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Florida Manatee Cold-related Unusual Mortality Event, January – April 2010
Final Report

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Executive Summary

Leslie I. Ward-Geiger

Record cold weather in Florida early in January 2010 followed by below-average temperatures in February and March led to a record number of manatee deaths. The magnitude of the 2010 manatee die-off is unprecedented in the history of manatee research and conservation in Florida because of the geographic range, severity, and duration of the event. The longer term impacts to the population are not currently known. This report of the 2010 manatee unusual mortality event (UME) describes the comprehensive response and investigative actions taken to thoroughly identify and assess the cause and extent of the event, to minimize deaths, and eventually to understand impacts to the population. Resultant information from the UME investigation includes preliminary data associated with mortality, rescue records, aerial and ground survey observations, and environmental data.

Throughout the UME, three divisions of the Florida Fish and Wildlife Conservation Commission (FWC)—the Fish and Wildlife Research Institute, the Division of Law Enforcement, and the Division of Habitat and Species Conservation—with assistance from several of FWC's conservation partners, made tremendous efforts to respond to a high level of mortality and to public reports of distressed live manatees. Aerial and ground monitoring were implemented to document the extent of the event and to augment standard rescue operations. Communication with Florida's power industry was ongoing during the event in order to increase water temperature monitoring efforts near primary winter habitat for manatees. The statewide 2010 UME lasted 89 days from January 11 through April 9 based on an algorithm used to identify UMEs. A total of 480 carcasses were verified over this time; preliminary cause of death for the majority of these manatees was attributed to cold stress (n=252). In addition, a large number of deaths were assigned to the undetermined category (n=197); however, the timing and location of these carcass recoveries suggests that a majority of the deaths from unknown causes were due to cold stress. Manatee mortality was particularly high in the central-east and southwestern regions of Florida. In total, 49 live manatee rescues were conducted, the majority related to cold stress. Although rescue operations occurred statewide, cold-related rescues most commonly occurred in the central-east region.

The unusual mortality event had two distinct phases based on the UME algorithm: an initial Acute Mortality Phase followed by a Chronic Mortality Phase. Disease and death associated with exposure to extreme low temperatures over a short period of time were more often reported in the Acute Mortality Phase. Manatee carcasses recovered during the Chronic Mortality Phase often showed "classic" cold stress signs, such as skin lesions, fat depletion, internal abscesses, gastrointestinal disorders, constipation and secondary infections. Overall, most carcasses (58%) with a known cause of death attributed to cold stress were calves. Most (89%) of the 55 adults whose deaths were attributed to cold stress occurred during the Acute Mortality Phase. Over the timeframe of the UME, 118 adult deaths from all causes were reported. Manatee population growth rate is most sensitive to adult survival and, therefore, the impacts of the 2010 UME will likely have a measureable impact on population vital rates.

The FWC will rely on data from monitoring programs conducted over the next few years to better understand the implications of the unprecedented number of cold-related deaths

reported in 2010. Updated survival estimates based on multi-agency photo-identification monitoring programs will be included in a mathematical model used to calculate the growth rate of the manatee population as well as the probability of extinction. However, it will be important to keep in mind that survival estimates calculated through current photo-identification monitoring data include adults only, and the UME resulted in the relatively large loss of immature animals. In addition, photo-identification techniques have proved to be very challenging in the far southwestern region therefore limiting our knowledge of adult survival for a region that clearly demonstrated effects of the UME.

Lessons were learned regarding the organizational effort required to respond to such an event. A multi-pronged response strategy in step with contingency plans facilitated the handling of large numbers of ill and dead manatees. Early activation of contingency actions was key in managing a broad scale investigation that was both structurally and operationally complex. On-site coordinators worked with team leaders to direct the course of the investigation, to provide timely information to external partners and the public, and to direct daily operational plans and resource assessment. It was critical that coordinators have flexibility in their point of view because problems ranged across scales and were complex. Some recommendations for future large scale events include having a consistent “command center” (to the extent that it is possible and practical), ensuring duplication of team leadership (assign alternates and keep them informed throughout the event), and assigning a volunteer coordinator to supplement staffing needs. The on-site coordinators must also have alternates (assigned as early as possible) to ensure that regardless of how complex and extensive the event may become, there will be a state of coordination capable to view the event from an appropriate scale. In the 2010 event, team leaders were assigned in pairs and the on-site coordinators identified an alternate who was prepared to take on the role of coordination if necessary. Contingency plans for catastrophic rescue and mortality events for the Florida manatee should be reviewed and updated to incorporate what was learned from this and previous events so that future responses will benefit from knowledge gained through experience.

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Expert Team of Investigators

A multi-disciplinary team of experts participated in response, data collection, and analysis of this mortality event. * Indicates team leaders

State On-site Response Coordinator	***Federal On-site Response Coordinator***	
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Lt. Colonel Buckson	FWC-LE	Sonny Wilson	National Park Service
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Introduction

Leslie I. Ward-Geiger

Background—Sirenians are unique among marine mammals in that they are herbivorous and truly hypometabolic. Florida manatees (*Trichechus manatus latirostris*) have a low rate of metabolism and high thermal conductance (Gallivan et al. 1983; Irvine 1983), which forces them to cope with cold weather by seeking warm-water refugia such as springs and warm-water outfalls from electric power generating plants or by migrating to coastal areas and estuaries in the southernmost parts of Florida where ambient water temperatures are usually warmer (Laist and Reynolds 2005). All Florida manatee winter aggregation sites are in peninsular Florida (Figure 1).

Prolonged exposure to water temperatures below 20°C (68°F) can cause a condition called manatee cold stress syndrome, which can result in death. Chronic cold stress can occur in any size class but occurs more frequently in immatures (<265cm in straight-line total body length; O'Shea et al. 1985, Ackerman et al. 1995) which is consistent with their metabolic scope. The problems related to cold stress may be acute, succumbing rapidly to hypothermia, or longer-lasting. The lethal exposure times to low water temperatures are not well documented. In general, cold stress syndrome is a complex disease process which involves metabolic, nutritional, and immunologic factors. Symptoms may include emaciation, skin lesions or abscesses, fat store depletion, dehydration, constipation and other gastrointestinal disorders, internal abscesses, and other secondary infections (Bossart et al. 2002). Behavioral alterations related to cold exposure can include shivering, changes in resting patterns, and cessation of feeding (Walsh and Bossart 1999). Over the nearly forty-year span of the statewide carcass recovery program, documented cases of cold-related mortality have been highest during the severe winters of 1976-1977 (n=38), 1980-1981 (n=30), 1983-1984 (n=34), and 1989-1990 (n=56) (O'Shea et al. 1985, Ackerman et al. 1995). In 1986, 'cold stress' was added as a cause of death category in the State's mortality database because of the relative frequency of its occurrence and magnitude over time. Over the most recent decade, the Florida Fish and Wildlife Conservation Commission's (FWC) Fish and Wildlife Research Institute (FWRI) has documented several winter seasons (December-April) with comparatively higher levels of cold stress mortality including 2000-2001 (n=32), 2002-2003 (n=40), 2003-2004 (n=48), 2004-2005 (n=45), 2005-2006 (n=35) and 2008-2009 (n=69) (FWRI unpublished data; these counts include perinatal mortalities that were cold-stress suspect).

Winter 2010—The National Oceanic and Atmospheric Administration (NOAA) National Weather Service described south Florida weather for January 2010 as a historic cold snap in both duration and magnitude caused by an atmospheric pattern that allowed arctic air to flow across the region. As far south as the Everglades National Park (ENP), daily minimum air temperatures in early January fell below 10°C (50°F) for twelve days and below 15°C (59°F) for fourteen days (Mazzotti et al. 2010). Mazzotti et al. (2010) reported ice on the surface of shallow water south of Florida City (Miami-Dade County) when air and water temperatures reached their lowest for the region on January 11. Following the extreme cold weather in the first half of January, subsequent periods of lower than normal temperatures continued to have impacts across much of the state.

The below-average temperatures had acute and chronic impacts on Florida plants and wildlife. The ENP reported fairly substantial frost damage observed on buttonwood trees and mangroves in coastal areas of the park (Hallac et al. 2010). Agricultural crop losses underscored widespread impacts from the extended cold temperatures; estimated crop losses by March 1 were approximately $500 million (NOAA 2010). During the first week of January 2010, the FWC Wildlife Alert Hotline dispatch centers and the FWC Fish Kill Hotline had received several reports of cold-related fish kills. Preliminary evidence suggested that thousands of fish were killed during this time period to the extent that the FWC temporarily prohibited the harvest or possession of snook (*Centropomus undecimalis*), tarpon (*Megalops atlanticus*), and bonefish (*Albula vulpes*) until further assessments could be made. Thousands of cold-stunned sea turtles—primarily green turtles (*Chelonia mydas*), with smaller numbers of loggerheads (*Caretta caretta*), Kemp's Ridley (*Lepidochelys kempii*) and hawksbill turtles (*Eretmochelys imbricata*)—were observed on both Florida coasts and led to massive rehabilitation efforts by the FWC and many wildlife conservation partners (FWC unpublished data).

Manatee Cold-related Response—Biologists with the FWRI Manatee Program are located at five field stations around the state in order to support a statewide manatee rescue and carcass salvage program (see Appendix C). The FWC responds to public reports of carcasses and transports most carcasses to a central necropsy facility to determine cause of death. The FWC also responds to public reports of animals in distress and, when necessary, rescues and transports sick or injured manatees to rehabilitation facilities. The first report of a live, cold-stressed manatee came from Duval County on January 4. Subsequently on January 7, a female manatee calf was rescued from a canal in Pinellas County where the water temperature was 12°C (54°F). On this same date, reports of cold stress-related manatee deaths started to occur, with the first cases of the year occurring in Brevard and Broward counties on the east coast of Florida. From there, the carcass count escalated. Over a three-month period from January through April (January 11-April 9), 480 manatee carcasses were recorded in state waters and 49 rescues of live manatees were conducted. The count during this period surpassed the record high *annual* count of 429 carcasses set in 2009. Mortality was particularly high in the central-east and southwest regions of the state.

The United States Fish and Wildlife Service (USFWS) and the FWC established federal and state on-site coordinators to direct and take responsibility for the response and to consult with the Working Group on Marine Mammal Unusual Mortality Events (WGMMUME). The WGMMUME declared the event to be an official Unusual Mortality Event (UME) on February 26 because at least four of their criteria established for designating a UME were met (UME criterion 1, 4, 5, and 6; Appendix B). Early on, the FWC assembled a response team as outlined in the Contingency Plans for Catastrophic Rescue and Mortality Events for the Florida Manatee and Marine Mammals (Florida DEP (Department of Environmental Protection) et al. 1998). The response team directed the course of the investigation, maintained close communication among response team leaders, provided information to partner agencies and organizations, and contributed to daily operational resource assessment, logistics, and planning. Other than the on-site coordination roles, teams included: Rescue and Salvage Logistics, Environmental Sampling, Aerial Survey, Data Management and GIS, Necropsy and Medical Investigations, and Media Relations.

FWC's response fell into three main categories: manatee carcass salvage and manatee rescue, monitoring environmental conditions, and aerial and ground surveys of free-ranging manatees. The objectives of this document are to report on general environmental conditions, the carcass count and preliminary assignment of cause of death, carcass distribution, and live animal monitoring results from in-air and on-ground efforts as well as rescue operations.

Summary of the Weather during the Winter of 2009-2010

Charles J. Deutsch

The winter season of 2009-2010 was one of the coldest on record in Florida. The following synopsis was compiled from a variety of sources, primarily the NOAA National Weather Service and the Florida Climate Center at Florida State University (NOAA 2010a, 2010b, National Weather Service 2010, Florida Climate Center 2010). The winter began with unseasonably warm temperatures in the first half of December and brief cold fronts passed through in the latter part of the month; overall, the average temperatures for the month of December were near normal across most of the state. The New Year, however, was ushered in with a blast of cold, arctic air on January 1, followed by additional cold air masses through mid-January that sent nighttime air temperatures dropping to near or below freezing in much of the state. This was a historic cold snap in terms of both duration and magnitude, and many long-standing temperature records were broken. The period of January 2-13 was the coldest twelve-day period on record in parts of south Florida (Naples, West Palm Beach) new records were set there with twelve consecutive days at or below 7.2°C (45°F). In central-east Florida average daily temperatures during this period were about 8 to 11°C (15 to 20°F) below normal. Weather patterns changed in the latter half of January, as air temperatures warmed to near or slightly above normal values, and continued into early February. Unseasonably cold temperatures returned on or about February 7, remained for much of the rest of the month, and lasted through March. The coldest period in March was during the first week when a cold air mass moved into south Florida, generating more record lows and freezing temperatures. The average March air temperatures at Vero Beach and Naples were the coldest on record; colder than normal Gulf of Mexico waters kept maximum air temperatures in southwest Florida much lower than normal.

Average air temperatures were well below normal (2.2-4.4°C / 4-8°F below) across the entire state for three consecutive months from January through March 2010. The average temperatures in parts of south Florida (Naples, West Palm Beach and Miami Beach) established new all-time records for this three-month period. In central-east Florida the combined January/February average air temperature departures from normal ranked in the top five coldest starts to the year: the coldest on record for Melbourne (tied with two other years, 13.0°C / 55.4°F) and for Stuart; the second coldest for Vero Beach and Fort Pierce; and the third coldest for Titusville. The number of days during the winter (December-February) when the minimum air temperature was less than or equal to 0°C (32°F) was broken (Vero Beach, eight days) or tied (Melbourne, eight days) in coastal areas of central-east Florida. Likewise, average winter temperatures were the coldest in Tampa since 1969 and the tenth coldest since record-keeping began in 1890.

Summary of the Operational Status of Power Plants during the Winter of 2009-2010

Ron Mezich

The extremely cold weather challenged Florida's power industry by increasing demand for electricity, which taxed old and new facilities alike. Mechanical problems experienced by individual power plants resulted in lapses of warm-water discharges into areas long used by manatees as warm-water refugia. The variations in the amount of warm water being discharged at some power plants resulted in extended periods of time when temperatures were below the biological minimum of 20°C that manatees require during long periods of cold weather.

Seven power plants in Florida produce warm-water discharges that are considered primary warm-water sites for manatees (FWC 2007). Five of these power plants are on the east coast of Florida; four of these power plants—Fort Lauderdale, Port Everglades, Riviera Beach and Cape Canaveral—are operated by Florida Power & Light Company (FPL) and one, Indian River, was operated by RRI Energy during this winter and is in the process of merging with another company to form GenOn Energy. The remaining two power plants that are considered primary warm-water sites are located on the west coast of Florida: Tampa Electric Company's (TECO) Big Bend power plant located in Tampa Bay and FPL's Fort Myers power plant, which is on the Caloosahatchee and Orange rivers (Figure 2). These seven power plants operate with a Manatee Protection Plan that is part of their National Pollution Discharge Elimination System (NPDES) permit. Although these power plants typically operate 24-hours per day during peak electrical demand, the FWC included a condition in the Manatee Protection Plans that would require these power plants to operate their discharge as a safe guard under certain conditions. When ambient water temperatures drop to 16.1°C (61°F), the power plants are required to endeavor to heat discharge waters to at least 20°C (68°F).

In addition to the primary warm-water power plants are five power plants that are considered secondary warm-water sites for manatees (FWC 2007). These power plants have discharges that are inconsistent in their operation resulting in fewer manatees using these sites and on a less frequent basis. Four of the secondary power plants are found on the west coast of Florida: TECO's H. L. Culbreath Bayside power station located near Port Sutton in Hillsborough Bay, Progress Energy's (PE) Anclote River power plant located along the Anclote River (Tarpon Springs), PE's Bartow power plant located on the western shore of Tampa Bay (St. Petersburg), and PE's Crystal River power plant located near the Crystal River. The lone power plant that offers manatees a secondary warm-water refuge on the Atlantic coast of Florida is the Vero Beach Municipal power plant (Figure 2).

