Manatee Response to the Conversion of the FPL Cape Canaveral Power Plant: Movements, Warm-water Habitat Use, and Thermal Regime of Satellite-tagged Manatees during Winters 2010-11 through 2014-15

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18 May 2016

Final Report to
Florida Power & Light Company
How to Cite this Report:

EXECUTIVE SUMMARY

Florida manatees (*Trichechus manatus latirostris*) require access to thermal refugia during winter because of their vulnerability to cold-related stress and mortality. The modernization of the Florida Power & Light Company’s Cape Canaveral power plant to create the Cape Canaveral Next Generation Clean Energy Center (FPL-CCEC) near Titusville (Brevard County, Florida) entailed a change in warm-water habitat at a primary manatee aggregation site that has been traditionally used by large numbers of these endangered marine mammals during winter. Arguably the most crucial manatee warm-water site on Florida’s Atlantic coast, the power plant discharge was offline for 3 years (2010-2013), during which time an on-site interim warm-water refuge (IWWR) was created and operated by FPL in the former intake canal during cold periods (Fig. 3). The IWWR was heated to at least 68 °F (20 °C) when ambient water temperatures dropped below 65 °F (18.3 °C).

We documented manatee use of the regional warm-water network during and after this change in warm-water habitat in the northern Indian River Lagoon (NIRL), which extends from the Mosquito Lagoon to the Sebastian River (Fig. 1). This report presents an analysis, summary, and synthesis of findings from a 5-year telemetry study (2010-2015) of warm-water habitat use, winter movements, thermal regime, and external signs of cold exposure of manatees tagged in the northern Indian River. Satellite-linked GPS tags, archival temperature loggers deployed on manatees and stationed in water bodies, and field tracking provided data and insights into the ecology and behavior of manatees in the lagoon during winter. The project encompassed all three winters of the construction phase when the IWWR was in place, and the two subsequent winters after construction when the modernized power plant was operating.

Our study had the following specific objectives: (1) to document tagged manatee distribution, winter range, and migratory movements, with primary focus on the NIRL; (2) to characterize manatee attendance patterns at warm-water refuges, especially those at the FPL Canaveral site, in relation to environmental factors (i.e., ambient temperature, time of day); (3) to document tagged manatee use of the regional warm-water network, including identification of secondary sites, frequency of movements between FPL and secondary sites, and use patterns in relation to operation of the power plant or interim heating system; (4) to map the tagged manatees’ fine-scale habitat use of the discharge plumes created by the power plant and the interim refuge; (5) to characterize the thermal regime experienced by manatees to assess level of cold exposure; and (6) to describe the occurrence, severity, and progression of putative cold exposure lesions on tagged manatees over the winter.

We captured and tagged a total of 57 manatees in Decembers of 2010 through 2014 (10-13 manatees per winter) and tracked them over the winter into March. Argos-linked GPS tags recorded GPS fixes at 15-min intervals, as well as tag diving and activity (Fig. 4). Temperature loggers deployed on manatees (5-min intervals) and at fixed stations (30-min intervals) allowed us to compare the thermal regime experienced by manatees to that of ambient lagoon waters and of warm-water sites such as FPL-CCEC. Observations made during field tracking gave us a better understanding of why manatees visited particular sites and what activities they were engaged in at those habitats.
Manatee GPS Data Collection and Performance

The GPS tags provided a large amount of high-quality data on manatee habitat use and movements over fine spatial and temporal scales, 24 hours per day throughout the winter season. The median individual tracking duration was 93.5 days (interquartile range = 78.2 – 97.0 days) (Table 1). Continuous GPS tracks were maintained throughout the winter for 37 (65%) study animals, from tagging in mid-December through programmed release or recovery in mid-March. A total of 423,299 manatee GPS locations was recorded over the course of the 5-year study. The percentage of GPS fix attempts that were successful in acquiring a location was very high, averaging 94.5% (SD = 6.5) (Table 1). GPS accuracy varied across tag models but was quite good, generally within about 10-25 m of the actual location (Table 2). Presence in warm-water refuges for all GPS locations was assigned and inspected in GIS. For records with unsuccessful GPS fix attempts (and for outliers), we assigned warm-water refuge presence based on a combination of locational information from before and after the unsuccessful attempt and water temperature at the manatee relative to ambient and warm-water site temperatures.

Winter Range and Migratory Behavior

The combined winter range of our 57 tagged manatees extended along nearly 800 km of waterways, encompassing almost the entire Florida range of the Atlantic subpopulation from northeast Florida to Biscayne Bay; one individual crossed into the upper St. Johns River subpopulation region. About one-third of tagged manatees migrated to southeastern Florida, most leaving in December; all of those that retained their tagging gear returned to Brevard County during their tracking periods, sometimes in mid-winter. About 15% of tagged manatees migrated northward out of the study area, most in February, and about half of those returned to Brevard County and the FPL Cape Canaveral plant site during the winter. Despite the considerable dynamism of long-range movements, the vast majority (84%) of the 50 tagged manatees that were tracked ≥45 days spent at least half of the winter (i.e., ≥45 days) in the Brevard study area.

Even though captures occurred in the northern Indian River, nearly ½ of tagged manatees visited the Banana River, nearly ½ visited the southern Indian River, and about ¼ visited the Mosquito Lagoon (Table 3). Most individuals (72%) used just 1 or 2 of these 4 water bodies. The vast majority (83%) of tagged manatees had a core range in the northern Indian River. 29% had one in the Banana River and there were relatively few core ranges in the southern Indian River (10%) or Mosquito Lagoon (5%) (Table 3). When in the study area, tagged manatees spent most time (66%) in the northern Indian River (i.e., north of Eau Gallie), followed by the Banana River and associated waterways (18%), the southern Indian River (12%), and the Mosquito Lagoon (4%) (Table 3).

Use of the Regional Warm-water Network

The entire warm-water network used by manatees that seasonally migrate between the NIRL and southeast Florida covers at least 200-300 km of coastline (Fig. 2, Table 4). The ‘regional warm-water network’ in this study includes known thermal refuges in Brevard County (Fig. 1), as there are clear discontinuities in manatee use and movements to the north and south. Over 90% of all tracked manatees (52/57) visited the FPL Cape Canaveral warm-water refuge (IWWR and/or CCEC) during their tracking periods; the Satellite Beach thermal basins (Berkeley and Desoto Canals) were visited by 16% (N=9) of the animals; and 32% (N=18)
visited the Sebastian River C-54 canal, most as a stopover site during migration (Table 5). The FPL Cape Canaveral site provided the sole source of known thermal refuge for 62% (26/42) of manatees that spent at least 45 days in the study area; this parameter did not differ between the 3 winters when manatees used the interim refuge versus the 2 winters when they used the main discharge of the modernized plant. Likewise, FPL-CC was the principal warm-water site within the study area for 88% (37/42) of tagged manatees (Table 5). Given the proximity of the capture area to FPL-CCEC, the relative use of warm-water sites by tagged manatees is not considered to be representative of the entire manatee population in the county, but it should fairly represent warm-water habitat use and movements for the large number of manatees inhabiting the northern Indian River.

Manatees that spent little time at the known primary and secondary warm-water refuges still sought thermal shelter during cold weather. The combination of manatee movement and temperature data revealed several passive thermal basins in the study area that were typically warmer (generally by ~3-5 °C) than ambient lagoon waters. These included specific Merritt Island residential canals and parts of the Eau Gallie River, Crane Creek, and the south prong of the Sebastian River. We identified a strong temperature-inverted halocline throughout much of this south prong, with bottom water being substantially warmer and saltier than surface water.

**Attendance Patterns at Warm-water Refugia**

Tagged manatees visited an identified primary or secondary warm-water refuge along the east coast of Florida on an average of 48.0% of days (SD = 17.4) during their tracking periods. Visitation varied considerably among individuals, ranging from 5.2% to 85.7% of days tracked (Table 7). The percentage of time that they spent in known warm-water sites averaged 34.2% (SD = 15.4) over the tracking period, with use varying from 1.9% to 79.0% among individuals (Table 7). Much of this inter-individual variation, and in particular the relatively low use of known warm-water habitat by some individuals, can be attributed to those animals spending considerable time during mild winters in areas with no known, reliable, warm-water sites; this includes a region along the central-east coast roughly between the St. Lucie and Loxahatchee Rivers, and the use of rivers and creeks in southern Brevard County.

**Effects of Ambient Water Temperature and Time of Day** — Use of known warm-water refuges by tagged manatees in northern Brevard County was nil when mean daily ambient water temperature was above 21 °C, but use increased steadily as lagoon temperatures declined below that threshold (Fig. 13). When ambient temperatures dropped to <15°C, manatees spent ~80-90% of their time at 3 known sites (FPL-CCEC/IWWR, Berkeley Canal, and Desoto Canal). When the mean daily ambient water temperature was between 16-20 °C, manatees in the northern Indian River showed a clear diel pattern of attendance at the FPL site, with highest use during the day (~0900–1600 hr) and lowest use at night (Fig. 14), suggesting a pattern of nocturnal foraging. Diel attendance patterns were similar whether using the constant-temperature IWWR or the main discharge area with its daily fluctuation in temperature (Fig. 15), indicating that manatees were not timing their warm-water site use patterns to correspond with predictable diel patterns of power plant operation.

**Duration of Visits to Warm-water Sites** — Most continuous refuging bouts at warm-water sites in Brevard County were not lengthy; preliminary analyses indicate that median bout duration was somewhat more than ½ day. Durations of stay in the FPL refuges (IWWR/CCEC) of about 1 week or more were not uncommon, however, occurring in every winter during very cold
weather. During the period of prolonged and severe cold from December 2010 into January 2011—when there was a cold-induced unusual manatee mortality event in the region—nearly all tagged manatees remained in the IWWR for the vast majority of time. In fact, one adult female fasted in the interim refuge continuously for 32.2 days, a record for a free-ranging Florida manatee. The longest continuous stay in a known warm-water site by one of our tagged manatees was 48.5 days by an adult male at the FPL Ft. Lauderdale power plant cooling ponds and discharge canal; this individual spent over 99% of a continuous 64-day period within the confines of this industrial warm-water site. Other tagged individuals spent long periods of time continuously in these warm-water ponds; their movements and habitat use suggest that they often foraged on overhanging mangrove and bank vegetation while at the site.

**Manatee Response to Changes in Location and Operation of Warm-water Sources**

Manatees appeared to readily find and use the interim warm-water refuge in the former intake canal of the FPL Cape Canaveral plant at the start of the 2010-11 winter and then switched back again to the traditionally-used main discharge area with the operation of the modernized plant at the start of the 2013-14 winter. They preferentially aggregated in the warmest areas within the discharges (Fig. 16).

Testing of new turbines in the latter half of winter 2012-13 resulted in intermittent discharges of heated effluent from the two discharge pipes on the north side of the intake mole. Tagged individuals discovered the ‘new’ warm-water area between 4 hours and 38 days after the plant started its intermittent thermal discharge in late January; most found the warm-water source in the main discharge area on their first visit back to FPL-CCEC after testing began. Of the 62 visits to FPL-CCEC during this time period, 45% were just to the IWWR, 11% were just to the main discharge area, and 44% were to both sites. Manatees commonly stopped in the main discharge area on the way to or from the IWWR, and sometimes they moved back and forth between the two sites during a visit. During this period with two asynchronous warm-water sources at FPL-CCEC, manatees split their time unevenly between the two thermal refuges, spending 4-fold more time in the warmer and more reliable IWWR than in the main discharge area (Fig. 7). This was reflected in the substantially longer bout durations in the IWWR compared to the main discharge area. Manatees did not linger in the latter area when there was no thermal discharge at the time of their visit; furthermore, they were responsive to plant operation, usually leaving the main discharge area within 1 hr after the thermal input to the discharge was turned off.

**Fidelity to a Former Warm-water Site** — Creation and operation of the interim heated refuge for 3 winters while the power plant was undergoing modernization presented us with an opportunity to investigate the development and potential loss of manatee fidelity to a temporary warm-water site. During the first winter (2013-14), after the IWWR was no longer operational, most tagged manatees visited the site, typically multiple times. Use of the former refuge by tagged manatees declined substantially in the subsequent winter (2014-15), in terms of the proportion of manatees making a visit, the number of visits per manatee, and the percentage of manatee-days at FPL-CCEC that involved a visit to that site (Table 8). Visits to the former refuge were consistently brief, averaging 2.2 hr in both winters, probably because water temperatures were nearly always a few degrees cooler there than in the main discharge area (Table 8). We infer that manatees developed site fidelity to the reliably heated IWWR over the 3 winters of operation, which resulted in manatees checking for the continued availability of that thermal source in the next
winter. The much lower use of the former IWWR in the last winter suggests that fidelity to this site had waned substantially over the course of another year.

**Foraging Areas and Freshwater Sources**

Manatees behaved as central-place foragers in winter, using various warm-water refuges in the NIRL as focal points from which to make feeding trips to seagrass beds, generally within ~30 km. The most heavily used feeding areas by tagged manatees were seagrass beds along the eastern shore of the lagoon between A. Max Brewer Parkway (SR 406, 17.5 km north of FPL-CCEC) to Rinker’s canal (3.5 km east of FPL-CCEC), a shoreline distance of about 25 km (Figs. 10 and 11). Manatee foraging range was constrained by water temperature, shrinking considerably during cold weather (Fig. 12), when foraging trips were often quite brief.

Freshwater sources were often focal points of manatee activity during the winter dry season (Figs. 10 and 21). Major sources of freshwater used by tagged manatees in the northern Indian River proximate to the FPL-CCEC power plant were identified (Table 11). The effort that manatees put forth to seek out and drink freshwater suggests that it is both important to their physiology and perhaps even limiting at times. This may have been especially true in winters 2011-12 and 2012-13, during which there was a severe drought in north-central Florida.

**Thermal Regime Experienced by Manatees**

Ambient waters in the northern Indian River during the period of tracking (mid-December to mid-March) were often below the Florida manatee’s thermoneutral zone: <16 °C 21% of the time, between 16–20 °C 43% of the time, and ≥20 °C 36% of the time (Table 9). In contrast, manatees in the study area were not exposed to these cold temperatures nearly as often: on average, only 2% of the time in waters <16 °C, 23% of the time between 16–20 °C, and the remaining 75% of the time in waters ≥20 °C. This demonstrates how effectively manatees shifted the thermal regime in their favor through active warm-water habitat selection (Fig. 20). This was especially true for the extremely cold winter of 2010-11 when lagoon temperatures were below 16 °C nearly half of the time, yet manatees averaged only 5% of their time below that threshold (Table 9). Manatees experienced a remarkably wide range in water temperatures in this region, from a minimum of 8.3 °C to a maximum of 33.9 °C. The minimum water temperature recorded by the manatee-borne loggers averaged 13.5 °C across individuals.

**Visual “Health” Assessments: Cold Exposure Signs**

External signs of exposure to cold on the manatees’ skin were assessed based on a review of field observations and photographs. This is the first time that such detailed longitudinal assessments of cold exposure signs have been conducted at the individual level over the course of a winter. All tagged manatees showed some signs of exposure to cold at capture and during field observations later in the winter. Small superficial lesions that were circular, linear, or irregular in shape and bleaching of the skin were the two most common types of cold exposure signs (Table 12). The cold signs were scored as slight for all but two individuals throughout the winter; those two manatees were scored as moderate during their mid-winter assessment and as slight during their late winter assessment. Superficial abrasions incurred during the capture process often later manifested as white marks or lesions, the healing of which may have been hampered by exposure to cold water temperatures or possibly by cold-induced immunosuppression. When considering changes in skin condition over all body regions, the
signs of cold stress generally worsened from early to mid-winter, whereas from mid- to late winter they either improved or showed a mixture of improvement in some signs and worsening in others (Table 14). Worsening of skin condition was most often seen on the fluke and improvement most often on the head (Table 13); this difference may be due to higher perfusion of blood in the skin of the head compared to the extremities. Contrary to expectations, the progression of apparent cold exposure signs over the winter was not significantly related to the amount of time that tagged individuals spent in waters <20 °C over their tracking period (Table 15). Future applications of this cold stress assessment system could benefit from subdividing the broad category 1 score into finer levels.
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2. Freshwater sources at FPL-CCEC intake canal (i.e., IWWR), including locations and flows, during winter.
INTRODUCTION

The modernization of the Florida Power & Light Company’s Cape Canaveral power plant (FPL-CC) to create the Cape Canaveral Next Generation Clean Energy Center (FPL-CCEC) near Titusville (Brevard County, Florida) entailed a change in warm-water habitat at a primary Florida manatee (Trichechus manatus latirostris) aggregation site that has been traditionally used by large numbers of these endangered marine mammals during winter. Manatees have overwintered at power plants in this area of Brevard County for decades (Shane 1984, Laist and Reynolds 2005a), often in significant numbers: 625 manatees were tallied at the two Indian River power plants in 2007 (FWC, unpublished data), and 930 and 1110 manatees were counted at the Cape Canaveral plant in December of 2013 and 2014, respectively (Reynolds and Scolardi 2014, 2015). The nearby Indian River power plant, now owned by the Orlando Utilities Commission (OUC), which had also been used regularly by manatees for thermal refuge over the past few decades, was shut down in the fall of 2010, hence further increasing the importance of having reliable warm water produced at the FPL site.

Manatees have limited ability to thermoregulate in cold waters due to their extremely low metabolic rate and high thermal conductance (Irvine 1983, Worthy et al. 2000). Typical ambient water temperatures in this region are too cool for manatees to survive throughout the winter without access to warm-water habitat (Deutsch et al. 2003b). A recent preliminary analysis of sighting histories for 585 manatees photo-identified at power plants in Brevard County during the months of December through February found that 37% had no sightings south of Brevard County during the winter season (Cathy Beck, U.S. Geological Survey, pers. comm.). This suggests that large numbers of manatees relying on the FPL-CCEC plant may lack familiarity with migratory pathways and other thermal refugia and may therefore be at particular risk. Given the strong site fidelity exhibited by manatees (Deutsch 2000, Deutsch et al. 2003b), and the observed behavioral responses to and mortality associated with loss or interruption of warm-water effluents (Campbell and Irvine 1981, Packard et al. 1989, Ackerman et al. 1995, Deutsch et al. 2000, Laist and Reynolds 2005b), it is generally recognized that the sudden unmitigated elimination of a key industrial thermal refuge could have catastrophic consequences for the manatee population in terms of immediate mortality and long-term reduction in carrying capacity (Laist and Reynolds 2005b).

The dismantlement of FPL’s former Cape Canaveral power plant started in mid-2010 and the modernized plant (FPL-CCEC) became fully operational in April 2013 (FPL 2008, Jodie Gless, FPL, pers. comm.). FPL complied with FWC’s manatee-related conditions of certification for the construction and operation of a temporary heating system at the power plant site during the winters of 2010-11 through 2012-13. In winters during the three-year construction period, FPL provided warm water for manatees with an electric heating system to create a thermal refuge in a portion of the existing intake canal. Pursuant to the conditions of certification, FPL was required to operate the system when ambient water temperatures dropped to 65 °F (18.3 °C), at which time the interim warm-water refuge (IWWR) would be heated to at least 68 °F (20 °C) and maintained at that temperature until the ambient waters exceeded 65 °F. After a 3-year hiatus, FPL-CCEC returned to operation in 2013 and, per its National Pollution Discharge Elimination System permit conditions, the ambient water temperature threshold returned to the previous 61 °F (16.1 °C), below which the plant would endeavor to discharge water of at least 68 °F.
The state’s Manatee Management Plan recognizes that “...it will be crucial to take advantage of temporary or permanent shutdowns through research and monitoring of manatee movements, behavior, and survival to gain better predictive ability on manatee population response to changes in warm-water availability” (FWC 2007, p. 102). This need was echoed in an interagency workshop that addressed manatee habitat conservation priorities (USFWS 2007) and in the federal Florida Manatee Recovery Plan (USFWS 2001). Furthermore, the state Manatee Management Plan identifies the assessment of management alternatives for the loss of industrial warm-water habitat as an important recovery task (FWC 2007, p. 59). Over the long term it will be desirable to shift manatees to a warm-water network consisting of warm-water sources not dependent on technology (Laist and Reynolds 2005b, FWC 2007, p. 58)—a view also recognized in FPL’s site certification permit conditions.

The principal approaches for studying manatee response to habitat change—aerial surveys, telemetry, and photo-identification—are complementary, each providing valuable data only obtainable from that approach. Aerial surveys, for example, provide synoptic snapshots of manatee distribution, relative abundance, and habitat use over large areas (along the survey route) at given points in time. In contrast, telemetry provides detailed information on movements, habitat use, and thermal regime continuously over the tracking period for a relatively small number of individuals, from which inferences can be made about behavior of the overall population.

Satellite-linked telemetry is the only approach that is not limited to finding manatees where and when we look for them. Thus, tagged individuals can lead us to additional potential sites to monitor via aerial surveys and photo-ID. Because this tool provides information on fine-scale movements and habitat use 24 hr per day, it provides a temporally more comprehensive perspective on distribution and movements, given that nocturnal behavior and habitat use in winter often differ from that during mid-day (Rathbun et al. 1990, Deutsch et al. 1998, 2006, Barton 2006, Deutsch and Carlson 2007).

This report presents an analysis, summary, and synthesis of findings from a 5-year telemetry study of warm-water habitat use, winter movements, thermal regime, and external signs of cold exposure of manatees tagged in the northern Indian River. Satellite-linked GPS tags, archival temperature loggers deployed on manatees and in water bodies, and field tracking provided data and insights into the ecology and behavior of manatees in the lagoon during winter. The project encompassed all three winters of the construction phase when the interim warm-water refuge was in place, and the two subsequent winters after construction when the modernized power plant was operating. Detailed findings from each of the five winters can be found in annual reports by Deutsch and Barlas (2011a, 2012, 2013, 2014, and 2015), which are provided as appendices to the Summary Biological Monitoring Report.

Objectives

The overall goal of this telemetry study was to document manatee behavioral response during winter to a change in warm-water habitat in the northern Indian River associated with the conversion of the Cape Canaveral power plant, the manatees’ principal winter aggregation site in the region. We address the following specific objectives:

1. To document tagged manatee distribution and winter range, with primary focus on the northern IRL;
2. To characterize warm-water refuge attendance patterns and movements in relation to environmental factors (e.g., ambient temperature, time of day);

3. To document tagged manatee use of the regional warm-water network, including identification of secondary sites, frequency of movements between FPL and secondary sites, and use patterns in relation to operation of the power plant or interim heating system;

4. To map the tagged manatees’ fine-scale habitat use of the discharge plumes created by the power plant and the interim refuge.

5. To characterize the thermal regime experienced by manatees to assess level of cold exposure;

6. To describe the occurrence and progression of putative cold exposure lesions on tagged manatees over the winter, and to relate that to inter-individual variation in thermal regime experienced; and

**STUDY AREA**

The study area encompasses waters in Brevard County, Florida, centered on the Cape Canaveral Next Generation Clean Energy Center (CCEC) located about 15 km south of Titusville near the town of Port St. John (Fig. 1). The plant lies along the western shore of the Indian River, which is actually a brackish estuary separated from the Atlantic Ocean by barrier islands. The portion of the Indian River Lagoon (IRL) within Brevard County comprises three major water bodies—the Mosquito Lagoon, the Indian River, and the Banana River. There are only three connections to oceanic waters in the northern portion of the IRL: Ponce Inlet (Volusia County), which is 43 km north of Haulover Canal (separating Mosquito Lagoon from the Indian River); Port Canaveral, which is separated from the Banana River by the Canaveral Locks and therefore has limited water exchange; and Sebastian Inlet at the southern border of Brevard County. Consequently, the flushing rate of this enclosed lagoon is very low; for the IRL as a whole, only 2-15% of the water is exchanged with oceanic water via inlets annually (Adams et al. 1995), and tidal residence periods can exceed one year in the northern IRL (Littler et al. 2008). This fact has a number of implications for manatee habitat: salinity levels are greatly influenced by amount of rainfall and proximity to creeks, varying from <10 to >35 ppt (Steward et al. 2006, McGinnis et al. 2008); variation in water levels away from inlets is largely driven by winds rather than tidal fluctuations (Woodward-Clyde Consultants 1994, Littler et al. 2008); and water-borne contaminants likewise have longer residence times and can build to higher concentrations than in water bodies with higher flushing rates. Except for dredged channels, such as the Intracoastal Waterway (ICW) that runs north-south throughout the length of the IRL, the lagoon waters are quite shallow, averaging no more than 2 m in depth (Steward et al. 2006, Littler et al. 2008).

**Warm-water Habitat**

Water temperatures in the northern IRL during winter frequently fall below 20 °C, which is the approximate lower limit of the manatee’s thermal neutral zone (Worthy et al. 2000) and the threshold at which manatees generally start to seek thermal refuge (Hartman 1979, Shane 1984, Deutsch et al. 2003b, 2006). Over a 10-year period (1988-1998), the mean daily water temperature in the upper Banana River and Banana Creek was less than 20 °C on two-thirds of days during the months of December through February (Deutsch 2000). Ambient water
temperatures in the northern Indian River during this 5-year study support this finding and are summarized in the Results below (see Table 9). The shallowness of the lagoon results in rapid drops in water temperature as cold fronts pass through the region; waters typically warm up quickly during milder periods between fronts. This temperature fluctuation above and below the animal’s known lower thermal limit provides numerous opportunities to record manatee response to cold.

