winter 2008-2009					
		Dec	Jan	Feb	Mar
Ambient Sites	IR	18.50	16.16	16.28	20.74
	IRN	-	-	-	-
	BR	-	-	-	-
	IRS	-	-	-	-
Warm Water Sites	BC_Z	23.75	21.83	22.56	24.21
	DC_B	21.36	19.21	19.22	22.43
	SR_Z	20.88	21.18	20.13	22.15

Winter 2009-2010					
		Dec	Jan	Feb	Mar
Ambient Sites	IR	18.03	12.79	13.73	17.27
	IRN	-	13.25	14.29	17.13
	BR	19.02	13.67	14.97	17.47
	IRS	20.24	15.55	16.05	17.73
Warm Water Sites	BC_Z	22.97	20.59	21.29	22.41
	DC_B	20.53	17.05	17.75	20.14
	SR_Z	23.09	18.10	19.85	18.84

Winter 2010-2011					
		Dec	Jan	Feb	Mar
Ambient Sites	IR	11.83	14.65	18.73	21.40
	IRN	12.52	14.72	18.84	21.48
	BR	12.97	15.45	19.60	21.70
	IRS	15.26	17.02	19.90	21.87
Warm Water Sites	BC_Z	20.14	21.38	22.98	24.46
	DC_B	16.06	18.25	21.71	23.65
	SR_Z	19.79	19.74	21.57	23.19

Winter 2011-2012					
		Dec	Jan	Feb	Mar
Ambient Sites	IR	-	-	-	-
	IRN	19.98	17.31	19.66	23.28
	BR	20.25	17.76	20.14	23.50
	IRS	20.87	19.19	20.67	23.45
Warm Water Sites	BC_Z	23.76	22.52	23.82	25.58
	DC_B	21.46	19.49	21.28	24.99
	SR_Z	23.00	19.74	21.57	23.19

APPENDIX C: INDIVIDUAL SITE MEAN MONTHLY WATER TEMPERATURE TABLES

Ambient		Indian River (IR_B)			
		Min	Max	Mean	St Dev
Winter 2008-2009	Dec	12.38	23.47	18.50	2.14
	Jan	7.11	21.58	16.16	3.36
	Feb	4.50	22.10	16.28	3.34
	Mar	11.20	26.10	20.74	3.35

Warm Water		Berkeley Canal (BC_Z)			
		Min	Max	Mean	St Dev
Winter 2008-2009	Dec	20.48	25.30	23.75	1.01
	Jan	16.10	24.14	21.83	1.44
	Feb	18.91	24.33	22.56	1.06
	Mar	20.24	26.06	24.21	1.31

Warm Water		Berkeley Canal (BC_C)			
		Min	Max	Mean	St Dev
Winter 2008-2009	Dec	19.57	25.21	22.40	1.17
	Jan	15.19	24.31	20.43	1.98
	Feb	13.47	24.67	20.67	2.10
	Mar	17.51	27.50	23.54	2.31

Warm Water		Berkeley Canal (BC_S)			
		Min	Max	Mean	St Dev
Winter 2008-2009	Dec	13.93	28.84	21.93	2.01
	Jan	9.43	29.59	19.05	3.71
	Feb	8.46	28.22	18.71	3.56
	Mar	12.60	27.62	22.43	3.04

Other		Desoto Canal (DC_B)			
		Min	Max	Mean	St Dev
Winter 2008-2009	Dec	17.08	25.81	21.36	2.01
	Jan	12.36	25.28	19.21	2.43
	Feb	12.12	24.02	19.22	2.21
	Mar	15.62	26.57	22.43	2.45

Warm Water		Sebastian River (SR_C)			
		Min	Max	Mean	St Dev
Winter 2008-2009	Dec	17.22	23.18	20.06	1.11
	Jan	12.79	22.63	19.21	1.89
	Feb	12.67	22.99	18.64	1.73
	Mar	16.03	26.01	21.59	2.04

Warm Water		Sebastian River (SR_Z)			
		Min	Max	Mean	St Dev
Winter 2008-2009	Dec	19.60	22.08	20.88	0.55
	Jan	18.39	22.84	21.18	1.75
	Feb	18.79	21.29	20.13	0.80
	Mar	20.46	23.90	22.15	1.29

Warm Water		FPL-CC Discharge (FD_B)			
		Min	Max	Mean	St Dev
Winter 2008-2009	Dec	15.48	28.89	19.74	1.95
	Jan	15.31	27.11	19.67	1.44
	Feb	15.10	26.35	20.59	1.80
	Mar	17.43	32.22	23.35	2.78

Other		Melbourne Tillman (MT_B)			
		Min	Max	Mean	St Dev
Winter 2008-2009	Dec	17.20	22.05	19.80	1.34
	Jan	12.46	21.24	17.63	2.40
	Feb	13.16	22.39	18.27	2.31
	Mar	16.53	25.01	21.80	2.39

Other		Sleepy Lagoon (SL_B)			
		Min	Max	Mean	St Dev
Winter 2008-2009	Dec	16.84	22.56	19.71	1.20
	Jan	14.40	21.53	18.48	1.87
	Feb	12.46	21.98	17.99	2.00
	Mar	15.86	25.28	21.55	2.35

Other		Lake Shepard (LS_B)			
		Min	Max	Mean	St Dev
Winter 2008-2009	Dec	17.70	22.08	19.69	1.04
	Jan	13.37	22.10	18.41	2.03
	Feb	12.60	22.48	17.89	2.15
	Mar	16.36	25.47	21.60	2.30

Ambient		FPL-CC (FI_C)			
		Min	Max	Mean	St Dev
Winter 2008-2009	Dec	15.81	23.73	19.32	1.82
	Jan	11.54	22.87	17.60	2.66
	Feb	11.88	22.15	17.53	2.28
	Mar	14.19	25.84	21.61	2.76

Ambient		Indian River (IR_B)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	9.82	22.99	18.03	2.97
	Jan	1.31	20.86	12.79	4.98
	Feb	7.92	19.96	13.73	2.45
	Mar	9.65	22.94	17.27	2.75

Warm Water		Berkeley Canal (BC_Z)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	19.36	24.87	22.97	1.38
	Jan	17.93	23.13	20.59	1.62
	Feb	19.72	22.68	21.29	0.81
	Mar	19.31	24.38	22.41	1.39

Warm Water		Berkeley Canal (BC_C)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	17.24	24.55	21.59	1.86
	Jan	13.83	23.16	18.57	2.30
	Feb	14.52	21.10	18.53	1.63
	Mar	14.05	24.96	20.40	1.98

Warm Water		Berkeley Canal (BC_S)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	16.72	25.57	21.47	1.96
	Jan	7.04	23.80	16.87	3.89
	Feb	11.75	21.84	17.58	2.33
	Mar	11.68	25.40	19.72	2.41

Other		Desoto Canal (DC_B)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	16.22	24.14	20.53	1.98
	Jan	8.81	22.87	17.05	3.40
	Feb	13.90	21.17	17.75	1.62
	Mar	15.15	25.04	20.14	2.31

Warm Water		Sebastian River (SR_C)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	19.48	24.72	22.27	1.52
	Jan	13.81	20.17	17.21	2.01
	Feb	16.86	20.19	18.43	0.99
	Mar	16.89	20.81	18.46	0.97