The daily operating status of each of these power plants during the winter of 2009-2010 is summarized below beginning on the Atlantic coast at the southernmost facility and moving north:

<u>FPL Fort Lauderdale Power Plant</u>—The FPL Fort Lauderdale power plant operated throughout the winter and experienced no significant operational issues. A new high number of manatees at this warm-water site was recorded.

FPL Port Everglades Power Plant—The FPL Port Everglades power plant operated throughout the winter and experienced no significant operational issues. A new high number of manatees at this warm-water site was recorded.

FPL Riviera Beach Power Plant—The FPL Riviera Beach power plant was put into reserve shutdown for economic reasons in November 2008 and will remain in this status until repowered. During the winter of 2009-2010, FPL, in preparation for repowering the power plant, installed a temporary electrical heating system for the purpose of providing an interim warm-water refuge for manatees in order to meet the conditions of their NPDES Manatee Protection Plan. FPL was required as part of their Power Plant Siting permit to conduct a test of this interim system during the winter of 2009-2010. This test occurred between December 7 and 11, 2009. After this testing period, the Riviera Beach power plant was required to operate according to their 16.1°C (61°F) trigger temperature during the rest of the winter. However, FPL also operated the interim system during additional subsequent test periods (December 21-23, January 26-27) and to provide a warm-water refuge for manatees during major cold periods (January 2-14, February 10-22, February 24-March 10, and March 18-19), even though the intake temperature never dropped below the 16.1°C (61°F) trigger temperature over the winter. The interim heating system experienced a mechanical shutdown on January 14, 2010 and did not return to fully operational status until January 27.

Vero Beach Municipal Power Plant—The Vero Beach Municipal power plant operated inconsistently during the winter, as is typical of power plants that provide secondary warm-water sites. During the January cold event, however, at least two, and as many as five, of their generating units were operating for a 13-day period (January 2-14, 2010). Two units also operated on February 14.

FPL Cape Canaveral Power Plant—The FPL Cape Canaveral power plant experienced no significant mechanical issues and operated within the requirements of its NPDES Manatee Protection Plan. However, because this power plant is aging and will be repowered over the winters of 2010 through 2013, it operated primarily when the NPDES trigger temperature of 16.1°C (61°F) was in effect. When ambient water temperatures rose above 16.1°C (61°F) the generating units were operated only when electrical demand was great enough to require it to do so. Due to this operation schedule, the Cape Canaveral power plant often ran at less than peak output and the warm-water refuge varied in size and temperature throughout the winter. A new high number of manatees at this warm-water site was recorded.

RRI Energy Indian River Power Plant—The FWC was notified in the fall of 2009 that the RRI Energy Indian River power plant would be going into a “mothball” status beginning January 1, 2010. In an agreement with the FWC, RRI Energy provided one electrical generating unit in operational status through the winter of 2009-2010. This unit operated through January 9 when it experienced a mechanical failure and was offline until January 13. During the period when the power plant was offline, manatee use was reduced to zero and the FWC agreed that operations during the remaining winter season would only occur when manatees with cold-stress symptoms were observed at the former discharge site. This criterion was not met, and the Indian River power plant did not operate during the winter after January 9.

The operational status for power plants on the west coast of Florida is summarized below beginning from the southern-most facility and moving north:

FPL Fort Myers Power Plant—The FPL Fort Myers power plant operated throughout the winter and experienced no significant operational issues. A new high number of manatees using this warm-water site was recorded.

TECO Big Bend Power Plant—The TECO Big Bend power plant has four electrical generating units. During the winter of 2009-2010, multiple units experienced mechanical problems that either took them offline or caused them to run at less than 100 percent capacity. Beginning on November 23, 2009, one unit was taken offline for repairs and was not expected to be back online until June 2010. That left three units operational during the winter; on December 26, a second unit had mechanical difficulties that placed the unit mostly offline until February 11, 2010. During this 37-day period the remaining two units were operational and producing warm-water; however, both of these units experienced temporary mechanical difficulties and were running at less than peak production for short periods of time on January 14, 16 and 17. Beginning on February 11, three of the four units remained operational for the remainder of the winter with the exception of a mechanical failure of one unit between February 20 and February 22.

PE Bartow Power Plant—The PE Bartow power plant is secondary to the TECO Big Bend power plant as a warm-water refuge in Tampa Bay and operates as a secondary warm-water refuge under its NPDES permit unless the TECO Big Bend power plant experiences an unplanned shutdown. Prior to the winter of 2009-2010, this power plant completed a repowering project, but the new units experienced multiple mechanical issues during the winter season. The Bartow power plant incurred mechanical problems and operated at partial power starting on January 8 and was subsequently taken offline for repairs on January 9; it remained offline or operating at low capacity due to mechanical problems for the remainder of the winter.

TECO H. L. Culbreath Bayside Power Station—The TECO H. L. Culbreath Bayside Power Station completed repowering in 2004, converting former coal-fired units to natural gas. During the winter of 2009-2010 this power plant operated throughout the winter and experienced no significant operational issues.

PE Anclote River Power Plant—The PE Anclote River power plant is a secondary power plant and operated inconsistently throughout the winter. Due to elevated electrical demand, however, this power plant operated more often than in a typical winter. Neither unit at the Anclote River power plant was operating for a period of time from February 25-27, 2010.

PE Crystal River Power Plant—The PE Crystal River power plant has both coal-fired and nuclear-fueled units. During the winter of 2009-2010, the nuclear plant was offline. The coal-fueled units operated as demand and maintenance allowed. These units were operated so that at least one unit was discharging water greater than 20°C and manatees were provided at least a small warm-water refuge throughout winter.

Response to the Unusual Mortality Event—Manatee Carcass Salvage and Necropsy

Response to Manatee Carcasses
Thomas Reinert

FWRI staff members from five coastal field stations respond to all reported carcasses, a key monitoring activity and source of information on known and emerging threats to manatees. These field stations are located around the state (Jacksonville, Melbourne, Tequesta, Port Charlotte, and St. Petersburg) and strategically divide Florida into five regions (Figure 3). Each region is covered by their respective staff with the assistance of FWC-Law Enforcement officers and dispatch (FWC-LE), and a 24-hour alert system. Field stations are staffed by at least one biologist from 8:00 am until 5:00 pm, seven days a week. The lead biologist at each field station also participates in a rotating On-Call Biologist position to maintain coverage after-hours (5:00 pm until 8:00 am) and during holidays, effectively covering the state 24 hours per day, 365 days per year. Locally, at least one biologist is available (on-call) to respond to emergencies after-hours or on holidays as directed by the On-Call Biologist (if that biologist is located elsewhere in the state). Most carcasses are transported by field personnel from recovery locations to FWRI's Marine Mammal Pathobiology Laboratory (MMPL) in St. Petersburg. MMPL biologists perform consistent, high quality, post-mortem examinations to determine cause of death. Mortality information is maintained in a database, and is made available in a timely manner on the FWRI website (http://research.myfwc.com/manatees).

During the 2010 UME, carcasses and suspected distressed manatees were reported mostly by the public through the Wildlife Alert Hotline (1-888-404-FWCC) and also directly to field staff. Collection of many carcasses proceeded as normal, with law enforcement officers or volunteers securing carcasses at boat ramps and field biologists or volunteers retrieving them for transport to the MMPL. As per Contingency Plan guidelines (see Appendix C), multiple carcasses transported simultaneously were initially grease-marked with mortality ID and then later were marked, additionally, with colored flagging tape specific to each field station. This became necessary as personnel (mostly from the Northeast and the Southeast Field Stations) began recovering carcasses from neighboring regions (primarily from the central-east coast) while en route to the MMPL with carcasses from their own region, thus delivering multiple carcasses from different areas. This method of both flagging and marking carcasses was helpful, particularly during the Chronic Mortality Phase, when carcass condition declined and previously grease-marked skin would slough off during transport (especially when multiple carcasses were being transported together). The majority of carcasses were necropsied at the MMPL and disposed of by rendering or burial at Fort DeSoto Park (Pinellas County). Some carcasses were necropsied in the field at or near their recovery location.

Carcasses were identified by aerial survey in the ENP, an extremely remote area of Florida. The National Park Service conducted surveys to document mortalities of multiple species of flora and fauna within the ENP boundaries (Hallac et al. 2010). After each aerial survey, ENP biologists provided manatee carcass locations (GPS coordinates) and photographs, when available, to FWRI biologists. In collaboration with ENP rangers and volunteers, FWRI biologists conducted ten field trips, between January 15 and February 17, in this region to collect

as much data as possible from the carcasses that were accessible by boat. Carcasses from remote locations remained where they were reported for decomposition.

Spatial and Temporal Patterns of Manatee Carcass Recoveries
Margaret E. Barlas, Stacie M. Koslovsky and Charles J. Deutsch

Shortly after the cold front passed over Florida in early January 2010, manatee carcasses exhibiting signs of exposure to cold water temperatures began to be discovered. These early carcasses were recovered on the east coast of Florida: on January 7, two carcasses were recovered, one each from Brevard and Broward counties; on January 9, one carcass was recovered from Flagler County; and on January 11, three carcasses were recovered from Brevard County. On January 13, eleven carcasses that exhibited gross signs of exposure to cold were recovered from multiple counties on both the east and west coasts of Florida (Figure 4). The Contingency Plans for Catastrophic Rescue and Mortality Events for the Florida Manatee and Marine Mammals (Florida DEP et al. 1998) define an unusual mortality event (UME) to be greater than seven manatee carcasses or distressed manatees found in a localized area within 72-hours. In previous manatee unusual mortality events, the localized area was defined as the area that was affected by the causative agent (e.g., within a *Karenia brevis* bloom boundary); in this case, the prolonged cold period, as the causative agent, affected water temperatures statewide. Thus, the area was defined as the entire state of Florida, and this initial indicator of an UME was met on January 13, 2010. The number of reported carcasses started to escalate on January 18, with at least 10 found per day for each of the next 12 days (through January 29) (Figure 5).

An algorithm to identify unusual manatee mortality, using the previous five-year period as a baseline, detected elevated counts of carcasses with non-human-related and undetermined causes of death statewide from January 11 through April 9, an 89-day period (Figure 6). This means that the 7-day cumulative carcass counts observed during this period exceeded the 99th percentile of such counts for the corresponding months over the five-year baseline period (excluding past known UMEs). The algorithm clearly identified two phases of the UME: an Acute Mortality Phase (January 11-February 9) and a Chronic Mortality Phase (February 17-April 9). For the purpose of analyses, the seven days with fewer carcass reports between the two phases were considered part of the Chronic Mortality Phase of the event; therefore, the acute and chronic phases of the UME lasted 30 and 59 days, respectively. Note that the terms ‘acute’ and ‘chronic’ used in reference to these mortality phases refer to the relative rate of carcass recovery, that is, a sudden onset with a high peak in number of carcasses (acute) versus a more gradual onset with a less elevated number of carcasses (chronic). The terms to denote these phases were not selected based on determination of cause of death (i.e. acute or chronic cold stress).

Manatees in all regions of the state (see Appendix D) suffered unusually high mortality, with the exception of the northwest region (Figure 7). The highest numbers of carcasses were reported and verified in the central-east and southwest regions (n=187 and 125, respectively, Table 1). Statewide, reports of carcasses were noticeably absent north and west of Tampa Bay on the Gulf Coast (with the exception of Crystal River, Citrus County) and on the Atlantic Coast from Nassau County through Flagler County and the central portion of Miami-Dade County (Figure 7).

Of the 480 dead manatees reported and verified during the statewide UME timeframe (January 11-April 9), more than half (52.5%, n=252, including 13 also classified as perinatal deaths) were determined to have died from cold stress (Table 1). Cold stress accounted for 89.0% of known causes of death (Table 2). Nearly three-quarters of the carcasses with a known cause of death attributed to cold stress were recovered from the central-east (53.6%) and the central-west regions of Florida (19.4%) (Table 1). Manatee carcasses in remote parts of Florida, specifically portions of ENP, were located by aerial surveys and were often inaccessible due to the extreme logistics of access to these areas. These carcasses, with an unknown cause of death, in the far southwest region made up the majority of the carcasses in the 'Verified: Not Recovered' category (Table 1). Therefore, the relatively smaller number of carcasses whose deaths were attributed to cold stress in the far southwest region was due to the fact that cause could not be determined for most of them. Excluding carcasses whose cause of death was unknown, the proportions of deaths due to cold was high in all regions (50-96%; Figure 8). Relatively few deaths were attributed to human-related causes (3.5%, n=17). The majority of carcasses with a known cause of death attributed to cold stress were calves (≤235cm in straight-line total body length), including perinatal calves (≤150cm in straight-line total body length) (57.9%; Table 2). Manatees with a known cause of death attributed to cold stress were nearly evenly divided between males and females (Table 3). Note that these figures should be viewed as preliminary, because cause of death has not yet been finalized for all carcasses necropsied during the UME.

The UME algorithm was run for each region separately to determine whether the carcass counts exceeded the regional 99th percentile thresholds to be considered a UME and to identify the regional start and end dates. This mortality event clearly exceeded UME levels in all but one (northwest) of the six regions (Figures 9-14). The timing and pattern of verified carcass counts during the Acute Mortality Phase were remarkably consistent among regions: starting in mid-January (varied from January 11 – January 19) and ending in early February (varied from February 3 – February 8) (Table 4). The maximum 30-day statewide carcass count (excluding known human-related causes of death) was 296 between January 11 and February 9, which corresponded precisely with the Acute Mortality Phase of the UME as determined by the algorithm. The corresponding maximum 7-day count (excluding known human-related causes of death) was 156, occurring between January 20-26, for an average of 22 carcasses per day.

The central-east region was the first region to experience the effects of the Acute Mortality Phase, approximately six days before any of the other regions. During this phase, two-thirds of the carcasses (all causes of death) were reported and verified in the central-east and far southwest regions (n=103 and 97, respectively; Table 5) and no carcasses were reported in the northwest region (Figure 12a). Most of the 480 dead manatees reported and verified during the statewide UME timeframe were found during the one-month-long Acute Mortality Phase (62.3%, n=299; Table 6). Additionally, about two-thirds of the 252 cases with a known cause of death attributed to cold stress were recovered during this phase (68.3%, n=172).

Unlike the timing of the Acute Mortality Phase, the timing and pattern of verified carcass counts during the Chronic Mortality Phase varied considerably among regions (Table 4, Figures 9-14). During this phase, nearly half of the carcasses were reported in the central-east region, with the rest distributed throughout the northeast, southeast, far southwest, central-west, and

northwest regions (Table 5). All of the carcasses reported in the northwest region during the statewide UME timeframe (n=8) were reported during the Chronic Mortality Phase. The majority of the carcasses with a known human-related cause of death were reported during the Chronic Mortality Phase, as well (82.4%, n=17; Table 6).

Most of the carcasses with a known cause of death attributed to cold stress were calves (including perinatals) in both the Acute and Chronic Mortality Phases (51.1% and 72.6%, respectively; Table 7). There were many more adult carcasses with a known cause of death attributed to cold stress recovered during the Acute Mortality Phase (28.5%, n=49) than during the Chronic Mortality Phase (7.5%, n=6). Individuals with a known cause of death attributed to cold stress recovered during the Acute Mortality Phase were very nearly evenly divided between males and females, while there were somewhat more male carcasses (60%) with a known cause of death attributed to cold stress recovered during the Chronic Mortality Phase (Table 8).

Findings from Gross Necropsy for Cases Determined to be Related to Cold Stress Syndrome
Martine de Wit and Brandon Bassett

The cause of death for 252 manatees reported between January 11 and April 9 was determined to be related to cold stress syndrome (preliminary data[1]). Of these, necropsies of 233 manatees were performed at the MMPL. Eighteen carcasses were severely decomposed and/or in remote locations, and, therefore, were necropsied in the field. One manatee that died at the Miami Seaquarium was necropsied on site. Carcasses ranged between 118 and 352cm (in straight-line total body length). Thirteen of the 252 cold stress carcasses were within the perinatal category.