**Warm-water Sources at FPL Cape Canaveral Plant**

For about five decades prior to this study, two power plants in Brevard County discharged heated effluents into the IRL on a fairly consistent basis: the OUC Indian River plant since 1959, and the FPL Cape Canaveral plant since 1965 (Shane 1983, 1984) (Fig. 1). Manatees found these man-made warm-water habitats and learned to use them and rely on them for thermal shelter in winter. With the retirement of the OUC Indian River power plant in 2010, there was only one industrial warm-water effluent remaining in Brevard County—the FPL Cape Canaveral power plant, which is considered a primary warm-water refuge for manatees (FWC 2007). Indeed, this site is the only primary warm-water refuge on the Atlantic coast north of Riviera Beach (Fig. 2). A history of the changes in the production and location of warm-water sources at the Canaveral plant between 2009 and 2015 is summarized below.

**Winter 2009-10 (FPL-CC, Pre-conversion, prior to study)**—During and prior to the winter of 2009-10, thermal discharges at this site occurred at one or both of two effluent pipes into an exposed area of the Indian River north of the intake mole (Fig. 3). As the plant neared retirement in the last years prior to modernization, it operated at a lower load because it was less efficient than other plants. Consequently, it operated more intermittently and sometimes did not produce warm water for periods of time (Barlas et al. 2011), except as required by permit.

**Winter 2010-11 (IWW, Construction Year 1)**—The heating system for the IWW was installed in fall 2010 in the former intake canal, but initially it failed to create a warm-water habitat. Subsequently, modifications were made in November and early December 2010 to ensure that the permit conditions for the thermal refuge would be met. This included the installation of surface-to-bottom curtain booms—one at the footbridge along the eastern end of the canal and one bisecting the canal (north to south) approximately in the middle—in order to reduce heat loss through exchange with cooler waters (Deutsch and Barlas 2011a) (Fig. 3). The yellow booms each had a 12-ft wide by 5-ft deep opening to allow manatees ingress to and egress from the IWW. This reduced the size of the originally designed IWW from 0.8296 hectares (2.05 acres) (FPL 2008) by 58% to approximately 0.3517 hectares (0.869 acres), as measured using imagery in Google Earth Pro. Because of the severe cold at the time, a second heater was added in early December 2010 to supplement the heat output of the primary system (by up to 82%) during periods of low ambient temperature conditions. The secondary discharge pipe was situated about mid-way between the main discharge pipe and the intake structure (Fig. 3).

**Winter 2011-12 (modified IWW, Construction Year 2)**—As construction on FPL-CCEC continued, modifications to the IWW were necessary. In the spring and summer of 2011, a sheet pile wall (running east to west) was installed in the former intake canal thereby dividing it into an heated northern half, which would provide cooling water to the plant intake structures, and a southern half, which would be heated in the winter to create a manatee refuge (Fig. 3). The sheet pile wall, constructed from durable, rigid vinyl, extended approximately 655 feet (200 m)
from the cement seawall at the western end of the canal to just beyond the footbridge at the eastern end of the canal (FPL 2011). Both of the surface-to-bottom curtain booms were removed, and an additional sheet pile wall was installed parallel to the footbridge to reduce the amount of heat loss through exchange with cooler ambient waters; this wall extended north-south approximately 65-ft (19.8 m) from the southern cement seawall to the intersection with the east-west sheet pile wall. A 10-ft wide by 5-ft deep (3.0 x 1.5 m) opening in this north-south wall allowed for manatee ingress to and egress from the IWWR. Removable panels were installed along the walls to allow for surface flushing of manatee fecal matter, dead fish, and other debris out of the enclosed canal, as needed. These modifications slightly reduced the size of the IWWR (by 11%) to approximately 0.3115 hectares (0.770 acres) in winters 2011-12 and 2012-13. The main discharge pipe for the heated water was moved to the western end of the canal. The submerged end of this pipe, which was secured just above the bottom, was “T”-shaped such that the water flowed from the pipe northward and southward; this design promoted diffusion of the hot water from the point source throughout the canal, but also drastically decreased visibility as the strong flow stirred up the silty, soft sediment on the bottom.

**Winter 2012-13 (modified IWWR and testing FPL-CCEC, Construction Year 3)**—The IWWR was operated in the same location and manner as the previous winter. A warm-water source was re-introduced in the main discharge area of FPL-CCEC (i.e., north of the intake mole) when the plant began testing its units in mid-winter (27 January 2013). This resulted in the discharge of thermal effluent from both of the discharge pipes (#1 and #2) on a near-daily but intermittent basis (89% of days, 65% of hours) throughout the remainder of the winter, albeit often at a low heat output. Unlike the former plant, which could direct its discharge into one or both pipes, the modernized plant always discharges at both sites simultaneously (Doug Foust, FPL, pers. comm.), meaning that the temperatures are nearly the same at both sites. Pumps circulated the water through the plant almost continuously, even when the plant was not operating and there was no thermal load to release. Although FPL-CCEC operated with one less intake pump (3) than the old plant (4), the bifurcation of the intake canal to create the IWWR resulted in a faster current into the intake canal than had previously existed.

**Winter 2013-14 (FPL-CCEC, Post-construction Year 4)**—The power plant started full-time operation in late April 2013 and henceforth, warm water has been discharged from both outfalls north of the mole (Fig. 3). Heaters in the intake canal were shut down at the end of winter 2012-13, but they were left in place as an emergency back-up system should the main plant fail or not produce sufficient heat during an extreme cold spell. The sheet pile wall dividing the intake canal was also left intact. During winter 2013-14, the main CCEC plant experienced full or partial shutdowns for periods of time, including: November 12-19 (scheduled full shutdown), January 8-13 (unanticipated partial shutdown for repairs, one combustion turbine offline), January 20-22 (unanticipated brief full and longer partial shutdown for repairs), and March 14-21 (scheduled full shutdown). The back-up heating system was not turned on during these events because ambient temperatures were sufficiently mild.

**Winter 2014-15 (FPL-CCEC, Post-construction Year 5)**—The power plant operated similarly to the previous winter. Likewise, it shut down for periods of time during winter 2014-15, including at least the following dates: November 14-27 (scheduled full shutdown), November 27 - December 2 (unanticipated partial shutdown) and March 14-21 (scheduled full shutdown). The IWWR was heated for approximately 41.5 hr when the plant was offline during a cold period
from November 19-21; ambient lagoon temperatures (at FWC IRN station) dropped to as low as 15.2 °C (59.4 °F) during that time period.

Passive Thermal Basins

There are three known non-industrial warm-water sites—termed passive thermal basins for their ability to retain heat longer than ambient waters—used regularly by manatees for thermal shelter in Brevard County during cold periods (Fig. 1). These have been considered secondary warm-water habitats, which are generally used by smaller aggregations of manatees—especially during cold weather—and may not provide sufficient thermal refuge during very cold periods. The degree to which these sites provided adequate thermal refuge for manatees during the unprecedented cold of winter 2010 is detailed in a report on the unusual mortality event (Barlas et al. 2011). Some sites have attracted relatively large numbers of manatees in recent winters and may provide sufficient warmth (Spellman 2014).

Berkeley Canal—This long, shallow east-west canal is located in the residential canal systems of Satellite Beach off the southern Banana River. In recent years, Berkeley Canal has attracted large numbers of manatees: up to 193 manatees have been counted there during the winter months and up to 261 in mid-March after southern migrants have returned to the area (Reynolds and Scolardi 2013, 2014, 2015). Spellman (2014) provides a site characterization as manatee warm-water habitat.

Desoto Canal—This site is actually a narrow (6-8 m wide), shallow stormwater drainage ditch (120 m long) off of Desoto Canal, also located in Satellite Beach about 4 km south of Berkeley Canal. Manatees were first observed aggregating here during the extreme cold period of winter 2009-10 (Spellman 2011). Various pieces of evidence suggest that manatees temporarily shifted from Berkeley to Desoto when temperatures dropped precipitously that winter (Spellman 2014). The discharge from the stormwater pipes was fresh or brackish and warm, from 19-24 °C (66.2-75.2 °F) along nearly the entire length of the drainage ditch, based on spot measurements taken that winter. Subsequent temperature monitoring has shown this site to have stable, spring-like temperatures, typically averaging ~23 °C and not falling below 20 °C. Three record high ground counts were made in the confined area of the ditch at Desoto Canal during the 2014-15 winter: 166 in January, and 197 and 261 in February 2015 (Ann Spellman, FWC, pers. comm.); the highest aerial count to date was 110 in January 2014 (Reynolds and Scolardi 2014).

Sebastian C-54 Canal—The most southern warm-water aggregation site in the study area is a large water management district canal (C-54) located at the west end of the north fork of the Sebastian River near the Brevard County-Indian River County border (Fig. 1). This passive warm-water habitat is an important stopover site for a large number of migrating manatees during the spring and fall and is used to a variable extent by manatees during the winter months (Deutsch 2000, Deutsch et al. 2003b). On 10 December 2010, 704 manatees were counted in the C-54 canal, representing 48% of all manatees counted in Brevard during that aerial survey (Reynolds et al. 2011); this almost certainly reflected the pulse of a relatively synchronous southern migration prompted by the extremely cold weather.

In addition to these three non-industrial warm-water aggregation sites, other sites used by manatees in Brevard County—including canals, dredged basins, and creeks—may act as passive thermal basins to varying extents. These include Eau Gallie River (at the upstream weir), Crane Creek (portions of middle and upper sections), Merritt Island High School canal, and the south prong of the Sebastian River where a temperature-inverted halocline has been documented.
(Deutsch and Barlas 2013, 2014) (Fig. 1). Our tagged manatees regularly visited these sites during some winters. It seems unlikely that any of them provide substantial thermal shelter during prolonged cold weather, but they do appear to provide a large amount of warm-water habitat for manatees during mild weather and short periods of cold weather.

During winter 2014-15 a new manatee aggregation site was discovered in a pond next to the Satellite Beach City Hall, located ~2 km north of Desoto Canal. Up to 59 manatees were counted there from the ground on 19 February 2015 (Ann Spellman, FWC, pers. comm.). Preliminary water temperature and salinity measurements indicate a warm freshwater source that appears similar to that at Desoto Canal: 22.4 °C and 2 ppt (Ann Spellman, FWC, pers. comm.). Water inputs are a combination of storm water and artesian well and ground water (Allen Potter, City of Satellite Beach to Ann Spellman, FWC, pers. comm.). Grating in the box culvert that had previously prevented manatee access to this pond was removed in mid-2013. Given the entrapment of 20 manatees on 23 February 2015 in stormwater pipes entering the pond, as well as considering other factors, managers decided to have the City of Satellite Beach replace the grate to preclude manatee access to this retention pond after this winter. Future temperature monitoring will evaluate the thermal quality of the site, which can be considered for potential manatee use as a warm-water refuge when other issues are adequately addressed.

**Submerged Aquatic Vegetation (SAV)**

The extensive shallows in the northern IRL are conducive to the proliferation of seagrass, which is normally found in abundance here (Virnstein et al. 2007). In fact, more seagrass is found in the NIRL than in all other areas along the east coast combined until one reaches Biscayne Bay (Yarbro and Carlson 2013). The most common species found are shoal grass (*Halodule wrightii*) and manatee grass (*Syringodium filiforme*), with much lesser amounts of widgeon grass (*Ruppia maritima*) and star grass (*Halophila engelmannii*). Three other species are found in the IRL from Sebastian Inlet south: turtle grass (*Thalassia testudinum*), paddle grass (*Halophila decipiens*), and Johnson’s seagrass (*Halophila johnsonii*) (Littler et al. 2008). In addition, there is a wide variety of species of benthic and drift macroalgae, including *Caulerpa prolifera*, *Ulva* sp., *Gracilaria* sp., and many others (Littler et al. 2008).

During our study, however, seagrass cover and density in the northern IRL was markedly reduced to the lowest point ever recorded. So the amount of forage for manatees in the lagoon was drastically reduced after the first winter of the project; then it started to slowly recover during the last two years. Researchers and water managers are concerned that this biologically diverse estuary might be undergoing a regime shift from a macrophyte-based system (seagrass, macroalgae) to a phytoplankton-dominated system of primary production (Steward 2013, Phlips et al. 2014). This concern stems from three consecutive years of algal (phytoplankton) blooms that dramatically reduced water clarity and killed seagrass throughout the IRL from the Mosquito Lagoon to Ft. Pierce (Phlips et al. 2014). First, prolonged phytoplankton blooms that started in the latter half of 2010 and continued from early spring through late fall of 2011 caused a massive seagrass die-off. The “superbloom” of unicellular algae—dominated by pico-cyanobacteria and a marine chlorophyte species (*Resulor* sp., class *Pedinophycaceae*)—severely reduced water clarity throughout the Banana River, northern Indian River (north of Eau Gallie), and southern Mosquito Lagoon (Lasi 2012, St. Johns River Water Management District et al. 2012, Phlips et al. 2014). Seagrass and water quality experts are referring to this event as a “superbloom” because it was unprecedented, “far exceeding any events previously documented in terms of
geographic scale, bloom intensity and duration, and rate and magnitude of seagrass loss” (St. Johns River Water Management District et al. 2012, p. 3). A large contraction of the depth distribution of seagrass occurred throughout the system, including the southern IRL, which was impacted by a different phytoplankton bloom (dominated by cyanobacteria and diatoms) in 2011. The extent of seagrass loss based on aerial imagery from 2009 to 2011 was significant: 87% decline in the Banana River, 69% loss in the central IRL (Melbourne to Vero Beach), 25% loss in the northern IRL (Turnbull Basin to Eau Gallie, with losses increasing from north to south), and actually a small gain (2.6%) in the Mosquito Lagoon (Morris et al. 2015). Total loss across the entire IRL during that time period was 42%, exceeding 33,000 acres (Morris et al. 2013, 2015, Morris and Chamberlain 2015); further losses occurred in 2011 after that year’s seagrass survey was conducted and again in 2012. Complete loss of seagrass was documented along 20 fixed transects in the central Indian River between Cocoa and Vero Beach, as well as along some transects in the Banana River (Morris et al. 2013, 2015, Morris and Chamberlain 2015). Seagrass biomass in the northern Indian River and the Banana River combined declined by 40% from 2010 to 2011 (Phlips et al. 2014). Long-term drought also resulted in hypersalinity of these lagoons in 2011, not causing mortality but potentially adding further stress to SAV communities.

Seagrass recovery was hindered in 2012 by the development of two different but very dense algal blooms that again severely attenuated light penetration: a dinoflagellate (Pyrodinium bahamense) bloom in the Banana River, and a dense ‘brown tide’ bloom of a single-celled pelagophyte (Aureoumbra lagunensis) in the northern Indian River and Mosquito Lagoon that discolored waters to a murky brown (Phlips et al. 2014). Both of these blooms resulted in further loss of seagrass habitat, especially in the Banana River, where formerly vast seagrass beds all but disappeared. Despite the occurrence of several smaller algal blooms during 2013—including brown tide in the northern IRL and Mosquito Lagoon, P. bahamense in both the Banana and Indian Rivers, and Takayama tasmanica, another dinoflagellate responsible for fish kills due to oxygen depletion—some seagrass recovery has been evident recently. Aerial photographs from 2013 show that there was a 12% increase in seagrass acreage lagoon-wide since 2011, although this is still 36% below pre-bloom 2009 levels (Morris and Chamberlain 2015, Morris et al. 2015). SAV transects have generally shown increasing extent of seagrass offshore through 2014, although it is sparse in those areas that suffered the greatest loss (Morris et al. 2015).

Another important change to the ecosystem was the unusual (and unexplained) disappearance of drift macroalgae, normally the most abundant aquatic macrophyte community in the IRL, in fall of 2010 and its lack of recovery in the subsequent two years (St. Johns River Water Management District et al. 2012, Phlips et al. 2014, Morris et al. 2015). Macroalgae plays an important role in soaking up and storing nutrients in the water column and so the decline in this vegetation and subsequent increased availability of nutrients may have helped to fuel the development of the large phytoplankton blooms that have occurred in the system (Morris et al. 2015). Macroalgae is also eaten by manatees, and so the simultaneous loss of large amounts of both types of SAV reduced forage availability. Macroalgae returned to some areas by 2012 (Phlips et al. 2014) and this recovery continued in 2013 and 2014 (Morris et al. 2015). It was abundant in some areas in 2014, especially Chaetomorpha in the northern Indian River and Ulva in the Banana River (Morris and Chamberlain 2015; Lori Morris, SJRWMD, pers. comm.).
Unusual Manatee Mortality Events

During the timeframe of our telemetry study the population of manatees in central-east Florida, including Brevard County, suffered 3 unusual mortality events (UME)s. Record cold weather led to a manatee die-off between January and April 2010 that was unprecedented in the history of manatee research and conservation in Florida because of its statewide extent, severity, and duration. In the central-east region of Florida, which encompasses the coastline between Brevard and Martin Counties, 187 manatee carcasses were recovered over the 89-day duration of the UME; 72% of those were assigned cold stress as cause of death; excluding those whose cause of death was undetermined, cold stress was the culprit in 95% of cases (Barlas et al. 2011). The following winter of 2010-11 began with severe cold in early December that lasted through most of January; this resulted in a cold die-off in the central-east region that lasted 58 days (Deutsch 2012). Water temperature data collected in this study shows how much colder winter 2010-11 was than the subsequent 4 winters (Table 9). In both cold events, calves and subadults suffered most from the severe cold in terms of health and mortality.

A multi-species UME that included manatees, brown pelicans (Pelecanus occidentalis), and bottlenosed dolphins (Tursiops truncatus) occurred in the NIRL in 2013 (Landsberg and de Wit 2014). Although there is no clear connection between the elevated deaths of these 3 species, these mortality events followed the dramatic reduction of seagrass in the lagoon caused by the long-lasting phytoplankton blooms described above. From the manatee UME’s inception in July 2012 to the end of this study in March 2015, a total of 149 manatee deaths were attributed to this event (including 6 carcasses found in Volusia County or the Sebastian River). The peak number of carcasses were found between February and April 2013. In March 2013 alone, 100 manatee carcasses were recovered from the county’s waterways, more than 10 times the baseline average for this month. Unlike recent winter UME’s in this region that were attributable to cold weather (Barlas et al. 2011, Deutsch 2012), the cause of this die-off remains unknown and is currently under active investigation (Landsberg and de Wit 2014). The animals appeared to have died suddenly and were in good body condition with full gastrointestinal tracts. The cause is thought to be somehow related to the major ecosystem disruption in the northern IRL described above. Manatee deaths meeting the UME case definition were concentrated in some of the areas of greatest seagrass loss and were generally associated with consumption of macroalgae.

METHODS

We monitored warm-water habitat use, winter movements, behavior, external signs of cold exposure, and thermal regime of individual manatees over fine spatial and temporal scales using Argos-linked GPS tags, archival temperature loggers at fixed stations in the northern IRL and attached to manatee tagging gear, and field tracking (Deutsch et al. 2003a, 2006).

Manatee Captures

Manatees were captured over two- or three-day periods in December from 2010-2014 between the NASA Causeway (SR 405) to the north and FPL-CCEC to the south (Fig. 1). The base of operations for boat launching and for conducting health assessments and tagging was established at the mouth of the FPL-CCEC intake canal in 2010, but became unavailable in later years due to construction activities that precluded shoreline access. The base of operations was moved ~3km north to the former intake canal of the OUC power plant in 2011. In addition to a larger space in which to work at the OUC site, the NASA Causeway and the OUC intake moles
provided suitable wind breaks that allowed us to carry out boat operations in calmer waters in the presence of northerly winds.

Standard capture techniques using nets deployed from a specialized manatee capture/rescue vessel were employed (Weigle et al. 2001). To increase the efficiency and safety of capture operations, one or two aerial observers flying in a single-engine Cessna airplane located target animals and guided the capture boat captain in setting the net. Other vessels waited nearby to collect data on the capture attempts, to carry gear, and to provide assistance if needed. In all but one instance, individuals were captured alone, secured on board, and transported to the work-up area. One modified land-based net set along the NASA Causeway resulted in the capture of three manatees, all of whom were secured on the beach at the capture site for work-up. Tagging and collecting health data on land instead of in a boat permitted better control of the environmental conditions, such as temperature, affecting the captured animals; and it allowed faster and more efficient processing by a larger ground crew.

As part of a health study being carried out in conjunction with the U.S. Geological Survey and the University of Florida, a full health assessment was conducted on each manatee, which included: morphometrics (lengths, girths) and weight; ultrasonic measurements of backfat thickness; blood chemistry and hematology; collection of urine and fecal samples; collection of a skin sample and blood for genetic analyses; photo-documentation of scars, wounds, and lesions; assessment of overall body condition; notes on presence, stage, and types of external signs of cold exposure; and a descriptive clinical assessment by a veterinarian experienced in assessing and treating manatees. Two PIT (passive integrated transponder) tags were inserted subdermally to aid in future identification (Wright et al. 1998). Blood gases and vital signs—including respiration rate, heart rate, and oral temperature—were monitored while the animal was out of the water. Oxygen was routinely provided during inspirations to further reduce stress on the animals.

Captured manatees were assigned an age class based on standard (straight-line) length measurements, as established by the interagency manatee photo-identification program: adults were >265 cm, subadults were between 236 cm and 265 cm, and calves were <236 cm. The 265 cm threshold for adults was based on a review of size-specific reproduction data for females (Marmontel 1993), and it has been used in manatee telemetry and other publications (e.g., Barlas et al. 2011, Deutsch et al. 2003b, Deutsch et al. 2006). Females less than 266 cm were also considered adults if they were pregnant, lactating, or with a nursing calf. Calf-sized animals that were at least 200 cm long and independent of their mother are referred to here as juveniles.

**GPS Tag Deployment and Recovery**

A buoyant Argos-linked GPS tag (Gen IV; Telonics, Inc.) was attached in the conventional manner to a padded belt around the manatee’s peduncle via a flexible 1.5-m-long tether (or 1.2 m for 3 small juveniles/subadults), allowing the transmission and reception of radio signals when the manatee was at depths up to 2 m (Deutsch et al. 1998) (Fig. 4). In addition to the GPS unit, each tag housed a 0.5 W PTT (platform transmitter terminal) to transmit the GPS and sensor data to polar-orbiting NOAA satellites, and a VHF transmitter for field tracking. The tags were programmed to acquire GPS fixes at 15-min intervals throughout the 24-hr cycle. Satellite orbital data programmed into the tag just prior to deployment permitted the PTT to transmit only when the satellites were passing overhead, hence increasing operational life and data throughput. This allowed us to track the tagged animals’ movements and activity (i.e., tag
activity and diving frequency and duration) remotely and in near-real-time via the satellite-based Argos Data Collection and Location System (CLS 2011). A saltwater switch was linked to both the PTT and GPS units in order to time transmissions and fix attempts to tag surfacings and, hence, increase Argos and GPS location success and save battery life. The entire data record was archived in the tag’s memory and downloaded to computers after tag recovery. A uniquely coded ultrasonic beacon (70-80 kHz, Sonotronics, Inc.) was incorporated into the belts to assist with close-range field tracking, as well as with identification and retagging of individuals that had lost their tags.

The original model of Gen IV tags (TMT-460) was acquired in 2005. Since then there have been considerable improvements in GPS technology that have resulted in improved accuracy, faster times to acquire a fix, higher fix success rates, and longer operational life during a single deployment (see Results). Four newer models (TMT-462, TMT-462-2, TMT-462-3, TMT-464-3) incorporate “quick fix pseudo-ranging” (QFP) technology to obtain locations based on only a brief snapshot of the GPS satellite constellation when the tag does not remain at the surface long enough to acquire a conventional GPS fix. The accuracy of QFP locations is about the same as regular 3-D GPS fixes, based on tests by Telonics and that is consistent with our observations; but only 1 QFP location can be transmitted per Argos message, so that constrains data throughput. The newest model is the TMT-464-3 GPS tag, which is considerably smaller and was acquired for deployment on juvenile and small subadult manatees.

The tagging assembly on each study subject was removed in mid-March through the use of a self-releasing unit incorporated into the belt or by approaching the manatee and cutting off the belt with a custom-made pole-mounted tool. We incorporated a programmable breakaway collar release unit (CR-2a, Telonics, Inc.) into the belts as a means to automatically release the entire tag assembly from the animal at a pre-programmed date and time. The CR-2a units employ a miniature pyrotechnic actuator enclosed within a machined plastic housing measuring approximately 4 x 5 x 1 cm. The use of self-releasing telemetry belts permits staff to quickly retrieve telemetry gear at the end of the study without disturbing the manatee.

Field Tracking and Observations

Study animals were tracked through the winter remotely through the Argos system and in the field through the use of conventional VHF and ultrasonic telemetry (Deutsch et al. 1998). Field observations from land and boat provided data on manatee activity, habitat, environmental conditions, and group size. The primary aims of field tracking efforts were to (1) identify secondary warm-water habitats and freshwater drinking sites used by tagged manatees and conspecifics, (2) record presence of skin lesions and other signs of potential cold exposure or deteriorating body condition over the course of the winter, and (3) monitor condition of the tags and replace them if needed. We attempted to track and observe each animal that was present in Brevard County approximately monthly. Photographs of other scarred manatees were taken opportunistically during field work and provided to USGS for incorporation into the statewide Manatee Individual Photo-identification System.