Warm Water		Sebastian River (SR_Z)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	21.72	24.62	23.09	0.81
	Jan	15.60	21.79	18.10	1.88
	Feb	19.17	20.57	19.85	0.53
	Mar	17.55	20.79	18.84	0.85

Warm Water		FPL-CC Discharge (FD_B)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	14.72	25.89	19.95	1.92
	Jan	11.58	24.05	18.14	2.03
	Feb	15.98	24.82	19.76	1.42
	Mar	15.79	26.50	20.63	1.96

Other		Melbourne Tillman (MT_B)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	15.31	24.09	19.82	2.41
	Jan	8.39	21.43	15.38	4.04
	Feb	12.92	20.03	16.67	2.00
	Mar	14.17	22.82	18.87	2.34

Other		Sleepy Lagoon (SL_B)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	16.51	23.76	20.68	1.82
	Jan	9.28	20.69	15.75	3.07
	Feb	12.84	18.98	16.09	1.76
	Mar	13.42	23.06	18.49	2.45

Other		Lake Shepard (LS_B)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	15.72	23.04	19.80	1.74
	Jan	8.14	20.67	14.68	3.53
	Feb	11.95	19.15	15.56	1.87
	Mar	12.89	22.82	18.09	2.61

Ambient		FPL-CC (FI_C)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	14.36	24.07	19.00	2.24
	Jan	6.91	20.88	14.35	3.88
	Feb	11.68	19.03	15.40	1.68
	Mar	12.87	23.28	18.22	2.35

Ambient		Indian River (IRN_C)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	-	-	-	-
	Jan	5.43	20.65	13.25	4.39
	Feb	10.44	18.22	14.29	1.90
	Mar	11.78	21.58	17.13	2.57

Ambient		Indian River (IRS_C)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	15.07	23.93	20.24	2.26
	Jan	6.83	20.98	15.55	3.49
	Feb	12.46	19.57	16.05	1.65
	Mar	12.55	22.32	17.73	2.11

Ambient		Banana River (BR_B)			
		Min	Max	Mean	St Dev
Winter 2009-2010	Dec	14.12	23.01	19.02	2.54
	Jan	5.74	20.50	13.67	4.33
	Feb	10.93	19.48	14.97	2.17
	Mar	12.07	23.16	17.47	2.65

Ambient		Indian River (IR_B)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	3.69	22.44	11.80	3.24
	Jan	5.97	20.34	14.65	2.29
	Feb	11.00	24.26	18.73	2.94
	Mar	14.40	25.62	21.40	2.06

Warm Water		Berkeley Canal (BC_Z)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	17.62	25.04	20.14	1.84
	Jan	18.69	22.99	21.38	0.81
	Feb	19.41	25.18	22.98	1.20
	Mar	22.77	25.76	24.46	0.81

Warm Water		Berkeley Canal (BC_C)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	11.29	24.31	17.68	2.14
	Jan	15.19	22.10	19.16	1.25
	Feb	17.77	26.74	22.37	1.74
	Mar	20.57	28.12	24.21	1.50

Warm Water		Berkeley Canal (BC_S)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	8.34	23.71	16.71	2.80
	Jan	11.97	22.92	18.21	1.97
	Feb	9.75	26.40	20.51	2.84
	Mar	16.53	27.99	22.88	2.21

Other		Desoto Canal (DC_B)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	10.51	23.28	16.06	2.35
	Jan	13.66	22.10	18.25	1.48
	Feb	17.41	26.25	21.71	1.81
	Mar	20.71	27.82	23.65	1.63

Other		Grand Canal (GC_B)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	9.33	22.65	14.09	2.58
	Jan	12.24	18.98	16.40	1.44
	Feb	15.46	24.94	20.31	2.14
	Mar	18.62	26.59	22.83	1.62

Warm Water		Sebastian River (SR_C)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	14.98	23.44	18.04	2.86
	Jan	15.15	19.49	18.02	1.10
	Feb	18.88	22.95	20.79	1.05
	Mar	22.15	25.28	23.27	0.95

Warm Water		Sebastian River (SR_Z)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	17.72	23.52	19.79	2.11
	Jan	18.15	20.98	19.74	0.88
	Feb	20.98	22.48	21.57	0.35
	Mar	22.48	24.55	23.29	0.62

Warm Water		Sebastian River (SR_B)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	14.88	23.54	18.15	2.93
	Jan	15.07	19.35	18.08	1.15
	Feb	19.12	22.82	20.84	1.04
	Mar	22.20	25.33	23.36	0.96

Warm Water		Sebastian River (SR_S)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	13.23	23.54	17.55	2.74
	Jan	14.40	19.88	17.49	0.93
	Feb	16.43	24.70	20.44	1.37
	Mar	19.48	26.79	22.71	1.61

Ambient		FPL-CC Discharge (FD_B)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	9.85	23.85	14.42	2.67
	Jan	12.87	20.67	17.08	1.57
	Feb	15.74	24.70	20.93	2.23
	Mar	18.53	26.37	22.89	1.74

Other		Melbourne Tillman (MT_B)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	3.35	23.13	13.62	3.78
	Jan	8.96	25.16	16.37	2.94
	Feb	6.84	30.57	19.86	4.83
	Mar	7.36	26.13	21.60	3.54

Warm Water		Berkeley Canal (BCE_Z)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	16.10	23.71	18.54	1.81
	Jan	17.77	20.84	19.50	0.72
	Feb	20.00	25.23	22.27	1.30
	Mar	22.10	26.20	24.37	1.08

Other		Berkeley Canal (BCW_B)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	11.29	23.01	14.64	2.55
	Jan	13.20	18.84	16.46	1.24
	Feb	16.48	24.31	20.26	1.99
	Mar	19.53	15.91	22.84	1.47

Warm Water		FPL-CC Intake (FI_C)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	12.17	24.26	19.84	2.84
	Jan	18.67	25.98	22.45	1.09
	Feb	19.24	27.70	22.24	1.59
	Mar	19.96	25.45	22.65	1.14

Ambient		Indian River (IRN_C)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	7.84	22.36	12.52	2.81
	Jan	11.12	17.41	14.72	1.46
	Feb	14.19	23.52	18.84	2.27
	Mar	17.39	24.55	21.48	1.72

Ambient		Indian River (IRS_C)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	9.85	23.68	15.26	2.62
	Jan	12.09	19.79	17.02	1.51
	Feb	15.05	23.08	19.90	1.77
	Mar	17.36	24.91	21.84	1.56

Ambient		Banana River (BR_B)			
		Min	Max	Mean	St Dev
Winter 2010-2011	Dec	8.09	23.06	12.97	2.82
	Jan	11.20	19.55	15.45	1.63
	Feb	14.29	24.31	19.60	2.35
	Mar	17.34	26.20	21.70	1.72

Warm Water		Berkeley Canal (BC_Z)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	21.70	24.87	23.76	0.53
	Jan	18.12	24.87	22.52	1.68
	Feb	21.15	24.67	23.82	0.73
	Mar	23.95	27.75	23.58	0.98

Warm Water		Berkeley Canal (BC_C)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	20.72	24.82	22.85	0.90
	Jan	15.00	25.33	21.47	1.94
	Feb	17.70	25.45	22.76	1.56
	Mar	21.48	28.71	26.15	1.70