Almost all carcasses with death attributed to cold stress demonstrated skin lesions associated with exposure to cold (see Appendix E for photographic examples of cold-related skin lesions). Skin lesions varied greatly in severity, distribution, and presentation. On gross necropsy, mild lesions included bleaching of the epidermis on body extremities or in skin creases, and bleached dots on the body. In some animals, the epidermis had a porous appearance on ventral regions or in body creases. Thickening of the epidermis was also observed around lesions, on body extremities, on larger regions of the body, or as a “cobblestone” pattern on focal or larger regions of the body. If the integrity of the epidermis was disrupted, changes varied from small pits to larger lesions in various shapes and sizes. Severe cold stress lesions penetrated into the dermis. Ulcerating cold stress lesions and abscesses were observed on all aspects of the body.

Internal findings ranged from non-specific acute signs associated with alterations in blood flow (congestion) to acute respiratory changes and signs consistent with chronic cold stress syndrome. Congestion (engorgement of vascular bed) was mostly found in the lung, pleura, and kidney. Acute respiratory changes included mucus-filled airways, wet lung surfaces, and fluid in the pleural cavities, which were probably associated with water inhalation and/or lung edema. Chronic cold stress signs grossly observed were depleted fats, serous atrophy of

[1] Necropsy reports from this event are still under review. Total mortality numbers will not change, but numbers for individual cause of death categories may be adjusted as reports are finalized.

fats, internal abscesses, enteritis, dried-out feces, and lung changes indicative of pneumonia. Also, many animals had relatively empty gastrointestinal tracts, indicative of fasting.

Findings of congestion and acute respiratory changes were mostly found during the Acute Mortality Phase. These findings were probably representative of disease and death associated with exposure to extreme low temperatures over a short period of time. Approximately two-thirds of the 172 cold stress carcasses during this phase demonstrated signs of congestion (indicative of shock) and/or acute respiratory changes (indicative of drowning). However, the majority of the deaths that were believed to be caused by 'acute cold stress' also showed some secondary signs of prolonged cold exposure, such as skin lesions, some fat depletion, and dried-out feces (for *Diagnosis of Cause of Death*, see below). Only three adult females reported in January were completely clear of internal and external signs of chronic exposure to cold. There were six pregnant females among the carcasses recovered during the Acute Mortality Phase. The unusual finding of vegetation in the esophagus in two manatees (MEC1007 and MSE1025) indicated a sudden death and supported a more acute type of cold stress after the animals moved through cold water to feed. Severe skin lesions typical for chronic cold exposure were observed in only a small fraction of carcasses during the Acute Mortality Phase (approximately 6% of cold stress carcasses).

Approximately 75% of the 80 carcasses reported during the Chronic Mortality Phase with cause of death attributed to cold were diagnosed as chronic cold stress. The majority (75%) of these chronic cases had severe skin lesions. The remainder of the chronic cases demonstrated less severe skin lesions, such as thickening of epidermis or small, superficial skin lesions, but had internal findings suggestive of chronic disease, including depleted fats, infections, and/or changes in the GI tract.

Findings from Histopathology[2]
Martine de Wit

Histopathology findings of thirteen cold stress cases were evaluated for this report. Significant lesions consistent with cold exposure were found in the skin of most manatees. There was loss of superficial or entire epidermis in many skin sections (ulceration). Other sections contained hyperplasia and hyperkeratosis of the epidermis. Lesions often extended into the dermis. Ulceration, necrosis and heterophilic dermatitis were commonly found. Vasculopathy and vasculitis were present in the dermis of eight cases.

Mild to moderate lymphoid depletion or lymphocytolysis were observed in all but one case. Approximately 50% of the cases demonstrated serous atrophy of fat tissue on histology. Most manatees demonstrated zymogen depletion in the pancreas, indicative of fasting.

No definitive histopathologic diagnosis could be made for primary acute changes grossly observed in five cases. The case of MEC1076 (male, total length=295cm, reported on February 1, 2010) illustrates this point. This animal's skin tissues contained marked necrotizing

[2] Additional histology cases are pending. Further assessment of acute versus chronic cold stress changes will occur as results become available.

dermatitis, dermal vasculopathy and dermal edema, but internal organs lacked any findings significant to cold stress or underlying infectious disease. Gross necropsy findings of this manatee included acute changes such as congestion, mucus- and foam-filled airways, and wet, bloody lungs. Of the other four cases, acute aspiration with mild pneumonia was found in one, and a lung lesion suggestive of pulmonary infarction (no cause detected) was detected in the other.

Diagnosis of Cause of Death
Martine de Wit, Brandon Bassett and Denise M. Boyd

Historically, the diagnosis of cold stress death has been determined by the presence of both external and internal signs on gross necropsy. External signs include significant thickening of epidermis, bleaching of epidermis, skin lesions, or abscesses. Internal findings significant to cold stress determination are depleted and/or serous fats, enteritis, pneumonia, dry hard feces (constipation), or internal abscesses. In addition to necropsy findings, environmental conditions are taken into consideration. Similarly, during this event, most of the cold stress cases were diagnosed based on presence of both external lesions and at least one internal sign. In contrast with previous years, cold stress lesions were mild and sparse in many carcasses, especially during the Acute Mortality Phase. Congestion and acute respiratory changes were considered a 'new' finding associated with more acute cold stress and were used as sole internal signs supporting cold stress in approximately 20% of total cold stress mortality.

Carcasses were diagnosed as 'Undetermined; Too Decomposed' when stage of decomposition precluded assessment of external lesions and/or presence of significant internal findings. It should be noted that decomposition often hinders determination of congestion, which may explain the high number of undetermined causes of death, especially during the Acute Mortality Phase. 'Undetermined; Other' was assigned when necropsy findings were inconclusive or when significant findings of both human-related and natural causes were present.

Carcasses were determined as 'Verified; Not Recovered' when documented by photographs or confirmed by an experienced observer, and a necropsy was not performed. FWC staff responded to 16 of these carcasses. Genetics samples, ear bones, morphometrics, and gender information were collected, but a full necropsy was not performed.

Tissue samples and gastrointestinal contents from field necropsies in ENP were submitted for brevetoxin analysis. Low background concentrations of brevetoxin were detected in most carcasses throughout the Park. Additional samples from field necropsies in Charlotte, Lee, Glades and Collier counties also contained very low concentrations of brevetoxin.

Response to the Unusual Mortality Event—Manatee Rescue

Response to Injured Manatees
Thomas Reinert

Similar to manatee carcass salvage, the FWC receives calls from the public reporting manatees in distress. Field staff members respond to these calls and coordinate a network of

personnel from various agencies and organizations to work with FWC biologists to rescue and, when necessary, transport manatees to rehabilitation facilities. Statewide, FWC rescue operations proceeded as normal. In an effort to proactively identify manatees in distress, however, on-water monitoring was enhanced by providing information on identifying cold stress symptoms and contact numbers for regional rescue staff to FWC Fisheries Program staff and law enforcement officers, both of whom were frequently on the water in regions of significant impact. Manatee program field staff assessed many animals, relocated some to warm-water sources, and transported those deemed to be in critical need to critical care facilities. During the event, critical care space at the three critical care facilities was taxed, particularly at Sea World in Orlando; several animals that were rescued in proximity to Sea World had to be transported further south to Miami Seaquarium due to space limitations. Transporting animals to facilities out of the region or further away hampered staff by increasing the time out of their designated response area. On several occasions, field staff from neighboring regions assisted by meeting part way or completing the entire trip, and on a few occasions, facility personnel traveled to a rescue site to pick up and transport the rescued animal(s). Discussions (coordinated by USFWS) were held to determine if critical care space could be increased by releasing captive manatees ready for release and by relocating manatees no longer needing critical care to other facilities. FWRI implemented weekly coordinating calls to facilitate enhanced coordination among rescue staff and facilities particularly regarding available critical care space.

Spatial and Temporal Patterns of Manatee Rescues
Margaret E. Barlas and Stacie M. Koslovsky

Manatees that exhibited external signs of and behaviors related to cold water exposure began to be rescued days after the cold front initially passed over Florida: on January 4, an adult female manatee (312cm) was relocated from an unfavorable cold-water location in Duval County to Blue Spring State Park in Volusia County as a precautionary measure; on January 7, a female manatee calf (210cm) was rescued from Pinellas County and taken to a critical care facility; on January 8, two manatees were rescued from Manatee County – one (~270cm subadult female that was also being monitored via satellite telemetry by the Manatee Rehabilitation Partnership) was taken to a critical care facility for treatment while the other (240cm, male calf) was relocated to Warm Mineral Springs in Sarasota County; and on January 12, a female manatee calf (170cm) was rescued in Brevard County and taken to a critical care facility. Unlike the distribution of carcasses recovered during this timeframe, these rescues occurred in various locations on both coasts of the state. On January 13, two manatees were rescued due to exposure to cold water temperatures, one on the west coast (Collier County, 226cm, female) and one on the east coast (Palm Beach County, 313cm, female), both of which died that day. These two rescues occurred on the same day that the number of carcasses surpassed the initial indicator of an UME and the protocols described in the Contingency Plans for Catastrophic Rescue and Mortality Events for the Florida Manatee and Marine Mammals (Florida DEP et al. 1998) were enacted.

Of the 49 manatees rescued during the statewide UME timeframe (January 11 – April 9), most (71%, n=35) were rescued due to cold stress (Table 9). About 10% were attributed to watercraft-related injures (n=5). More than half of the manatees rescued for cold stress were recovered from the central-east region (54%), while the rest were evenly distributed amongst the other five regions (Table 9, Figure 15). Overall, the majority of the manatees rescued due to cold

stress during the event were calves (57%; including perinatal; Table 10), and 57% were female (Table 11).

Of the 35 manatees rescued due to cold stress during the statewide UME timeframe, most (71%) were rescued during the longer Chronic Mortality Phase (Table 10). Most of the manatees rescued due to cold stress during both mortality phases were calves when compared to other size classes within the same mortality phase (Table 10). All but one manatee rescued due to cold stress during the Acute Mortality Phase were females; however, a few more males (56%) than females (44%) were rescued during the Chronic Mortality Phase (Table 11).

Summary of Clinical Signs for Rescue Cases Determined to be Related to Cold Stress Syndrome
Mark Flint, Martine de Wit and Donna Szemer

Clinical signs specific to cold stress in manatees are 'cold stress lesions' (ulcers, abscesses, patchy whitening, and possible hyperkeratinization of the epidermis) and lethargy, in association with potential gastrointestinal disturbances, a decrease in core body temperature, and secondary infections. In addition to these signs, environmental information, such as water temperature (20°C (68°F) or less), is taken into consideration when making a field diagnosis of 'cold stress' disease. When a manatee is rescued due to suspected cold stress and transported to a rehabilitation facility, additional clinical assessment is conducted to confirm the field diagnosis and to select an appropriate treatment regime for the individual animal. Indicators of interest to clinicians and biologists fall into three categories: morphometric (see *Spatial and Temporal Patterns of Manatee Rescues* above for findings) and physical examination findings (e.g., age and sex class, external examination and primary clinical data), behavioral assessment (e.g., lethargy and neurological changes), and clinical pathology (e.g., abnormal findings on internal examination and blood profiles). This section of the report summarizes the signs and findings from 35 manatees rescued due to suspected cold stress throughout Florida between January 11 and April 9, 2010.

Physical Examination Findings[3]**—**The most frequently occurring clinical sign noted in rescued, cold stress-suspect manatees was the presence of cold stress lesions. This was followed by observations of thin and emaciated animals, and respiratory compromise. All other reported clinical signs occurred infrequently (Table 12). As a noteworthy aside, two manatees were pregnant at admission to the rehabilitation facilities.

Behavioral Assessment—On presentation, only one animal (REC1014) exhibited neurological deficits (noted as 'neurological systems are affected from sub-thermal temperatures' in the USFWS/FWC Captive Manatee Database) and lethargy, and subsequently died after two days of treatment. A further five animals were recorded as lethargic, of which one (RSE1007) died during transport, two (SWFTm1004B and SWFTm1005B) were released after veterinary treatment, one (LPZ102796) was transferred to another rehabilitation facility, and one (LPZ102818) is still in rehabilitation as of September 30, 2010.

[3] Full clinical examination information was not available, which precludes confirmation of these findings and may exclude other important clinical signs.

Clinical Pathology—Results of blood biochemistry and hematological profiles analyzed at the University of Florida were available for a subset (n=14) of animals transported to rehabilitation facilities. Pertinent anomalous findings were toxic changes noted on hematology (57% [95% Confidence Interval, 29-82]), moderate to severe rouleaux (79%, [49-95]), and elevated serum amyloid A levels (64% [35-87]). Results were consistent with previous findings that examined the generalized inflammatory disease syndrome of manatees, particularly cold stress syndrome (Harr et al. 2006).

Manatees Rescued Multiple Times for Cold Stress—Two of the 35 rescued manatees (REC1018 and REC1019) had been rescued previously for cold stress. REC1018 was originally rescued on March 6, 2009 in Sykes Creek (Brevard County) as a large calf with abscesses as well as 'classical cold stress symptoms' (REC0903 Rescue Report and SWFTm0908 Rehabilitation Report). This individual again succumbed to cold stress this past winter, being rescued on April 6, 2010 in Palm Bay, Brevard County. REC1019 (TBC055) was first rescued on December 27, 2008, as a 195cm dependent calf suffering cold stress lesions. He was released with a satellite-linked GPS tag on February 8, 2010 at Berkeley Canal (Satellite Beach, Brevard County), and tracked by the Manatee Rehabilitation Partnership (MRP). Due to his movement to unsuitable winter habitat in cold ambient waters, inappropriate behavior, and mild cold stress signs, TBC055 was relocated six days later to Port St. John, near the FPL Cape Canaveral power plant. On April 4, he was reassessed as suffering from chronic cold stress (matted with algae, abdominal folds, and not 'passing gas') and was taken to a rehabilitation facility on April 6.

Two other manatees (RNW1003/TCR014 and CR1016/TCR015) were being monitored by the MRP via satellite-linked GPS tag at the time they were rescued during the UME. Both of these animals were originally rescued as calves. Field observations indicated they did not have the learned behavior necessary to seek warm water; thus, they were brought back into rehabilitation on January 8, 2010, and March 13, 2010, respectively, due to mild cold stress clinical signs and using unsuitable habitats during cold weather.

Outcome for Rescued Manatees *(as of September 30, 2010)*
Mark Flint, Martine de Wit and Donna Szemer

Of the 35 cold-stress rescue cases occurring during the UME time frame, 29 were distributed between three rehabilitation centers: twelve to Lowry Park Zoo, seven to Sea World Orlando and ten to Miami Seaquarium. From the facility of admission, five transfers (three out-of-state and two intra-state) occurred. In addition, six died during rescue or during transportation to a rehabilitation facility: three small calves ($\leq$175cm in straight-line total body length), two large calves (206-235 cm in straight-line total body length), and one adult ($\geq$266cm in straight-line total body length).

Based on presenting clinical signs, the attending facility veterinarians recorded a prognosis (stable, critical, and guarded) for 22 of the 35 rescued manatees (USFWS Captive Manatee Database, unpublished data, 2011). Of the five stable animals, all were released. Of the ten critical animals, five died, three are still in rehabilitation, and two were released. Of the seven guarded animals, four are still in rehabilitation, one was released, and two were transferred

to an out-of-state rehabilitation facility. Initial prognosis appears to correlate with rehabilitation success only if the animal presents as stable.

Of the twelve manatees taken to Lowry Park Zoo in Tampa during the cold stress event, two were released, five were transferred to other rehabilitation facilities (two to South Florida Museum in Bradenton and three to Columbus Zoo in Columbus, Ohio), and five are still in rehabilitation at Lowry Park Zoo. There were no recorded deaths. Of the seven manatees taken to Sea World Orlando during the cold stress event, three were released, three are still in rehabilitation at the park, and one died. Of the ten manatees taken to Miami Seaquarium during the cold stress event, five were released, one is still in rehabilitation at the aquarium, and four died.