External Signs of Cold Exposure

Given the prevalence of cold exposure symptoms on manatees in Brevard County during the unusual mortality event in winter 2009-10 (Deutsch and Barkas 2011b), and given our limited understanding of how to interpret the meaning of these signs, we collected information on the
presence, types, and severity of putative cold exposure symptoms in our tagged manatees over the course of the winter. We attempted to document this with photographs during each visual observation. This provided the potential to describe the development and progression of cold-induced lesions in relation to the thermal regime experienced by the animals. The stages, criteria, and descriptions of apparent cold exposure signs were taken from a document developed by an interagency team of manatee biologists in 2009 (see Barlas et al. 2011 for full details). These are the same criteria as those used by ground observers at FPL’s IWWR during the three winters when the plant was not operating (Provancha et al. 2013). The head, trunk, and fluke were scored separately on a four-point scale, as summarized below.

Severity of Skin Symptoms:

0 = None. No cold-induced lesions observed.

1 = Slight. Whitening/bleaching of skin on body extremities (on face, flippers, or “halo” of fluke margin); or scattered, small superficial cold-induced lesions (usually circular) anywhere on body.

2 = Moderate. Widespread blistering/ulcerating cold-induced lesions; or scattered, larger (>quarter size), ulcerating cold stress lesions; or abscesses (large bulges filled with pus).

3 = Severe. Extensive areas of open cold-induced lesions; or extensive sloughing of epidermis; or blown-out abscesses.

U = Unknown. Body part not seen or insufficient observation.

Types of Cold-related Symptoms on Skin:

- Whitened or bleached skin
- Grayish mottling of skin
- Skin lesions of various types (typically white; includes circular ‘pock marks’; eroded margins of fluke or flippers; ulcerations, usually on the snout)
- Abscesses
- Sloughed skin (typically large patches)

To evaluate changes in cold exposure signs over the course of the winter, the condition of each part of the manatee’s body (head, trunk, fluke) was compared from capture (mid-December) to late winter (late February through mid-March). From 2010-11 through 2013-14, additional comparisons of condition were made from capture to mid-winter (early January to early February) and from mid-winter to late winter (late February through mid-March). These changes in condition were assigned to one of the following categories:

- Improved: All signs of cold exposure improved or some sign(s) of cold exposure improved while other(s) remained the same.
- Worsened: All signs of cold exposure worsened or some sign(s) of cold exposure worsened while other(s) remained the same
- Constant: No observed change
- Mixed: Some sign(s) of cold exposure improved while other(s) worsened
- Undetermined: Not observed or not able to be compared because it was not seen during the previous assessment.
**Water Temperature Monitoring**

Water temperatures experienced by the tagged manatees were collected using a temperature data logger (Tidbit, Onset Computer Co., Bourne, MA) secured to the tether with black Cold Shrink™ approximately 30 cm above the animal's peduncle. These instruments recorded water temperature at 5-min intervals throughout the winter and were accurate to ± 0.2 °C. Temperature data were interpolated at 1-min intervals and merged with manatee GPS data (to the nearest minute) to associate a water temperature with each location and to provide a spatial reference for each temperature measurement. These 15-minute records were used in analyses of manatee temperature data.

Water temperature was also monitored continuously at several stations in Brevard County throughout the winter using data loggers (HOBO, Onset Computer Co.). These sites included the FPL-CCEC discharge area and intake canal, known secondary aggregation sites (Berkeley Canal, Desoto Canal ditch, C-54 Canal in Sebastian River), several ambient sites in the Indian and Banana Rivers, and residential canals off those lagoons. When feasible, a vertical array of loggers was placed at the main aggregation area within secondary warm-water sites, including surface, bottom, and sometimes in the sediment. Ambient loggers were typically deployed about 0.3 m above the bottom. The data loggers recorded water temperature at 30-min intervals and were periodically downloaded to computers. The manufacturer’s stated accuracy is ± 0.2 °C.

Temperatures at and near FPL-CCEC, including the IWWR, were also collected for FPL by Golder Associates, Inc. at 5-minute intervals and shared with us. The maximum temperature of the stations within the IWWR were used as the refuge temperature during the first 3 years of the construction phase. Because Golder’s monitoring stations north of the mole were not close to the discharge pipes, we used our FWC logger data for plant discharge temperatures in years 3, 4, and 5. Except in winter 2012-13, the ambient lagoon temperature data used in analyses for this report came from the column probe at FWRI’s IRN station located in the Indian River just south of the NASA Causeway, ~5.5 km NNE of FPL-CCEC. This station was far away from the direct influence of the power plant’s thermal plume. The IRN logger was lost in winter 2012-13, so we used the bottom logger at FPL station 5 located on the east end of the breakwater this winter; temperature comparisons showed this to be very similar to the ambient station 6 north of the mole (when there was no thermal discharge there), which was known to be quite similar to IRN. During the three construction years, Golder provided intake temperatures from within the IWWR. During the two post-construction years, the FPL intake temperatures were recorded with an FWC logger deployed at the east end of the intake canal at the footbridge.

**Habitat Assessments**

During each winter manatee ‘hotspots’ were identified based on an assessment of repeated use by one or more tagged individuals. Some of these sites were visited to search for likely habitat attractants, such as freshwater sources, warm-water sources, or sheltered resting areas. Information recorded during site visits included most or all of the following: presence and types of aquatic vegetation; type of shoreline and vegetation; types of development and human activities in the area; sources and availability of freshwater; temperature and salinity at various locations and depths; weather; general description of bottom type and bathymetry; and the number of manatees observed and their activities. Photographs were taken to document the habitat. These observations over the course of this multi-year study were compiled in order to gain a better understanding of manatee ecology and habitat use in the region, and to share that
with managers and other researchers so that our observations, measurements, and insights did not remain lost in field notebooks and memories (Appendix 1).

Due to the massive seagrass die-off in the Indian River Lagoon during 2011, presumptive manatee foraging sites were identified by clusters of GPS locations in suitable habitat (typically seagrass) from winters 2011-12 through 2013-14. We visited these feeding sites, generally within a week or so of the manatee visit, to observe the condition of the seagrass beds and to measure the depths at which tagged manatees had been feeding. Observations were usually made from the boat and included: seagrass species composition, presence of macroalgae, water depth, number of manatees observed, qualitative comments on seagrass cover and relative density, and any other notable observations.

In winter 2014-15, a more comprehensive, semi-quantitative assessment of forage was conducted in collaboration with USGS Sirenia Project biologists. The primary objective of this field work was to identify the characteristics of seagrass beds most heavily used by manatees that overwinter at the FPL Canaveral plant and forage in the northern Indian River, as identified by habitat use of tagged manatees. Using tagged manatee data that were supplemented with aerial survey data, seagrass beds with high manatee use and low manatee use (control areas) were identified and locations for transects were selected. Comparison of the attributes of these two types of sites may suggest why manatees are selecting some seagrass areas over others. A joint team of USGS and FWC biologists visited the sites over a 3-day period in late January 2015 and assessed depth and SAV attributes at intervals along the transects. At each sampling location, a specially designed “Quad-Cam” was used to observe the bottom. The “Quad-Cam” consisted of a low-light, high-resolution camera (SDC-CAL with 2.9 mm lens, Sartek Industries) mounted on a swiveling PVC frame and aligned straight down 13 cm from the substrate (Slone et al. 2013). The frame was attached to a PVC pole that allowed the operator to keep the frame upright on the seafloor while rotating the camera to capture four quadrants on video. At each location, the “Quad-Cam” was dropped randomly four times and the video feed was viewed live by a single, experienced biologist who scored each quadrant in the field. Species identification, estimated percent cover, approximate canopy height, and number of shoots were recorded along with bottom type and presence of macroalgae. Any questionable frames were marked and later reviewed using digital recordings. Core samples were taken at locations with significant biomass; for each species, the number of shoots was counted and the maximum and median shoot lengths were recorded. Sediment type was also recorded. Water depth was recorded with a measuring pole and also with a water level logger (HOBO U20-001-04, Onset Computer Co.), programmed at 30-second intervals, which was attached to a buoy anchor and deployed at each location for the duration of the sampling period. USGS is taking the lead on analyzing and presenting these data.

Data Processing and Analysis

Telonics software utilities were used to program and download the tags and to decode the compressed GPS data transmitted through the Argos system for daily tracking. The data archived in the tags’ memory were successfully downloaded for all recovered tags. Archived data were processed for analysis, as they provided a complete record of GPS locations and fix attempts, as well as finer spatial resolution than data transmitted through Argos. The tag on TBC067 went offline during mid-winter 2011-12 and was not subsequently sighted or recovered; therefore, the GPS data transmitted through Argos were used for this individual. The
downloaded files were converted into spreadsheets and Google Earth files using Telonics Data Converter (TDC). Database manipulation and data analyses were accomplished using SAS 9.3 or SAS Enterprise Guide 5.1 and Microsoft Excel 2007 and 2010. ArcGIS 10.2 and 10.3 and ArcView GIS 3.3 software (ESRI, Redlands, CA) were employed for visualization of GPS locations and movement tracks and for spatial analyses of telemetry data in relation to locations of warm-water refugia. GIS analyses were done in the NAD-83 datum and the UTM Zone 17N coordinate system. Analyses excluded the day of tagging to allow for an acclimation period after capture.

Manatee GPS locations were initially reviewed in Google Earth to identify and flag outliers; this included review of the animated tracks in the last 3 years. A second check of locations in GIS flagged those points >250 m from a navigable water body using the best available shoreline layer as a base map; these records were assigned as outliers once it was determined from a review in Google Earth that there was no way the manatee could have reached the site. Additionally, movement rate between sequential GPS locations was calculated and records with relatively high rates were manually inspected in Google Earth to evaluate the plausibility of locations and movements. Threshold rates for inspection were: >5 km/hr when time interval was ≥2 min (year 2); 4-5 km/hr when time interval was ≥5 min and >5 km/hr for intervals ≥2 min (year 3); and 4-5 km/hr when time interval was ≥5 min and ≥5 km/hr for all time intervals (years 4 and 5). The 99th percentile of movement rate was remarkably consistent across years at just over 3 km/hr (3.1, 3.0, 3.1, and 3.2 km/hr in years 2, 3, 4, and 5, respectively), but we confirmed that manatees occasionally traveled considerable distances at rates of 4-5 km/hr during migration.

Assignment of Presence in a Warm-water Refuge

Presence at a warm-water site was defined as a GPS location occurring within a defined area representing the boundaries of the thermal refuge. The polygons delineated for the secondary sites were approximated based on known manatee use and available temperature data. Three areas at FPL-CCEC were monitored for use by tagged manatees, as indicated by the blue polygons in Figures 5-9: (1) the entire intake canal, which encompassed the two configurations of the IWWR during the first 3 winters; (2) the waters just outside of the intake canal and enclosed by the breakwater; and (3) the main discharge area north of the mole, starting in mid-winter 2012-13. A polygon for the main discharge area at FPL-CCEC was used to indicate presence at that site during the two years of the post-conversion phase (Figs. 8 and 9). The boundaries of this polygon were partly based on the distribution of tagged manatee use and partly on an evaluation of a preliminary spatial analysis of delta-T values from manatee tidbit loggers, corresponding approximately to at least 70% of the delta-T at the discharge pipes. A slightly smaller polygon was used to define this main discharge area in winter 2012-13, starting on 27 January when thermal effluent was first discharged during plant testing and continued intermittently for the remainder of the winter; this polygon corresponded approximately to tagged manatee use during the presence of these smaller thermal discharges (Fig. 7).

For the analyses of manatee use of warm-water sites, the following polygons at the FPL-CCEC site were considered warm-water habitat: winters 2010-11 and 2011-12, just the intake canal (IWWR); winter 2012-13, the intake canal (IWWR) and, starting on 27 January 2013, the main discharge area (smaller polygon); winters 2013-14 and 2014-15, just the main discharge area (Figs. 5-9). GPS locations were still assigned to the other polygons each winter; this allowed us to tabulate frequency and duration of visits to the former interim refuge during the
post-conversion phase when it was no longer being heated. Initial warm-water refuge assignments (based solely on location) were reviewed in GIS and some were re-assigned based on locations of temporally adjacent fixes and inspection of manatee tidbit temperatures in relation to ambient and warm-water temperatures.

Some GPS fix attempts were unsuccessful, most often because the tag was pulled underwater during diving or traveling. When manatees traveled at moderate to fast speeds, the tag typically remained underwater most of the time, sometimes resulting in extended periods of no locations between destinations for the older TMT-460 model tags. Omitting these no-location records from the analyses would bias the results on use of the refuges. Therefore, we assigned presence/absence in a warm-water refuge for records with unsuccessful GPS fix attempts (and for outliers) based on a combination of locational information from before and after the unsuccessful attempt and tidbit temperature relative to ambient and warm-water refuge waters. All assignments were inspected manually in GIS and sometimes corrected to assure accuracy. Two gaps in GPS tracking bouts (TBC056 – 19 days, TBC081 – 15 days) due to tag detachment followed by retagging could still have their warm-water assignments made because the manatees continued to carry a tidbit logger on the attached tether; the continuous temperature records permitted clear determination of when the manatees were in ambient waters and when they were present in the warm-water habitat at FPL-CCEC during these periods.

Frequency of Use of Warm-water Refugia

The frequency with which manatees utilized warm-water sources was measured in two ways: (1) the percentage of full tag-days from tagging in mid-December through gear recovery in mid-March in which each manatee visited one of the known warm-water sites; and (2) the percentage of time spent in these warm-water sites. These statistics were calculated for all of the animals in each winter and also for just the principal study area in Brevard County and southern Volusia County. Manatees with less than 60 full tracking days of data were excluded from analyses of overall use of warm-water sites, but data for all manatees were used for analyses of percent use of warm-water sites in relation to ambient temperature. Use of warm-water sites was based solely on presence (actual or inferred) of the manatee within the site boundaries, regardless of whether the industrial facility was discharging warm water or not.

Warm-water Refuge Use vs. Ambient Water Temperature

For analyses of manatee use of warm-water sites (i.e., percent time spent at sites) in relation to mean daily ambient water temperature, we restricted the data set to the northern IRL within Brevard County; that is, from the border with Volusia County—including the southern Mosquito Lagoon portion in Brevard, plus the northern end of Turnbull Basin and Turnbull Creek, which are in Volusia—south to Eau Gallie, and therefore including all of the Banana River. This encompassed 3 known warm-water sites—FPL-CCEC, Berkeley Canal, and Desoto Canals (Fig. 1)—and distances of about 40 km to the north and south of the FPL plant. The ambient water temperature data were taken from the center of the main manatee use area (FWC IRN station) just south of NASA Causeway in all years except winter 2012-13, when these data were unavailable due to logger loss and we used Golder station 5 at the east entrance to the breakwater instead; this station was determined to be fairly similar to IRN.
**Core Winter Range within Study Area**

The study area was divided into 4 water bodies in order to examine patterns of core range use during the winter: Mosquito Lagoon (up to Edgewater), northern Indian River (Haulover Canal south to Eau Gallie Causeway, including Turnbull Basin, Banana Creek, and the western half of the Barge Canal), southern Indian River (Eau Gallie Causeway south to Wabasso, including creeks and rivers), and Banana River (including Sykes Creek, Newfound Harbor, and the eastern half of the Barge Canal). The percentage of locations (GPS fixes and interpolated locations) within each water body was determined for each tagged individual, and a weighted mean calculated across all animals, using the duration spent in the study area as the weight. Core range use was further examined for those individuals spending most of the winter (i.e., ≥45 days) in the study area. A water body was considered to be part of a manatee’s core range if at least 30% of its location records occurred there.

**Mapping High-use Areas**

Density of GPS locations was calculated using the kernel density function in the Spatial Analyst extension of ArcGIS or ArcView. The spatial extent for the main analysis was from the Mosquito Lagoon to the Sebastian River; cell size was 10 m and search radius was set to 100 m. The upper quartile of non-zero density values was mapped using ArcGIS in order to highlight the general areas and specific sites used most intensively by tagged manatees. A second kernel density analysis was conducted just at the FPL-CCEC site to show the distribution of tagged manatee use there at a finer resolution; cell size was 5 m and search radius was 25 m.

**RESULTS**

**Tagged Manatee Attributes**

Over this 5-year study we tagged 10-13 manatees with GPS tracking devices and temperature loggers each December, for a total of 57 manatees (22F:35M). All but one were captured between the NASA Causeway (SR 405) to the north and the FPL Cape Canaveral power plant to the south; most were captured near the OUC Indian River power plant, a facility that was no longer discharging thermal effluent, located approximately 3 km north of FPL-CCEC. We also tagged one rehabilitated manatee that was released at Parrish Park, Titusville.

Tagged animals included 12 adult females, 22 adult males, 8 subadult females, 12 subadult males, 2 juvenile females, and 1 juvenile male. One of the females was accompanied by a calf and two others were lactating at capture but were not with a calf (having presumably lost their calves recently); of the adult females tested with a progesterone assay during the last two winters, two were determined to be pregnant. Minimum and maximum standard lengths of tagged manatees each winter ranged from 211-246 cm and 298-327 cm, respectively. Minimum and maximum weights each winter ranged from 211-293 kg (466-645 lb) and 443-1161 kg (970-2560 lb), respectively (Table 1). Physical attributes for each of the tagged manatees can be found in Deutsch and Barlas (2011a, 2012, 2013, 2014, 2015; see Appendices of final Biological Monitoring Report).

**Tracking Duration and Gear Recovery**

The median individual tracking duration was 93.5 days (interquartile (IQ) range = 78.2 – 97.0 days) and ranged from 5 to 116 days (Table 1). Continuous GPS tracks were maintained
throughout the winter for 37 (65%) of the 57 subjects, from tagging in mid-December through programmed release or recovery in mid-March. The tracks of 4 additional animals were nearly continuous, with gaps of just 4-15 days in GPS data before retagging or end of the season; 2 of these individuals continued to carry temperature loggers during these periods, so information on their use of warm-water sites was continuous throughout the winter. Premature termination of tracks due to belt or tag detachment occurred when the tag became caught on an object such as a dock piling and the tether broke at the designed weak link; tags were sometimes struck by a boat and the reason for some gear detachments was unknown. Tracking duration, number of GPS locations, and GPS fix success for each individual are presented in Deutsch and Barlas (2011a, 2012, 2013, 2014, 2015; see Appendices of final Biological Monitoring Report).

All except one GPS tag and 2 manatee-borne tidbit temperature loggers were recovered. Archived data were successfully downloaded from all recovered instruments, including one GPS tag in which the housing was flooded from a boat strike. For the manatees which carried their GPS tags through the full winter season, tagging assemblies were completely removed and recovered in mid-March of each year (except one animal that was tracked by Sea to Shore Alliance researchers after April). Most (49, 86%) of the 57 tagged manatees had been fitted with self-releasing belts that incorporated the CR-2a (collar-release) units. Of the 36 manatees with self-releasing belts that were still carrying GPS tags in mid-March, the CR-2a worked in 22 cases (although 3 required a tug on the tag or the belt and 3 were removed before the programmed release time) and it failed to separate in 14 cases. So the success rate of these units was 61%. For the animals that did not have a CR-2a unit on their belt or for which the CR-2a failed to function properly, a researcher approached the animal in the water and cut off the belt.

**GPS Tag Performance**

The mean number of GPS locations recorded per full day of tracking was 90.6 (SD = 6.2, N = 57) out of 96 fix attempts (Table 1). Over the course of the 5-year study, a total of 423,299 GPS locations was recorded out of 449,672 fix attempts. The percentage of GPS fix attempts that were successful in acquiring a location was very high, averaging 94.5% (SD = 6.5, N = 57) and varying from 72.8–99.96% across individuals (Table 1). Telonics’ newer models of Gen IV GPS tags, which incorporated “quick fix pseudo-ranging” technology (QFP) were deployed in greater numbers as the study progressed, increasing average fix success over time. The lowest success in obtaining location data generally occurred during periods of travel. It also occurred when manatees sought thermal refuge at the bottom of deeper water bodies, such as dredged areas of canals and creeks; when the manatee’s diving pattern brought them to the surface only briefly to breathe, the older TMT-460 tags were sometimes unable to obtain a successful fix. Overall, most GPS locations were standard 3D fixes (94.1%); the other fix types included resolved QFP (4.7%), standard 2D (0.6%), resolved but uncertain QFP (0.4%), and unresolved QFP (0.2%). The 2D and various types of QFP locations were usually obtained when regular GPS fixes were not attainable (e.g., tag mostly underwater during travel).

The accuracy of the GPS locations varies with the tag model, the configuration of the satellites at the time of the fix attempt, atmospheric and sea conditions that affect signal transmission, and behavior of the manatee as it affects the tag’s time above the surface. We have rooftop data for one older model tag (TMT-460) which shows the following error statistics: median = 7.8 m, 25<sup>th</sup> percentile = 4 m, 75<sup>th</sup> percentile = 12 m, 95<sup>th</sup> percentile = 25 m, 99<sup>th</sup> percentile = 48 m, and maximum error = 292 m; N = 43,806 fixes. Realized accuracy in the field
for this tag model is probably not this good because a tag on the animal is sometimes underwater and is moving with the animal. The newer models of GPS tags generated GPS locations with finer accuracy (e.g., see Fig. 7 in Deutsch and Barlas 2013). An estimated locational error value was provided by Telonics for each successful non-QFP fix, with the true location asserted to be within this distance; no percentile value is associated with this distance, so we cannot compare it directly to the TMT-460 performance statistics above, but we presume that actual errors should usually be less than these statistics denote. The median, 75th and 95th percentiles of this statistic for all newer tag models combined were 8.7, 10.5, and 27.5 m, respectively. There was some variation among tag models in this estimate of locational accuracy: TMT-462-2 tags had the least error because they required 30 seconds to download the satellite orbital (Ephemeris) data with each fix, which resulted in more QFP fixes; the older TMT-462 and the newest TMT-464-3 models were least accurate, with 95th percentile about 40 m (Table 2). The latter model contains the same electronics as TMT-462-3 tags but with a considerably smaller housing and flotation collar, designed to be deployed on smaller animals to reduce drag. Based on our experience and on statements from the manufacturer, the accuracy of resolved QFP locations is similar to that of standard 3D locations.

Visual examination of GPS locations generated by these new tags in narrow water bodies supports these findings that the fixes were generally within about 10-20 m of the actual location, although larger errors (e.g., several 100 m) were also noted, especially for 2D fixes. Based on verification of locations and movement rates, 626 GPS fixes (0.15%) were identified as outliers. The percentage of records that were considered locational outliers was generally consistent with Telonics’ description of the relative accuracy of each location type: 6.6% (n=52) of unresolved QFP fixes, 2.6% (n=45) of resolved but uncertain QFP fixes, 0.07% (n=13) of resolved QFP fixes, and 0.06% (n=240) of successful standard 3D fixes; but the highest number of outliers were associated with successful 2D fixes (10.7%, n=276). Two of the newest TMT-462-3 tags and one TMT-464-3 tag generated most of the outliers associated with 2D fixes. Changes in the GPS engine in these newer tags favored the retention of standard 2D fixes over QFP fixes, which was unfortunate because the latter are more accurate; however, 2D fixes only made up 0.6% of all successful fixes in the study.

**Winter Range and Migratory Behavior**

The combined winter range of the 57 study animals was exceptionally large, covering a waterway distance of approximately 794 km from the central St. Johns River and Fernandina Beach in northeast Florida to Biscayne Bay in southeast Florida (Fig. 2); that includes 174 km upstream (south) from the St. Johns River mouth to Lake George and an additional 37 km north of the river mouth to Fernandina Beach. The combined range was also extensive each winter:

1. Winter 2010-11: 373 km from Green Cove Springs, lower St. Johns River to Indian Harbour Beach (i.e., southernmost extent of the Banana River).
2. Winter 2011-12: 682 km from Lake George in the central St. Johns River to Ft. Lauderdale.
4. Winter 2013-14: 416 km from Daytona Beach to Miami.
5. Winter 2014-15: 450 km from Ormond-By-The-Sea to the town of Cutler in central Biscayne Bay.
Migratory Movements

As we expected, not all tagged manatees remained in the study area for the duration of the winter season. About one-third migrated southward out of Brevard County to central-east and southeast Florida: 18/57 (31.6%) for all tagged animals; 16/53 (30.2%) for those with tracks of ≥30 days; and 12/48 (25.0%) for those with tracks of ≥60 days. Most of these southern migrants (72%, N=13/18) departed the study area in December—8 leaving within 1 week of capture and 5 within ~2 weeks. Four individuals waited until January before migrating south and one (TBC110) did not leave until 20 February, nearly the end of the winter! Of these 18 southern migrants, 8 returned to the study area during the tracking period, one (TBC107) even making two 610-km round-trip migrations between the northern Indian River and the FPL Ft. Lauderdale power plant! All of the other 10 southern migrants lost tags before the end of the season; it is likely that they would have returned to Brevard County by the end of March, if not sooner.

Seven manatees migrated northward out of the study area to northeast Florida: this represents 12.3% of all 57 tagged animals; 13.2% of the 53 individuals with tracks of ≥30 days; and 14.6% of the 48 individuals with tracks of ≥60 days. Most northern migrants (4/7) departed the study area for the first time in February, with 2 leaving in January and 1 in March. Three individuals returned to the study area after a brief journey, and 2 of those set off again to the north about a month or more later. The range of these northern migrants during the winter did not include the southern Indian River or Sykes Creek, and only one individual (TBC112) briefly visited the Banana River.