Warm Water		Berkeley Canal (BC_S)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	17.67	25.08	22.38	1.14
	Jan	10.02	25.69	19.71	2.91
	Feb	16.34	26.54	22.10	1.82
	Mar	16.60	29.31	24.70	2.20

Other		Desoto Canal (DC_B)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	19.05	23.97	21.46	1.02
	Jan	14.72	23.37	19.49	1.97
	Feb	15.48	24.75	21.28	1.69
	Mar	19.79	27.92	24.99	1.75

Other		Grand Canal (GC_B)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	18.74	23.76	20.99	1.04
	Jan	12.50	22.75	18.58	2.29
	Feb	15.15	24.60	20.73	1.77
	Mar	19.96	27.57	24.38	1.70

Warm Water		Sebastian River (SR_C)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	21.12	22.63	21.85	0.35
	Jan	18.88	22.25	20.66	0.95
	Feb	19.27	22.58	21.76	0.85
	Mar	22.29	26.37	24.14	1.25

Warm Water		Sebastian River (SR_Z)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	23.63	23.59	23.00	0.21
	Jan	21.19	23.01	21.76	0.52
	Feb	21.74	22.63	22.30	0.25
	Mar	22.63	25.01	23.59	0.66

Warm Water		Sebastian River (SR_B)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	22.68	23.35	23.11	0.09
	Jan	20.57	23.25	21.39	0.69
	Feb	21.34	22.60	22.17	0.38
	Mar	22.56	25.50	23.76	0.84

Warm Water		Sebastian River (SR_S)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	18.81	23.52	21.05	0.79
	Jan	14.86	22.65	19.77	1.41
	Feb	18.10	24.70	21.39	1.02
	Mar	19.65	27.80	23.94	1.56

Warm Water		Desoto Canal (DCN_B)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	20.34	25.18	23.18	0.93
	Jan	19.91	25.91	12.36	0.87
	Feb	19.55	26.23	13.12	1.22
	Mar	21.60	29.24	16.06	1.61

Warm Water		Desoto Canal (DCS_Z)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	22.17	24.94	23.88	0.67
	Jan	21.03	24.60	22.85	0.95
	Feb	21.48	24.65	23.27	0.75
	Mar	22.92	27.03	25.41	1.11

Warm Water		Berkeley Canal (BCE_Z)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	22.05	24.41	22.96	0.52
	Jan	19.53	24.05	21.87	1.29
	Feb	20.74	24.17	23.04	0.86
	Mar	23.35	27.48	25.72	1.31

Other		Berkeley Canal (BCW_B)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	19.24	23.08	20.98	0.95
	Jan	14.48	23.06	18.86	2.28
	Feb	15.91	23.97	20.97	1.61
	Mar	20.29	26.74	24.48	1.51

Warm Water		Berkeley Canal (BCC_B)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	20.48	24.58	22.73	0.86
	Jan	17.01	25.01	21.43	1.86
	Feb	17.96	25.64	22.70	1.48
	Mar	21.17	28.89	26.21	1.78

Ambient		Indian River (IRN_C)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	17.29	22.65	19.98	1.06
	Jan	11.88	22.17	17.31	2.48
	Feb	14.43	23.06	19.66	1.81
	Mar	18.79	26.20	23.28	1.71

Ambient		Indian River (IRS_C)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	18.29	23.61	20.87	1.12
	Jan	13.83	22.72	19.19	1.95
	Feb	14.57	24.19	20.67	1.58
	Mar	19.29	26.15	23.45	1.37

Ambient		Banana River (BR_B)			
		Min	Max	Mean	St Dev
Winter 2011-2012	Dec	17.77	22.92	20.25	1.18
	Jan	12.26	22.68	17.76	2.64
	Feb	13.73	24.24	20.14	1.92
	Mar	19.17	26.30	23.50	1.65

APPENDIX D: NUMBER OF DAYS MEAN WATER TEMPERATURE WAS ≥18°C AND ≥20°C

	WINTER 2008-2009		WINTER 2009-2010		WINTER 2010-2011		WINTER 2011-2012	
Site Code	**Days ≥18°C (%)**	**Days ≥20°C (%)**	**Days ≥18°C (%)**	**Days ≥20°C (%)**	**Days ≥18°C (%)**	**Days ≥20°C (%)**	**Days ≥18°C (%)**	**Days ≥20°C (%)**
BC_S	99 (82)	76 (63)	84 (69)	47 (39)	79 (65)	55 (45)	115 (94)	111 (91)
BC_C	116 (96)	96 (79)	94 (78)	58 (48)	98 (81)	67 (55)	121 (99)	102 (84)
BC_Z	121 (100)	118 (98)	121 (100)	105 (87)	121 (100)	101 (83)	122 (100)	119 (98)
BCE_Z	* *	* *	* *	* *	107 (88)	72 (60)	122 (100)	120 (98)
BCC_B	* *	* *	* *	* *	* *	* *	121 (99)	111 (91)
BCW_B	* *	* *	* *	* *	58 (48)	50 (41)	108 (89)	93 (76)
GC_B	* *	* *	* *	* *	60 (50)	49 (40)	107 (88)	91 (75)
DC_B	101 (83)	73 (60)	81 (67)	48 (40)	80 (66)	57 (47)	113 (93)	95 (78)
DCN_B	* *	* *	* *	* *	* *	* *	122 (100)	122 (100)
DCS_Z	* *	* *	* *	* *	* *	* *	122 (100)	122 (100)
SR_S	* *	* *	79 (65)	28 (23)	78 (64)	57 (47)	121 (99)	100 (82)
SR_C	108 (89)	61 (50)	80 (66)	35 (29)	91 (75)	59 (49)	122 (100)	112 (92)
SR_B	* *	* *	* *	* *	91 (75)	60 (50)	122 (100)	122 (100)
SR_Z	121 (100)	96 (79)	101 (83)	56 (46)	119 (98)	87 (72)	122 (100)	122 (100)

	WINTER 2008-2009		WINTER 2009-2010		WINTER 2010-2011		WINTER 2011-2012	
Site Code	**Days ≥18°C (%)**	**Days ≥20°C (%)**	**Days ≥18°C (%)**	**Days ≥20°C (%)**	**Days ≥18°C (%)**	**Days ≥20°C (%)**	**Days ≥18°C (%)**	**Days ≥20°C (%)**
MT_B	91 (75)	50 (41)	67 (55)	30 (25)	59 (49)	42 (35)	* *	* *
SL_B	90 (74)	50 (41)	64 (53)	29 (24)	* *	* *	* *	* *
LS_B	91 (75)	47 (39)	61 (50)	23 (19)	* *	* *	* *	* *
IR_B	64 (53)	40 (33)	37 (31)	18 (15)	47 (39)	36 (30)	* *	* *
IRN_C	* *	* *	* *	* *	52 (43)	36 (30)	99 (81)	66 (54)
IRS_C	* *	* *	54 (45)	25 (21)	66 (55)	45 (37)	111 (91)	89 (73)
BR_B	* *	* *	41 (34)	20 (17)	56 (46)	42 (35)	103 (84)	73 (60)
RI_C	75 (62)	39 (32)	43 (36)	19 (16)	53 (44)	37 (31)	* *	* *
RD_C	93 (77)	46 (38)	51 (42)	23 (19)	54 (45)	40 (33)	* *	* *
FD_B	112 (93)	73 (60)	101 (83)	53 (44)	65 (54)	51 (42)	* *	* *
FDS_B	* *	* *	97 (80)	52 (43)	* *	* *	* *	* *
FI_C	79 (65)	45 (37)	51 (42)	19 (16)	114 (94)	106 (88)	* *	* *
FIW_B	84 (69)	44 (36)	51 (42)	22 (18)	118 (98)	103 (85)	* *	* *