Of the two pregnant manatees admitted to Lowry Park Zoo, one (LPZ102809) gave birth to a healthy male calf (LPZ102836) on June 27, 2010. Both calf and cow are scheduled to be released in the fall of 2010. The other pregnant female (LPZ102808) aborted her calf, as evidenced by discharge of fetal bones in the summer of 2010, and is scheduled for release in the fall of 2010.

Response to the Unusual Mortality Event—Monitoring Environmental Conditions

Water Temperature Monitoring in Response to the Mortality Event

Charles J. Deutsch

Given that this UME was caused by severe and extended cold weather, the environmental monitoring focused on water temperatures around the state, particularly at sites of high manatee concentration. The FWRI's Manatee program maintains a winter temperature monitoring program at key manatee warm-water aggregation sites around the state of Florida (excluding springs). The overall goal is to monitor and assess the quality of warm-water habitat for manatees and how that changes within winters and across years. Specific objectives include: (1) providing a long-term record of water temperatures at industrial thermal discharges (primarily power plants) used by manatees to document changes in the thermal regime as a result of operational changes, such as altered delta-T (i.e., number of degrees above ambient), temporary shutdowns or intermittent discharges; (2) determining whether selected passive thermal basins can sustain manatees during prolonged cold periods—an important component of long-term warm-water carrying capacity; and (3) providing a long-term record of winter severity in manatee habitat outside of warm-water sites. The last objective is accomplished incidentally through the monitoring of ambient sites in proximity to each warm-water site, and through the extensive, long-term monitoring programs established by the U.S. Geological Survey (USGS), the NOAA, and other research organizations. These temperature data enhance manatee population, ecological, and behavioral studies; for example, by providing data to correlate shifts in winter distribution or changes in mortality with changes in the thermal regime of warm-water sites.

Temperature loggers (HOBO Pro, Onset Corp.) are usually deployed in October and recovered in April, providing a record of water temperature at 30-minute intervals from

November 1 through March 31 of each winter. Loggers are generally secured to record temperature in the middle or bottom of the water column. In protected basins or canals where thermal stratification is more likely to occur, sometimes a vertical array of loggers are placed to record surface, mid-column, bottom, and occasionally sediment temperatures. As noted above, an ambient site is monitored in the vicinity of each warm-water site in order to be able to assess the thermal benefit provided by the warm-water site relative to surrounding ambient waters. When feasible, the loggers are checked periodically during winter to remove biofouling organisms, to assure proper placement, and to download data. Acquiring the data during the winter is important to ensure data recovery in case the unit is later lost or stolen, as well as to assist managers in decision-making during the winter.

During winter 2009-2010, the FWRI monitored a total of 23 warm-water sites and nearby ambient waters with 62 HOBO loggers (Figure 16). Additional important sites for manatees in southwest Florida were monitored by USGS (Everglades, Ten Thousand Islands) and by Mote Marine Laboratory (Matlacha Isles and Pass, and the Caloosahatchee and Orange rivers).

As the UME unfolded in January, specific sites with large aggregations of manatees in two geographic areas were of particular concern. Because of their potential to lead to catastrophic mortality, they lent themselves to enhanced scrutiny and possible management intervention. Power plants used by manatees in both areas of concern—two in Tampa Bay and one in the Indian River Lagoon—underwent partial or full shutdowns during the cold event. Therefore, directed efforts were made to download loggers or otherwise monitor temperature at these sites during January and February. The temperature data were evaluated and findings were presented to researchers and managers as needed to assist with decision-making and with shaping response efforts in the field.

UME Response: Temperature Monitoring at the TECO Big Bend Power Plant—One site of management concern was the TECO Big Bend power plant discharge canal, located in Apollo Beach. This power plant discharge canal is the primary warm-water site used by manatees in the Tampa Bay area (Wright et al. 2002). As described above (see *Summary of the Operational Status of Power Plants during the Winter of 2009-2010*), a mechanical failure at the power plant in early January 2010 resulted in operation of only two of its four boiler units. The reported water temperatures in the canal were dropping as the cold event continued, and the possibility that one or both of the remaining units would trip offline was a serious concern. Furthermore, the secondary warm-water site used by manatees in Tampa Bay at the Progress Energy Bartow power plant also incurred mechanical problems and was operating at partial power and was subsequently taken offline for repairs for much of January starting on the 9th. Two actions were taken in response to the need for more accurate and timely information on the thermal regime manatees were experiencing in the TECO Big Bend discharge canal: (1) the area of monitoring was expanded by adding a second HOBO logger on January 7, 2010 at the observation platform at the most easterly part of the canal and the aggregation area (the original logger was located at the walkway near shallow flats on the south side of the canal opposite the discharges); and (2) the loggers were downloaded and the data were evaluated three to four times in the first half of January, until the canal temperatures were stabilized and reliable daily updates from the utility staff were provided to the FWC. In addition, manatees were observed at the site for external and behavioral signs of cold stress (see *Manatee Cold Stress Monitoring* below). Manatees were

clustered at the far eastern end of the discharge canal; the unusual turbidity stirred up by their activities at this site suggested that they were actively burrowing into the bottom sediment.

The information learned during that time period was valuable in shaping the response to the UME: (a) the water temperatures reported by the TECO Big Bend Manatee Viewing Area docents were biased low, so the situation was not as dire as initially thought; (b) water temperatures during early January at the walkway site averaged 1.5°C (2.7°F) cooler and were more variable than at the platform (Figure 17), where most manatees were aggregated, thus the thermal regime experienced by the main aggregation was better than what was inferred from the data at the original walkway site; and (c) the water temperatures reported by TECO Big Bend power plant staff at the west end of the canal averaged 2.8°C (5.0°F) cooler than at the east end by the platform during January, so their daily reports could be used to infer thermal conditions in the manatee aggregation area. On January 11, towards the end of the main cold event, an evaluation of the platform water temperatures indicated that they remained relatively stable and consistent, averaging between 19.8-22.8°C (67.6-73.0°F) over the prior 5 days; so to that point there appeared to be adequate warmth for manatees in the most eastern end of the canal (Figure 17). Although management options were limited, more drastic actions to prevent cold-related mortality were deemed unnecessary at that time. The delta-T of the discharge canal averaged about 11-12°C (~20-22°F) at the platform site during the week of coldest ambient waters (Figure 18). Ambient water temperatures generally increased over the subsequent two weeks, resulting in temperatures in the aggregation area well above the lower critical limit of the manatee's thermoneutral zone (Figure 17).

UME Response: Temperature Monitoring at the FPL Cape Canaveral Power Plant—The other area of intense management interest during the emerging cold-related mortality event was Brevard County. The area along the central-east coast of Florida (from Brevard County south through Martin County) was the first region to show a spike in carcasses that triggered the UME (on January 11). Of particular concern was the operational status of the two power plants that manatees in the northern Indian River Lagoon rely on for warmth. The aging RRI Energy (formerly Reliant Energy) Indian River power plant went offline due to a boiler tube failure in the single operating unit on January 10; attempts to activate a second unit failed and the power plant remained offline for the remainder of the winter (see *Summary of the Operational Status of Power Plants during the Winter of 2009-2010*). Manatees had been using the RRI Energy Indian River power plant's thermal effluent for refuge from the cold, with 165 manatees counted during an aerial survey on January 5. RRI Energy staff reported 65 manatees present on the day before the power plant shutdown, and none after the failure for the following two weeks. Manatees using the RRI Energy site left quickly after cessation of warm-water discharge, presumably shifting back to the nearby FPL Cape Canaveral power plant (3km to the south) which had been operating more reliably and consistently. However, the FPL Cape Canaveral power plant had also been operating at a lower capacity and frequency than in past years, as this was its last winter of operation before deconstruction and conversion to a more modern and efficient facility. Of particular note, all five manatee deaths in Brevard County during the first three days of the UME (January 11-13) were due to cold stress, four of which occurred within 10km of the FPL Cape Canaveral power plant. Of interest, three of these animals were adult females, which are typically less susceptible to cold temperatures than are smaller, immature manatees. Two of these adult females were actually recovered in the FPL Cape Canaveral discharge area.

Although it is likely that the manatees suffered cold stress away from the power plant and then died after reaching it, it still raised concerns about the adequacy of the site as a warm-water refuge during this extended period of extreme cold.

Given the large numbers of manatees using and depending on the FPL Cape Canaveral site (860 manatees counted at the two power plants on January 5), it was essential to maintain sufficient warmth at this site through the cold event. Nighttime air temperatures in the area repeatedly dropped below freezing during early January and the only online real-time water temperature site in the area (USGS, Haulover Canal) showed ambient water temperatures dropping to <10°C (50°F) —levels known to cause hypothermia and death in manatees (Figure 19). FPL was unable to provide the FWC with daily reports of intake and discharge temperatures at the Cape Canaveral power plant and the FWRI's East Coast Field Lab staff were working overtime to recover carcasses and to rescue manatees in distress. Other than a single hydrographic survey conducted on January 5 by FWRI staff, and five days (January 10-14) of multiple outlet pipe temperatures provided by FPL that could not be converted into an overall discharge temperature, the FWC had little information during the event on the thermal regime experienced by manatees in the FPL Cape Canaveral discharge. Likewise, little was known about the level of cold stress experienced by manatees at this site. Two actions were taken in response to the need for more timely information on the conditions at the FPL Cape Canaveral site: (1) the temperature loggers at the intake canal, at both discharge pipes, and at a nearby ambient site were downloaded and the data were evaluated in relation to manatee thermal tolerances; and (2) external signs of cold stress on a sub-sample of animals present at the site were recorded and photographed, and general observations of manatee condition and behavior that might be indicative of cold stress were made (see *Manatee Cold Stress Monitoring* below). This information was summarized and shared with researchers and managers.

The preliminary assessment indicated that most manatees were suffering signs of cold stress, but it did not appear to be severe in most cases. The water temperature of the southern discharge #1 (which ran continuously during the cold snap) averaged 20.7°C (69.3°F), and mean daily temperatures ranged from 19.8-22.5°C (67.6-72.5°F) during the period (December 29, 2009 to January 19, 2010) when mean daily intake temperature was <16°C (60.8°F) (Figure 20). Temperatures at discharge #1 remained above 18°C (64.4°F), except for a cumulative 9.5 hours during this cold three-week period (Figure 20). The effluent pipe at discharge #1 (close to the temperature logger) was surrounded by a shallow shoal, making it inaccessible to manatees most of the time, complicating analysis of how these temperatures related to those actually experienced by the manatee aggregation. A comparison of discharge #1 temperatures to those collected by boat at the edge of the shoal found little difference, indicating that the temperature data collected should be representative of the warmest temperatures accessible to manatees using the site.

Water Temperature Monitoring Summary: Ambient and Key Warm-water Sites
Charles J. Deutsch

Temperature Monitoring at Ambient Sites—The weather patterns described above in the *Summary of the Weather during the Winter of 2009-2010* resulted in a similar temporal pattern of change in water temperatures in manatee habitat throughout the state of Florida. Figure 21

shows mean daily ambient water temperatures over the winter for eight of the sites monitored by the FWRI along the east coast of Florida, from the lower St. Johns River (Jacksonville) to Biscayne Bay (Coconut Grove). Corresponding data for the west coast is given in Figure 22, which incorporates data sources from other agencies. Temperatures were mild in early December, started declining during the latter half of December, and then dropped precipitously during early January, reaching a nadir between January 10-12 (Figures 21 and 22). Water bodies warmed quickly over the subsequent two weeks as the weather moderated. The continued passage of cold fronts over Florida dropped water temperatures again during the middle two weeks of February and in the first week of March, although the magnitudes of the declines were far less than in early January.

Along the east coast mean daily water temperatures during the January cold snap reached as low as 6.3°C (43.3°F) in the Indian and Banana rivers of Brevard County, 7.7°C (45.9°F) in the lower St. Johns River, and 7.8°C (46.0°F) in the Indian River at Vero Beach (Indian River County) (Figure 21). At Fort Pierce (St. Lucie County) the mean daily low reached 11.4°C (52.5°F; data from Smithsonian Marine Station at Fort Pierce). Lowest mean daily temperatures were considerably warmer in the southeast region of the state: 14.3°C (57.7°F) in Jupiter Sound (Tequesta, Palm Beach County), 18.4°C (65.1°F) at Riviera Beach (Palm Beach County), 17.1°C (62.8°F) at Port Everglades (Broward County), and 16.3°C (61.3°F) in Fort Lauderdale (inland Broward County). Interestingly, the southernmost site that was monitored in Biscayne Bay (Miami-Dade County) dipped to a daily average low of 11.0°C (51.8°F) on January 11 (Figure 21); the temperatures here closely mirrored those at the Fort Pierce site about 190km to the north. Note that the two sites least impacted by the cold snap—Riviera Beach and Port Everglades—were close to inlets that are moderated by the warming influence of the Gulf Stream on the Atlantic Ocean.

The reporting of daily means tends to mask substantial within-day fluctuations in temperature, such as that associated with tidal patterns near ocean inlets. Tidal effects on temperature are particularly remarkable at Riviera Beach; the recorded low was 14.4°C (57.9°F) on January 11, a full 4°C (7.2°F) lower than the lowest daily mean (Figure 23). In a shallow seagrass area on Lake Worth located just 5km north of the Riviera Beach site, the recorded water temperatures were <15°C (59°F) nearly continuously for about ten days (Figure 23). Hence, in the absence of manmade warm-water sources such as the local FPL power plant or interim heating system, manatees in Lake Worth have the potential to be exposed to critically low water temperatures, depending on their proximity to the inlet, water depth of habitat, and the tidal stage at any given time.

The water temperature patterns along the west coast of Florida were generally similar to those along the east coast, with one major exception. Unlike southeast Florida, average temperatures at nearly all ambient sites from northwest Florida south through the Everglades briefly dropped to under 10°C (50°F) at the peak of the cold event (Figure 22). The waters of southwest Florida are not influenced by the warming effect of the Gulf Stream, as is the southeast region. Temperatures for several sites were not displayed in this figure because they showed nearly identical patterns: Anclote River (Tarpon Springs) was similar to the TECO Big Bend power plant (Tampa); Lemon Bay (Englewood) was similar to Matlacha Pass (Matlacha); and Turner River (Chokoloskee, Ten Thousand Islands) was similar to North River (Everglades).

The other interesting finding is that the upper Caloosahatchee River was far warmer than nearby Matlacha Pass during the cold snap (minimum average daily temperatures of 14.5°C (58.1°F) and 7.6°C (45.7°F), respectively) (Figure 22). Although the difference may have been due to differences in water depth at these sites (S. Barton, pers. comm.), the river appeared to act as a thermal buffer in this region. That might be affected by freshwater releases from Lake Okeechobee or possibly by tidal effects drawing warm water from the Orange River (into which the FPL Fort Myers power plant discharges) into the Caloosahatchee River 800m upstream to the recording station.

Temperature Monitoring in Manatee Habitat in the Central-East Region—The central-east region, from Brevard County south through Martin County, has been a particular focus of the UME investigations because more carcasses were reported there (187 carcasses) than in any other region. The association between the rapid and extreme drop in water temperature and carcasses is clear. According to the interpretation of the algorithm results, the UME in this region began on January 11, which corresponds to the same date of the lowest water temperatures (see above) and which occurred nine days after mean temperatures throughout most of Brevard County waters had dropped below 15°C (59°F) (Figure 24). The UME peaked in the central-east region one to two weeks later during January 18-30. Evaluation of the temporal dynamics of water temperature at the key warm-water sites in this region, all located in Brevard County, provides crucial insight as to why so many manatees perished there. Water temperature was monitored at the FPL Cape Canaveral power plant (Port St. John), Berkeley Canal (Satellite Beach), and the C54 canal off the north fork of the Sebastian River (Roseland). In addition, numerous manual temperature measurements were taken in the Desoto Canal drainage ditch (also Satellite Beach), where a large number of manatees aggregated during the winter for the first time.