That leaves 32 manatees (56.1% of 57) that remained within the study area for the entirety of their tracking period; or 30/53 (56.6%) for those with tracks of ≥30 days, and 29/48 (60.4%) for those with tracks of ≥60 days. In addition, even most migrants spent the majority of the winter season in the study area. We considered 45 days to represent half of the ~3-month-long winter tracking period (for full tracks); 7 of the 18 southern migrants and 6 of the 18 southern migrants spent ≥45 days in the study area. For the 50 manatees tracked ≥45 days, 42 (84.0%) spent ≥45 days—or at least half of the winter—in the study area! Relaxing the minimum tracking duration and minimum stay in the study area to 30 days, the corresponding figure is 46/53 (86.8%); increasing that threshold to 60 days, the figure is 37/48 (77.1%). Detailed information on the movements and range of each tagged manatee can be found in the annual reports by Deutsch and Barkas (2011a, 2012, 2013, 2014, 2015; see Appendices of final Biological Monitoring Report).

Core Range in Study Area

When in the study area, tagged manatees spent most time in the northern Indian River (i.e., north of the Eau Gallie Causeway, including Banana Creek and Turnbull Basin); the weighted mean across individuals being 65.5% (±SD = 34.1%). The next highest overall use was the Banana River (including Sykes Creek and Newfound Harbor) at 17.9% (±26.1%), followed by the southern Indian River at 12.4% (±32.2%); the Mosquito Lagoon received relatively little use at 4.1% (±8.1%), mostly towards the end of the winter as temperatures moderated (Table 3). The high variance around these means reflects the inter-individual variation in range use, with most individuals (41/57, 71.9%) using no more than 2 of these 4 water bodies; 13 animals (22.8%) were found in 3 of the lagoons and only 3 individuals (5.3%) used all 4 waterways. Eight tagged manatees (14.0%) used only the northern Indian River. Nearly half of the manatees
visited the southern Indian River, including of course all of the southern migrants; nearly half visited the Banana River; and about $\frac{1}{4}$ visited the Mosquito Lagoon, including all of the northern migrants (Table 3). In addition, 15 tagged manatees (26.3%) visited Sykes Creek during their tracking period.

Restricting the analysis to just those animals (N=42) that spent at least 45 days (i.e., about half of the winter or more) in the study area, we examined how their core ranges were distributed among water bodies. The vast majority (83%) of tagged manatees had a core range in the northern Indian River; 29% had one in the Banana River and there were relatively few core ranges in the southern Indian River (10%) or Mosquito Lagoon (5%) (Table 3). The same pattern among water bodies holds when focusing on each individual’s primary core range—the single water body where it spent the most time (Table 3). Most of the southern migrants had a core range, typically the primary core range, in the southern Indian River, but most were excluded from this analysis because they spent insufficient time in the study area.

Foraging Areas

Manatees behaved as central-place foragers in winter, using various warm-water refuges as focal points from which to make feeding trips. Individuals were fairly consistent in their movement patterns and showed fidelity to resting and drinking sites and foraging grounds. Here we focus on manatee distribution and density within the northern Indian River, as this area was consistently used by tagged manatees in each winter and provided the closest feeding areas to manatees using the FPL Canaveral site. The results of kernel density analyses of manatee GPS locations in the northern Indian River are shown for each winter in Figures 10 and 11, which highlight the top quartile of areas used by tagged manatees. Similar density maps for other parts of Brevard County waterways are shown in the annual reports by Deutsch and Barlas (2011a, 2012, 2013, 2014, 2015; see Appendices of final Biological Monitoring Report). The vast majority of presumptive foraging trips from FPL-CC (IWW or CCEC) headed north of the plant and crossed to the eastern side of the lagoon, where most of the seagrass beds were located. The most heavily used feeding areas were seagrass beds along the eastern shore of the lagoon from A. Max Brewer Parkway (SR 406, 17.5 km north of FPL-CCEC) to Rinker’s canal (3.5 km east of FPL-CCEC), a shoreline distance of about 25 km (Figs. 10 and 11). Moderately used areas included extensive seagrass flats on the eastern side of Turnbull Basin (between Haulover Canal and the Titusville railroad bridge) and narrow seagrass beds and macroalgal patches along the western shore of the Indian River from A. Max Brewer Parkway to Bennett Causeway (SR 528) (Figs. 10 and 11).

One must be cautious about inferring broad-scale changes in distribution from a limited number of tagged individuals, however winter 2010-11 stands apart from the other 4 winters. The distribution of tagged animals was shifted south relative to subsequent years, with relatively little use north of NASA Causeway (Figs. 10 and 11). Moreover, the manatees tagged in that winter used the Banana River heavily; of the 10 manatees tracked in winter 2010-11, 9 had core ranges in the Banana River and 4 had their primary core range in this lagoon. Interestingly, the aerial survey data showed a similar pattern of higher use of the Banana River; within the Indian River, the areas of highest sighting concentrations (away from FPL) were along the eastern shore between the NASA and Bennett Causeways (see Figs. 5, 6, and 7 in Reynolds et al. 2011). This matches the relative distribution of tagged manatee density fairly well. Our original explanation for the lack of southern migrants and the high use of the Banana River by tagged manatees
during the first winter was that the extreme and prolonged cold for the two weeks prior to the December captures drove migrants to leave and many animals in the Banana River to seek shelter at the FPL plant site. This explanation still seems reasonable, but perhaps the spatial distribution from our sample of tagged manatees during winter 2010-11 was more representative than we had originally thought.

Manatee foraging range was constrained by water temperature. At the coldest temperatures, manatees in the northern Indian River could mostly be found at the FPL-CC site (IWWR or CCEC); foraging trips were brief (e.g., several hours) and directly across the lagoon from the power plant. As temperatures warmed, the foraging range expanded to north of NASA Causeway, north of A. Max Brewer Parkway, and into Turnbull Basin (Fig. 12). At the warmest temperatures (>20 °C), manatees were dispersed throughout the NIRL, including the Mosquito Lagoon and the upper Banana River.

Seagrass is restricted to shallow waters in the NIRT due to the plants’ light requirements and limited water clarity in the lagoon. The severe algal blooms in 2011 and 2012 resulted in the disappearance of most seagrass in waters deeper than about 1 m, further restricting manatee foraging habitat in inshore waters. Manatees adjusted their fine-scale use of seagrass beds accordingly, moving inshore to shallower waters (Slone et al. 2015). Field visits to presumptive foraging sites for tagged manatees in the NIRT generally found water depths no shallower than 0.4 m (Deutsch and Barlas 2012, 2013, 2014). However, manatees were observed to feed on inshore seagrass patches in water as shallow as 20 cm (8 in) deep (see Deutsch and Barlas 2012 for description and photographs). During winter 2012-13, manatees were also tracked in deeper, more offshore waters where seagrass was completely absent and where they were presumably foraging on drift macroalgae, which was quite abundant in some areas.

Use of the Regional Warm-water Network

For our purposes we consider the ‘regional warm-water network’ to include the sites in Brevard County, as there are clear discontinuities in manatee use and movements to the north and south of the county, as shown earlier by Deutsch et al. (2003b) and confirmed in this study. For manatees that regularly migrate to southeast Florida, as well as for facultative migrants, the warm-water network with which they are familiar is much more extensive, covering 200-300 km of coastline or more (Deutsch 2000, this study). Most (13/18, 72%) of the tagged manatees that migrated south of Brevard visited the FPL Riviera Beach power plant discharge embayment (Table 4), even though the plant was offline until the last winter. Likewise, a few tagged manatees visited the FPL Port Everglades power plant discharge canal for cumulative periods of up to 7 days (Table 4), even though the plant was offline until the last winter. Over 90% of all tracked manatees (52/57) visited the FPL-Cape Canaveral warm-water refuge (IWWR and/or CCEC) during their tracking periods, although 4 stayed only briefly immediately after their capture (Table 4). This high level of visitation was not surprising, given the proximity of the capture areas to this site—immediately adjacent in winter 2010-11 and about 3 km to the north for most manatees in subsequent winters. The Satellite Beach thermal basins (Berkeley and Desoto Canals) were visited by 16% (N=9) of the animals; 32% (N=18) visited...
the Sebastian River C-54 canal, most as a stopover site during migration. The importance of C-54 Canal as a migratory stopover site was also highlighted in a previous tracking study (Deutsch et al. 2003b). One manatee (TBC079) migrated directly out of Brevard County without stopping at any of these known warm-water sites.

Restricting the sample to manatees that spent at least 45 days (i.e., about half of the winter) in the study area, including some southern and all northern migrants, the distribution of warm-water site use was similar to that described above, except that only 19.0% of animals visited C-54 canal because most of the southern migrants were dropped from the analysis (Table 5). We found that 64.3% (27/42) only visited one known warm-water site anywhere during their tracking period; an additional 2 animals (so 29/42, 69.0%) used other sites outside of Brevard County but only one known site in the study area. FPL-CC (either IWWR or CCEC) was the sole source of known thermal refuge for all except one of these individuals, meaning that 61.9% (26/42) used only FPL-CC during their tracking period and 66.7% (28/42) used only this site when in Brevard County; there was no difference in this parameter between the 3 years when manatees used the IWWR (15/25 = 60% and 17/25 = 68%, respectively) and the 2 years when they used FPL-CCEC (11/17 = 65%). The other sole site used by one individual was Berkeley Canal. When considering just the 4 known warm-water sites in the study area, 7 individuals visited 2 sites (6 - FPL-CC and C-54 Canal; 1 – Berkeley and C-54 Canals), 6 visited 3 sites (5 - FPL-CC and Berkeley and Desoto Canals; 1 - FPL-CC and Berkeley and C-54 Canals), and none visited all 4 sites during the winter.

The primary warm-water site used by a manatee was defined as the single site within the study area at which the individual spent the most time. Clearly that was dominated by the FPL-CC site, which was the principal site used in Brevard County for 88% (N=37) of the 42 tagged manatees that spent at least 45 days in the study area (Table 5). Each of the other three sites in the county was the primary warm-water site was only 1 or 2 tagged individuals (Table 5).

Movements among Warm-water Sites

For the purpose of summarizing movements within the warm-water network, we have simplified it in the form of a matrix that includes the following “sites”: FPL-CC (IWWR and/or CCEC), Satellite Beach (Berkeley and Desoto Canals), Sebastian C-54 Canal, and all sites in southeast Florida (Table 6). The analysis was restricted to manatees (N=48) with a total track duration of at least 60 days. The table shows, for example, that 10 manatees that had visited FPL-CC moved to the Sebastian C-54 Canal but only 1 manatee moved in the other direction between the 2 sites. The largest number of animals that moved to FPL-CC came directly from southeast Florida without stopping at C-54 or Satellite Beach canals. Of the 21 individuals that moved between sites, 12 showed only unidirectional movement between sites and 9 returned to the original site.

Attendance Patterns at Warm-water Refugia

Attendance patterns (i.e., timing of presence/absence) at the FPL-CCEC warm-water refuge, at secondary warm-water refugia in Brevard County, and at other warm-water sites along the Atlantic coast of Florida are illustrated for each tagged manatee over the entire winter with charts in each of the annual reports (see Appendices of final Biological Monitoring Report). The periods of highest use of warm-water sources by tagged manatees generally corresponded to the coolest water temperatures, which varied in timing within the winter and in severity across years.
Tagged manatees visited an identified primary or secondary warm-water refuge along the east coast of Florida on an average of 48.0% of days (SD = 17.4, N = 47) during their tracking periods, excluding the day of tagging and those individuals with less than 60 full days of tracking. Visitation varied considerably among individuals in all winters except 2010-11 when no manatee ventured south of the NIRL (i.e., Eau Gallie Causeway); overall, it ranged from 5.2% to 85.7% of days tracked (Table 7). Of course, the manatees did not always spend the entire day at the warm-water site during their visits, so the percentage of time that they spent in known warm-water sites was less than the above statistic, averaging 34.2% (SD = 15.4, N = 47) over the tracking period. Use varied greatly among individuals, from 1.9% to 79.0% of time (Table 7).

**Warm-water Refuge Use in Northern Indian River Lagoon vs. Ambient Water Temperature**

Tagged manatee use of known warm-water refugia (i.e., FPL-CCEC, Berkeley Canal, and Desoto Canal) in northern Brevard County (i.e., north of Eau Gallie, ~40 km to the north and south of the FPL plant—see Methods) was very low (<5%) when mean daily ambient water temperature was above 21 °C, but use increased steadily as lagoon temperatures declined below that threshold (Fig. 13). On average, manatees spent approximately half of their time in one of these sites when the Indian River was about 16-17 °C. The time manatees spent at these sites was much higher below 15 °C, however, averaging 78-80% from 13-14.9 °C and 89% from 9-10.9 °C (Fig. 13). Only in winter 2010-11 did the ambient temperature drop below 12 °C. This relationship between use of warm-water sites and ambient temperature was fairly similar between the conversion phase when the IWWR was operating and the post-conversion phase when the plant resumed normal operation and discharge into the traditional area. The most striking difference among years was in 2010-11, during which most tagged individuals used the Banana River when ambient temperatures in the northern Indian River exceeded 16 °C; this resulted in lower values for use of the 3 identified warm-water sites between 17-20.9 °C (see Fig. 9 in Deutsch and Barlas 2011a).

**Diel Variation in Use of the IWWR versus FPL-CCEC**

For analyses of diel variation in attendance patterns at warm-water sites, we focused on the FPL Cape Canaveral site (i.e., the IWWR and/or the FPL-CCEC, depending on year). The data were limited to waters in the northern Indian River in the vicinity of the FPL plant—specifically, to manatees present between Titusville, just north of the SR406 A. Max Brewer Causeway (17 km north of FPL) and Cocoa, 1 km south of the SR528 Bennett Causeway (8 km to the south of FPL), including lower Banana Creek. Manatees in the northern Indian River showed a clear diel pattern of attendance at the FPL site, with highest use during the day (~0900 – 1600 hr) and lowest use at night (Fig. 14). This suggests a pattern of nocturnal foraging, although that should be confirmed with further analyses of presence in seagrass beds. The diel signature of refuge use was strongest when the mean daily ambient water temperature was between 16-20 °C (57.2-68.0 °F); there was little use at warmer temperatures and near-constant use at colder ones (Fig. 14).

We wondered what effect, if any, the pattern of warm-water generation at the FPL site had on the diel pattern of refuge use. We limited the analysis to days when the mean daily ambient water temperature in the northern Indian River (FWC station IRN) was between 16.0-20.0°C; data from winter 2012-13 were excluded because both warm-water sources were operating for half of the winter and IRN temperature data were not available. The IWWR temperature and delta-T were nearly constant over the 24-hour cycle whereas the main CCEC
discharge varied considerably with electrical demand, being lowest in the early morning hours of the night and reaching a peak in the early evening (Fig. 15). Despite the contrast in diel patterns of warm-water temperature between the IWWR and CCEC, manatee use patterns by hour were quite similar (Fig. 15). There is an indication, however, that manatees may have delayed their late-day departure to later in the evening during the post-conversion phase, perhaps taking advantage of the increased discharge temperatures at that time.

Duration of Visits to Warm-water Sites

Most continuous refuging bouts at FPL-CCEC or the IWWR were not lengthy. For example, in winter 2014-15, the median duration of visits to the CCEC discharge area was 0.64 days (interquartile range = 0.38 – 1.21 days, n = 233). The values would be higher if we excluded brief excursions outside of the delineated polygons, which can fragment one long bout into two or more shorter bouts and therefore have a substantial effect on the statistics. This occurrence was not uncommon at the unconstrained FPL-CCEC discharge area and therefore, more refined analyses are needed to better characterize this parameter. Bout durations for 3 manatees using Berkeley Canal were similar to FPL-CCEC that winter: median = 0.52 days (interquartile range = 0.13 – 1.02 days, n = 11).

Durations of stay in the FPL refuges (IWWR/CCEC) of about 1 week or more were not uncommon, occurring in every winter. During the period of prolonged and severe cold weather from early December 2010 into mid-January 2011, in which ambient water temperatures in the northern Indian River dropped to as low as 8.2 °C, nearly all tagged manatees remained in the IWWR for the vast majority of time (see Fig. 8 in Deutsch and Barlas 2011a). In fact, adult female TBC062 remained in the IWWR continuously for 32.2 days (from 16 December 2010 to 17 January 2011), while fasting! Likewise, adult male TBC057 remained in the IWWR for 31.2 days, with just one 6.8-hr foraging trip (only 2.8 hr actually on a seagrass bed) to the east side of the Indian River 8.3 days into his stay; at the end of this period he made a similar foraging trip that lasted 6.3 hr (2.3 hr on the grass bed) before returning to the IWWR. It is likely that these manatees were also present at the FPL refuge continuously or nearly so for the 2 frigid weeks prior to capture. Two other individuals remained in or just outside of the IWWR for periods of 11.3 days (TBC058) and 11.6 days (TBC059) during the extremely cold December 2010 weather. Even these longer durations of stay were not limited to just one severely cold winter. Besides winter 2010-11, long-duration stays (≥10 days, including brief forays outside of the refuge for no more than 1 hr) in the Canaveral refuges included: 21.6 days (TBC066) during winter 2011-12; 10.5 and 10.6 days (TBC098) and 12.3 days (TBC092) in winter 2012-13; and 10.6 days in winter 2014-15 (TBC112).

Interestingly, the longest continuous stay in a known warm-water site by one of our tagged manatees was 48.5 days by TBC113 at the FPL Ft. Lauderdale power plant cooling ponds and discharge canal from 21 December 2014 to 8 February 2015. Over the subsequent 15.7 days, the manatee spent all except 11.5 hr (on 3 brief excursions into the New River) within the cooling ponds, meaning that this individual spent 99.3% of a continuous 64.2-day period at this site! The temperatures recorded by the manatee at FPL-FL were quite warm during this 2-month period, averaging 27.4 °C (81.3 °F) and ranging from 23.3 to 31.0 °C (74.0 – 87.9 °F). Several other tagged individuals spent lengthy continuous periods in the cooling ponds and discharge canal of this inland plant during the study, including: 27.7 days (TBC070) in winter 2011-12; 22.0 days (TBC097) in winter 2013-14; and 16.9 days (TBC107), 10.4 and 22.9 days (TBC114), and 13.4 days (TBC115) in winter 2014-15.
Finally, one tagged manatee (TBC094) spent 6.5 days continuously in the FPL Port Everglades discharge canal and adjacent ‘mangrove lagoon’ system in late January 2014. The length of this visit was noteworthy because the power plant was not discharging any warm water all winter, having been demolished as part of the modernization process 6 months prior.

Manatee Fine-scale Distribution in Waters around the FPL Cape Canaveral Plant in Relation to Changing Warm-water Sources

Not surprisingly, tagged manatees found the thermal effluents at the FPL Cape Canaveral plant site each winter, even though the location shifted across years (Fig. 16). They preferentially aggregated in the warmest areas within the discharges. Manatee fine-scale distribution in waters around the plant is summarized in relation to warm-water sources for each winter below.

Winter 2010-11: Manatee distribution was concentrated in the eastern half of the IWWR (Fig. 5), where extremely dense aggregations of manatees formed around the outlets of the heated discharges during cold weather (Fig. 17). The refuge encompassed the full width of the canal but was partitioned with surface-to-bottom curtain booms to the eastern half this winter. Manatees generally surface-rested and milled in the thermal plume—presumably because warm water was discharged at the surface, resulting in warmer surface waters in parts of the IWWR (Golder Associates, Inc. 2011)—but bottom-resting was also observed. Manatees made less frequent visits to the far western end of the canal to drink freshwater runoff from pipes and to rest on the bottom (Figs. 5 and 21).

Winter 2011-12: Manatee distribution shifted to the western half of the IWWR this winter (Fig. 6), where the primary thermal discharge pipe was moved (Fig. 3). The modified refuge encompassed the entire length of the former intake canal, but the width was reduced in half by a sheet pile wall extending the length of the canal (Fig. 18). Manatee distribution within the narrow canal was most likely related to the east-west temperature gradient that formed during heater operation. The western end averaged 2.7 °C (4.9 °F) warmer than the eastern end when the heater was presumably operating (i.e., delta-T of ≥4 °C over ambient); sometimes the horizontal thermal gradient within the canal was quite steep, as indicated by a 95th percentile temperature difference between these two stations of 5.5 °C (9.9 °F). However, manatees were found resting and milling throughout the IWWR, which reliably maintained temperatures of ≥20 °C up to the entrance throughout the winter.

Unlike the previous winter, tagged manatees in winter 2011-12 also spent time just outside of the IWWR (typically within the breakwater) when the heater unit was not operating during mild weather (Fig. 6). When delta-T at the site was no more than 1 °C, 37.2% of the locations at FPL-CCEC (i.e., IWWR plus breakwater basin) were actually within the breakwater area east of the footbridge.

Winter 2012-13: Manatee distribution and behavior was similar to the previous winter, as the configuration and operation of the IWWR remained the same (Fig. 7). There were two important changes at the site that affected the spatial extent of warm water and manatee habitat use. First, one or more of the intake pumps circulated almost continuously for most of the winter. Hence, the discharge from the IWWR was effectively sucked into the intake canal, very slightly warming the otherwise ambient discharges from the pipes north of the mole and making the
waters outside of the footbridge essentially ambient temperature (Fig. 19). Probably for this reason, the waters enclosed by the breakwater were little used by manatees (Fig. 7).

Second, testing of the plant’s turbines resulted in the intermittent but near-daily discharge of warm water at the main effluent pipes north of the mole, starting on 27 January 2013. Subsequently, there were two asynchronous warm-water sources at FPL-CCEC during the latter half of the winter—the heating system in the IWWR and the two discharge pipes of the CCEC. Manatees visiting FPL-CCEC after 27 January split their time between the two warm-water areas, but the vast majority of refuge locations (mean=80.2%, SD = 5.9%, N=6 individuals) were in the IWWR versus the main discharge area on the north side of the mole (19.8%) (Fig. 7).

Within the main discharge area, manatees typically spent most time at or close to discharge #2 (the northern effluent), but often spent considerable time up to 300 m offshore of both discharges. In fact, they frequently found waters that were 1-3 °C warmer than recorded near discharge #2 (Golder station 6 bottom), sometimes 200-300 m offshore; this indicates active selection and movement to remain in warmer ‘pools’ of heated water. Use of the main discharge area by tagged manatees during testing between January and March 2013 is described further below.

Winter 2013-14: After 3 winters of using the IWWR established in the former intake canal, manatees followed the shift in warm-water habitat back to the traditional site north of the mole with the operation of the modernized plant (Fig. 8). Within this area, there were two clusters of highest use (illustrated in dark red): (1) a tight inshore cluster within about 100 m of discharge #2 (the northern pipe); and (2) a larger offshore area about 150-300 m east of discharge #2 (Fig. 8). There was also a small area of focused use immediately around discharge #1 (the southern pipe), which is more difficult for manatees to access because it is surrounded by a shallow sandy shoal. Note that manatee GPS locations occurred throughout and beyond the main discharge area polygon, but location density for those areas was in the lowest class for this kernel density analysis, and the lowest density class is not shown in the figure.

Notably there was also an area of moderate location density in the west end of the former IWWR (Fig. 8). A small number of manatees were often observed in the intake canal (mostly south of, but sometimes north of the bisecting wall) during field visits. Although tagged manatees visiting FPL-CCEC spent nearly all of their time in the main discharge area north of the mole (97.2% of 31,224 records within the 3 polygons), a small amount of time was spent in the intake canal (2.0%), including the former unheated IWWR, and very little time in the small area outside of the former IWWR but within the breakwater (0.8%).

Winter 2014-15: The location and extent of warm-water habitat, as well as manatee distribution, at FPL-CCEC during winter 2014-15 was similar to the previous winter (Fig. 9). Virtually all of the high-density use occurred in the main discharge area north of the mole. Within this area, there were 3 clusters of highest use: two small inshore clusters within about 100 m of each of the discharges; and a more expansive offshore area about 150-300 m east of discharge #2 (Fig. 9).

The IWWR was offline during the entire period that manatees were tracked during winter 2014-15; however, the heating system was turned on in the canal for almost 2 days during a cold period in mid-November 2014 when the power plant was shut down for about 2 weeks. Use of the former IWWR by tagged manatees was considerably lower than last winter, but there was an area of relatively low location density in the canal (Fig. 9). While at the FPL-CCEC site (i.e., in
one of the 3 polygons), tagged manatees spent nearly all of their time in the main discharge area north of the mole (99.6% of 23,088 records) and only a very small amount of time in the intake canal (0.3%), including the former IWWR, and in the small area outside of the former IWWR but within the breakwater (0.1%).

**Discovery of New Warm-water Sources and Fidelity to Former Warm-water Sites**

*Manatee Discovery and Use of the Re-established but Intermittent Warm-water Source in the Main Discharge Area: Winter 2012-13*

As noted above, FPL began testing its turbines on 27 January 2013 at 1800 hr. This resulted in intermittent discharges of heated effluent from the two discharge pipes on the north side of the intake mole—what is referred to as the ‘main discharge area’. No warm water had been discharged at this site for over 2.5 years, since the summer of 2010; it would have been nearly 3 years since a manatee could have encountered a warm-water discharge here during the winter. During the period of plant testing in which manatees were tagged (i.e., 27 January to 22 March 2013), thermal effluent was discharged on 89% of days (49/55) and 65% of hours (FP&L, unpublished data). This provided us with an opportunity to observe the discovery (or re-discovery) and subsequent use of the main discharge area by tagged manatees as they moved between the IWWR and foraging areas in the NIRL. Manatee arrivals to and departures from the IWWR were compiled for the 6 tagged manatees that used FPL-CCEC during this period, in relation to the presence/absence of thermal effluent from the main discharge, as well as the delta-T of that outflow (i.e., Golder station 6_B minus 5_B), in order to identify opportunities for detection of any thermal plume and to record when manatees first used the main discharge area.