APPENDIX E: 2009-2011 SYNOPTIC SURVEY MAPS SHOWING WINTER MANATEE DISTRIBUTION IN REALTIONSHIP TO WARM WATER SITES IN BREVARD COUNTY

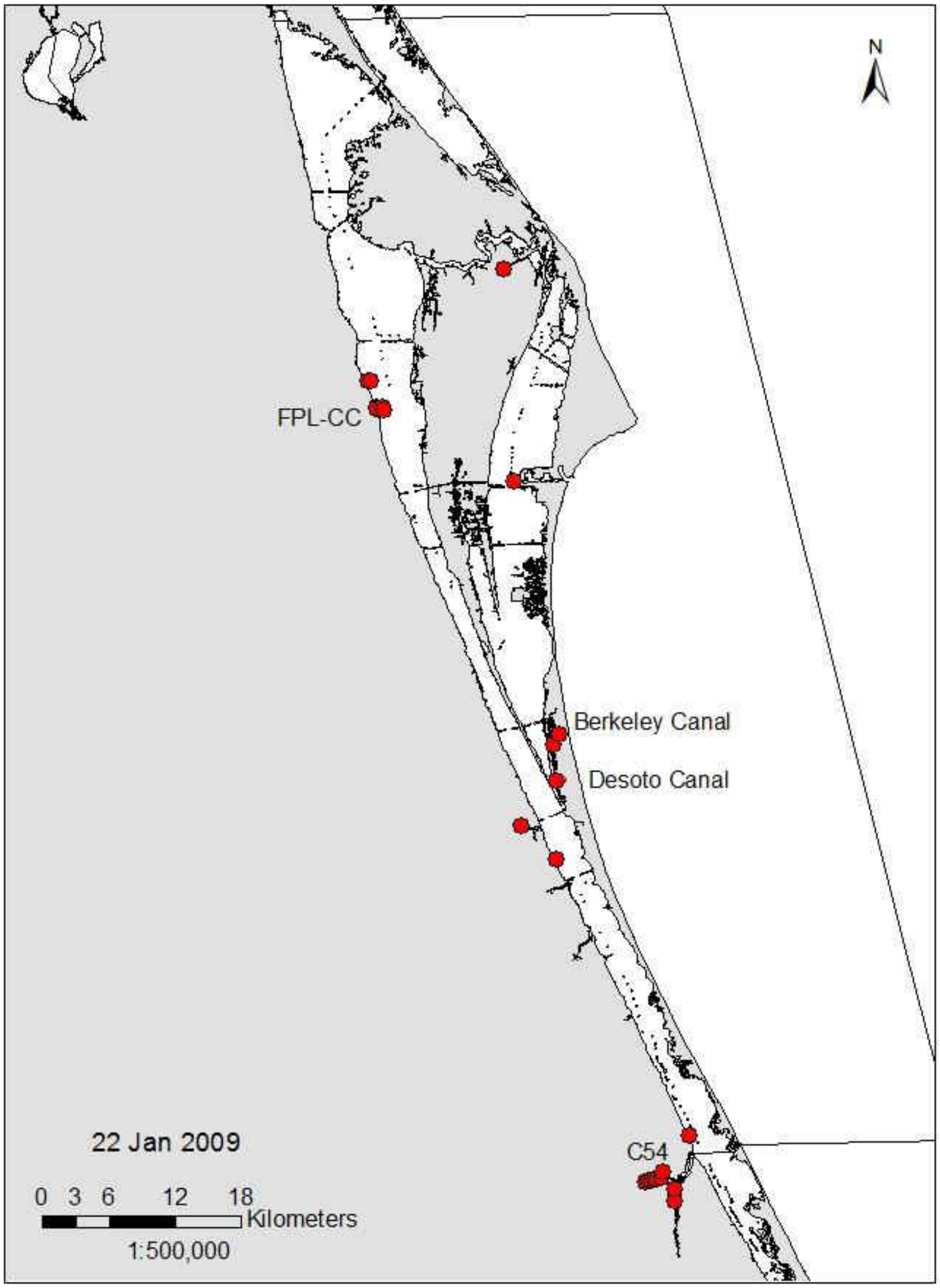


Figure 53 2009 Winter synoptic survey: Manatee distribution in Brevard County