<u>FPL Cape Canaveral Power Plant</u>—The warmest and most consistent effluent was switched from Unit 1 in late December and January to Unit 2 in February and March. Taking the warmer of the two discharge sites at each 30-minute interval, the mean ± SD discharge water temperature was 20.4 ± 1.80°C (68.7 ± 3.24°F) from December through March; the mean daily temperature ranged from 17.2°C (63.0°F; January 27) to 23.9°C (75.0°F; January 21) (Figure 25). Although intake temperature dropped as low as 6.9°C (44.4°F), the lowest temperature recorded at the warmer of the two discharges was about 16°C (61°F) on several different dates. A summary of the temperature patterns at this site during the cold snap in early January was provided in *UME Response: Temperature Monitoring at FPL Cape Canaveral Power Plant* (above). The power plant generally raised the temperature of the cooling water by about 4 to 12°C (7-22°F) during the January cold spell, although delta-T's of 3 to 7°C (5-13°F) were more common when operating at other times of the winter (Figure 25). FPL did not operate this power plant at all for several periods throughout the winter, including most of the first three weeks of December, late January, and mid to late March (Figure 25). Once ambient (intake) temperatures exceeded the trigger temperature (>16.1°C (61°F)), there was essentially no thermal effluent (or very little on brief occasions) for a 10-day period from January 22-31 (Figure 25). During this time, there was little difference between discharge and intake temperatures, the former averaging 18.8 ± 1.33°C (65.8 ± 2.39°F) and dropping as low as 16.1°C (61.0°F); during the last six days of this period the discharge temperature averaged 17.9°C (64.2°F).

Berkeley Canal—Berkeley Canal is a secondary manatee aggregation site located off the southern Banana River near Satellite Beach (Figure 26). The temperature loggers were placed on a residential dock 85m west of the canal end, or approximately 50-80m from the primary area where manatees aggregate on cold days. Water depth was only ~1m at this site (similar to much of the canal), with temperature loggers placed ~0.1m deep (surface), ~0.5m deep (column), and in the silty sediment on the bottom. The surface showed the most variability in temperature within and across days, as expected, and it was considerably cooler than the mid-column water during the cold periods, reaching a low of 7°C (44.6°F) on January 11 (Figure 27). The sediment layer was the most stable and the warmest of the three sites. Vertical temperature stratification was therefore the most pronounced during the cold periods, as occurred in early January. The average daily temperature fell below 20°C (68°F) during the cold snap for a consecutive 25, 25, and 14 days in the surface, column, and sediment sites, respectively. The sediments remained relatively warm, however, dropping only as low as 17.9°C (64.2°F) at the peak of the cold event; the sediment layer was consistently between 20-25°C (68-77°F) for most of the rest of the winter season (Figure 27). The mid-water column dipped briefly to 13.8°C (56.8°F; January 10) and averaged between 15-17°C (59-63°F) during the cold snap in early January (Figure 27).

The extent of thermal benefit provided by the Berkeley site is shown as the area plot of degrees above ambient Banana River water temperature (bottom temperature near Pineda Causeway) in Figure 27. The delta-T over the winter (December 1 – March 31) averaged 2.6 (4.7°F), 3.5 (6.3°F), and 5.5°C (9.9°F) for the surface, column, and sediment sites, respectively. During the period of the extreme cold snap (December 29 – January 19) when the southern Banana River averaged 11.5°C (min=5.7°C), the mean delta-T (min-max) of the surface, column, and sediment sites in Berkeley Canal was 3.9°C (-0.1-9.1°C), 5.8°C (2.1-10.3°C), and 8.3°C (3.7-12.6°C), respectively. The delta-T of the sediment layer in Berkeley Canal therefore rivaled that produced at a power plant (compare Figures 25 and 27), with the column temperature averaging about 2°C (3.6°F) lower.

Sebastian River C-54 Canal—The C-54 canal off the north fork of the Sebastian River is a secondary warm-water aggregation site for manatees used especially as an important stopover point during seasonal migrations (Deutsch et al. 2003). A vertical array of temperature loggers—including surface, mid-column and sediment—was stationed in about 4m of water just below the water control structure (S-157), which is the principal area used by manatees. Despite the observation of a distinct halocline during a hydrographic survey on March 1 (FWRI, unpublished data), the extent of vertical temperature stratification was relatively minor throughout the winter (Figure 28). The average daily temperature fell below 20°C (68°F) for a consecutive 93, 27, and 24 days in the surface, column, and sediment sites, respectively; after a 5-day period at about 20°C (68°F), the column site averaged below this temperature for a further 55 consecutive days until March 27. The average daily temperatures remained below 16°C (60.8°F) in the water column for 11 consecutive days (January 10-20), indicating that this no longer provided suitable thermal refuge during this time. The lowest average daily temperatures were 12.8°C (55.0°F), 14.0°C (57.2°F), and 15.6°C (60.1°F) for the surface, column, and sediment sites, respectively, occurring in mid-January (Figure 28).

The thermal benefit provided by the Sebastian River C-54 site was only about half that at Berkeley Canal. Over the winter (December 1 – March 31) delta-T at C-54 averaged 1.3 (2.3°F), 1.7 (3.1°F), and 2.6°C (4.7°F) for the surface, column, and sediment sites, respectively, compared to an ambient mid-column site in the Indian River near the Sebastian River mouth. During the period of the extreme cold snap (December 29 – January 19) when the southern Indian River site averaged 14.0°C (min=6.8°C), the mean delta-T's (min-max) of the surface, column, and sediment sites in Berkeley Canal were 2.6°C (-3.7-8.5°C), 3.0°C (-4.1-8.6°C), and 4.4°C (-2.5-9.7°C), respectively.

Temperature Monitoring in Manatee Habitat in far Southwest Region—The far southwest region, including Collier County and peninsular Monroe County, also incurred a large number of manatee deaths during the UME period (125 carcasses). As in the central-east region, there was a clear association between the sharp drop in water temperature and the subsequent increase in reported carcasses (Figure 29). The UME threshold in this region was exceeded on January 17; the first carcasses within the seven-day time window of the algorithm were reported on January 13—two days after the nadir in water temperatures (Figure 29). The UME peaked in this region one to weeks later during January 19-28. USGS monitored water temperatures in this region.

Minimum water temperatures fell to about 8°C (46.4°F)at the peak of the cold event (January 11) throughout the Ten Thousand Islands (TTI) and Everglades region, including the Broad, Turner and North rivers (USGS online data, http://waterdata.usgs.gov/fl/nwis). Manatees in this region use passive thermal basins to thermoregulate; two important aggregation sites in the TTI are Port of the Islands (POI) and the Big Cypress National Park Headquarters (BCNP) basin. These sites provide thermal refuge through the presence of temperature-inverted haloclines, where freshwater input forms a cool lens over a warm saltwater bottom wedge (Stith et al. 2010a). Strong haloclines created a warm bottom layer that provided suitable thermal refuge for manatees even during the coldest part of the 2009-2010 winter (Stith et al. 2010b). Temperature of the deep bottom waters at BCNP was remarkably stable and warm, remaining between 24-28°C (75-82°F) through nearly the entire winter, while surface water temperature at that site behaved like nearby ambient waters, dipping to as low as 11°C (52°F) in January (USGS online data, http://waterdata.usgs.gov/fl/nwis). The saline bottom waters at POI dropped to only about 18°C (64°F) during the cold spell, whereas the fresher surface waters were much colder (B. Stith, pers. comm.). Less is known about warm-water refugia in the Everglades, but the USGS Sirenia Project collected temperature data at Mud Bay and other minor winter aggregation sites in the region. The North River, a tributary of Whitewater Bay in ENP, was a hotspot for mortality, suggesting that the thermal refugia in this region were likely insufficient to prevent cold-related deaths.

Response to the Unusual Mortality Event—Aerial and Ground Surveys of Free-Ranging Manatees

Manatee Distribution Based on Aerial Surveys during the UME

Holly H. Edwards and Katherine Frisch

Aerial surveys were used to examine the distribution of live manatees in relation to carcass recovery locations as well as to inform response actions and effective use of resources

during the UME. FWC biologists identified regions to implement reconnaissance flights based on carcass distribution and regional gaps among various ongoing aerial efforts. Figure 30 shows the spatial extent of aerial surveys conducted during the cold event. The extensive aerial coverage during the UME was made possible with the help of several conservation partners and the FWC-LE. To maximize coverage and information gained from surveys, FWC coordinated with federal, state, county and non-governmental agencies including: Broward County, Chassahowitzka National Wildlife Refuge, ENP, Kennedy Space Center, Miami-Dade County, Mote Marine Laboratory, Palm Beach County, and Sea to Shore Alliance (S2S). Survey results from various on-going regional studies are not summarized in this report but may be found in reports prepared by individual organizations.

UME reconnaissance surveys were conducted by the FWC in the following six areas: the Northern Indian River Lagoon-Banana River was flown January 27 (including the NASA Restricted Airspace; Brevard County), the Lake George and St. Johns River area was flown February 3 (Marion, Volusia, Putnam, St. Johns, Clay and Duval counties), the east coast of Tampa Bay (Hillsborough and Manatee counties) was flown January 28, the upper Caloosahatchee River and western part of Lake Okeechobee was flown February 7 (Lee, Hendry, and Glades counties), the lower Caloosahatchee River and Charlotte Harbor was flown March 10 (Lee and Charlotte counties), and the TTI was flown January 27 (Collier County) (Figure 30). Flights were conducted by FWC-LE's aerial division or by a private fixed-based operator with FWRI manatee biologist(s) on board each flight. Live manatees were observed during each flight, and locations were reported to regional field staff.

A total of two manatee carcasses were found during two of the six UME reconnaissance surveys. The flight over the Northern Indian River Lagoon-Banana River on January 27 resulted in locating a carcass in the NASA Restricted Airspace. The Lake George-St. Johns River survey resulted in a report of a carcass later identified during necropsy as a captive-released manatee formerly monitored by the MRP. Approximately 40 live manatees were seen during the TTI survey, mostly in the Port of the Islands canals. Remarkably, no carcasses were observed during the TTI survey, which focused on searching for live and dead manatees only, despite the high numbers of carcasses reported in the adjacent ENP region just to the south of the TTI survey area, where focus was placed on documenting the death of multiple species.

Live manatees, including cow-calf pairs, were observed in the upper Caloosahatchee River and western Lake Okeechobee area on February 7 despite the cool water temperatures. Although the expectation was that manatees would be located closer to the warm-water refuge at the FPL Fort Myers power plant on the Orange River, the Caloosahatchee River appeared to have some thermal benefit (see *Temperature Monitoring at Ambient Sites* above) possibly allowing animals to travel further away from their thermal refuge. Additionally, this survey occurred at the end of a three-week warming period when manatees, in typical winters, would be expected to disperse. As the season progressed and water temperatures increased, manatees were expected to migrate further away from their thermal refuges to foraging areas. The March survey of the lower Caloosahatchee River—an area of management interest related to watercraft-related mortalities during spring dispersal from refuges—confirmed that manatees had started to leave local winter aggregation sites.

Eastern Tampa Bay was surveyed on January 28 because the primary industrial warm-water site, TECO Big Bend power plant, had mechanical problems (see *Summary of the Operational Status of Power Plants during the Winter of 2009-2010*). One manatee of concern was observed on the flight but it was not re-sighted by the ground crew. Manatee distribution appeared typical and no carcasses were observed. The count of live animals at the TECO Big Bend power plant included 107 manatees near the platform at the easternmost part of the canal; others were noted throughout the canal but were not counted due to time restrictions.

Statewide Synoptic Survey—On January 12-15, 2010, the FWC conducted a statewide manatee synoptic survey, a nearly-simultaneous count of manatees in all known manatee winter habitats in Florida. These surveys, used by the FWC to obtain a minimum count of the manatee population in Florida, are conducted each year to meet Florida State statute §379.12 (4) which requires an annual, impartial, scientific benchmark census of the manatee population. From 1991 through 2010, these surveys have been conducted 26 times. The 2010 statewide synoptic survey resulted in the highest minimum count on record (5,076 manatees). This number was considerably higher than the previous high count of 3,802 manatees in 2009. The extended duration of extreme cold made for ideal counting conditions in that a high proportion of the population likely was located at surveyed sites. Figure 31 illustrates the counts in each county surveyed. More manatees (1,087) were counted in Brevard County than in any other single county in the state. Although it is not the purpose of the survey to search for carcasses, no observer sighted a carcass during the 2010 synoptic flights.

To help inform response activities, a broad-scale survey was conducted on February 18 for east coast counties inhabited by large concentrations of manatees to identify possible large-scale changes in distribution since the January synoptic flights. Counties surveyed included Brevard, Palm Beach, Broward and Miami-Dade (Figure 32). Overall, the raw, multi-county count of manatees was similar to the mid-January statewide synoptic survey for those counties, although regionally the February Miami-Dade count of manatees nearly doubled (79% change in count, Table 13) possibly indicating movement southward.

Brevard County Aerial Survey Pilot Study—A collaborative pilot study to document manatee use of aggregation sites in Brevard County in winter was conducted by the Mote Marine Laboratory and the FWC; surveys were flown five times between January 5 and March 19, 2010. The objective of the study was to apply binomial mixture models to infer abundance from repeated count data collected at aggregation sites throughout Brevard County, and the study was underway prior to the event. Figure 33 depicts manatee abundance estimates at known winter aggregation sites in Brevard County. Abundance estimates were derived from the unadjusted repeat aerial counts in Table 14. In addition, maximum counts were calculated for the county using the highest unadjusted counts obtained from the repeated count surveys and from photographs taken during some of those surveys. Table 15 reports the maximum unadjusted counts for all sites surveyed.

With the exception of the RRI Energy Indian River power plant, which was operating only during the first survey, and Crane Creek on 18 February 2010, all locations showed manatee occupancy during all of the surveys (Table 14, Figure 33). Despite extreme cold temperatures, not all manatees in Brevard County used the primary industrial source of warm-water (FPL Cape

Canaveral power plant) for refuge (Figures 33 and 34). Many animals used secondary warm-water sites, particularly in mid-March when ambient water temperatures were highest and southern migrants were likely returning to Brevard County waters. Figure 35 illustrates that the number of manatees over-wintering in Brevard County remained fairly stable. The similarity in counts and abundance estimates at these aggregation sites between the mid-January and mid-February surveys suggests that manatees did not migrate out of the county in large numbers. Temperature-related variation in presence at the sites was likely important, as indicated by the low mid-winter count during milder temperatures (Figure 35). The lower aerial count at the FPL Cape Canaveral power plant on February 8 (Figure 33) likely reflected temporary movement of manatees to local foraging areas following an increase in ambient water temperatures. GPS tagged manatees in Brevard County moved out from the FPL Cape Canaveral power plant to forage for short periods during this time period in February. In addition, the FPL Cape Canaveral power plant operated in a way that affected availability of manatees to be counted. During the February 8 flight, discharge # 2 was operating instead of discharge #1 which operated during the January synoptic survey. On February 8, manatees were assembled in deeper more turbid water and therefore more difficult to count. Figure 34 shows the overall distribution of manatees during these five Brevard surveys.

Manatee Distribution Based on Ground Surveys of Secondary Warm-water Sites in Brevard County
Ann C. Spellman

In addition to primary industrial warm-water sites, manatees use passive thermal refuges in Brevard County including a residential canal off the Banana River in Satellite Beach, locally referred to as Berkeley Canal, a water management district canal (C-54) located at the west end of the north prong of the Sebastian River near the Brevard County-Indian River County border (Figure 26), and Desoto Canal (Figure 36), a storm water drainage ditch located off of the Banana River in Satellite Beach. These Brevard County sites are part of a multi-year study of secondary warm–water sites and are included in the collaborative aerial survey pilot study conducted by the Mote Marine Laboratory and the FWC (see *Manatee Distribution Based on Aerial Surveys during the UME*).