During the testing period, tagged manatees spent a mean of 23.9% (SD = 10.3%, min – max = 16.4 - 39.9%, N = 6,) of their time at FPL-CCEC. At FPL-CCEC, use of the IWWR was heavily favored over the main discharge area during the testing period: a mean of 80.2% (SD = 5.9%) of refuge locations were in the IWWR versus 19.8% in the main discharge area; use of IWWR ranged from 73.1% to 87.7% across individuals. Of the 62 visits to FPL-CCEC, 45.2% (N = 28) were just to the IWWR, 11.3% (N = 7) were just to the main discharge area, and 43.5% (N = 27) were to both sites. It was common for manatees to stop in the main discharge area on the way to or from the IWWR, and sometimes to move back and forth between the two sites during a visit.

Timing of the discovery of the warm water in the main discharge area by the study animals ranged from 27 January to 6 March 2013, which corresponds to 0.2 to 37.9 days after the start of testing. Most tagged manatees (4/6) found the warm-water source in the main discharge area on their first visit back to FPL-CCEC after testing began; one individual (TBC081) discovered it on her second visit and another (TBC088) found it on his fourth visit. For the combined 4 visits of the latter two individuals when the main discharge had not yet been discovered, the thermal discharge was off upon their arrival to FPL-CCEC 3 times and the animal arrived from the south 3 times; thus, there was no opportunity to find it on arrival. For these refuge bouts, however, the warm water in the main discharge area was present during all 4 departures from the IWWR: in two cases, TBC088 departed to the south and so had no opportunity to detect the thermal plume; in one case this same individual rounded the intake mole and encountered slightly warmer water but then headed south; the missed opportunity for TBC081 came when it headed NNE after leaving IWWR and bypassed the main discharge area.
Interestingly, the first tagged manatee to discover the thermal effluent in the main discharge area was TBC085, a small subadult female that was probably born in 2010 (based on size) and would therefore have had no experience with this warm-water site. Yet she found it only 4 hr after it started to discharge! During this encounter on the evening of 27 January, TBC085 was heading north about 190 m NNE of discharge #2 when she reversed course and approached the discharge closely, spending 2.5 hr in the area. She probably detected the weak thermal plume (delta-T of 2°C) or possibly she followed conspecifics. It should be noted that TBC085 spent considerable time at and near FPL-CCEC this winter (63.2% of days), so that may explain why she was the first individual in our sample to locate the new warm-water source, despite her inexperience. Nevertheless, this was actually the first time that TBC085 had fixed a GPS location anywhere in the discharge polygon since she was tagged in mid-December, so it does not seem a coincidence that she was here on the first day of warm-water discharge.

Somewhat surprisingly, she did not return to use the main discharge area for the next 24.4 days, despite having visited the IWWR 7 times during that time period; in most cases that was because she was only ranging south of the plant. However, she missed an opportunity to use the main thermal plume on 1 February, when she passed it from the north and the IWWR heater was offline; yet she used the unheated IWWR anyway and did not visit main discharge plume. TBC085 also used the IWWR a few other times when the heater was offline and ambient temperatures were mild.

The duration of bouts in the main discharge area (starting on 27 January) averaged 6.0 hr (SD = 7.2, min – max = 0.2 – 33.0, N = 48). In comparison, the duration of bouts in the IWWR during the testing period averaged 20.4 hr (SD = 20.9, min – max = 0.3 – 88.6, N = 61); this included a few visits when the heating system was offline and the manatee just stopped in for a short time. Notably, manatee visits to the main discharge area were short when there was no thermal discharge (mean = 1.8 hr) compared to when a thermal discharge was present for all or most of the visit (mean = 7.4 hr). In 5 out of 6 cases, manatees left the main discharge area within about 1 hr after the discharge was no longer heated (and water of ambient temperature continued to be discharged).

**Use of the Former Interim Warm-water Refuge: Winters 2013-14 and 2014-15**

Once the warm-water refuge was permanently switched from the IWWR to the main discharge area in 2013, we wondered whether manatees would still check for the presence of warm water in the former site that the manatee aggregation had used for the previous 3 winters. In winter 2013-14, 8 of 13 tagged manatees (62%) visited the former IWWR/current intake canal at least once; 4 of those individuals were present at FPL-CCEC for <½ day, so excluding those yields 89% (8/9). In winter 2014-15, 5 of 12 manatees (42%) visited the former IWWR at least once; excluding those present at FPL-CCEC for <1 day, the proportion is similar (4/9 = 44%). More telling is the average number of visits per manatee that fixed GPS locations in the former IWWR—9.1 in the first winter and only 1.6 in the subsequent winter (Table 8). Expressed in terms of the percentage of ‘tagged manatee-days’ at FPL-CCEC that involved a visit to the former IWWR, use during 2013-14 was 7-fold higher than in 2014-15 (Table 8). Remarkably, two individuals (TBC095, TBC101) visited the former IWWR on more than ¼ of the days they spent at FPL-CCEC, although the actual percentage of time spent there was quite small. The duration of visits to the former IWWR averaged only 2.2 hr in both winters, probably because water temperatures experienced by the tagged manatees here were considerably cooler than the main discharge area during the time of the visit (Table 8). Although the mean temperature
experienced by the manatee was 20-21 °C while in the former IWWR, average temperatures during a visit reached as low as 15.7 °C (Table 8).

**Thermal Regime of Manatees’ Environment**

The temperature loggers attached to the tagging assembly provided a continuous record of the thermal regime experienced by manatees over the entire winter. The spatial scope of the temperature analysis was restricted to Brevard County and the southern half of coastal Volusia County—an area extending approximately 80 km north and south of FPL-CCEC from Spruce Creek (Port Orange) to the Sebastian River (including the southern prong). Figure 20 shows a frequency distribution of temperatures (361,256 measurements at 15-min intervals) for 48 tagged manatees that spent at least 4 weeks in this region. Pooling all of these tidbit data over the 5 years of the study, the median temperature was 21.6 °C (1st – 3rd quartiles = 20.0 - 23.1 °C); 5th and 95th percentiles were 17.2 and 25.7 °C, respectively. Manatees experienced a remarkably wide range in water temperatures in this region, from a minimum of 8.3 °C to a maximum of 33.9 °C! The low record occurred during a period of extreme cold on 28 December 2010 when TBC064 explored the waters within ~2 km north and south of the FPL-CC IWWR over an 11-hr period; maximum temperatures recorded by the Golder sensor array within the IWWR had been 19.3 – 19.9 °C during the 12 hr prior to this animal’s foray from the refuge into cold ambient waters (~8-10 °C). The maximum recorded tidbit temperature occurred in the main discharge area of FPL-CCEC on 22 February 2013 (TBC085) during a period of mild weather (intake temperature was 23.9 °C).

Mean temperatures experienced by manatees in the Brevard to southern Volusia study area varied relatively little, from 20.0 – 23.0 °C (68.0 – 73.4 °F) among 48 individuals (Table 9). The minimum water temperature recorded by the manatee-borne loggers averaged 13.5 °C (SD = 2.2 °C) (56.3 °F, SD = 3.9 °F) across individuals. On average, these manatees spent only 2.2% (SD = 2.6) of the time in waters <16 °C (60.8 °F), 22.8% (SD = 7.4) of the time between 16–20 °C (60.8–68.0 °F), and the remaining 75.0% (SD = 9.1) of the time in waters ≥20 °C (68 °F). Individuals varied from 0% to 10.7% in the time spent in waters <16 °C; they varied from 55.2% to 97.2% in the time spent in waters ≥20 °C. The thermal regime experienced by manatees varied somewhat among winters, with time spent in waters <16 °C being highest in 2010-11 (mean = 5.4%) and averaging only ~1-2% in the following 3 winters; mean time spent in waters ≥20 °C ranged from 68.9% in 2010-11 to 79.4% in 2011-12 (Table 9). However, interannual variation in the extent to which manatees experienced cold waters was not nearly as much as might be expected based on interannual variation in winter severity (Table 9).

Relative to what manatees experienced, ambient waters in the northern Indian River showed a much higher frequency of cool temperatures during the period of tracking (mid-December to mid-March): 20.8% of the time <16 °C (range across winters = 5.9% - 48.3%), 43.0% between 16–20 °C (29.3% - 51.6%), and 36.2% ≥20 °C (22.5% - 51.2%) (Table 9). This demonstrates how effectively manatees shifted the thermal regime in their favor through active warm-water habitat selection in the northern IRL. This was especially true for the extremely cold winter of 2010-11 when lagoon temperatures were below 16 °C nearly half of the time, yet manatees averaged only 5% of their time below that threshold (Table 9). For all tidbit data pooled in the Brevard and southern Volusia study area, tagged manatees were warmer than the northern Indian River by a median of 1.8 °C (1st – 3rd quartiles = 0.4 – 5.7 °C); 5th and 95th percentiles were -0.6 and 9.7 °C, respectively. The maximum temperature difference was a
noteworthy 18.8 °C, when the manatee (TBC059) was next to the main discharge pipe in the IWWR on 18 December 2010. Large temperature differences of ≥12 °C occurred in ~1% of the records.

Manatees that migrated south of Brevard County typically experienced considerably milder temperatures than those that remained in the study area. These temperature data are not presented here but can be found in the annual reports (see Fig. 12 in Deutsch and Barlas 2012; Fig. 12 in Deutsch and Barlas 2014; Fig. 11 in Deutsch and Barlas 2015).

Field Observations

Over 5 winter seasons, the project team spent a total of 143 days in the field after the December captures and through the period of gear recovery in March (Table 10). An additional 7 field days in April were spent recovering temperature data loggers. Project staff observed tagged manatees 358 times, ranging from 46-102 sightings per winter and 0 to 16 sightings per individual. Seven manatees (TBC067, TBC079, TBC080, TBC93, TBC097, TBC113, and TBC115) were not seen by project staff after capture and prior to tag detachment. An additional 207 sightings were reported by concerned citizens and by other staff from FWC or other agencies. These were typically verified through Argos queries to ensure that one of our tagged manatees was at the reported site, as public sighting reports of “tagged” manatees could actually be a crab trap entanglement instead. Tagged manatees were observed by staff away from FPL-CCEC on 189 occasions; in 83% of these sightings with recorded group size (n = 184), the study animal was with at least one other conspecific (median group size = 6, maximum = 101). Since it is typically difficult to observe and count animals from a boat or shore, these figures represent minimum group sizes. Generally, larger groups (e.g., > 40) were seen at warm-water sites in Satellite Beach; however, large groups were also observed in the northern Indian River north of the NASA Causeway on grass flats on the east and west side of the river and at a freshwater site at Riverside Inn (Fig. 10). Sites that we identified as ‘hotspots’ due to their repeated and frequent use by tagged manatees typically had a number of other manatees present during our field visits.

Freshwater Sources and Drinking Behavior

Freshwater sources were often focal points of manatee activity during the winter, as that generally corresponds to the dry season when freshwater is more limited in availability. That was particularly the case during some winters, such as 2011-12 and 2012-13, which followed an extended and severe drought in north-central Florida; according to the Palmer Drought Severity Index, this region of Florida was in severe drought status for most months between Oct 2010 and May 2012 (particularly winter 2011-12) and again from February to April 2013 (NOAA National Climate Data Center, http://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers/psi/200909-201504). It was not feasible to identify all of the potential freshwater sources in the study area, many of which have intermittent flows, such as stormwater drainage pipes, hoses at marinas and docks, and air conditioning condensate drains in residential canals. We have identified the major sources of freshwater used by tagged manatees in the northern Indian River proximate to the FPL-CCEC power plant.

The closest freshwater source for manatees using the warm-water discharges at FPL-CCEC can be found in the intake canal (i.e., the IWWR). In winter 2010-11, 17 pipes were identified as potential sources of freshwater in the IWWR: 2 were large-diameter (~15-36
inches) stormwater pipes at the far west end of the canal and 15 were small-diameter (~3-4 inches) ground drainage pipes along the western and southern seawalls (Fig. 21). Salinity and flow rate were measured at some of these pipes on 15 Feb 2011 and all of the pipes on 17 Mar 2011. Freshwater did not consistently flow from every pipe and flow rates varied between the pipes (from 15 – 3320 ml/min) and between dates of measurement. For example, flow rate decreased at the large-diameter stormwater pipe in the far northwest corner of the IWR from a minor flow (steady drip) of 320 ml/min on 15 February to a negligible flow (slow drip) of 42 ml/min on 17 March. Conversely, flow rate at a small-diameter ground drainage pipe on the southern seawall increased between visits from 2550 ml/min to an estimated 3320 ml/min. No flow was observed at 9 of the pipes on either visit. Manatees were often observed drinking the available freshwater from these pipes, positioning themselves to catch slow drops or a steady flow and sometimes sucking the water flowing flat down the seawall at some sites (Fig. 21). Although flow rate was not measured at these pipes after March 2011, similar observations were made in the following winters, 2011-12 and 2012-13, while manatees were sighted in the IWR. It should be noted that pipe flow rates measured in late winter 2010-11 may not be representative of typical or later years, because geo-technical construction activities at that time may have elevated levels of the local surficial groundwater, resulting in more frequent or higher flow rates from the seawall pipes along the IWR (Edd Jantz, FPL to Jim Reid, USGS, pers. comm.). These measurements and observations are summarized in more detail in Appendix 2.

The two most frequently visited freshwater sources in the area were the Kennedy Point Marina and Riverside Inn, located on the western side of the IRL about 9.8 and 14.0 km north of FPL-CCEC, respectively (Fig. 10). Nearly half of tagged manatees visited these two sites (Table 11); of the 33 manatees that spent at least 1 day north of NASA Causeway, 79% (N = 26) and 76% (N = 25) visited Kennedy Point Marina and Riverside Inn, respectively. At Kennedy Point Marina, manatees drank from the surface of a small cove where a thin lens of fresh water flowed from under the road. At the Riverside Inn site, a stormwater drainage pipe discharged freshwater. Tagged manatees were observed in groups of conspecifics actively jockeying for placement at the mouth of the pipe to drink. We observed groups of manatees drinking at both of these sites on every field visit except in the final winter season. The flow from the stormwater pipe at Riverside Inn was much weaker during 3 visits to the site in late February and early March 2015, during 2 of which no manatees were observed.

Manatees that traveled up Banana Creek often visited the Shuttle Runway Canal (Kennedy Space Center) (see Fig. 7C in Deutsch and Barkas 2015). Freshwater was observed flowing over a weir at the end of this canal in winter 2010-11, and that was likely the case at least some of the time in other winters as well. Manatee Cove was a favored spot of our tagged manatees in the first winter when most of their foraging activity in the Indian River was directly across from the power plant (Fig. 11), but it received little use after that (Table 11). Three minor freshwater sources were found in Manatee Cove in March 2010, nearly a year prior to the start of this study. In March 2011, freshwater was in evidence at only one of those sites—a thin lens of brackish water (4 ppt) on the surface of the far eastern end of the canal, where there must have been a freshwater source on the bottom or back in the vegetation. Based on manatee GPS locations, however, none of the tagged manatees visited that part of the cove in winter 2010-11. We concluded that the cove was used primarily as a resting spot, as it was generally a quiet area, well-protected from wind and seas, and with little to no boat traffic. Based on citizen reports and our observations, however, the amount of human interaction in Manatee Cove has apparently increased with the frequent presence of kayak tours, which launch at this site. This increased
level of disturbance may have acted to deter manatees from using the cove and might have contributed to the limited use of the area by tagged manatees in subsequent seasons. An evaluation of the aerial survey data may shed further light on this matter.

Finally, the effort that manatees put forth to obtain freshwater suggests that it is both important to their physiology and perhaps even limiting at times during the dry season. Tagged manatees made directed trips from seagrass beds on the east side of the Indian River to freshwater sources on the west side, specifically Riverside Inn and Kennedy Point Marina. Above we noted the behavioral observations of manatees in the IWWR sitting under pipes with open mouths in order to capture slow flows of dripping water. On another occasion, we observed two manatees engaged in similar behavior under the Rt. 3 bridge over Banana Creek; both were catching very slow drips from a leaking pipe several feet overhead in what appeared to be a painfully slow means of satiating their thirst.

Cold Exposure Signs

At capture in mid-December, all of the tagged manatees \((n = 56)\) showed what appeared to be early signs of exposure to cold on at least one part of their body, more typically on two or three regions. One additional tagged manatee (TBC091) showed no signs of exposure to cold in early December because it had been housed in a temperature-controlled environment prior to release from rehabilitation. The severity of putative cold exposure signs on the skin was slight \((\text{score} = 1)\) in all cases. These signs included small, superficial lesions that were circular, linear, or irregular in shape \((\text{present in 95\% of 56 individuals})\), bleaching or whitening of the skin \((88\%)\), gray mottling \((75\%)\), and sloughing skin \((16\%)\); in addition, one manatee (TBC092) had two small abscesses at capture \((\text{Table 12, Figs. 22-25})\). There was some variability in prevalence of these cold exposure signs among winter seasons \((\text{Table 12})\). Small superficial lesions were found on all of the manatees at capture except for 3 individuals captured in December 2011. Likewise, gray mottling was present on fewer individuals captured in December 2011 \((2/10)\) than in any other winter season.

Of the 57 tagged manatees, 42 were assessed at the end of the winter season from late February to mid-March. Given the challenges of observation in the field, either due to turbidity of the IWWR or consistently windy weather conditions in the study area, it was not always possible to obtain complete views or photographs of each animal \((\text{all 3 body regions viewed and scored})\). The severity of putative cold exposure signs on the skin remained slight \((\text{score} = 1)\) and again included the same types of small, superficial lesions \((\text{present in at least 95\% of 42 individuals})\), bleaching or whitening of the skin \((\geq 81\%)\), gray mottling \((\geq 12\%)\), and sloughing skin \((\geq 26\%)\) \((\text{Table 12})\).

Field observations and photographs were used to link the presence of minor skin abrasions, scratches, chafing or sloughing noted at capture—or later detected in photographs taken at capture—to the subsequent development of skin lesions or whitening at these very same sites. Most of these abrasions were presumably incurred during the capture process. Such patches of abraded skin manifested themselves as white patches or swaths, which were initially mistaken for scars in the field, and as cold-induced lesions with fine pitting or open sores \((\text{Fig. 26})\). This condition was seen on 41 of the 49 manatees \((84\%)\) that were assessed at some point during the winter season. The condition had progressed on two individuals \((\text{TBC057 and TBC063})\) to the point that the cold lesions were considered to be moderate \((\text{score} = 2)\) in severity during a January 2011 assessment; cold signs for those two manatees were scored as slight.
during their late winter assessment. For the 8 individuals where this condition was not observed, one was released without a capture event so abrasions were not incurred (TBC091), three showed no signs of abrasions in their capture photos (TBC068, TBC069, TBC085), two were not photographed or not photographed well after their capture event (TBC071, TBC082), and two were photographed well enough to make the connection but it did not exist (TBC086, TBC088). The summaries below are presented both with and without the inclusion of these abrasions that later turned white or became lesions.

End-of-season assessments for potential signs of exposure to cold allowed us to examine changes from the beginning to the end of winter. Changes in skin condition over the entire winter mostly worsened on the trunk (58\%) and fluke (83\%), but varied on the head with worsening for some individuals (36\%), improvements for others (29\%), and a mixture of worsening in some signs and improvement in other signs for the rest (36\%) (Table 13). If the abraded skin from capture that later turned white or developed lesions is excluded from our assessment of changes in these signs, the overall results change slightly. The skin condition of most manatees still worsened on the fluke (71\%) and still varied on the head with worsening for some individuals (31\%), improvements for others (38\%), and a mixture of worsening in some signs and improvement in other signs for the rest (31\%). These signs also now varied on the trunk with some individuals worsening (42\%), a few improving (25\%), and some showing a mixture of worsening in some signs and improvement in other signs (33\%).

All three body regions were assessed on 34 tagged manatees at the end of their field seasons. When these individuals were assessed as a whole, taking into account all three body regions, the overall skin condition of very few individuals showed improvement over the entire winter, regardless of whether abraded skin that later turned white or developed lesions was included or excluded (3\% and 12\%, respectively) (Table 14). Signs of exposure to cold on most individuals either worsened (41\% and 38\%, respectively) or showed a mixture of improvement in some signs and worsening in others (56\% and 50\%, respectively). All three body regions were assessed on 27 tagged manatees in mid-winter (early January to early February), and the overall skin condition of most individuals had worsened since capture regardless of whether abraded skin that later turned white or developed lesions was included or excluded (74\% and 63\%, respectively) (Table 14). From mid-winter to late winter all three body regions were assessed on 18 tagged manatees. Changes to overall skin condition varied, with most individuals showing improvement or a mixture of improvement in some signs and worsening in others (Table 14).

We hypothesized that the amount of time that tagged individuals spent in cold waters would be related to the progression of putative cold exposure signs over the winter. On average, individuals that showed overall worsening of cold exposure signs spent slightly more time (28.8\% ± 11.1 SD) in water temperatures <20 °C than individuals that showed a mixture of improvement in some signs and worsening in others (23.5\% ± 10.1 SD) (Table 15), but the difference was not significant (two-tailed t-test, t = 2.04, df = 31, p = 0.16). The only individual that showed overall improvement spent 21.5\% of its time in waters <20 °C. If abraded skin at capture that later turned white or developed lesions was excluded from the assessment of overall skin condition, the 4 individuals who showed overall improvement in cold exposure signs spent, on average, about as much time in water temperatures <20 °C as individuals who showed overall worsening of cold exposure signs (28.9\% ± 7.5 SD and 29.8\% ± 10.9 SD, respectively). Individuals that showed a mixture of worsening in some signs and improvement in other signs
spent, on average, less time in water temperatures <20 °C (21.7% ± 9.9 SD). Again, there was no significant difference in the amount of time that individuals in the three groups spent in waters < 20 °C (1-way ANOVA, $F = 2.62, df = 2, 31, p = 0.09$).

**DISCUSSION**

Manatees overwintering in the northern Indian River Lagoon experienced major changes in their environment over the course of this 5-year study (2010-2015). First, the warm-water areas that manatees had used for decades at the only two power plants in the region disappeared: the OUC plant initially went offline during the major cold event in January 2010 and then shut down permanently in fall 2010; the FPL Cape Canaveral plant shut down for modernization in 2010, but it was replaced by an on-site heated refuge in the former intake canal, which operated for 3 winters. Subsequently, the plant resumed operation and thermal discharge into the traditional area, providing more reliable warm water than had been the case just prior to modernization. This change in warm-water habitat and availability at a primary manatee aggregation site provided the motivation behind the intensive monitoring of manatees and water temperatures at the site. Second, there was considerable variation in winter severity among years; hourly temperatures below 20 °C occurred 78% of the time in winter 2010-11 and only 49% of the time in the next winter; likewise temperatures were below 16 °C for 48% of the time during 2010-11 and only 6-21% for the other 4 winters (Table 9). It is important to recognize and account for ambient temperature conditions in any analysis of how warm-water habitat use is affected by other factors. Third, the dense phytoplankton blooms in 2011 and 2012 blocked light penetration to the bottom for prolonged periods, resulting in massive, unprecedented die-offs of seagrass throughout most of the IRL (Morris et al. 2015). Losses were especially drastic in the Banana River and the central Indian River (e.g., Melbourne area) during those two years, with partial recovery in some areas since that time. Benthic macroalgae—another key component of the lagoon’s submerged aquatic vegetation—also displayed large swings in abundance (Morris et al. 2015).

The sources of interannual environmental variation and changes spanned the gamut from one over which humans have complete control (i.e., quantity, quality, and timing of warm-water availability at an industrial site) to one in which we have no control (i.e., severity and duration of cold weather). Human activity likely affects the observed ecosystem changes indirectly through coastal development and resulting inputs of nutrient pollution into the IRL, so we can exert some control over the system through our actions (or inactions) over the long term. Moreover, the past several years have highlighted the manatee’s vulnerability in the NIRL to these various environmental and anthropogenic factors. Manatee susceptibility to cold-related mortality and morbidity has been well-documented (Ackerman et al. 1995, Bossart et al. 2002). This physiologically-based vulnerability was exposed in stunning fashion during two major UMEs caused by severe and prolonged cold in two consecutive winters (2009-10 and 2010-11) (Barlas et al. 2011, Deutsch 2012, Deutsch et al. 2015). The central-east region of the manatee’s range, including Brevard County, was hit the hardest by these UMEs. As distressing as these cold-induced mortality events can be, a more serious concern is the recent and dramatic loss of seagrass due to the unprecedented series of micro-algal blooms in the IRL, and what that may portend for the future. If this biologically diverse estuary undergoes a regime shift from a macrophyte-based system to a phytoplankton-dominated system of primary production, as some researchers have warned (Steward 2013, Philips et al. 2014), then manatees, along with a wide
range of seagrass-dependent species, will be adversely impacted. Manatees in the NIRL have already suffered from another UME of unknown etiology, starting in the summer of 2012 and peaking in the late winter/spring of 2013 (Landsberg and de Wit 2014). Based on the spatio-temporal coincidence of seagrass loss and sudden manatee deaths meeting the UME case definition, among other factors, the cause may be somehow linked to this major ecosystem disruption in the lagoon.