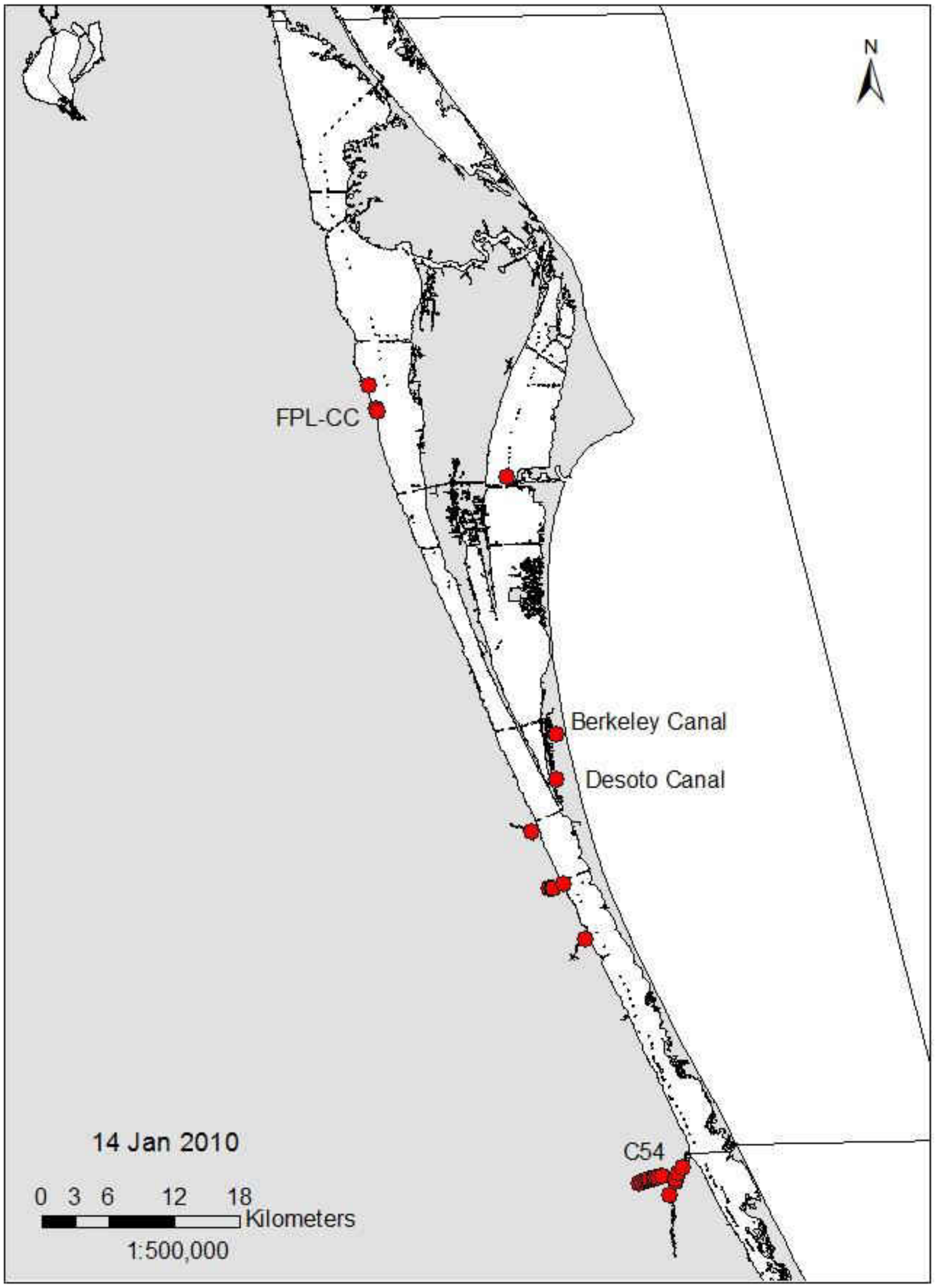


Figure 54 2010 Winter synoptic survey: Manatee distribution in Brevard County

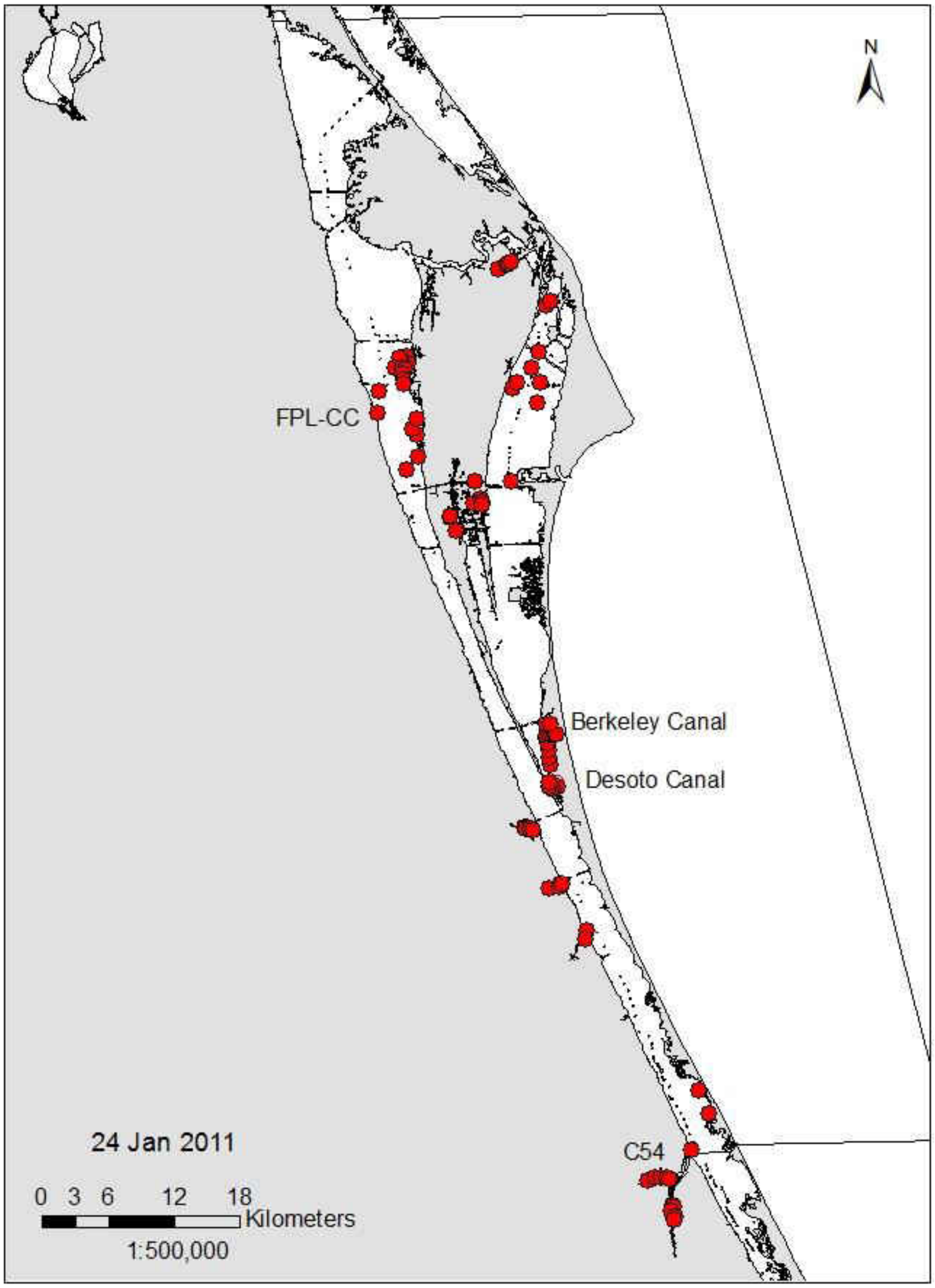


Figure 55 2011 Winter synoptic survey: Manatee distribution in Brevard County