Berkeley Canal Passive Thermal Site—Although Berkeley Canal was used by manatees during the 2009-2010 winter season, counts were considerably less than in previous winters, when more than 100 manatees were regularly counted at the site per day. Manatees observed in Berkeley Canal during some of the cold snaps in 2010 generally entered the canal close to the bottom, swam to the east end, and wallowed in the mud (as indicated by sediment plumes when animals surfaced) surfacing only to breathe. This behavior made it very difficult to count and photograph individuals at the aggregation site, from the air or the ground. Counts of individuals were likely underestimated (Figure 37). Preliminary review of photo-identification data and field observations shows that some individuals used both Berkeley Canal and Desoto Canal. Many of the manatees at Desoto Canal were documented multiple times during the winter at that site. Ground observations indicate that during the coldest days more manatees were present in Desoto Canal than in Berkeley Canal (Figure 38). Conversely, when water temperatures increased, manatee numbers decreased at Desoto Canal and increased at Berkeley Canal.

Desoto Canal—On January 5, 2010, 100 manatees were counted in the drainage ditch during an aerial survey. Decreasing water levels during the month of January made manatee movement into and out of the drainage ditch increasingly difficult, particularly for the larger manatees, due to a wide mudflat at the intersection of the main canal and the drainage ditch. A team of state and federal researchers determined that it was necessary to deepen the entrance to the ditch with dredging equipment. After confirming with the DEP that the dredging could be done to restore the canal to a previously authorized depth under a current city maintenance permit, this work was completed on January 15 by staff from Brevard County and the City of Satellite Beach, effectively improving manatee access for the remainder of the winter season.

Field observations showed that manatees used the Desoto Canal throughout much of the winter (Figure 38). The discharge from the storm water pipes was consistently 19-24ºC (66.2-75.2ºF) when sampled during the day, with the water temperatures remaining within the manatees' thermoneutral zone for almost the entire length of the drainage ditch. Salinity measurements taken with a handheld conductivity meter (YSI Model 30, YSI Incorporated) indicated that the storm water run-off was fresh, and the water along the length of the ditch ranged from 2.0-8.1ppt. Manatee counts were higher in the morning hours (0730-1130 EST), with manatees exiting the site in the early afternoon presumably to feed in the Banana River, and returning to the canal after dark. There was little to no vegetation available for feeding in the drainage ditch, and the manatees had apparently removed most of the accessible shoreline grass prior to the biologists' first site visit on January 3, 2010.

Sebastian River C-54 spillway—Manatee counts at the Sebastian River C-54 spillway were conducted almost daily by a volunteer sighting network under the DEP. These data indicate that manatee numbers were highest during the first major cold front in early January (n=98 minimum on January 4) and remained high until air and water temperatures began to warm up after January 12 (Figure 39). Interestingly, there was a precipitous drop in counts between January 14 and 16. Counts remained low throughout the remainder of January, then increased again in early to mid-February, peaking on February 8 (n=73 manatees). Another smaller peak in manatee numbers occurred on February 28 (n=41) and gradually decreased through March. Disparities in the number of manatees counted from day to day may be explained by the variable time of day volunteers conducted their counts, observer experience with conducting counts, and environmental factors that may have hindered or facilitated the counts (e.g., by affecting manatee surfacing behavior). Similar peaks in counts were seen at the Desoto site at the same times of the season, but the counts were generally higher at Desoto Canal.

Manatee Cold Stress Monitoring
Charles J. Deutsch and Margaret E. Barlas

In the fall of 2009, biologists from state, federal, and non-governmental research agencies met to develop criteria for assessing external signs of cold stress on manatees aggregated at thermal refuges. Typically, evaluation of these external signs is employed as a tool, along with behavioral assessment, to determine whether or not an animal needs to be rescued and placed at a critical care facility for rehabilitation from harm sustained from exposure to cold water. As a result, limited information is available on the frequency with which free-ranging manatees show signs of cold stress that do not result in intervention and on the severity of cold stress

experienced by those individuals. Thus, the overall goal was to detect geographic patterns and seasonal trends in the proportion of manatees with external signs of cold exposure. As the UME unfolded in January 2010, this new protocol to evaluate the condition of animals in the field was employed and, as with the environmental monitoring during the UME, directed efforts were made in the two geographic areas that were of particular concern for their potential to lead to catastrophic mortality.

FWC staff conducted four field trips during the UME dedicated to obtaining quantitative data on the frequency and severity of cold stress: one at the TECO Big Bend power plant discharge canal in February, two at the FPL Cape Canaveral power plant discharge area in January and February, and one at the Desoto Canal drainage ditch (Desoto Canal) in February. Additional cold stress monitoring was conducted opportunistically in association with photo-identification field work at the TECO Big Bend power plant and Desoto Canal, and with telemetry field work in the Indian River Lagoon throughout the winter season. In addition, biologists with S2S collected quantitative data on cold stress at the FPL Riviera Beach power plant (Koelsch and Powell 2010). During the dedicated sampling trips, individual manatees were chosen at random as they came within visual distance of the observer(s), who was either stationed on shore (TECO Big Bend power plant and Desoto Canal) or on a boat (FPL Cape Canaveral power plant). Each individual was scored for the presence and severity of cold stress abscesses and lesions on their head, trunk, and tail (see Appendix E for Criteria to Assess External Signs of Exposure to Cold Temperatures). If a region of the manatee's body showed no evidence of cold stress lesions, it was recorded as "not present", and if a region of the manatee's body was not viewed sufficiently, it was recorded as "undetermined". Using this methodology, the portions of the manatee that were viewable could be evaluated and scored, and the data were not skewed toward the absence of cold stress lesions when the entirety of the manatee was not viewable. Observers attempted to avoid documenting the same individual more than once on the same day, often by sketching scar patterns, noting details of cold stress signs, and digitally photographing the individuals.

The cold stress data collected opportunistically and from dedicated sampling trips were analyzed and findings were presented to researchers and managers as needed to assist with decision-making and with shaping response efforts in the field. If particular individuals showed signs of severe cold stress and behavior indicative of poor health (e.g., lethargy and disorientation), rescue staff were notified to evaluate the individual(s) for possible intervention. Photographs were made available to researchers at the MMPL for later comparison to carcasses.

The most commonly observed cold stress lesions were whitish or gray mottling or blanching of the snout (Figure 40); a whitish or gray halo around the margin of the tail (Figure 41); small, usually circular lesions that varied from superficial to deep erosions of the skin (Figure 42); and 'bald' patches where large areas of the epidermis had sloughed off, leaving clear patches amongst an otherwise algae-covered skin (Figure 43). Less common, but notable, observations include individuals with extensively white faces (mostly snout) or extensively white heads with blotches extending back over their shoulders (Figures 44 and 45, respectively). Ulcerating white lesions protruding above the skin (Figure 46) were rarely observed. Manatees aggregating at the power plants showed no obvious signs of emaciation despite the amount of time they spent in a thermal refuge away from feeding grounds (based on FWC telemetry data).

However, a number of individuals at the Desoto Canal appeared thin. Some manatees at the Desoto Canal showed a slight dip in the contour behind the head (i.e., peanut head) and others exhibited a depression in the dorsal shoulder region (Figure 47). Variations of these external signs among individuals were evident regardless of whether they aggregated at the same or different thermal refuges (Figure 48). None of the manatees observed at the Desoto Canal showed indications of acute hypothermia (i.e., lethargic, positively buoyant, producing no intestinal gas, normal external appearance, often found almost beached in shallow water), but five manatees were rescued from that site due to signs of cold stress.

Most manatees observed at the two sites in Brevard County showed external signs of exposure to cold (Table 16). For example, two-thirds of manatees sampled at the FPL Cape Canaveral power plant in January had cold stress lesions (typically whitening) on the head. Comparing the data across the three sites in February, manatees at the TECO Big Bend power plant fared the best, with the least amount of individuals exhibiting external signs of cold exposure on all body regions (Table 16). Qualitative observations of manatees sheltering at the Blue Spring refuge in the upper St. Johns River showed no cold stress lesions in January (C. Deutsch, pers. obs.). A park volunteer collected similar data through the winter at Blue Spring; although these data have not yet been compiled, the general pattern appears to be one of very little cold stress signs at this first magnitude spring. The frequency of cold stress lesions increased from January to February at the FPL Cape Canaveral power plant, with a marked increase in external signs on the trunk and tails of manatees overwintering at that site (Table 16). Of those manatees exhibiting cold stress lesions, over 90% of the cases were rated as Stage 1 severity, with only a handful of Stage 2 observations (Table 17). Only the external signs of cold stress and body condition could be observed and evaluated; internal physiological effects indicative of cold-related harm, including the extent of dermal necrosis, would not necessarily be manifested externally.

A few individuals were observed on both sampling trips at the FPL Cape Canaveral power plant discharge area, thereby allowing comparative evaluation of how the severity of cold stress lesions changed over time for those specific animals at that site. No major changes in extent of areas affected with cold stress lesions were evident in the month between observations (Figure 49). S2S staff working at the FPL Riviera Beach power plant collected more quantitative data on how cold stress symptoms progressed for individually recognizable manatees (Koelsch and Powell 2010). They evaluated changes in the appearance of cold-related lesions, including number of lesions, extent of affected area, degree of apparent healing or deterioration, and changes in skin pigmentation. Of 140 distinct individuals identified with external cold stress signs, at least fifty were observed more than one day; most were observed less than ten days apart. Of the 19 individuals observed and scored >30 days apart (range, 36-46 days), nine (47%) showed apparent signs of improvement; five (26%) appeared to worsen; and five (26%) showed mixed changes (i.e., one area of the body improved but another area worsened; Koelsch and Powell 2010).

Discussion

Overview of the Unusual Mortality Event
Charles J. Deutsch

An unprecedented number of manatees died in Florida during the winter of 2010 as a result of extended and severe cold that set temperature records in many parts of the state. The statewide UME lasted 89 days from January 11 through April 9; these dates were based on a UME algorithm that used rather conservative criteria in which 7-day cumulative carcass counts had to exceed the 99th percentile of such counts for the corresponding months over the prior five-year period (Figure 6). A total of 480 carcasses was reported and verified over this three-month period, resulting in the most massive carcass salvage and necropsy effort in the history of manatee research and conservation. Preliminary cause of death for the majority of these animals (52.5%, n=252) was attributed to cold stress (Table 1). However, cause of death could not be determined for a large proportion of carcasses (41.0%, n=197), mostly due to advanced stage of decomposition or remote location of the carcass that prevented access for necropsy. Cold stress accounted for 89% of deaths for which cause could be determined. Preliminary cause of death for only 17 manatees was attributed to human activities (Table 1). During the UME timeframe 49 manatees were rescued, most (71%) due to cold stress (Table 9).

After the UME began on January 11, it was soon followed by a steep spike in manatee carcasses during what is referred to as the Acute Mortality Phase of the mass die-off event. The start of the UME corresponded with the date of lowest water temperatures in most of the state and occurred nine days after the start of the statewide cold weather event. Most of the deaths (62.3%, n=299) occurred during this 30-day period (Table 6). An average of 10 manatee carcasses was reported per day during this period, and during the peak week an average of 22 was reported per day. As discussed below (see *Cause of Death*), many manatees appeared to have died relatively quickly from cold shock during this phase, which ended on February 9. After a transient dip below statewide UME threshold levels, there followed a Chronic Mortality Phase during which 181 carcasses were reported over a period of two months (average of about 3 per day). This persistently elevated level of mortality still exceeded the threshold for a UME on the statewide scale (Figure 6). Manatees that were determined to have died from cold stress during the chronic phase typically showed the “classic” signs of cold stress syndrome (Bossart et al., 2002), indicating less extreme cold exposure over longer periods (see *Cause of Death* below).

The timing and pattern (but not magnitude) of the acute phase of the UME was similar in regions across the state (Figure 50). The striking correspondence in this temporal pattern across regions and its close association with the severely cold weather provide a strong case for arguing that the vast majority of the carcasses with unknown causes of death during this acute phase of the event were also due to cold stress. Indeed, nearly 90% of carcasses for which cause of death was determined over the entire UME were due to cold stress. A similar but weaker inference could be made for the undetermined deaths during the chronic phase of the mortality event. The timing and pattern of carcass counts during the Chronic Mortality Phase, and the degree to which it exceeded UME thresholds, varied considerably among regions (Figure 50, Table 4).

Geographic Variation in Mortality
Charles J. Deutsch

Analysis of the spatial and temporal distribution of carcasses around the state provides insights into warm-water habitat correlates of this extraordinary episode of cold-related mortality. The level of mortality, as indicated by carcass reports, exceeded UME levels in all regions of Florida except for the northwest (Figure 50). The effects of the UME were most clearly demonstrated in the central-east and far southwest regions (relative to the other regions) during the Acute Mortality Phase. When making comparisons among geographic regions, it is important to keep in mind that the carcass counts do not represent mortality rate and are not even a reliable index of mortality rate. This is because regional differences in abundance (known to exist) and in carcass detection rate (unknown but likely to exist) would need to be taken into account. One of the advantages of the UME algorithm is that it shows the degree to which carcass counts are elevated above a statistical measure of baseline levels (99th percentile in this case). Assuming that regional abundance and detection rate this year are not greatly different from the five-year baseline period, the ratio of carcass counts to this baseline level provides an objective means of comparing the relative proportionate increase in mortality across geographic regions. During the Acute Mortality Phase in January, the maximum value of this ratio for each region was: 16.0 in far southwest, 10.0 in central-east, 6.3 in southeast, 5.5 in northeast, 3.5 in central-west, and 0.0 in northwest. The maximum ratio is somewhat sensitive to spikes in carcass reports and does not take duration of the event into account, so other statistical measures of this ratio may be more appropriate to explore in future analyses.

Ambient coastal and estuarine waters dropped below 10°C (50°F) throughout Florida, with the exception of most of the southeast region. One might have expected that cold-related mortality would be greatest at the highest latitudes and decline toward southern Florida. That was not the case this winter, however, as the sensitivity of ambient waters to cold fronts and the quality of thermal refugia within a region played the most important roles in affecting the extent of cold-related deaths. Manatee subpopulations that rely on artesian springs generally fared well during this winter, especially in the northwest region where most manatees rely on the multitude of springs in Crystal River (Kings Bay) and Homosassa Springs. The upper St. Johns River (USJ) subpopulation (i.e., south of Palatka), on the other hand, exhibited a relatively high level of mortality for that region: 15 carcasses (excluding known human-related causes of death) from January through March, versus a total of 2-7 such carcasses reported over each of the previous five calendar years (12-mo. periods); cause of death was cold stress for about three-quarters of these cases in 2010. Most of those carcasses in the USJ region were found north of Lake George, so it would be interesting to know what springs or other warm-water sources these manatees had been using prior to the cold spell. Freezing air temperatures extended into most of peninsular Florida during the cold snap and manatees died of cold exposure in the Everglades and even the Florida Keys (Figure 7). This region has extensive shallow waters that rapidly plummeted in temperature during January (Figure 29); it seems likely that temperatures at many thermal basins used by manatees in the Everglades dropped below levels necessary for survival. Analyses of temperature data at some of these monitored sites are currently being completed by USGS biologists. In contrast, artificial passive thermal basins in the TTI maintained strong temperature-inverted haloclines that may have provided sufficient warm-water shelter throughout the winter (Stith et al. 2010b). Relatively fewer carcasses were found in the TTI in

comparison to adjacent regions thus providing additional support for the link between quality of regional thermal refugia and cold-related mortality during the 2010 UME. It should be noted, however, that manatee abundance in the TTI area may have declined during the winter as aerial survey results from mid and late January suggest.