Large numbers of manatees use the NIRL in Brevard County during certain times of year, especially in early spring when migrants have returned from south Florida but most northern migrants have not yet departed (Deutsch et al. 2003b). Aerial surveys have counted up to nearly 2000 manatees in Brevard waters during the winter and slightly over 1000 manatees in January of recent years (Reynolds and Scolardi 2014, 2015). These numbers represent a large fraction of the Atlantic coast subpopulation; Martin et al. (2015) estimated that 70% of the manatees on the east coast were located in Brevard County during a coast-wide survey in March 2012. So clearly the vulnerabilities and threats to manatees in the NIRL discussed above apply to most of the Atlantic subpopulation.

Despite these serious issues, manatees have shown themselves to be quite adaptable to many anthropogenic and natural challenges. Tagged manatees showed a phenomenal ability to discover and use warm-water habitats throughout their home ranges and to take advantage of horizontal and vertical gradients in temperature, such as the temperature-inverted haloclines found in the south prong of the Sebastian River. Manatees switched from the main discharge area at FPL Cape Canaveral to the interim warm-water refuge and then back again, apparently without problem. (Although we do not know if there were manatees that did not find the IWWR and just migrated or otherwise left the area.) In milder winters some tagged individuals spent little time at FPL-CCEC, instead using the tributaries in the southern part of the county (Eau Gallie River, Crane Creek, Sebastian River) for warmth. The difference in the thermal regimes experienced by manatees in the NIRL versus ambient waters (Table 9, Fig. 20) provides a compelling argument as to how effectively manatee habitat selection reduces their exposure to potentially harmful cold in the winter. Finally, manatees are generalist herbivores and have shown the ability to switch to feeding on benthic macroalgae when seagrass is scarce. They also accessed quite shallow waters (<1 m) when the outer edge of the seagrass beds receded due to light limitations; the shallowest depths measured at feeding locations were generally about 0.4 m, with one observation at 0.2 m (Deutsch and Barlas 2012, 2013, 2014).

Winter Range and Migratory Movements

The combined winter range of our 57 tagged manatees extended nearly 800 km between mid-December and mid-March, encompassing almost the entire Florida range of the Atlantic subpopulation, with the exception of the Florida Keys; one individual even crossed into the upper St. Johns River subpopulation region. Based on past studies of telemetered manatees along the Atlantic coast (Deutsch et al. 2003), we expected some of our study subjects to migrate out of the study area, either to the south in early winter or to the north in early spring. Indeed, about one-third of tagged manatees migrated to southeastern Florida, most leaving in December. Nearly half of these southern migrants returned to Brevard County during the study. For example, one adult male (TBC094) migrated as far as Port Everglades—traveling rapidly southbound at speeds of ~60 km/day, much of which was alongshore in the Atlantic Ocean; but he stayed in the Port Everglades area for only 1 week and so was outside of our study area for only 3 weeks! Another adult male (TBC107) made two round-trip migrations between the
northern Indian River and the FPL Ft. Lauderdale power plant during the winter, a total waterway distance of over 1200 km. Similar mid-winter migrations were observed by Deutsch et al. (2003b), emphasizing the considerable dynamism of winter movements along the Atlantic coast. All of the other southern migrants that did not return to Brevard County during their tracking periods lost their tagging gear prematurely. About 15% of tagged manatees migrated northward out of the study area and about half of those returned to Brevard County and the FPL Canaveral plant during the winter. Rates of travel of ~50 km/day were typical for manatees migrating along this corridor (Deutsch et al. 2003b).

Manatee Response to Changes in Warm-water Site Location and Operation

There are a number of pressing management questions related to manatee response to changes in warm-water availability, especially at industrial sites (Laist and Reynolds 2005b). Some of these questions are difficult to rigorously address because they represent scenarios that manatees have not experienced or that researchers have not studied. Furthermore, the answers may depend on specifics of the situation, including the time of year when a warm-water source disappears, whether an industrial thermal discharge stops completely or is intermittent, the severity of cold during the winter, the geographic region (which affects thermal regime and manatee behavior), and the locations of alternate warm-water sites in relation to the normal range of the manatees who find that the warm-water source they have used in the past is no longer present. Here we pose a few such questions and discuss what we have learned from monitoring manatees for this project.

How Quickly Do Manatees Find New Sources of Warm Water Close to a Primary Aggregation Site?

There were three opportunities to address this issue during the 5-year study: (1) in early winter of 2010-11 when the interim warm-water refuge was established to replace the warm-water discharge from the power plant for the next 3 winters; (2) during the latter half of winter 2012-13 when FPL began testing its turbines and generating intermittent discharges of heated effluent from the two discharge sites on the north side of the intake mole; and (3) in early winter of 2013-14 when the switch from the IWWR to FPL-CCEC was made permanent. The aerial surveys were better suited to address the first and third situations because they started in October (2010-2012) or November (2013-2014) of each year, whereas tagging sessions took place in mid-December to reduce our chances of capturing migrants. The tracking study was ideally suited to address the second situation. Furthermore, it is clear that tagged manatees quickly found the thermal effluents at the FPL Cape Canaveral plant site each winter, even though the location shifted across years (Fig. 16). They also preferentially aggregated in the warmest areas within the discharges.

(1) Switch to the Interim Warm-water Refuge at Start of Winter 2010-11: Soon after the FPL IWWR was established and modified to actually contain and maintain warm water in a portion of the former intake canal in November 2010, it became clear that a large number of manatees discovered and were using the new warm-water site. On 10 December 2010 a count of 521 manatees in the IWWR was made (Reynolds et al. 2011). Given the short distance (≤1.7 km via waterway) from the traditionally-used main discharge area north of the intake mole, the rapid discovery and adoption of the replacement site was not surprising. Furthermore, most (if not all) manatees were apparently not deterred by the need to enter the refuge through a 12 ft by 5 ft opening in the newly erected curtain boom barrier. It was fortunate that manatees showed these
two behavioral responses because extremely cold weather arrived in the area in early December and it remained remarkably cold through January. Despite the presence of the IWWR, an unusual mortality event occurred in this region due to the prolonged cold. We do not know whether there was a change in the abundance of manatees using FPL-CCEC from one winter to the next because surveys that account for availability and detection probability were not conducted.

(2) Discovery of the Main Discharge during Plant Testing in Mid- to Late Winter 2012-13: Once the newly modernized plant initiated testing of its turbines in late January 2013, there were two asynchronous warm-water sources at FPL-CCEC—the heating system in the IWWR (i.e., south side of partitioned intake canal) and the two discharge sites on the north side of the intake mole (Fig. 3). It had been nearly 3 years since a manatee could have encountered a warm-water discharge in the latter area during the winter. The fine spatio-temporal resolution of the GPS data, combined with fixed station and manatee-borne temperature loggers, allowed us to ascertain with a resolution of 15 minutes when a manatee visited the main discharge area and when it first encountered warm water (i.e., effluent raised above ambient temperatures) there. Tagged manatees discovered the ‘new’ warm-water source in the main discharge area 0.2 to 37.9 days after the plant resumed discharge of heated water. Most individuals found the warm-water source on their first visit back to FPL-CCEC after testing began. The relative proportion of time manatees spent in the IWWR after testing began was 4-fold greater than that in the main discharge area. Reasons for this differential use include: (1) it took a while for some manatees to find the new thermal discharge (see Results); (2) the IWWR was more reliable than the new discharge, which was intermittent in its thermal output (on arrival the IWWR heater was on for 93.4% of bouts versus only 72.9% for the main discharge); and (3) the IWWR was usually (but not always) warmer than the main discharge area. Manatees were responsive to plant operation, usually leaving the main discharge area within 1 hr after the thermal input to the discharge was turned off.

(3) Switch to the Main Discharge Area at Start of Winter 2013-14: The location and extent of warm-water habitat at FPL-CCEC during winter 2013-14 differed substantially from the previous 3 winters, during which it had been confined to a restricted area within the intake canal. Tagged manatees, as well as the local manatee population, apparently had no trouble in locating the thermal plume north of the mole. This was fully expected for a few reasons: (1) this was the traditional site of thermal discharge for 45 years prior to modernization, so any adult manatees overwintering in the area would have been very familiar with its location; (2) the thermal plume generated by the effluent was extensive, so any manatees approaching from the north or east (i.e., the headings from principle foraging areas) would have encountered the temperature gradient prior to reaching the former IWWR; and (3) testing of the modernized plant resulted in intermittent releases of warm water from the two discharge sites on a near-daily basis starting in late January 2013, and probably many manatees discovered (or re-discovered) this warm-water source during the latter half of that winter.

Will Manatees Continue to Exhibit Fidelity to the Site of a Warm-water Source After It Is No Longer Heated?

Creation and operation of the interim heated refuge for 3 winters while the power plant was undergoing modernization presented us with an opportunity to investigate the development and potential loss of manatee fidelity to a temporary warm-water site. We hypothesized that (1) manatees would visit the site of the former IWWR during the post-conversion phase to check for
the presence of warm water, and (2) use of the former IWWR would decline over time as manatees realized that warm water was no longer present at this site. Indeed, during the first winter (2013-14) after the IWWR was no longer operational, most tagged manatees visited the site, typically multiple times (for a total of 73 visits); they visited the former IWWR on 15% of days that they were present at FPL-CCEC (Table 8). Use of the former refuge by tagged manatees declined substantially in the subsequent winter (2014-15), in terms of the proportion of manatees making a visit, the number of visits per manatee, and the percentage of manatee-days at FPL-CCEC that involved a visit to that site (Table 8). Visits to the former refuge were consistently brief, averaging 2 hr in both winters, and water temperature was nearly always a few degrees cooler there (Table 8). We infer that manatees developed site fidelity to the reliably heated IWWR over the 3 winters of operation (December 2010 to March 2013), which resulted in manatees checking for the continued availability of that thermal source in the next winter.

Furthermore, the much lower use of the former IWWR in the last winter suggests that the fidelity to this site substantially waned over the course of another year. An alternative hypothesis is that manatees visited the former refuge site in order to seek out freshwater which flows in small amounts from various pipes (see Field Observations above). This idea cannot be completely dismissed, but it would not explain the several-fold decline in use between winters. The two smallest tagged individuals in winter 2014-15 did not visit the former IWWR; based on length they were likely in their second winter, meaning that they had no experience with that site as a warm-water refuge and so had no reason to visit except as a freshwater source for drinking.

During winter 2010-11, we might have expected manatees to have checked for the presence of warm water in FPL’s main discharge area north of the intake mole, a site that fairly reliably generated a thermal refuge during winter cold periods for decades. Likewise, they might have been expected to also check for the presence of warm water in the former OUC discharge canal 3 km to the north of FPL, a far less reliable thermal source which had gone offline in the middle of the previous winter. In fact, there were only 41 GPS locations from 9 of the 10 tagged manatees found within 500 m of the FPL discharge pipes during that winter: 61% in the latter half of December, 37% in January, and 2% in February. None of the manatees stayed long in the former discharge area; most visits involved only 1-2 locations (<30 min) and the maximum visit duration was 1.25 hr. Four tagged manatees traveled to and entered the OUC discharge canal, but there were only 22 GPS fixes in the canal, representing 8 visits (6 in December, 2 in January); visits were brief, ranging from 15 min to 1.5 hr. Three manatees visited the former OUC warm-water site just once; 1 manatee (TBC063) visited 5 times over the 3 frigid days immediately after tagging in mid-December; TBC063 also visited the IWWR 3 times during that time period, so she had discovered the new thermal source. Given that the tagged manatees had already found the IWWR and that the waters were very cold in the lagoon (including FPL’s former discharge area), the behavior shown by the manatees was adaptive and not too surprising. Examination of the aerial survey data earlier in the winter, upon the arrival of the first cold fronts when the interim refuge was not functioning well, could provide further insights.

Do Manatees Modify Their Behavior, Specifically Their Attendance Patterns, in Response to Operation of the Warm-water Source?

We hypothesized that the diel pattern of manatee refuge use would mirror the diel pattern of warm-water generation at the FPL Canaveral site. Were manatees timing their presence to correspond with predictable periods of higher delta-T and warmer discharge temperatures? The operation of the IWWR presented us with an unplanned experiment to compare manatee
behavior under contrasting hourly patterns of thermal production because the average IWWR temperature (and delta-T) was nearly constant over the 24-hour cycle whereas the main CCEC discharge varied considerably with electrical demand. The pattern of higher manatee attendance during the daytime and lower at night held even during the winters when average water temperatures in the interim refuge stayed relatively constant over the diel cycle (Fig. 15). This finding indicates that the diel pattern of manatee warm-water attendance is driven by factors outside of the site, likely related to use of foraging areas. In Tampa Bay, manatees showed a strong pattern of nocturnal foraging on shallow, inshore seagrass beds; while much of that was driven by tidal fluctuations in water level (not a factor in the NIRL), a separate diel effect still existed (Deutsch and Carlson 2007).

Manatee Use of Secondary Passive Thermal Basins

When considering the findings from the analyses presented in this report (e.g., percent time spent in a warm-water refuge), it is important to recognize that just because a manatee was located outside of one of the known aggregation sites does not mean that it was experiencing ambient water temperatures. In fact, we discovered several suspected passive thermal basins that provided some warmth relative to the ambient lagoon waters, as evidenced by the temperature differential shown by the tidbit loggers when entering and exiting these systems. Residential canals on the eastern side of Merritt Island and off Sykes Creek, for example, were often slightly warmer (~2-4 °C) than the Banana River. Manatees used them during cool weather as a place to rest, stay warm, and drink freshwater. During the winter of 2010-11, for example, when ambient temperatures in the northern Indian River were between 16-20 ºC, there was remarkably little use of the known aggregation sites because our tagged manatees were using these secondary sites that were not included in the analyses.

In addition to the 3 passive thermal basins (Berkeley, Desoto, and Sebastian C-54 Canals) considered in this study, another 4 sites in the study area often attracted manatees during some winters and appeared to act as passive thermal basins, at least under some conditions (Fig. 1). Summaries of our observations, descriptions, and hydrographic measurements taken during field site visits for these sites can be found in Appendix 1.

Merritt Island High School Canal (MIHS): During cool weather some tagged manatees used the east-west residential canal that lies on the north side of the Merritt Island High School’s football field. A shallow, freshwater drainage ditch (inaccessible to manatees due to its 1.5-ft depth) opens into the southwest corner of the canal, which is up to 7-8 ft deep. They also used a shallow, north-south canal along the Winar Mobile Home Park (“Winar Canal”), where 4 pipes with freshwater flows provided a thin surface lens of freshwater in the canal; manatees were observed to drink from the surface at this site. These canals were visited by 8 tagged manatees over 4 winters, including 4 that spent a cumulative total of ≥12 hr there. When ambient waters in the northern Indian River were <20 ºC, the difference between the temperature experienced by manatees at the far end of the MIHS canal and the temperature in the northern Indian River averaged 3-4 ºC, with a maximum difference of 5.0 ºC; for the south end of Winar Canal, the mean difference was 4.6 ºC, with a maximum difference of 7.1 ºC. However, Winar Canal received less use than MIHS Canal. Starting in November 2015, we established temperature monitoring stations at both sites to investigate patterns of temperature over the winter.

Eau Gallie River Weir: When manatees entered the Eau Gallie River, they nearly always traveled all the way upstream until their continued movement was blocked by a concrete weir.
The upper 350 m of the river was their favored place for resting. Freshwater regularly flowed over the weir; in addition to being a source of drinking water, it is possible that a temperature-inverted halocline may have formed here. Amazingly, this stretch of the river was visited by 20 of our 57 (35%) tagged manatees over 4 winters, including 14 that spent a cumulative total of ≥12 hr there. When ambient waters in the northern Indian River were <20 °C, the difference between the temperature experienced by manatees in this reach of the river and the temperature in the northern Indian River averaged 3-4 °C, with a maximum difference of 6.0 °C.

Crane Creek: Tagged manatees also frequently used the middle and upper sections of Crane Creek, but there was no single aggregation site. The upstream half of this tributary was visited by 22 (39%) tagged manatees over 4 winters, including 18 that spent a cumulative total of ≥12 hr there. The tagged animals that visited Crane Creek spent the majority of their time north and east of the mid-stream island, in a cove ~500 m upstream from the island, and in the upper canals. Surface salinities generally decreased moving upstream and freshwater lenses were most pronounced in the uppermost canals. When ambient waters in the northern Indian River were <20 °C, the difference between the temperature experienced by manatees in the upstream half of the river and the temperature in the northern Indian River averaged 3.5-4.5 °C, with a maximum difference of 7.6 °C.

South Prong of the Sebastian River, Dale Wimbrow Park Cove: Some tagged manatees frequently sought refuge in the south prong of the Sebastian River during cold periods and one of the favored spots was a protected cove just south of Dale Wimbrow Park and boat ramp. That cove was visited by 12 manatees over 4 winters, including 6 that spent a cumulative total of ≥12 hr there. Through hydrographic measurements we identified a temperature-inverted halocline at this site and throughout much of the river—with surface water being cooler and fresher than the bottom water. The bottom substrate in the river is a soft, black, organic muck with strong sulfurous odor. While tracking TBC109 on 28 January 2015, we observed the animal in an aggregation of ~25 conspecifics in a 9-foot deep hole in the middle of this cove; the manatees were bottom resting and possibly burrowing in mud, as plumes of sediment were observed when individuals surfaced and some had piles of mud on their heads when they broke the surface to breathe. The vertical temperature differential was ~5 °C: surface layer was 16.8 °C and 5.5 ppt; bottom layer was 21.7 °C and 17.3 ppt. When ambient waters in the northern Indian River were <20 °C, the difference between the temperature experienced by manatees in this cove and the temperature in the northern Indian River averaged 4-5 °C, with a maximum difference of 9.2 °C! Given the ~80-km distance between those sites, it is not the ideal comparison but it provides an idea of the thermal potential of the site. Starting in November 2015, we established a temperature monitoring station to further investigate the thermal dynamics in this cove. Similar temperature differentials and manatee use were observed in the middle of the river outside the boat ramp, so it is probably not a unique feature of the cove and may extend throughout much of the river’s south prong where a halocline forms.

Duration of Visits to Warm-water Sites: New Records for the Florida Manatee

At most warm-water refuges in Florida, manatees do not have access to forage and so must fast while sheltering from the cold. That was certainly the case at the FPL Canaveral sites, both the IWWR and the main CCEC discharge area. During the prolonged period of severe cold weather from December 2010 to January 2011 most manatees spent lengthy periods in the IWWR. Adult male TBC057, for instance, remained in the IWWR for 31.2 days, with just one
brief foraging trip to the east side of the Indian River; so this individual spent 22.8 days continuously in the IWWR and >99% of the 31-day period there. Adult female TBC062 remained continuously in the IWWR for 32 days, during which she fasted in the warm waters of the refuge. To our knowledge, this is a record for documented fasting duration by a free-ranging Florida manatee. Amazonian manatees (*Trichechus inunguis*) are thought to fast for periods of 3-4 months during the dry season, when they may consume detritus and other organic matter of limited nutritional quality (Best 1983).

The longest continuous stay in a known warm-water site was 48.5 days by an adult male at the FPL Ft. Lauderdale power plant cooling ponds and discharge canal during winter 2014-15. Including 3 subsequent brief excursions into the New River, totaling <12 hr, this individual spent over 99% of a continuous 64-day period within the confines of this industrial warm-water site! As far as we are aware, this is also a record. The fact that a number of tagged individuals spent long periods of time continuously in these ponds suggests that it provides the necessary habitat to harbor a large number of manatees for at least a short period of time. It certainly provides excellent thermal shelter, as the waters were quite warm (e.g., average temperature from the manatee tidbit logger was 27.4 °C during the record bout); it is well-protected from boat traffic; and it apparently also provides some forage, as there are reports of aquatic vegetation available to manatees at this site (Kit Curtin, pers. comm.). These long stays, combined with movements and habitat use highly suggestive of active foraging on overhanging mangrove and bank vegetation, indicate that manatees are not fasting at this site. This is unlike the situation at most other warm-water sites used by manatees.

**Visual “Health” Assessments: Cold Exposure Signs**

All of the individuals captured in mid-December showed what appeared to be early signs of exposure to cold. This is somewhat surprising because, with the exception of individuals captured in December 2010, the manatees were unlikely to have been recently exposed to very cold water temperatures. Our temperature logger data in the IRL does show, however, that mean daily temperatures dropped with early cold fronts to between 16-19 °C for periods of time in November of each year except 2011-12. Furthermore, some animals may have migrated from northerly areas, where water temperatures are cooler. The presence of signs of exposure to cold was expected in December 2010 due to strong cold fronts that dropped the local ambient water temperature to under 20 °C continually for the two weeks prior to captures and to below 10 °C for the previous two days.

Regardless of pre-capture ambient water temperatures, the severity of cold stress signs at captures was not considered to be more than slight (score = 1) in any year; however, there was variability in the amount and severity of these signs among individuals, both within and between winter seasons. Some individuals presented with few cold exposure signs, such as TBC070 who had some gray mottling on its trunk, while others presented with multiple signs of exposure to cold, such as TBC094 who had 5 small superficial lesions on its head, ~15 superficial lesions on its trunk, 2 superficial lesions on its fluke, gray mottling on each body region, and sloughing skin on its head and fluke. While no individuals showed significant signs of exposure to cold that would have triggered intervention (i.e., re-location to a warm-water site or rescue), the current scoring system is not designed to capture these more minute differences (e.g., an individual with one small superficial lesion is scored the same as an individual with 25 small superficial lesions).
Depending on future applications for this assessment system, modifications of the scoring should be considered, including division of this broad category (score = 1).

Similar signs of exposure to cold were observed on tagged manatees at the beginning and end of the winter season. Small superficial lesions that were circular, linear, or irregular in shape and whitening or bleaching of the skin were the two most common types of cold exposure signs at capture and at the end of the winter (Table 12). Nearly all individuals exhibited superficial lesions at capture (95%, n = 56) and at the end of the winter (95%, n = 42). Likewise, the vast majority of individuals showed whitening or bleaching of the skin at capture (88%) and at the end of winter (81%). More manatees had gray-mottled skin at capture (75%) than at the end of the winter (12%); however, this sign of cold exposure was much easier to identify in capture photographs while the manatee could be closely observed on land than in subsequent photographs taken during the field season while the manatee was mostly underwater. Furthermore, an algal mat developed or thickened on many of the tagged individuals over the winter season and that feature would have precluded identification of gray mottling on tagged individuals. Sloughing of skin was identified on fewer manatees at capture (16%) than at the end of the winter season (26%). These were generally smaller patches of sloughing skin often covered with algae, smaller patches of sloughed skin free from algae, or areas along the fluke margin that were peeling away.

Progression of Cold Exposure Signs on the Skin over the Winter

When analyzing data after the winter 2010-11 season, we first made the connection between minor injuries to the epidermis (e.g., abrasions, scratches, chafing or sloughing skin), presumably incurred during the capture process, and subsequent observations of white marks or lesions on the skin during the winter field assessments (e.g., Fig. 26). Although manatee captures usually take place during the winter and it is common for the captured individuals to incur minor skin abrasions during the event, this is the first time that these fine-scale assessments of cold exposure signs have been conducted at the individual level over the course of the winter. More than 80% of the 49 individuals that were assessed after mid-December showed white patches of skin or lesions that were later linked to abraded skin when photographs were reviewed. Once we made this discovery, we took great care (through scrutiny of photographs) to attempt to distinguish between skin features that were initially caused by the capture net and those that developed afterward. For the 8 individuals where this connection was not made, just two incurred abrasions at capture and were photographed well enough during subsequent assessments that a connection could have been made if it had existed. These changes observed in the skin might indicate that the normal healing process for superficial scratches or abrasions was hampered by (a) exposure to cold which reduced perfusion of skin and extremities and/or (b) an immune system that was compromised by cold exposure (Walsh et al. 2005) or other factors. The generally poorer state of these marks on tagged manatees during winter 2010-11—including the two animals given a severity score of 2 on 5 January 2011—compared to individuals tagged in subsequent winters is likely due to the severe cold experienced during the first half of that winter.

Environmental conditions and manatee behavior often made it challenging to assess tagged individuals for changes in cold exposure signs. During winter 2010-11, the configuration of the IWWR resulted in manatees resting at the surface in the thermal plume that spanned the entire width (north-south) of the former intake canal (Figs. 3 and 17). This design facilitated
visual assessments and photography from land as long as tagged individuals were near the shoreline on the south side of the canal. During winter 2011-12, the IWWR was reconfigured such that the canal was divided lengthwise (east-west) and the discharge pipe was submerged (Figs. 3 and 18). While these changes concentrated individuals to the south side of the former intake canal where observations could be made more easily, the turbidity increased and individuals were more likely to rest on the bottom. These conditions often made it difficult to identify our tagged manatees among the many in the dense aggregation, despite their proximity to the observer. Return of warm water to the traditional discharge area north of the mole in the post-conversion phase meant visual assessments and photographs were conducted from a boat when manatees were aggregated in the discharge area. Consistently windy conditions meant that observations were only successful when winds were from the south or west or seas were calm; even light winds from the north or east caused a chop on the surface that distorted features on manatees underwater. Windy conditions also provided challenges in all seasons for any assessment conducted when tagged manatees were away from the warm-water sites, and field work was often planned to target individuals that were in favorable locations. As a result, we often could not fully assess an individual at each visual event; for example, the head and anterior trunk may have been assessed and photographed while the posterior trunk and fluke were not.