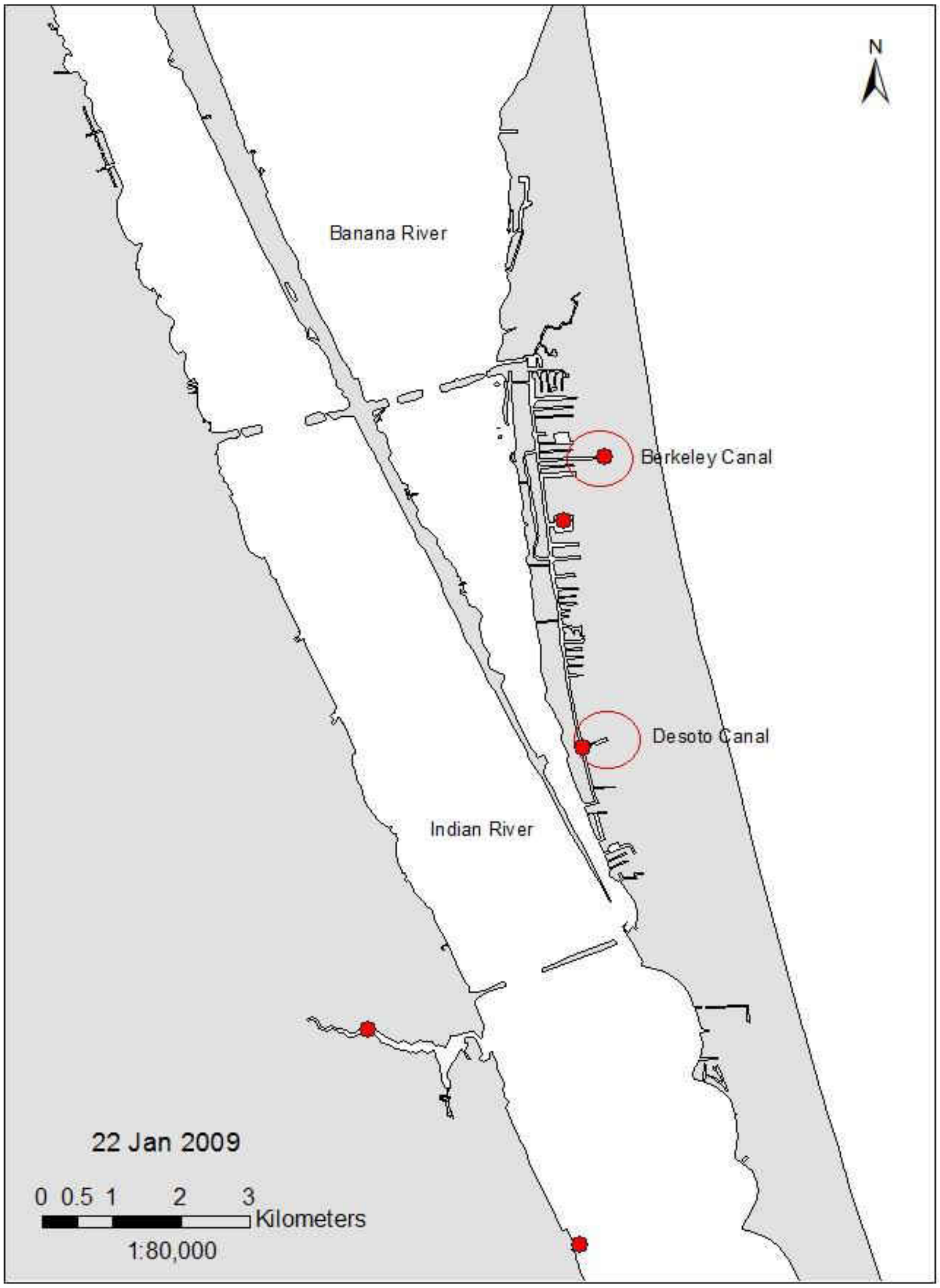


Figure 56 2009 Winter synoptic survey: Manatee distribution around Satellite Beach

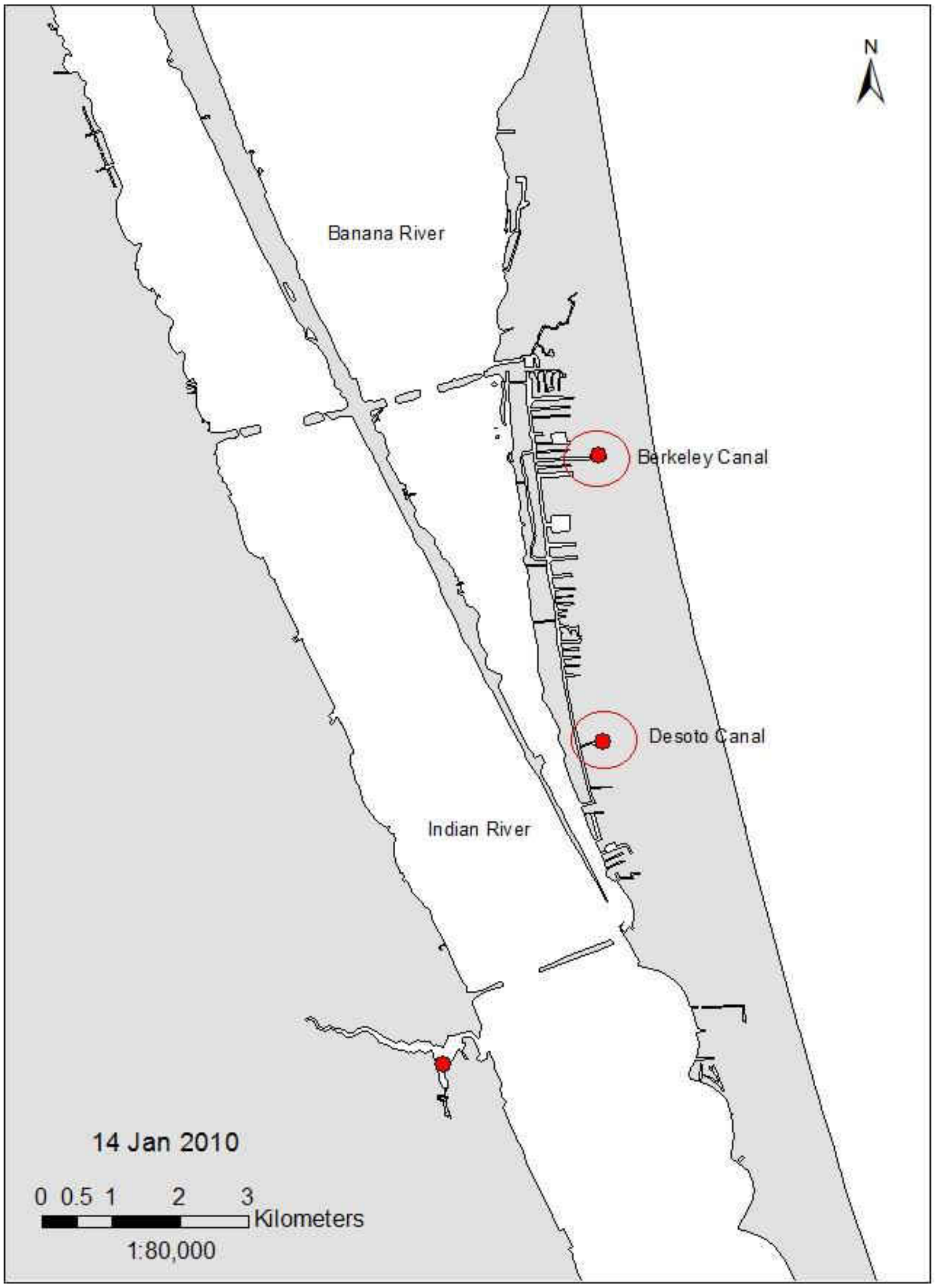


Figure 57 2010 Winter synoptic survey: Manatee distribution around Satellite Beach