In contrast to the western Everglades which sustained high manatee mortality and low water temperatures in January 2010 (Figure 29), the southeastern side of the peninsula experienced more moderate temperatures and mortality (Figures 21 and 13). Of the five regions that experienced a UME, the southeast region had the lowest absolute number and lowest proportion of carcasses with known causes of death attributed to cold stress (Table 1, Figure 8). The proximity of the Gulf Stream in this region moderated air and water temperatures, most noticeably in waters close to inlets such as Jupiter, Lake Worth (Riviera Beach), and Port Everglades (Figures 21 and 23). Satellite imagery of sea surface temperature taken at the height of the cold snap on January 12 clearly shows (a) the warm Gulf Stream waters along the southeastern coast up to about Jupiter, (b) the cold shallow waters of Biscayne Bay, Florida Bay, and associated sounds, and (c) the cold waters along the entire Gulf coast of Florida (Figure 51). Of the 30 carcasses (excluding known human-related causes) reported in the southeast region during the acute phase of the UME, the vast majority (n=26, 87%) came from the Florida Keys and Florida Bay. In contrast none of the 18 carcasses (excluding known human-related causes) reported in the southeast region during the chronic phase were found in that southernmost area. Manatees inhabiting the shallow waters of Florida Bay would have been subjected to the same rapid and lethal drop in water temperature during the cold snap as those in Whitewater Bay and surrounding waterways of the Everglades. This suggests that any thermal basins in that locale provided inadequate protection from the cold, or that many manatees were unable to reach those sites that did provide sufficient thermal protection. In addition to the warming influence of the Gulf Stream, manatees in the northern portion of the southeast region had access to several warm-water sources: two FPL power plants that operated consistently in Broward County, an interim heating system at the FPL Riviera Beach power plant site in Palm Beach County that operated during cold weather, and other thermal basins (e.g., Coral Gables Waterway) that exist in northern Miami-Dade County (Figure 1).

The highest overall and cold-related mortality occurred in the central-east region, from Brevard through Martin Counties (Figure 7, Table 1). Coastal Atlantic waters were cold in this region (Figure 51) and the shallow lagoon waters cooled quickly in response to passing cold fronts. The relation between the UME in this region and the availability of warm water is explored in detail below (see *Warm-water Refugia and Mass Cold-related Mortality in the Central-east Region*).

Cause of Death
Martine de Wit

The absence of severe cold stress lesions in many manatees, in combination with extreme low temperatures and non-specific necropsy findings such as congestion, suggests death was probably related to cold shock response and hypothermia. In humans, immersion in cold water produces a large and fast fall in skin temperature which, in turn, initiates an immediate gasp response, the inability to breath-hold, and hyperventilation (Datta and Tipton 2006). These

respiratory responses occur before any drop in core temperature and are neural in origin. The cardiovascular responses to extreme cold include an increase in heart rate, cardiac output, and blood pressure. These responses increase the workload of the myocardium, and may induce cardiac arrhythmias.

In many carcasses recovered during this event, gross necropsy findings of abnormal distribution of blood (congestion) may have been related to changes in cardiac output. Cardiogenic shock in association with cold stress has not been documented previously in manatees. The presence of apparently healthy adult animals among the carcasses suggests that all manatees are susceptible to this acute pathway when subjected to sufficiently low temperatures. As previously noted in cases of brevetoxicosis (Bossart et al. 1998), congestion is a non-specific change and is typically associated with any cardiovascular collapse. Without underlying disease, it is difficult to determine a primary cause for shock on histopathology. Similarly, in the manatees suspected to have succumbed to acute cold shock, histopathology could not determine a definitive cause for gross changes of congestion.

In humans immersed in cold water, aspiration may occur subsequent to cardiovascular failure (Golden et al. 1997). The observation of wet lungs in a significant portion of carcasses, especially during the Acute Mortality Phase of this event, suggests that a similar situation occurred in these manatees. Histopathology of one manatee revealed foreign material and bacteria in the lungs. There was little inflammation associated with some, but not all of this material. This may indicate that there were multiple aspiration episodes. Given that much of the material lacked an inflammatory component, it was speculated that there was terminal aspiration and drowning. However, diagnosis of drowning can be extremely difficult and is often impossible. In human autopsy studies on drowning accidents, as many as 10% of patients demonstrated no evidence of fluid aspiration (Kringsholm et al. 1991, Hasibeder 2003). Acute lung injury can be initiated by even small amounts of aspirated fluids, which is not grossly visible.

The classic cold stress signs, such as serous atrophied fats, internal abscesses, enteritis, and dried out feces, observed in most carcasses during the Chronic Mortality Phase were consistent with those previously described (Bossart et al. 2002). As observed in previous winters, these signs were mostly found in subadult carcasses and were related to chronic exposure to cold temperatures.

Population Impacts
Charles J. Deutsch

The spatial scale, severity, and duration of this UME were unprecedented in the history of manatee carcass salvage efforts in Florida. The number of manatees that were known to have perished during this three-month mortality event (480) exceeds the calendar-year record for number of verified manatee carcasses (429 in 2009). It is almost certain that other carcasses were not discovered, especially in the more remote areas of the state, so this is a minimum number of deaths. Quantifying the impact of this UME on the Florida manatee population will await sight-resight analyses of adult survival rates and further population modeling. The number of carcasses documented during the 2010 UME timeframe in Florida is 3.9 times the average

number for the same time period over the past five years (mean=124.0, min-max=74-170). If known human-caused deaths are excluded from the totals, the number during the 2010 event (463) is 4.6 times the five-year mean (101.2, min-max=52-141). Even given the appropriate caveat that some interannual variation in carcass discovery rate probably exists and therefore hampers quantitative statistical analyses, the extent of increase in verified carcass reports this winter is so tremendous that temporal variation in detection rate can be discounted as a major factor.

Although manatee abundance in Florida is not known, a record synoptic count of 5,076 manatees was made in January 2010. Clearly, the extended duration of extreme cold made for ideal counting conditions and it can be surmised that a high proportion of the population was located at surveyed sites. This count is considered a minimum count because it does not take into account detection probability or proportion of manatees outside of surveyed areas. The number of verified manatee carcasses of all causes during the UME timeframe represents 9.5% of the recent synoptic count. Caution should be used in interpreting this calculation because it represents a minimum number of deaths out of a minimum population size and therefore cannot be considered a valid measure of mortality rate. Nevertheless, past UMEs have not reached this magnitude.

Manatee population growth rate is most sensitive to adult survival rate (Runge et al. 2004), and the vital rates (survival, reproduction) of females drive the dynamics of the population. A total of 63 adult female carcasses were recovered during the UME. However, there were an additional 58 carcasses of unknown sex (31 of known size). Assuming that carcasses with unknown sex or size class had the same sex ratio and size class ratio as those for the known carcasses during the UME, there would be an estimated 72 adult female carcasses among those found and verified (Table 18). As in past cold-induced mortality events (O'Shea et al. 1985, Ackerman et al. 1995), the younger animals died in disproportionate numbers: 74% of carcasses were of immature size (i.e., <266cm), and 72% of those were of calf size (i.e., <236cm) (Tables 2 and 18). Past population modeling efforts have estimated that about 30% of the population is immature (<4 years old) (Haubold et al. 2006). Assuming that carcass discovery rate did not vary with age class, the immature classes would have, on average, a mortality rate that was 6.6 times that of adults; given that detection of calves was probably lower than that of adults, differential mortality was likely even greater than this. Certainly one can conclude that the immature segment of the population, particularly the two years of calf cohorts, suffered a relatively large loss during the UME.

Power Plant Operations and Manatee Mortality
Charles J. Deutsch

Manatees currently use the warm-water discharges of twelve power plants around the state during winter cold periods, seven of them as primary thermal refugia (Figure 2). The high electrical demand during the height of the January cold event coincided with mechanical problems at three plants that led to partial or full shutdowns. This reduced the amount of warm water produced at these sites—completely in two cases—both of which were located in regions (Tampa Bay, northern Indian River Lagoon) where manatees depend on industrial warm water during cold weather events. Fortunately, this change in the functionality of the warm-water

network did not appear to result in increased mortality because: (a) the two secondary sites (Progress Energy Bartow power plant, RRI Energy Indian River power plant) that shut down were located in close proximity to primary sites (TECO Big Bend and FPL Cape Canaveral, respectively) that maintained sufficient warm water during the cold event; and (b) the TECO Big Bend power plant was able to maintain a sufficiently high delta-T—by operating on two of its four units and by restricting cold-water circulation through non-functioning units—to keep the water temperature at the far eastern end of the discharge canal from falling to dangerously low levels (Figures 17 and 18).

The spatial extent and configuration of the warm-water network along the Atlantic coast of Florida has been evolving over the years as older power plants and other industrial sites have retired or have become more intermittent in operation. In contrast to the early 1990's, when there were seven power plants and a few pulp mills north of Broward County used to various degrees by overwintering manatees, in winter 2009-2010 there was only one consistent warm-water refuge at a power plant (FPL Cape Canaveral) along that entire coastline. The FPL Cape Canaveral power plant provided vital thermal shelter during the January cold event and other cold periods, with effluent temperatures averaging about 20°C (Figure 25). Even this power plant operated at lower capacity than in past years, however, because it was only a few months away from demolition and reconstruction to a modernized energy facility. This power plant did not operate at all for extended periods when ambient temperature exceeded 16.1°C (61°F, per NPDES permit conditions), including for ten consecutive days during late January (Figure 25). What impact those cool temperatures (16-19°C) might have had on the health of manatees using the site, particularly of immature animals immediately following a severe and extended cold spell, is an important unresolved question. Of two additional power plant sites operating along the east coast this winter, one (RRI Energy-Indian River power plant) went offline during the January cold spell due to a mechanical failure and remained shut down for the remainder of the winter, and the other (Vero Beach Municipal power plant) only operated for a total of 14 days. This was the first winter of operation of an interim heating system at the FPL Riviera Beach power plant's "manatee embayment". Including tests early in the season, it operated for a cumulative 42 days; a blown transformer on January 14 put it out of commission for about eight days. Manatees quickly dispersed from the site when the interim heating system was turned off even though the ambient water temperatures at the site did not dip below 67°F during that period.

As serious as this winter's catastrophic mortality event was, it could have been much worse had primary refugia at key power plants failed—in particular at TECO Big Bend in Tampa Bay, FPL Fort Myers along the Caloosahatchee River (Lee County), or FPL Cape Canaveral in Brevard County. This reliance on a small number of industrial sites for crucial warm-water habitat, along with the mechanical failures experienced at some older power plants this winter, further highlights the vulnerability of the manatee population to catastrophic cold-related mortality. Reliance on passive thermal basins also has serious risks, as demonstrated this winter in Brevard County. Envisioning how a similar cold weather event would play out in a future scenario without power plant thermal refugia, it seems likely that cold-related mortality would be even higher unless steps are taken to provide reliable alternative warm-water habitat in the coming years.

Manatee Behavioral Response to Cold: Movements and Distributional Changes on the Atlantic Coast
Charles J. Deutsch

Manatees sought out thermal refuges in record numbers in response to the severe and extended cold in early January. Observations from ground counts, aerial counts, photo-identification, and satellite-tagged animals indicate that manatees in Brevard County responded behaviorally to the cold event in at least three different ways: (1) many remained at the warm-water site that they had been using; (2) some switched to nearby warm-water sites within the county; and (3) some migrated south out of the county. Of four manatees carrying satellite-linked GPS tags that were tagged at the FPL Cape Canaveral power plant in mid-December 2009, three remained at that site continuously for approximately two weeks during the cold spell, presumably fasting given the lack of forage at the site. The similarity in most aerial abundance estimates at this site during the winter (Figure 33) suggests that remaining at this warm-water refuge was the most common response to the cold weather by manatees using the FPL Cape Canaveral power plant.

Evidence indicates that some manatees moved between nearby warm-water sites within Brevard County. Certainly the manatees using the RRI Energy power plant in the northern Indian River (aerial count of 165 on January 5; ground count by RRI Energy staff of 65 on January 9) immediately left after the mechanical failure led to a shutdown (Figure 33). Most or all of those manatees probably moved 3km south to the FPL Cape Canaveral power plant—as previous telemetry studies have shown (Deutsch 2000). Ground counts and preliminary photo-identification matching suggest that some manatees using Berkeley Canal in the Satellite Beach area shifted 5.5km southward to Desoto Canal at the start of the cold snap, and then some shifted back as it warmed up in mid-January (compare Figures 37 and 38). Further analysis of photo-identification data will be needed to identify other within-winter movements among warm-water sites.

A relatively high number of manatees remained in Brevard County waters throughout the winter. The extent to which manatees migrated out of Brevard County in response to the cold is uncertain, because of the lack of good estimates of detection probability to correct visual aerial counts. Replicate-count methodology and the binomial-mixture model sometimes resulted in large underestimates of the number of manatees present at the FPL Cape Canaveral power plant because of the problems associated with the visual counts (discussed above) and because of some technical problems associated with these models when there is some heterogeneity in the probability of detecting manatees. Counts obtained from review of aerial photographs indicate that at least 1068 and 1087 manatees were present in Brevard County on January 5 and 14, respectively. This would suggest that numbers remained relatively stable during the cold spell. However, counts from photos can also be biased due to poor photo angle, poor resolution, lighting, and other issues that can make enumerating manatees on a photograph difficult. Furthermore, raw counts take no account of inter-survey variation in detectability and, as such, it is not appropriate to infer abundance changes from them.

Some manatees probably migrated south out of Brevard County. One tagged adult male (TBC050) left the FPL Cape Canaveral power plant on January 5 and migrated to southeast

Florida, reaching the operating interim refuge at the FPL Riviera Beach power plant 4.5 days later on January 9 (FWC, unpublished data). He encountered water temperatures as low as 9.6°C (49.3°F) and temperatures below 15°C (59°F) for a cumulative total of 59.5 hours (2.5 days) during the journey. GPS data show that TBC050 made brief stops in the Eau Gallie River (9.5 hr) and in the C-54 canal off the north fork of the Sebastian River (12 hr); he then headed out the Sebastian Inlet and migrated south along the Atlantic coastline in more moderate temperatures, traveling continuously about 130km over the next two days. While in transit between aerial surveys at FPL power plants on January 5, the aerial observer noted 11 manatees in Hobe Sound, all swimming south (Reynolds 2010; J. Reynolds III, pers. comm.); these animals were presumably migrating to warmer water several days into the cold event, just as TBC050 did. Furthermore, the precipitous decline in ground-based counts at the Sebastian River C-54 aggregation site from over 80 to less than 10 in mid-January (Figure 39) may indicate a migratory response immediately after the cold event, or it may simply reflect dispersal to foraging areas by hungry manatees as the waters warmed. Matching of individuals from photo-identification research at warm-water sites may provide further insights into this question.

Large-scale Distributional Changes along the Atlantic Coast— Comparison of raw aerial survey counts in the four counties (Brevard, Palm Beach, Broward, and Miami-Dade) encompassing the principal winter concentrations of manatees along the Atlantic coast provides some indication of potential distributional shifts from mid-January to mid-February 2010 (Figure 32, Table 13). From the statewide synoptic survey, which occurred at the end of the severe cold event (January 14), to an extensive east coast survey which occurred during a moderate cold period (February 18-19), raw counts declined by 98 animals (9.0%) in Brevard County and increased by 158 animals (11.2%) in the southern three counties surveyed. These data do not point to a mass movement out of Brevard *after* mid-January; however, interpretation of raw counts and even the replicate-count abundance estimates has limitations related to variation in detectability and other sources of biases.

Analysis of temporal variation in manatee counts from twice-monthly distribution surveys in northeast Florida (St. Johns, Duval, and Volusia counties) and in southeast Florida (Palm Beach, Broward, and Miami-Dade counties) during this winter will likely yield further information and insights into large-scale distributional shifts (or lack thereof) of manatees along the east coast. For example, counts in Broward County increased rapidly with the onset of cold weather: December 23 (n=54), December 29 (n=101), January 7 (n=517), and January 14 (n=813) (Broward County Natural Resources Planning & Management Division, unpublished data). The eight-fold increase in counts during the first half of January largely represent a pulse of migrants moving into the county from more northerly areas in response to the extremely cold weather.

Overall, this preliminary synthesis of the available data suggests that: (a) most manatees present in Brevard County in early January remained in county waters, at the same or at a nearby warm-water site; (b) raw winter aerial survey data suggest potential broad-scale distributional shifts across coastal counties, however current aerial survey methods have limitations that should be considered when interpreting this information and additional winter aerial data collected by county government agencies should be included in this evaluation; and (c) ground counts and

temperature data suggest that manatees using the Sebastian River C-54 canal might have emigrated south after the January cold event ended.