Despite these challenges, and the loss of tagging gear by some individuals prior to the end of the winter, 60% of the 57 tagged manatees received a full assessment at the end of their winter season. When assessed as whole individuals, taking into account changes in all three body regions (i.e., head, trunk, and fluke), very few individuals showed improvement in cold exposure signs between capture and the end of the winter season, which is to be expected. Manatees were more often exposed to cold water temperatures during the winter than the months prior to it, and cold exposure signs are expected to develop when individuals are exposed to cold water temperatures. Regardless of inclusion or exclusion of abraded skin that turned white or developed lesions, the number of individuals that worsened overall during the winter season was slightly less than the number of individuals that showed a mixture of changes in cold exposure signs with some signs improving while others worsened (Table 14).

When seasonal progression of putative cold exposure signs was analyzed separated by body region, improvement was more often seen on the head regardless of inclusion or exclusion of abraded skin that turned white or developed lesions (29% and 38%, respectively) than on the trunk (6% and 25%, respectively) or the fluke (6% and 14%, respectively) (Table 13). Likewise, worsening was more often seen on the fluke (83% and 71%, respectively) than on the trunk (58% and 42%, respectively) or the head (36% and 31%, respectively). This difference may be due to higher perfusion of blood in the skin of the head compared to the extremities, such as the fluke. Most of the tagged manatees developed a halo on their fluke margin, of varying degrees in width and shade (from light gray to white, Fig. 25), during the winter season.

We expected that the progression of apparent cold exposure signs over the winter (i.e., worsened, improved, or mixed) would be related to the amount of time that tagged individuals spent in cold waters. The average percentage of time manatees spent in water temperatures <20 °C over the entire tracking period was not much different among the three categories, however (Table 15). Moreover, the ranges of the percentage of time that individuals spent in water temperatures <20 °C overlapped among groups. Thus, some of the individuals that spent the least amount of time in cooler water temperatures exhibited overall worsening of cold exposure signs while others that spent similar amounts of time in cooler water temperatures showed mixed
changes. Likewise, some of the individuals that spent the most time in cooler water temperatures exhibited overall worsening of cold exposure signs while others showed mixed changes. The few individuals that showed overall improvement of cold exposure signs spent more time in cooler waters than some of the individuals that worsened. This variability could be due to several factors, including: (a) the timing of the final visual assessment within the end of winter period, which spanned 5 weeks from late Feb to mid-March, (b) the timing of exposure to cooler waters during the winter season, or (c) the underlying health of the individual. Individuals that received their final assessment in late February had less time to exhibit signs of improvement than individuals who were assessed in mid-March. Mid-season assessments conducted from 2010-2014 showed mostly worsening of signs of exposure to cold by mid-winter with general improvement in these signs by the end of the winter season (Table 14). Although cold snaps at the end of winter (e.g., early March 2013) could have caused the development of new lesions or worsening of pre-existing signs of exposure to cold just prior to an individual’s final visual assessment, many of the signs of exposure to cold had developed earlier in the winter season and had begun to heal near winter’s end. This trend may be responsible for the number of individuals exhibiting mixed changes in presumptive cold exposure signs, with some signs showing improvement while others worsened, at the end of the winter season. End-of-season captures and health assessments were not conducted during this study, so health parameters examined at capture (e.g., blood chemistry, weight, backfat thickness) cannot be compared to the end of the winter season. Yet, presumably, individuals with a less compromised immune system should be better able to heal superficial lesions, bleaching, and mottling. Further analyses that take into account the severity of cold exposure (e.g., degree-hours below 20 °C), in addition to its duration, may provide further insights.

Despite the variability in progression of cold exposure signs among individuals, the prevalence and severity of these signs were not considered to be more than slight regardless of the thermal regime experienced, even for individuals that spent approximately 40% of their time in water temperatures <20 °C! This suggests that the incidence of more significant signs of exposure to cold (score = 2 or 3) may be explained by one or more of the following scenarios: manatees with moderate to severe cold stress signs spend more time in water temperatures <20 °C than our tagged individuals; they are exposed to prolonged periods of even colder water temperatures (e.g., <16 °C) than the tagged individuals; the thermal quality of the warm-water site(s) used is inferior to those used by tagged manatees; or they may have an underlying health issue. The prevalence and severity of cold stress observed during the cold-related unusual mortality event in winter 2009-10—when some manatees at FPL-CC were observed with nearly-white heads and others showed large areas of sloughed skin—suggests that acute exposure to severe cold and marginal warm-water quality at aggregation sites combine to result in the more severe cases of cold exposure signs, sometimes leading to death (Barlas et al. 2011).

While there are certainly limitations associated with the current system of cold lesion assessment, the longitudinal assessments of tagged individual skin condition over the winter have provided important baseline information and insights. First, manatees can enter the winter season with minor lesions, gray mottling, and slight whitening of the skin that may not necessarily be due to recent exposure to cold water temperatures (or may have been incurred in early winter prior to captures). Such lesions have been seen on individuals in photographs taken during the summer (FWC, unpublished data); whether these are persistent residual effects from cold exposure in the previous winter(s) or caused by other factors is unknown. Second, exposure
to cold water may hamper the ability of the manatee to heal these pre-existing signs and may spur the development of additional cold-related lesions or other changes to the epidermis. The severity of these signs were typically considered to be slight even for tagged individuals that spent 40% of their time in water temperatures <20 °C. Third, superficial abrasions incurred during the capture process can later manifest as white marks and lesions, the healing of which may also be hampered by exposure to cold water temperatures or by cold-induced immunosuppression (Walsh et al. 2005). The healing or worsening of such minor abrasions may therefore provide a window into the health status of the manatee. Preliminary review of photographs of individuals captured in early winter for a previous study in Tampa Bay showed that this condition also occurred on some of those individuals monitored over a winter season. Cursory review of selected photographs of individuals captured in the late spring or summer for a study in southwest Florida did not show similar development of abraded skin; however, the photographs were limited and were not taken to facilitate this type of assessment. It is possible that the condition occurred but was not observable in the available documentation. Finally, limitations of the current scoring system do not capture the variability of less severe signs of exposure to cold and the wide range that a score of 1 covers. Manatees can begin a winter season with a single dime-size lesion or with some gray motting of the skin (score = 1) and end the season with multiple lesions, whitening of the head, and a halo along the fluke margin (score = 1), but the score itself does not capture the worsening condition of the individual. While this suffices on the larger scale regarding presence and severity of cold stress at the population level, it does not adequately represent changes in signs of exposure to cold over a winter season on an individual level without a verbal description of these changes. Additionally, smaller presumptive signs of exposure to cold can be missed during visual field assessments. Photographs of the tagged individuals greatly improved our ability to assess individuals and to track changes in the presumptive signs of exposure to cold over the winter season.

ACKNOWLEDGMENTS

Manatee captures were made possible by the hard work and dedication of the staff of the Florida Fish and Wildlife Conservation Commission (FWC) and U.S. Geological Survey (USGS), with assistance from staff of the University of Florida and other organizations (including Jacksonville Zoo, St. Johns River Water Management District, Sea World of Florida, South Florida Museum, and Volusia County Department of Environmental Management). We thank Andy Garrett, Bob Bonde, Martine de Wit, and Mike Walsh for leading capture and health assessment operations, and Kat Frisch for providing crucial aerial support. This research project is a collaborative effort with the USGS’ Sirenia Project, which is evaluating seagrass resources in the northern Indian River Lagoon in collaboration with the St. Johns River Water Management District and us. We are indebted to Jim Reid and Susan Butler (USGS) for their substantial contributions to field tracking, gear recovery and field logistics. We also heartily thank Jamie Shelley, Mary Jo Melichercik, Jaylene Flint, and Caitlin Karniski for assistance with all aspects of field work and data management. We express gratitude to FPL staff—including Jodie Gless, Doug Foust, Jackie (Lorne) Kingston, and Edd Jantz—for their cooperation and willingness to accommodate our needs during this study. We appreciate the assistance of staff at Merritt Island National Wildlife Refuge (MINWR)—including Mike Legare, Kim Bennett, and Dorn Whitmore—and at the Kennedy Space Center and Cape Canaveral Air Force Station for providing access to land and waters under their authority. We thank Jodie Gless of FPL and Michael Harrington of Golder Associates, Inc. for providing operational and temperature data.
from the FPL Cape Canaveral plant, respectively. We appreciate the information and expertise provided by Lori Morris (SJRWMD) on changes in seagrass and macroalgal communities in the IRL. Thanks go to Stacie Koslovsky for creating Figure 1. Financial support was provided by Florida Power & Light Company, pursuant to the Florida Department of Environmental Protection’s Final Order of Certification #09-1015. In-kind support was provided by FWC’s Save the Manatee Trust Fund and the U.S. Geological Survey. Work for this project was authorized and conducted under USFWS research permits (#MA773494-9, MA773494-10, MA773494-11 and MA791721-4, MA791721-5), MINWR special use permits (#2011 SUP 3 and extensions #2011 SUP 003 and, 2014-2011 SUP 003), and FWC permits (#MPZ-0003-10, MPZ-0004-13).

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Deutsch, C. J. and M. E. Barlas. 2013. Manatee response to the conversion of the FPL Cape Canaveral power plant: Movements, warm-water habitat use, and thermal regime of


Table 1. Annual and overall statistics on the number, sex, and size of tagged manatees and GPS tracking information.

<table>
<thead>
<tr>
<th></th>
<th>Conversion Phase (IWWR)</th>
<th>Post-conversion Phase (CCEC)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Tagged Manatees</td>
<td>10</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Sex</td>
<td>5M, 5F</td>
<td>8M, 2F</td>
<td>7M, 5F</td>
</tr>
<tr>
<td>Standard Length (cm): Mean (min-max)</td>
<td>270.1 (246 - 298)</td>
<td>272.7 (211 - 317)</td>
<td>265.4 (238 - 301)</td>
</tr>
<tr>
<td>Body Mass (kg): Mean (min-max)</td>
<td>371.5 (286 - 443)</td>
<td>435.9 (211 - 639)</td>
<td>390.8 (277 - 569)</td>
</tr>
<tr>
<td>Tracking Bout Duration (days): Median (min-max)</td>
<td>89.0 (60.3-90.9)</td>
<td>93.6 (28.6-96.6)</td>
<td>94.7 (13.3-97.6)</td>
</tr>
<tr>
<td>No. GPS Locations</td>
<td>75,823</td>
<td>65,059</td>
<td>80,140</td>
</tr>
<tr>
<td>% GPS Fix Success: Mean (min-max)</td>
<td>93.8 (88.2 - 99.8)</td>
<td>90.0 (72.8 - 98.8)</td>
<td>93.1 (79.9 - 99.6)</td>
</tr>
</tbody>
</table>
Table 2. Estimated accuracy of GPS locations and the number and percentage of fixes assigned as outliers for the newer models of Telonics Gen 4 GPS tags when deployed on manatees along the east coast of Florida during winters 2010-11 through 2014-15.

<table>
<thead>
<tr>
<th>Tag Model</th>
<th>No. Tags</th>
<th>No. Tag Deployments</th>
<th>Locational Error Estimate (m)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Locational Outliers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Median</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile</td>
</tr>
<tr>
<td>TMT-462</td>
<td>3</td>
<td>12</td>
<td>17.0</td>
<td>19.0</td>
</tr>
<tr>
<td>TMT-462-2</td>
<td>2</td>
<td>8</td>
<td>5.8</td>
<td>7.8</td>
</tr>
<tr>
<td>TMT-462-3</td>
<td>7</td>
<td>14</td>
<td>8.6</td>
<td>9.6</td>
</tr>
<tr>
<td>TMT-464-3</td>
<td>2</td>
<td>4</td>
<td>9.2</td>
<td>10.0</td>
</tr>
<tr>
<td>All</td>
<td>14</td>
<td>38</td>
<td>8.7</td>
<td>10.5</td>
</tr>
</tbody>
</table>

<sup>a</sup> An estimated locational error value was given for each successful non-QFP fix, with the true location asserted to be within this distance.
Table 3. Use of water bodies within the study area by tagged manatees during winters 2010-11 through 2014-15.

<table>
<thead>
<tr>
<th>No. Tagged Manatees in Analysis</th>
<th>Mosquito Lagoon&lt;sup&gt;a&lt;/sup&gt;</th>
<th>N. Indian River&lt;sup&gt;b&lt;/sup&gt;</th>
<th>S. Indian River&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Banana River&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>% (No.) Manatees Visited Water Body</td>
<td>57</td>
<td>28.1% (16)</td>
<td>100% (57)</td>
<td>45.6% (26)</td>
</tr>
<tr>
<td>% Time Spent in Water Body: weighted mean (SD)&lt;sup&gt;e&lt;/sup&gt;</td>
<td>57</td>
<td>4.1% (8.1)</td>
<td>65.5% (34.1)</td>
<td>12.4% (32.2)</td>
</tr>
<tr>
<td>% (No.) Manatees with a Core Range in Water Body&lt;sup&gt;f&lt;/sup&gt;</td>
<td>42</td>
<td>4.8% (2)</td>
<td>83.3% (35)</td>
<td>9.5% (4)</td>
</tr>
<tr>
<td>% (No.) Manatees with the Primary Core Range in Water Body&lt;sup&gt;f&lt;/sup&gt;</td>
<td>42</td>
<td>0% (0)</td>
<td>76.2% (32)</td>
<td>9.5% (4)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Mosquito Lagoon includes the area north to Edgewater.

<sup>b</sup> Northern Indian River encompasses the lagoon from Haulover Canal south to Eau Gallie Causeway, including Turnbull Basin, Banana Creek, and the western half of the Barge Canal.

<sup>c</sup> Southern Indian River covers the waters from Eau Gallie Causeway south to Wabasso, including creeks and rivers.

<sup>d</sup> Banana River includes Sykes Creek, Newfound Harbor, and the eastern half of the Barge Canal.

<sup>e</sup> Individual values weighted by duration spent in the study area.

<sup>f</sup> Censored to just those manatees that spent ≥45 days in the study area. A water body was considered to be part of the manatee's 'core range' if the individual spent ≥30% of its time there. 'Primary core range' refers to the single water body where the manatee spent most of its time during the winter.
Table 4. Use of known warm-water sites by tagged manatees along the east coast of Florida: number of manatees visiting site and minimum to maximum number of days that the site was visited over the winter.

<table>
<thead>
<tr>
<th>Warm-water Site</th>
<th>Conversion Phase (IWWR)</th>
<th>Post-conversion Phase (CCEC)</th>
<th>All Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010-11</td>
<td>2011-12</td>
<td>2012-13</td>
</tr>
<tr>
<td>No. Tagged Manatees</td>
<td>10</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Welaka Spring, SJR</td>
<td>0</td>
<td>(7)</td>
<td>0</td>
</tr>
<tr>
<td>JEA District 2 Outfall</td>
<td>0</td>
<td>(4)</td>
<td>0</td>
</tr>
<tr>
<td>FPL-Cape Canaveral PP (includes IWWR)</td>
<td>10 (12 - 51)</td>
<td>10 (2 - 51)</td>
<td>8 (4 - 60)</td>
</tr>
<tr>
<td>Berkeley Canal</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Desoto Canal</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sebastian C54 Canal</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Vero Beach PP</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>FPL-Riviera Beach PP</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>FPL-Port Everglades PP</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>FPL-Ft. Lauderdale PP</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Four individuals (2 in winter 2013-14, 2 in winter 2014-15) only visited the FPL-CCEC site briefly on the first day of tagging; they were excluded from analyses in which the capture day was excluded.
Table 5. Use of known manatee warm-water sites within the study area by tagged manatees during winters 2010-11 through 2014-15.

<table>
<thead>
<tr>
<th></th>
<th>No. Tagged Manatees in Analysis</th>
<th>FPL-CC&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Berkeley Canal</th>
<th>Desoto Canal</th>
<th>Sebastian C-54 Canal</th>
</tr>
</thead>
<tbody>
<tr>
<td>% (No.) Manatees Visited Site [All manatees]</td>
<td>57</td>
<td>91.2% (52)</td>
<td>15.8% (9)</td>
<td>7.0% (4)</td>
<td>31.6% (18)</td>
</tr>
<tr>
<td>% (No.) Manatees Visited Site [Manatees with ≥45 days in study area]</td>
<td>42</td>
<td>95.2% (40)</td>
<td>19.0% (8)</td>
<td>9.5% (4)</td>
<td>19.0% (8)</td>
</tr>
<tr>
<td>% (No.) Manatees Using as Primary Site&lt;sup&gt;b&lt;/sup&gt; [Manatees with ≥45 days in study area]</td>
<td>42</td>
<td>88.1% (37)</td>
<td>4.8% (2)</td>
<td>2.4% (1)</td>
<td>4.8% (2)</td>
</tr>
<tr>
<td>% of Warm-water Habitat Records Spent at Site: mean (SD) [Manatees with ≥45 days in study area]</td>
<td>42</td>
<td>86.1% (29.2)</td>
<td>6.1% (18.3)</td>
<td>2.2% (11.0)</td>
<td>5.6% (17.3)</td>
</tr>
</tbody>
</table>

<sup>a</sup> FPL-CC refers to both the IWWR and the CCEC areas at the FPL Cape Canaveral power plant site.

<sup>b</sup> Primary warm-water site refers to the single site that the manatee spent most of its time during the winter.
Table 6. Number of tagged manatees that moved among known warm-water sites in Brevard County and to southeast Florida during winters 2010-11 through 2014-15. The number in parentheses refers to the total number of movements, as one manatee moved from SE FL to FPL-CC twice during the winter. The shaded blue cells show the number of manatees that used only one of these sites. The analysis was restricted to 48 manatees with a total track duration of ≥60 days.

<table>
<thead>
<tr>
<th>From:</th>
<th>To:</th>
<th>FPL-CC</th>
<th>Satellite Beach</th>
<th>Sebastian C-54</th>
<th>SE FL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capture</td>
<td></td>
<td>45</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>FPL-CC</td>
<td></td>
<td>26</td>
<td>7</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Satellite Beach (Berkeley, Desoto)</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sebastian C-54</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>SE FL</td>
<td>6 (7)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 7. Use of warm-water sites by tagged manatees along Florida’s east coast from mid-December through mid-March: percentage of days and of time spent at known warm-water sites.

<table>
<thead>
<tr>
<th>Warm-water Site</th>
<th>Conversion Phase (IWWR)</th>
<th>Post-conversion Phase (CCEC)</th>
<th>All Years Across Subjects</th>
<th>Across Winters</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Tagged Manatees in Analysis</td>
<td>9</td>
<td>7</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>% Days Visited Warm-water Site$^a$</td>
<td>50.9 (5.1)</td>
<td>39.1 (13.2)</td>
<td>33.7 (17.0)</td>
<td>57.7 (17.4)</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>42.5 - 57.3</td>
<td>17.9 - 53.7</td>
<td>5.2 - 63.2</td>
<td>21.3 - 81.3</td>
</tr>
<tr>
<td>Min-Max</td>
<td>35.2 - 50.3</td>
<td>7.2 - 36.3</td>
<td>1.9 - 40.1</td>
<td>10.3 - 56.2</td>
</tr>
<tr>
<td>% Time Spent at Warm-water Site$^a$</td>
<td>42.7 (5.6)</td>
<td>24.6 (10.0)</td>
<td>22.2 (11.6)</td>
<td>37.9 (15.3)</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>35.2 - 50.3</td>
<td>7.2 - 36.3</td>
<td>1.9 - 40.1</td>
<td>10.3 - 56.2</td>
</tr>
<tr>
<td>Min-Max</td>
<td>35.2 - 50.3</td>
<td>7.2 - 36.3</td>
<td>1.9 - 40.1</td>
<td>10.3 - 56.2</td>
</tr>
</tbody>
</table>

$^a$ Analyses exclude day of tagging and manatees with short tracking durations (<60 full days).

$^b$ Statistics for winters 2013-14 and 2014-15 differ slightly from the annual reports because they were censored to be consistent with the other winters (i.e., data for 1 animal tracked for <60 full days were dropped in each winter).
Table 8. Descriptive statistics on tagged manatee visits to the FPL Cape Canaveral Energy Center’s former interim warm-water refuge (intake canal) during the tracking period for the two winters (mid-December through mid-March) after the modernization of the plant when the interim heating system was no longer operating.

<table>
<thead>
<tr>
<th></th>
<th>2013-14</th>
<th>2014-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Manatees that Visited IWWR (N)</td>
<td>62% (8/13)</td>
<td>42% (5/12)</td>
</tr>
<tr>
<td>No. Non-zero Visits per Manatee: Mean (SD)</td>
<td>9.1 (7.2)</td>
<td>1.6 (0.9)</td>
</tr>
<tr>
<td>[Min - Max]</td>
<td>[1 – 23]</td>
<td>[1 – 3]</td>
</tr>
<tr>
<td>% of Days at FPL-CCEC that Manatees Visited IWWR: Pooled average $^a$</td>
<td>15.4% (75/487)</td>
<td>2.3% (8/349)</td>
</tr>
<tr>
<td>IWWR Visit Duration (hr): Mean (SD)</td>
<td>2.2 (1.8)</td>
<td>2.2 (2.5)</td>
</tr>
<tr>
<td>[Min-Max]</td>
<td>[0.2 – 11.8]</td>
<td>[0.3 – 7.8]</td>
</tr>
<tr>
<td>Average Water Temperature in IWWR (°C) at Time of Visit: Mean (SD) [Min-Max]</td>
<td>20.8 (2.2)</td>
<td>19.7 (1.8)</td>
</tr>
<tr>
<td></td>
<td>[15.7 – 24.6]</td>
<td>[17.4 – 22.5]</td>
</tr>
<tr>
<td>Average Temperature Difference between IWWR and FPL-CCEC (°C) at Time of Visit: Mean (SD) [Min-Max]</td>
<td>-4.2 (2.2)</td>
<td>-2.3 (0.7)</td>
</tr>
<tr>
<td></td>
<td>[-8.3 – 1.9]</td>
<td>[-3.1 – -1.1]</td>
</tr>
</tbody>
</table>

$^a$Percentage is expressed in relation to total days spent in the 3 polygons at FPL-CCEC (Fig. 8), so they are not comparable to the numbers in Table 7. Includes day of capture.

Note: Statistics for each individual manatee can be found in annual reports for winters 2013-14 (Deutsch and Barlas 2014, Table 5) and 2014-15 (Deutsch and Barlas 2015, Table 5).
Table 9. Water temperatures experienced by tagged manatees in the northern IRL (Spruce Creek, Port Orange to Sebastian River—a distance of ~80 km north and south of FPL-CC) from mid-December through mid-March during winters 2010-11 through 2014-15. Summary data for ambient 30-min water temperatures in the northern Indian River are shown for comparison.

<table>
<thead>
<tr>
<th>Conversion Phase (IWWR)</th>
<th>Post-conversion Phase (CCEC)</th>
<th>ALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Tagged Manatees</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Mean % Time ≥20 °C</td>
<td>68.9% (55.2 - 78.7%)</td>
<td>79.5% (75.3 - 84.4%)</td>
</tr>
<tr>
<td>Mean % Time 16–20 °C</td>
<td>25.6% (19.6 - 34.4%)</td>
<td>19.5% (14.9 - 23.4%)</td>
</tr>
<tr>
<td>Mean % Time &lt;16 °C</td>
<td>5.4% (1.7 - 10.7%)</td>
<td>1.1% (0.1 - 2.8%)</td>
</tr>
<tr>
<td>Mean Temperature, °C</td>
<td>20.9 (20.0 - 21.5)</td>
<td>22.0 (21.5 - 22.4)</td>
</tr>
<tr>
<td>Mean Minimum Temperature, °C</td>
<td>10.2 (8.3 - 13.0)</td>
<td>13.8 (10.4 - 15.2)</td>
</tr>
</tbody>
</table>

$^a$ The FWC station IRN column was used for all winters except 2012-13, for which the Golder Station 5 bottom logger (located at the mouth of the breakwater, south side of intake mole) was used.

Note: Analyses exclude the day of capture for each manatee and they exclude manatees with less than 4 weeks of records in the study area. Ambient temperature analyses were matched to the timeframes of the manatee data.
Table 10. Annual and overall statistics on the field effort and sightings of tagged manatees by project staff, other staff from FWC and affiliated agencies, and citizens.

<table>
<thead>
<tr>
<th></th>
<th>Conversion Phase (IWWR)</th>
<th>Post-conversion Phase (CCEC)</th>
<th>ALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. days in the field (Dec-Apr)</td>
<td>27</td>
<td>34</td>
<td>32</td>
</tr>
<tr>
<td>No. citizen and other staff sightings of tagged manatees</td>
<td>59</td>
<td>34</td>
<td>43</td>
</tr>
<tr>
<td>No. staff sightings of tagged manatees away from FPL-CC with recorded group size</td>
<td>30</td>
<td>34</td>
<td>37</td>
</tr>
<tr>
<td>% with other manatees</td>
<td>90%</td>
<td>71%</td>
<td>92%</td>
</tr>
<tr>
<td>Median Group Size</td>
<td>9</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Maximum Group Size</td>
<td>101</td>
<td>51</td>
<td>71</td>
</tr>
</tbody>
</table>
Table 11. Use of known freshwater drinking sites by tagged manatees in the northern Indian River (NIR) close to the FPL-CCEC during winter (mid-December through mid-March). Values show the number of tagged manatees that visited the site, with the total number of manatee-days in parentheses.