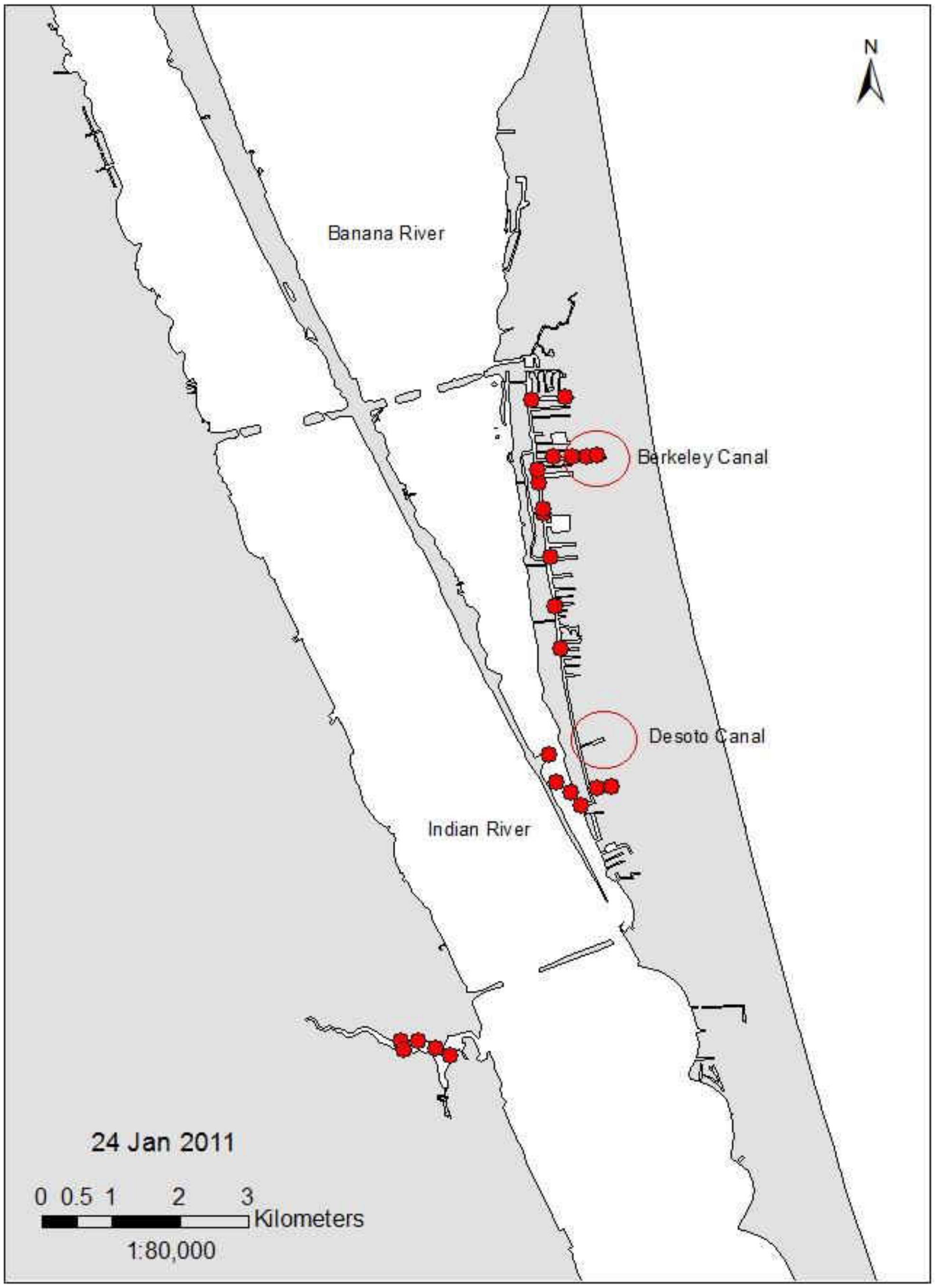


Figure 58 2011 Winter synoptic survey: Manatee distribution around Satellite Beach