<table>
<thead>
<tr>
<th>Warm-water Site</th>
<th>Distance (Bearing) from FPL-CCEC (km)</th>
<th>Conversion Phase (IWWR)</th>
<th>Post-conversion Phase (CCEC)</th>
<th>All Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riverside Inn (NIR, W shore)</td>
<td>14.0 (N)</td>
<td>0</td>
<td>6 (44)</td>
<td>25 (134)</td>
</tr>
<tr>
<td>Kennedy Point Marina (NIR, W shore)</td>
<td>9.8 (N)</td>
<td>0</td>
<td>9 (26)</td>
<td>27 (83)</td>
</tr>
<tr>
<td>Shuttle Runway Canal (Banana Creek, KSC)</td>
<td>19.7 (NE)</td>
<td>1 (18)</td>
<td>2 (7)</td>
<td>8 (39)</td>
</tr>
<tr>
<td>Manatee Cove&lt;sup&gt;a&lt;/sup&gt; (NIR, E shore)</td>
<td>4.8 (SE)</td>
<td>6 (16)</td>
<td>2 (6)</td>
<td>15 (37)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Sources of freshwater were minor in Manatee Cove and manatees may have used it as mostly as a protected resting site.

Note: A visit of any duration on a given day by a manatee was considered equal to 1 manatee-day. Polygons denoting presence at a site were delineated as follows: within 100 m of the freshwater source for Riverside Inn and Kennedy Point Marina; halfway down the Shuttle Runway Canal from the weir (a distance of 250 m); and the entire water body enclosed by Manatee Cove.
Table 12. Presence and types of signs of exposure to cold seen on tagged manatees at capture and during late winter field assessments for each winter season.

<table>
<thead>
<tr>
<th>Cold Exposure Signs At Capture</th>
<th>Cold Exposure Signs in Late Winter&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td># Manatees</td>
<td>10 10 12 12&lt;sup&gt;b&lt;/sup&gt; 12 56</td>
</tr>
<tr>
<td>With Cold Signs</td>
<td>10 10 12 12 12 56 (100%)</td>
</tr>
<tr>
<td>Bleaching</td>
<td>7 9 12 11 10 49 (88%)</td>
</tr>
<tr>
<td>Mottling</td>
<td>9 2 8 11 12 42 (75%)</td>
</tr>
<tr>
<td>Lesions</td>
<td>10 7 12 12 12 53 (95%)</td>
</tr>
<tr>
<td>Sloughing</td>
<td>1 0 0 5 3 9 (16%)</td>
</tr>
<tr>
<td>Abscesses</td>
<td>0 0 0 1 0 1 (2%)</td>
</tr>
</tbody>
</table>

<sup>a</sup> All regions of every manatee were not observed during late winter assessments.

<sup>b</sup> TBC091 was released from rehabilitation and excluded from capture assessment.
Qualitative changes in extent and severity of putative cold-exposure signs on the skin by body region for tagged manatees for each winter season. Comparison of symptoms were made between capture (mid-Dec) and late winter (late Feb to mid Mar); body regions were placed into three categories: worsening of symptoms (-), no changed observed (0) and mixed changes with some improvement and some worsening (M), and improvement of symptoms (+). Numbers in parentheses denote totals if areas of skin that were abraded during capture that later turned white or developed lesions were excluded. All body regions of every manatee were not assessed at the end of every winter season, as shown by the total scored.

<table>
<thead>
<tr>
<th>Winter</th>
<th>Body Region</th>
<th>Worsened (Sum of -)</th>
<th>Mixed (Sum of 0 and M)</th>
<th>Improved (Sum of +)</th>
<th>Total Scored</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010-11</td>
<td>Head</td>
<td>2 (1)</td>
<td>3 (4)</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Trunk</td>
<td>6 (3)</td>
<td>2 (3)</td>
<td>0 (2)</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Fluke</td>
<td>8 (7)</td>
<td>0 (1)</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>2011-12</td>
<td>Head</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Trunk</td>
<td>3 (2)</td>
<td>3 (4)</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Fluke</td>
<td>6 (5)</td>
<td>0 (1)</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>2012-13</td>
<td>Head</td>
<td>2 (2)</td>
<td>3 (2)</td>
<td>4 (5)</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Trunk</td>
<td>6 (5)</td>
<td>2 (2)</td>
<td>0 (1)</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Fluke</td>
<td>7 (5)</td>
<td>0 (2)</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>2013-14</td>
<td>Head</td>
<td>4 (4)</td>
<td>4 (2)</td>
<td>0 (2)</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Trunk</td>
<td>3 (3)</td>
<td>4 (1)</td>
<td>0 (3)</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Fluke</td>
<td>5 (5)</td>
<td>1 (0)</td>
<td>0 (1)</td>
<td>6</td>
</tr>
<tr>
<td>2014-15</td>
<td>Head</td>
<td>6 (5)</td>
<td>2 (2)</td>
<td>1 (2)</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Trunk</td>
<td>3 (2)</td>
<td>2 (2)</td>
<td>2 (3)</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Fluke</td>
<td>3</td>
<td>3 (1)</td>
<td>1 (3)</td>
<td>7</td>
</tr>
<tr>
<td>All Years</td>
<td>Head</td>
<td>15 (13)</td>
<td>15 (13)</td>
<td>12 (16)</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Trunk</td>
<td>21 (15)</td>
<td>13 (12)</td>
<td>2 (9)</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Fluke</td>
<td>29 (25)</td>
<td>4 (5)</td>
<td>2 (5)</td>
<td>35</td>
</tr>
<tr>
<td>All Years (% of Manatees)</td>
<td>Head</td>
<td>36% (31%)</td>
<td>36% (31%)</td>
<td>29% (38%)</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Trunk</td>
<td>58% (42%)</td>
<td>36% (33%)</td>
<td>6% (25%)</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Fluke</td>
<td>83% (71%)</td>
<td>11% (14%)</td>
<td>6% (14%)</td>
<td>35</td>
</tr>
</tbody>
</table>
Table 14. Qualitative changes in extent and severity of putative cold-exposure signs on the skin of tagged manatees for each winter season, without division into body region. Comparisons were made from capture (mid-Dec) to mid-winter (early January to early February), mid-winter to late winter (late Feb to mid-Mar), and from capture to late winter. Individuals were placed into three categories: worsening of symptoms (-), no changed observed (0) and mixed changes with some improvement and some worsening (M), and improvement of symptoms (+). Numbers in parentheses denote totals if areas of skin that were abraded during capture that later turned white or developed lesions were excluded. All body regions of every manatee were not assessed in each period, as shown by the total scored.

<table>
<thead>
<tr>
<th>Winter</th>
<th>Assessment Period</th>
<th>Worsened (Sum of -)</th>
<th>Mixed (Sum of 0 and M)</th>
<th>Improved (Sum of +)</th>
<th>Total Scored</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010-11</td>
<td>Capture to Mid-winter</td>
<td>6 (6)</td>
<td>4 (2)</td>
<td>0 (2)</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Mid-winter to Late Winter</td>
<td>0 (1)</td>
<td>4 (1)</td>
<td>3 (5)</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Capture to Late Winter</td>
<td>2 (2)</td>
<td>5 (4)</td>
<td>0 (1)</td>
<td>7</td>
</tr>
<tr>
<td>2011-12</td>
<td>Capture to Mid-winter</td>
<td>4 (3)</td>
<td>0 (1)</td>
<td>0 (0)</td>
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</tr>
<tr>
<td></td>
<td>Mid-winter to Late Winter</td>
<td>0 (1)</td>
<td>1 (0)</td>
<td>1 (1)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Capture to Late Winter</td>
<td>4 (3)</td>
<td>2 (3)</td>
<td>0 (0)</td>
<td>6</td>
</tr>
<tr>
<td>2012-13</td>
<td>Capture to Mid-winter</td>
<td>3 (2)</td>
<td>3 (3)</td>
<td>0 (1)</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Mid-winter to Late Winter</td>
<td>2 (3)</td>
<td>3 (1)</td>
<td>0 (1)</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Capture to Late Winter</td>
<td>2 (2)</td>
<td>6 (5)</td>
<td>0 (1)</td>
<td>8</td>
</tr>
<tr>
<td>2013-14</td>
<td>Capture to Mid-winter</td>
<td>7 (6)</td>
<td>0 (1)</td>
<td>0</td>
<td>7</td>
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<tr>
<td></td>
<td>Mid-winter to Late Winter</td>
<td>1 (0)</td>
<td>2 (3)</td>
<td>1 (1)</td>
<td>4</td>
</tr>
<tr>
<td></td>
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<td>3 (3)</td>
<td>3 (2)</td>
<td>0 (1)</td>
<td>6</td>
</tr>
<tr>
<td>2014-15</td>
<td>Capture to Mid-winter</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Mid-winter to Late Winter</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Capture to Late Winter</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>All Years</td>
<td>Capture to Mid-winter&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20 (17)</td>
<td>7 (7)</td>
<td>0 (3)</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Mid-winter to Late Winter&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3 (5)</td>
<td>10 (5)</td>
<td>5 (8)</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Capture to Late Winter</td>
<td>14 (13)</td>
<td>19 (17)</td>
<td>1 (4)</td>
<td>34</td>
</tr>
<tr>
<td>All Years  (% of Manatees)</td>
<td>Capture to Mid-winter&lt;sup&gt;a&lt;/sup&gt;</td>
<td>74% (63%)</td>
<td>26% (26%)</td>
<td>0% (11%)</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Mid-winter to Late Winter&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17% (28%)</td>
<td>56% (28%)</td>
<td>28% (44%)</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Capture to Late Winter</td>
<td>41% (38%)</td>
<td>56% (50%)</td>
<td>3% (12%)</td>
<td>34</td>
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</table>

<sup>a</sup>Totals and percentages exclude winter 2014-15 because mid-winter assessments were not conducted.
Table 15. Average % time tagged manatees spent in water temperatures <20 °C in relation to the progression of putative cold exposure signs from early winter (mid-December captures) to late winter (late February to mid-March field assessments). This only includes individuals that were assessed for cold exposure signs on every body region during both periods (n= 34).

<table>
<thead>
<tr>
<th>Cold Stress Assessment</th>
<th>Worsened (-)</th>
<th>Mixed (0 and M)</th>
<th>Improved (+)</th>
</tr>
</thead>
</table>
| Includes abrasions that turned white or developed lesions  
Mean % ± SD (n) [Min - Max] | 28.8 ± 11.1 (n = 14) [10.0 - 44.8] | 23.5 ± 10.1 (n = 19) [6.7 - 41.1] | 21.5 (n = 1) |
| Excludes abrasions that turned white or developed lesions  
Mean % ± SD (n) [Min - Max] | 29.8 ± 10.9 (n=13) [10.0 - 44.8] | 21.7 ± 9.8 (n = 17) [6.7 - 44.1] | 28.9 ± 7.5 (n = 4) [21.5 - 36.2] |

*The difference between the Worsened and the Mixed groups was not significant (two-tailed t-test, t = 2.04, df = 31, p = 0.16).

*There was no significant difference in the amount of time that individuals in the three groups spent in waters < 20 °C (1-way ANOVA, F = 2.62, df = 2, 31, p = 0.09).*
Figure 1. Locations of manatee aggregation sites in Brevard County, Florida, including the power plants and known and suspected passive thermal basins.
**Figure 2.** Locations of known warm-water manatee aggregation sites along the Atlantic coast of Florida.
Figure 3. Locations of warm-water discharges (red squares) and ambient water intakes (blue squares) at FPL-CCEC during the construction and post-construction phases. Placement of discharges 1 and 2 north of the mole did not change between construction phases (top), but there was no thermal discharge here in winters 2010-11 and 2011-12. An interim warm-water refuge (IWWR) was established in the intake canal starting in November 2010. The configuration of this IWWR during winter 2010-11 (bottom left) included a primary discharge placed to the east of a curtain boom that bisected the canal into east and west sections. The configuration changed prior to winter 2011-12 (bottom right) with the installation of a sheet pile wall that bisected the canal into north and south sections and with the movement of the primary discharge to the western end of the canal. This second configuration remained throughout the post-construction phase. Alternate and back-up heater discharges were only used if the primary discharge was unable to maintain required temperatures in the IWWR.
Figure 4. Satellite-linked tracking assembly showing the buoyant Argos/GPS tag tethered to a padded belt around the base of the manatee’s fluke. In addition, a small temperature logger was secured to the tether (with black Cold Shrink™) about 30 cm above the belt. (Drawing by Llyn French, FWC; Photo by Jamie Shelley, FWC).
Figure 5. Site of FPL Cape Canaveral Energy Center showing density of tagged manatee GPS locations (number per hectare) during winter 2010-11 for all but the lowest 10th percentile class, based on a kernel density analysis. The blue polygon was used to assign manatee GPS locations to the interim warm-water refuge (heated canal).
Figure 6. Site of FPL Cape Canaveral Energy Center showing density of tagged manatee GPS locations (number per hectare) during winter 2011-12 for all but the lowest 10th percentile class, based on a kernel density analysis. The blue polygons were used to assign manatee GPS locations to the interim warm-water refuge (heated canal) and to the area outside of the IWWR enclosed by a breakwater.
Figure 7. Site of FPL Cape Canaveral Energy Center showing density of tagged manatee GPS locations (number per hectare) during winter 2012-13 for all but the lowest 10th percentile class, based on a kernel density analysis. The blue polygons were used to assign manatee GPS locations to the intermittent warm-water refuge (north of the intake mole, starting 27 January 2013), to the interim warm-water refuge (heated canal), and to the area outside of the IWWR enclosed by a breakwater.
Figure 8. Site of FPL Cape Canaveral Energy Center showing density of tagged manatee GPS locations (number per hectare) during winter 2013-14 for all but the lowest 10th percentile class, based on a kernel density analysis. The blue polygons were used to assign manatee GPS locations to the main warm-water refuge (north of the intake mole), to the former interim warm-water refuge (non-heated intake canal), and to the area outside of the former IWWR enclosed by a breakwater.
Figure 9. Site of FPL Cape Canaveral Energy Center showing density of tagged manatee GPS locations (number per hectare) during winter 2014-15 for all but the lowest 10th percentile class, based on a kernel density analysis. The blue polygons were used to assign manatee GPS locations to the main warm-water refuge (north of the intake mole), to the former interim warm-water refuge (non-heated intake canal), and to the area outside of the former IWWR enclosed by a breakwater.
Figure 10. Areas of relatively high-use (top quartile) by tagged manatees over 5 winters in the northern Indian River, north of NASA Causeway. Areas were identified by a kernel density analysis of GPS locations; percentiles of density were based on cells with non-zero values. MB Cswy/Pkwy = Max Brewer Parkway (SR 406); RIV = Riverside Inn; KEN = Kennedy Point Marina; NASA Cswy = NASA Causeway (SR 405).
Figure 11. Areas of relatively high-use (top quartile) by tagged manatees over 5 winters in the northern Indian River, in the vicinity of the FPL-CCEC interim warm-water refuge and power plant. Areas were identified by a kernel density analysis of GPS locations; percentiles of density were based on cells with non-zero values. NASA Cswy = NASA Causeway (SR 405); RRI/OUC = Orlando Utilities Commission power plant (not discharging warm water); FPL = FPL Cape Canaveral Energy Center; RC = Rinker’s Canal; MC = Manatee Cove; Bennett Cswy = Bennett Causeway (SR 528).
Figure 12. Distribution of the relative density of tagged manatee locations for 5 winters (mid-December to mid-March, 2010-11 through 2014-15) in the northern Indian River Lagoon in relation to mean daily ambient water temperature in the Indian River. Areas were identified by a kernel density analysis of GPS locations; darker red represents higher density; the lowest density class is not shown.
Figure 13. Mean percentage of time that 57 tagged manatees spent in known warm-water refugia in northern Brevard County (i.e., north of Eau Gallie River) in relation to mean daily ambient water temperature during 5 winters, from 2010-11 through 2014-15 (mid-December through mid-March). Each temperature category is labeled with its low end value (e.g., 20 = 20.0-20.9 °C). The number of individuals and the number of days in which the mean temperature was within each category is given at the top of the figure.
Figure 14. Percentage of time that tagged manatees present in the northern Indian River (Bennett Causeway to A. Max Brewer Causeway) during winters 2010-11 through 2014-15 spent in the FPL Cape Canaveral warm-water refuge (the interim warm-water refuge or the main discharge area) in relation to hour of day and mean daily ambient water temperature in the northern Indian River. Dashed lines denote approximate times of sunrise and sunset.
Figure 15. Percentage of time that tagged manatees present in the northern Indian River (Bennett Causeway to A. Max Brewer Causeway) spent in the FPL Cape Canaveral warm-water refuge (red lines) when mean daily lagoon temperature was 16-20 °C in relation to hour of day and mean hourly discharge temperature (blue lines). Top: During the conversion phase (winters 2010-11 and 2011-12) when only the IWWR was operating. Bottom: During the post-conversion phase (winters 2013-14 and 2014-15) when only the main discharge from CCEC was operating. Shaded areas denote nighttime.
Figure 16. Site of FPL Cape Canaveral Energy Center showing density of tagged manatee GPS locations for each of the 5 winters of the study, based on a kernel density analysis. Darker red depicts higher density; all but the lowest 10\textsuperscript{th} percentile class is shown.
Figure 17. Dense aggregation of manatees in the heated plume of the FPL Cape Canaveral interim warm-water refuge (former power plant intake canal) on 17 December 2010 (i.e., first winter of IWWR). A manatee GPS tag can be seen near the sole entrance/exit formed by a bottom-to-surface curtain boom along the footbridge. (Photo by Chip Deutsch, FWC).
Figure 18. Dense aggregation of manatees in the heated plume of the FPL Cape Canaveral interim warm-water refuge (former power plant intake canal) on 8 January 2012 (i.e., second winter of IWWR). Top: A sheet pile wall bisects the canal, separating the heated south (right) side from the unheated north (left) side. The discharge pipe is in the foreground and the sole exit is at the far eastern end. Bottom: three GPS tags indicate the presence of our study animals hidden under the murky water. (Photos by Chip Deutsch, FWC).
Figure 19. Discharge of muddy water from the heated plume of the FPL Cape Canaveral interim warm-water refuge on 19 February 2013. Photograph was taken from the footbridge looking southeast. Note the IWWR discharge is being sucked around the sheet pile wall into the intake canal by the operation of the plant’s intake pumps. (Photo by Chip Deutsch, FWC).
Figure 20. Mean percent frequency distribution (with standard error bars) of water temperatures during 5 winters (mid-December through mid-March of 2010-11 through 2014-15): (A) experienced by 48 tagged manatees in Brevard County and southern coastal Volusia County (an area extending ~80 km north and south of FPL-CCEC from Spruce Creek, Port Orange to the Sebastian River); and (B) in the northern Indian River (see Methods). Time spent in each temperature bin (e.g., 20 = 20.0-20.9 °C) is broken down by presence at a power plant, at thermal basins, and outside of the 4 known warm-water sites in the region. The 20 °C threshold at which manatees fall below their thermoneutral zone and seek warm water is shown with the dashed line.
Figure 21. Locations of stormwater and drainage pipes that were potential sources of freshwater to manatees in the FPL-CCEC intake canal (Google Earth, 4 Dec 2010). Although the IWWR was to the right of the yellow curtain boom during this winter, a large number of manatees can be seen throughout the canal. Bottom images show manatees drinking freshwater from some of these pipes. (Photos by Margie Barlas, FWC, 17 Mar 2011).
Figure 22. The head of a captured manatee (TBC084) showing three skin conditions potentially related to cold exposure: bleaching or whitening of the skin, superficial lesions (circular, linear, and irregularly shaped), and gray mottling. Additionally, a few patches of abraded skin are present at the back of this manatee’s head. (Photo by Megan Martz, FWC, 15 Dec 2012).
Figure 23. Bleaching of the skin on the right flipper of a manatee (TBC062) at capture (Photo by Alex Hill, FWC, 16 Dec 2010).

Figure 24. Gray mottling on the head of a manatee (TBC056) at capture. (Photo by Kari Rood, FWC, 16 Dec 2010).
Figure 25. A white halo along the tail margin of a tagged manatee (TBC062) in early January. (Photo by Chip Deutsch, FWC, 5 Jan 2011).
Figure 26. Abraded skin on the trunk of a manatee (TBC063) at capture that later turned white or developed lesions. Three areas (as indicated with numbered arrows) are shown to highlight similar patterns in abraded skin and the corresponding white patches 16 days apart. (Top photo by Kari Rood, FWC, 17 Dec 2010; Bottom photo by Chip Deutsch, FWC, 5 Jan 2011).
APPENDICES

The annual reports for this telemetry-based project provide more detail than given in this summary final report. They can be found in the annual Biological Monitoring Reports, which are provided as appendices to the Final Summary Biological Monitoring Report. The appendices can be accessed at the following FTP site:  https://explorer.myflorida.com/

Appendix 1. Site visit field reports: summaries of field observations and measurements at sites in the northern Indian River Lagoon, Brevard County, frequented by tagged manatees over the course of the study. These sites do not include foraging areas such as seagrass beds. A summary and maps are provided below, whereas the actual site visit reports have been posted to the FTP site.

Appendix 2. Freshwater sources at FPL-CCEC intake canal (i.e., IWWR), including locations and flows, during winter.
Appendix 1: Site Visit Reports

During each winter, manatee ‘hotspots’ were identified based on an assessment of repeated use by one or more tagged individuals. Sites were visited to search for likely habitat attractants, such as freshwater sources, warm-water sources, or sheltered resting areas. Particular emphasis was placed on identifying fresh water sources and secondary warm-water sources available to manatees that use the FPL Cape Canaveral Energy Center as primary thermal refuge during the winter season. Information recorded during site visits included most or all of the following: presence and types of aquatic vegetation; type of shoreline and vegetation; types of development and human activities in the area; sources and availability of freshwater; temperature and salinity at various locations and depths; weather; general description of bottom type and bathymetry; and the number of manatees observed and their activities. Photographs were taken to document the habitat. These observations over the course of this multi-year study were compiled in order to gain a better understanding of manatee ecology and habitat use in the region, and to share that with managers and other researchers.

Locations spanned the entire study area from Terra Mar Village in the northern Mosquito Lagoon (Edgewater, Volusia County) to the South Prong of the Sebastian River (Sebastian, Indian River County). In all, 41 locations were visited. When appropriate due to their proximity, multiple sites were compiled into a single report. While most sites were visited by project staff for the purposes of these habitat assessments once or twice during a single winter season, a few were visited multiple times during multiple winter seasons (e.g., Riverside Inn, Kennedy Point Marina). Note that some sites (e.g., Berkeley Canal, Desoto Canal) that provide important secondary warm-water habitat for manatees were visited but have already been characterized in some detail by Spellman (2014) and so are not included here. The list of sites below are organized alphabetically by main waterbody. Nearest city or other major landmark is noted in brackets.

Banana River
- Banana River Park (BRP), Manatee Sanctuary Park (MSP), and Cape Canaveral Sewage Treatment Plant (CCSTP) [Cape Canaveral]
- Center Street Park [Cape Canaveral]
- Hangar AF [Cape Canaveral Air Force Base]
- Holiday Cove [Merritt Island]
- Kars Park [Merritt Island]
- Orange Cove Marina [Cocoa Beach]
- Ridge Manor Canals [Merritt Island]
- Surfside Estates Canal System [Merritt Island]
- T-30 Powerline Cove [Kennedy Space Center]
- Treasure Island Club (TIC) Canal [Cape Canaveral]
- Vehicle Assembly Building (VAB) Turning Basin and Mobile Services Structure (MSS) Basin [Kennedy Space Center]

Indian River
- Banana Creek and Happy Creek [Kennedy Space Center]
- Crane Creek [Melbourne]
• Dummit Creek and Dummit Cove [Merritt Island National Wildlife Refuge]
• Dummit Cove Inland Canals [Merritt Island National Wildlife Refuge]
• Eau Gallie River [Melbourne]
• Haulover Canal [Merritt Island National Wildlife Refuge]
• Indian River Canals: River Moorings and Indian Bay Estates [Merritt Island]
• Kennedy Point Marina [Titusville]
• Kennedy Space Center (KSC) Runway Canal [Kennedy Space Center]
• Manatee Cove [Merritt Island]
• Rinker’s Canal [Merritt Island]
• Riverside Inn [Titusville]
• Sandpoint Basin [Titusville]
• Sebastian River C54 Canal [Sebastian]
• Sebastian River South Prong and Dale Wimbrow Cove [Sebastian]
• SR528 West Side [Cocoa]
• Sunnyland Beach Canals [Melbourne Beach]

Mosquito Lagoon
• Terra Mar Village Canal [Edgewater]

Sykes Creek and Newfound Harbor
• “4” Canal [Merritt Island]
• Merritt Island High School Canal System including Winar Canal [Merritt Island]
• Merritt Island Runway Canal [Merritt Island]
• Vetter Isles Canal [Merritt Island]

Site visit locations are shown in the maps below (Figures 27-31). The summary reports from these field visits are posted on the FTP site noted above.
Figure 27. Overview map showing Site Visit Report locations (yellow stars) in relation to the FPL Cape Canaveral Energy Center (red dot).
Figure 28. Map showing Site Visit Report locations in the northern section of the study area, including Mosquito Lagoon, the northern Indian River, and the upper Banana River.
Figure 29. Map showing Site Visit Report locations in the study area between NASA Causeway (SR405) and SR528 Causeway, including the Indian and Banana rivers.
Figure 30. Map showing Site Visit Report locations in the study area from SR528 Causeway to just south of SR520 Causeway, including the Indian River, Sykes Creek, Newfound Harbor, and the Banana River.
Figure 31. Map showing Site Visit Report locations in the southern section of the study area including the southern Indian River and the Sebastian River.