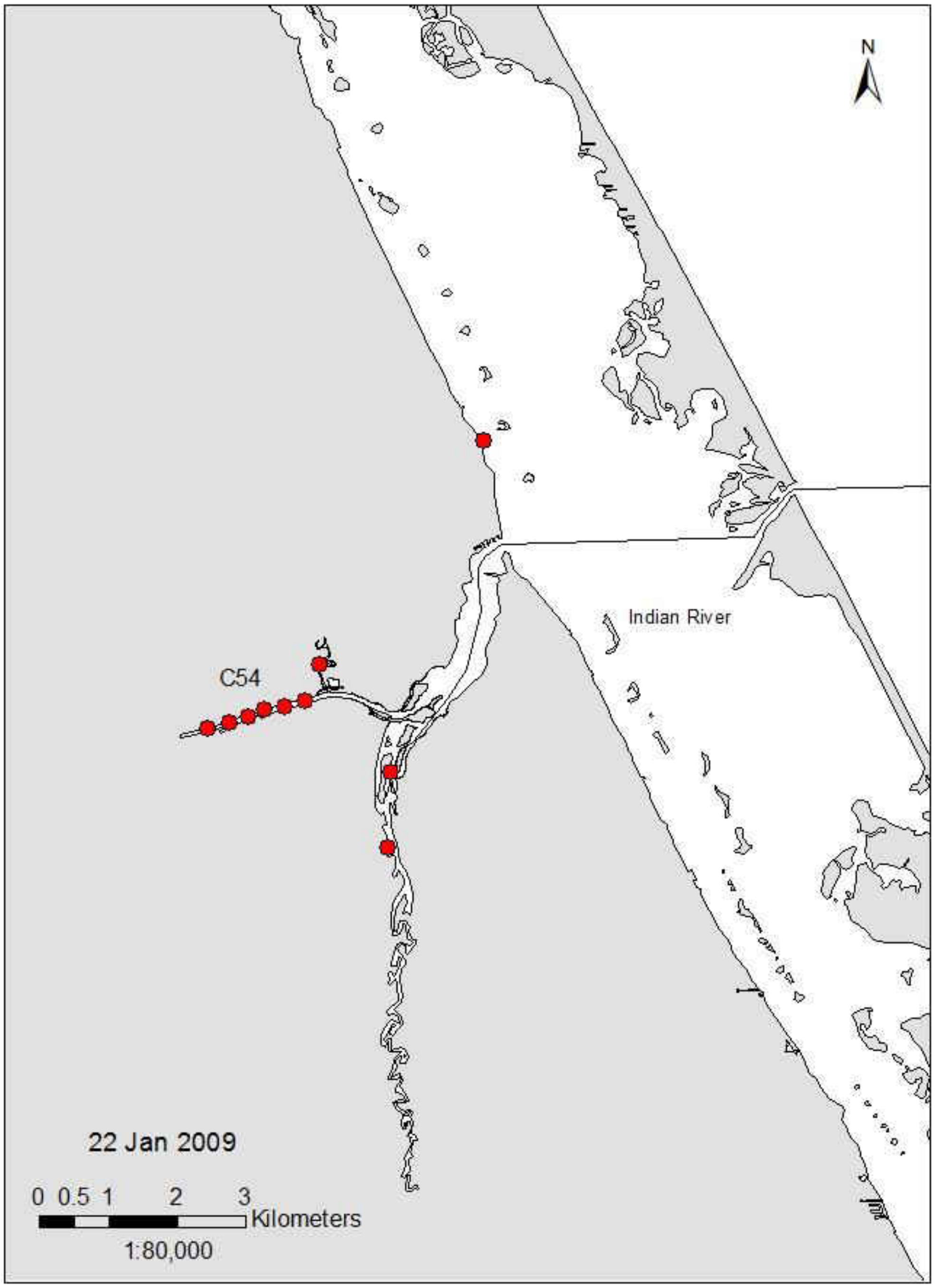


Figure 59 2009 Winter synoptic survey: Manatee distribution around C54

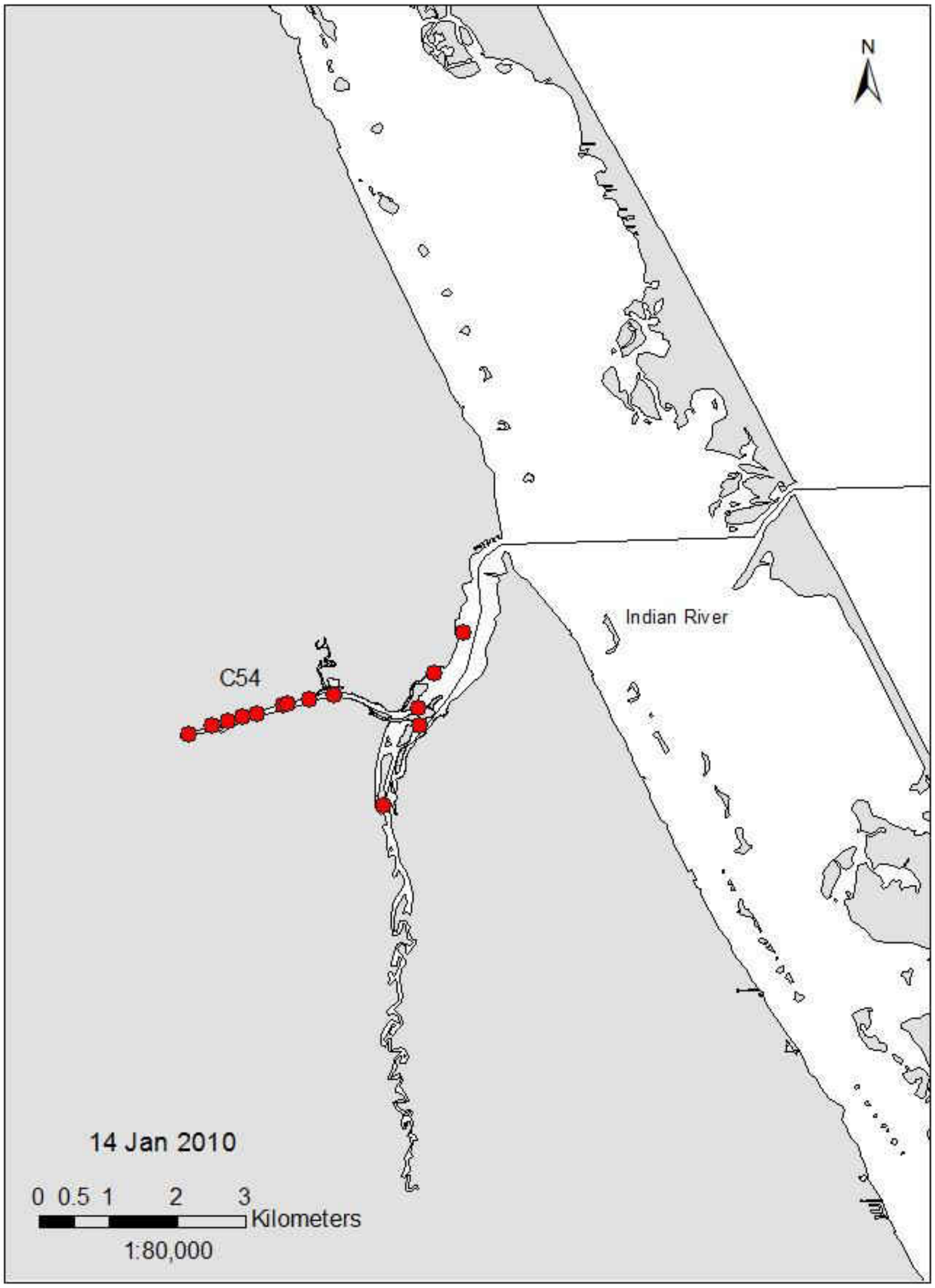


Figure 60 2010 Winter synoptic survey: Manatee distribution around C54

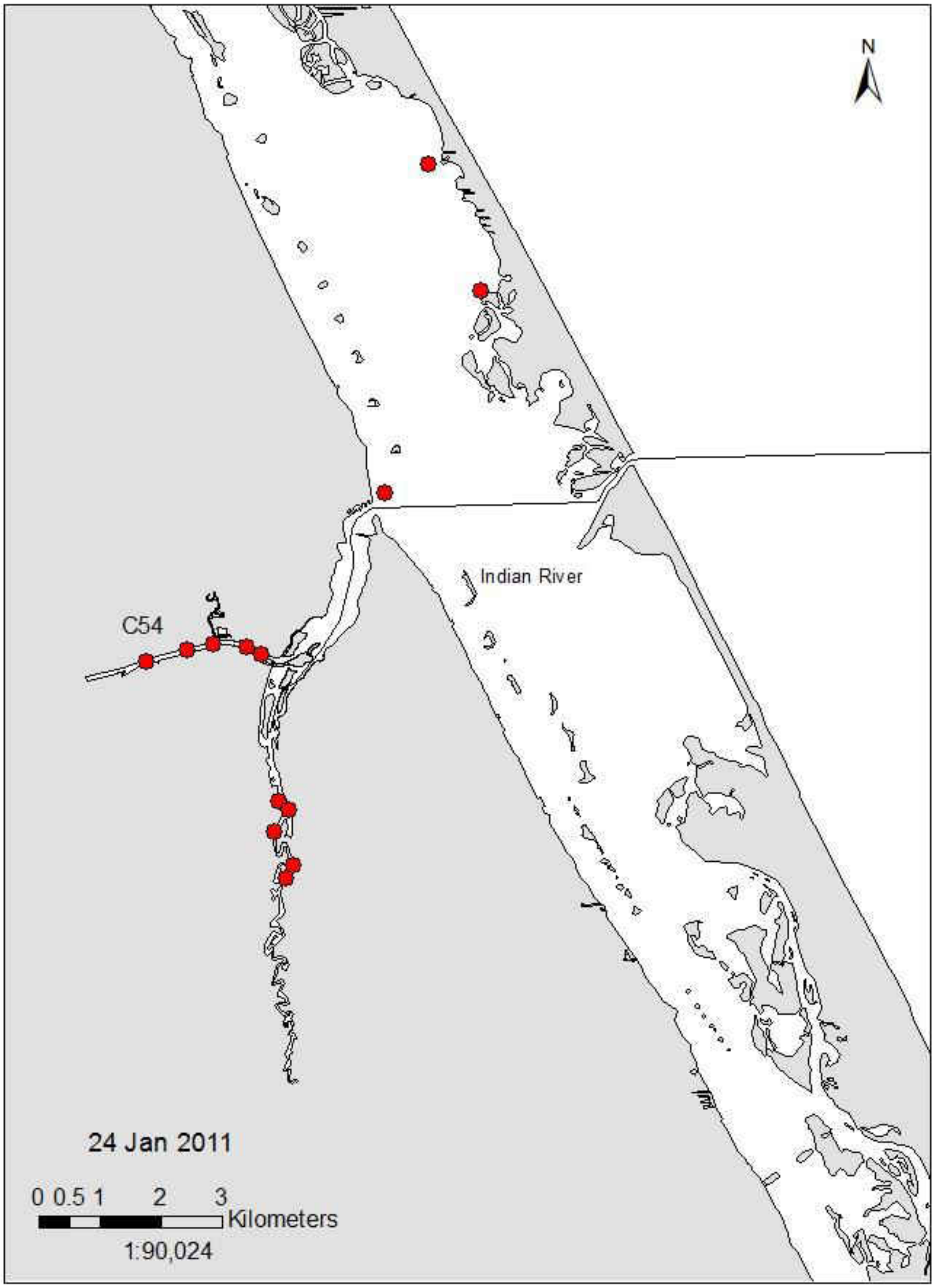


Figure 61 2011 Winter synoptic survey: Manatee distribution around C54