Warm-water Refugia and Mass Cold-related Mortality in the Central-east Region
Charles J. Deutsch

The region on the east coast of Florida encompassing 215km of coastline from Brevard through Martin counties reported the highest number of manatee carcasses during the UME (n=187), including far more deaths attributed to cold stress (n=135) than any other geographic region (Table 1, Figure 7). Cold stress accounted for 95% of known causes of death in the central-east region, similar proportionately to that in the far southwest region (Figure 8). The UME peaked in intensity in this region about one to two weeks after the low point in water temperatures, which dropped to a daily mean of about 6°C (43°F) in the northern Indian and southern Banana rivers and averaged below 10°C (50°F) for 9-11 consecutive days (Figure 24). Such temperatures proved to be lethal to manatees, as occurred in this region during the winter 1989-90 unusual mortality event, when water temperatures in the lagoon plummeted to a similar extent (Ackerman et al. 1995). Thus, the cause of the UME in this region, as in the rest of the state, is not in question; clearly cold exposure during an unusually prolonged and severe cold spell was the culprit. The real puzzle is why so many manatee carcasses were found away from warm-water habitats between southern Brevard and Martin counties, mostly during a period of moderate temperatures between late January and early February.

Two main hypotheses can be put forward to explain the observed carcass distribution in this region during the Acute Mortality Phase of the UME: (a) manatees fled warm-water refugia in Brevard County during or immediately after the cold event because these sites failed to provide adequate thermal protection and then died en route south; and (b) manatees were residing in the east-central region outside of known primary and secondary warm-water sites and then died after temperatures dropped. The first hypothesis is evaluated independently for three separate warm-water sites in Brevard County: FPL Cape Canaveral power plant, Satellite Beach (including Berkeley and Desoto canals), and Sebastian River C-54 Canal. Summary of the temporal dynamics of water temperature at these warm-water sites, along with examination of distributional shifts inferred from aerial and ground counts, provide means to evaluate the relative merits of these hypotheses, which are not mutually exclusive.

Temporal changes in ground counts at the secondary sites, supplemented by sparser aerial survey counts, clearly indicate a sharp drop in manatee use of Desoto Canal and Sebastian River C-54 Canal in mid-January (Figures 38 and 39), and a corresponding increase in use of Berkeley Canal at that time (Figure 37). The most parsimonious explanation is that manatees overwintering in the southern Banana River shifted from Berkeley Canal to Desoto Canal in late December, relied on the Desoto Canal drainage ditch for warmth during the cold spell, and then shifted back to Berkeley Canal as the weather warmed in mid-late January. This is supported by preliminary photo-identification matching of scarred individuals. The fact that the combined Satellite Beach aerial counts were nearly identical on January 5 (n=109) and February 18 (n=115) implies that there was no massive exodus from this area. Nearly 100 manatees were counted at the Sebastian River C-54 Canal in early January and it is likely that these ground counts considerably underestimated the actual numbers present. Two weeks later the counts at

this site had dropped by over 90% (Figure 39). Although counts did increase again in February, it seems plausible that some proportion of manatees that used the Sebastian River C-54 Canal during the cold spell migrated south at the end of the event.

The other part of the equation is documenting the temperature regimes at these Brevard sites that might have motivated manatees to depart the county. Of the three warm-water aggregation sites for which water temperature was continuously monitored (see *Temperature Monitoring in Manatee Habitat in the Central-East Region*), the two passive thermal basins provided inadequate warmth during the cold spell (at least at the locations of the temperature stations). The average daily water column temperatures at the Sebastian River C-54 Canal spillway, for instance, were below 16°C (61°F) for 11 consecutive days (January 10-20) and fell as low as 14°C (57°F) (Figure 28); this likely motivated the manatees to leave during that time period. Although Berkeley Canal provided considerably more thermal benefit than the Sebastian River C-54 Canal, the column temperature also dropped briefly to 14°C (57°F) and averaged between 15-17°C (59-63°F) during the cold snap (Figure 27). Sediment temperatures were substantially warmer than water temperatures but the degree to which manatees can rely on burrowing in sediment for cold-water survival at this site is unknown. Continuous water temperature measurements at the Desoto Canal drainage ditch were not available, but daytime spot samples indicate that the water was consistently warm (19-24ºC). A shoal at the mouth of the ditch may have precluded access for larger manatees during the cold spell, possibly forcing them to find warm water elsewhere. Finally, the FPL Cape Canaveral power plant discharged warm water (average daily temperatures of about 20ºC) adequate for survival throughout the cold spell (Figure 25). So, while some manatees (e.g., tagged manatee TBC050) migrated from the FPL Cape Canaveral power plant during that timeframe and most manatees overwintering there showed external symptoms of cold stress (Table 16), it can be inferred from the temperature monitoring data that adequate warmth was provided most of the time. It should be noted that individual manatees have different temperature thresholds at which they show a migratory response to cold (Deutsch et al. 2003), and that what is adequate for an adult may be inadequate for a smaller subadult. It is possible that the lack of warm-water discharge at the FPL Cape Canaveral power plant from January 22-31, which corresponded with the period of peak carcass recovery, may have encouraged some manatees to migrate south in late January and that some died of cold stress en route.

The second major hypothesis presented above is that manatees were overwintering in the east-central region outside of known primary and secondary warm-water sites, presumably in unidentified or minor secondary sites, and then died after temperatures dropped. This hypothesis is difficult to test, especially because of the lack of survey data for the three-county region south of Brevard County. In the presumed absence of suitable warm-water habitat, one would have expected manatees in this region to migrate south after the arrival of the first cold fronts to traditionally used warm-water sites in Palm Beach County or further south, rather than remaining at marginal sites. That is the typical behavior shown by tagged manatees in past telemetry studies (Deutsch et al. 2003) and is often observed during aerial manatee surveys as well (e.g., Reynolds 2010). The idea that a large number of manatees were overwintering south of the Sebastian River and north of St. Lucie River, using sites unknown to manatee biologists seems improbable. However, aerial survey counts show that some manatees are present in these areas even during cold periods. Past distribution surveys have found an average of 116 manatees in

these three counties during January and February (FWRI, unpublished data), so it's clear that manatees forage in these waters during winter. The Ft. Pierce and Vero Beach power plants provided secondary warm-water refugia to manatees in this region in past winters, but the former has been 'mothballed' and the latter rarely operates now. During winter synoptic surveys, small numbers of manatees have been observed in a variety of places—canals, creeks, and rivers, for example—that are outside of the traditionally used and surveyed warm-water sites. The fact that the record synoptic count of 2010 was nearly 1300 higher than the previous record count from 2009 suggests that many manatees may not have been at the surveyed aggregation sites on the synoptic date in 2009. It is possible that these cold-tolerant manatees are able to survive cold spells in most winters but perished in this extreme winter. On the other hand, a long-term telemetry study on the Atlantic coast (1986-1998) found that all 37 tagged manatees north of the Florida Keys used multiple thermal refugia, including at least one power plant, during winter. Furthermore, none of those tagged manatees remained within the region between the Sebastian and St. Lucie rivers for the entire winter (Deutsch 2000).

At this time it is not possible to clearly differentiate between these hypotheses that attempt to explain the relatively large number of cold stress carcasses between southern Brevard and Martin Counties. Both scenarios may have contributed to an increase in mortality in this region. Based on timing and distribution of carcass reports, it seems plausible that some manatees died while migrating south after having been compromised by sub-lethal cold exposure at the Sebastian River C-54 site during the prolonged January cold event. Some manatees using warm-water sites further north (FPL Cape Canaveral power plant, Berkeley and Desoto Canals) may have likewise succumbed to cold stress after migrating south. Smaller immature animals may not have had the energetic reserves and the thermogenic capacity to maintain core body temperatures after an extended period of fasting in cool waters. It is also possible that some of them may not have had familiarity with southerly warm-water sites and so perished while searching outside of their known network. If there is a large proportion of the population that typically does not use the known warm-water sites covered by synoptic surveys, that will dramatically alter our views of what habitat manatees require to survive over winter and how manatees use the warm-water network. Future analyses that include photographic matching of carcasses and live animals within and between winters, and a finer spatio-temporal analysis of carcass reports, will bring additional information to bear on these alternative hypotheses.

Implications for Warm-water Carrying Capacity
Charles J. Deutsch

Environmental carrying capacity (K) is an important component of population models that project future manatee population trends and abundance (Haubold et al. 2006, Runge et al. 2007). Warm-water carrying capacity (WWK) has been highlighted in the state's Manatee Management Plan as one of three key "measurable biological goals", along with adult survival rate and population size (FWC 2007). WWK has been defined conceptually as the number of manatees that can be supported by available warm-water habitat during prolonged cold periods, such that death due to exposure to cold is avoided. This can be measured at the scale of either a specific site or a regional warm-water network. The amount of forage available to manatees in the area surrounding a warm-water site also needs to be taken into account when assessing environmental factors potentially limiting future population size at a local or regional level

(FWC 2007). It's important to recognize that K is a dynamic parameter that varies as the availability of limiting resources changes in response to natural events or human activities.

The most likely explanation for the large cold-related die-offs of manatees during winter 2010 is that manatees did not have access to sufficiently warm water, particularly in the east-central and far southwest regions of Florida. If the thermal basins in these two regions had provided adequate warmth, then there should not have been such a large spike in cold-related deaths in these areas. In fact, water temperatures at both of the two principal passive thermal basins in Brevard County—Berkeley Canal and Sebastian River C-54 Canal—dropped below 20°C for extended periods (Figures 27 and 28). Notably, the two main thermal basins in the Ten Thousands Islands (Port of the Islands and Big Cypress National Park Headquarters basin) remained reasonably warm due to a steady temperature-inverted halocline (Stith et al. 2010b), and relatively few manatee carcasses were found in this area compared to the high mortality in the Everglades to the south. Alternative explanations for the spike in carcass counts during the Acute Mortality Phase of the UME include: manatees that died from cold exposure early in the event did not find and use the existing suitable warm-water sites soon enough to avoid death; and hungry manatees, in poor body condition after a long fast in a suboptimal thermal regime, ventured away from their warm-water refuge to forage in cold waters and succumbed to the cold before returning to the refuge. Evidence for the latter idea comes in the form of two carcasses, whose deaths were attributed to acute cold stress, with vegetation still in the esophagus. Their GI tracts were otherwise relatively empty and at least one had severely depleted fat stores; this indicates that the animals resumed foraging after a long fast, and then died while feeding.

This UME highlights the perspective that WWK needs to be viewed as a dynamic variable, one that must be measured with respect to a particular set of ambient conditions. A site may provide adequate thermal space for hundreds or (theoretically) even thousands of manatees in mild or average winter conditions, but it may be unable to support any manatees under extremely cold conditions. Vertical stratification presents additional complexity, as temperature of the water column may vary with depth, time of day, and time relative to passage of a cold front; furthermore, a thick sediment layer may provide more warmth than the water column. All of that complexity was observed at the Berkeley and Sebastian sites. This presents a challenge for operationally defining and quantifying WWK for use in population models. A simple solution is to select a threshold temperature (e.g., 20°C) and to consider WWK equal to zero when the water temperature at the warmest depth at that site falls below the threshold. A more realistic approach would incorporate both temperature thresholds and durations below those thresholds into a site-specific WWK model.

Finally, given the strong differential mortality by size/age class, it should also be clear that the thresholds for what constitutes sufficiently warm water differ between adults, subadults and calves. This idea is supported by differential ability to raise metabolic rate in response to water temperatures below 20°C as a function of animal size (Worthy et al. 2000). This means that a particular site during cold conditions might provide WWK for *x* number of adults, for a smaller *y* number of subadults, but for zero calves. Recently independent calves (~1.5-2 years old) are probably most vulnerable because they no longer receive nutrition through nursing and they do not have the guidance of an experienced adult to lead them to alternative warm-water sites. Dependent calves also have a thicker backfat layer, which should provide more insulation

from the cold, than independent juveniles (Ward-Geiger 1997). Definitions of WWK need to explicitly address whether they refer to the adult age class or the most vulnerable younger segments of the population.

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Figures

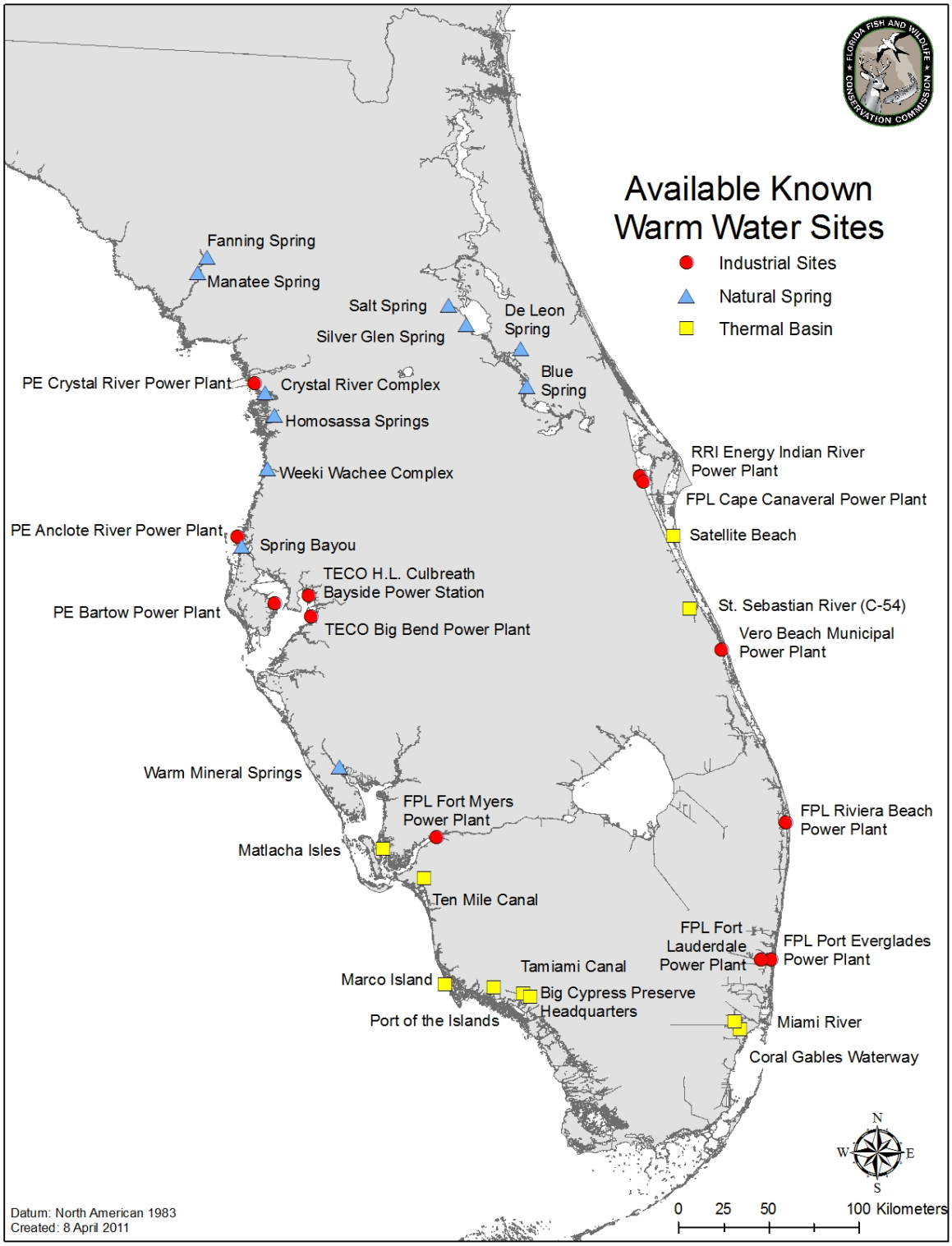


Figure 1. Locations of important winter warm-water manatee aggregation sites in peninsular Florida.

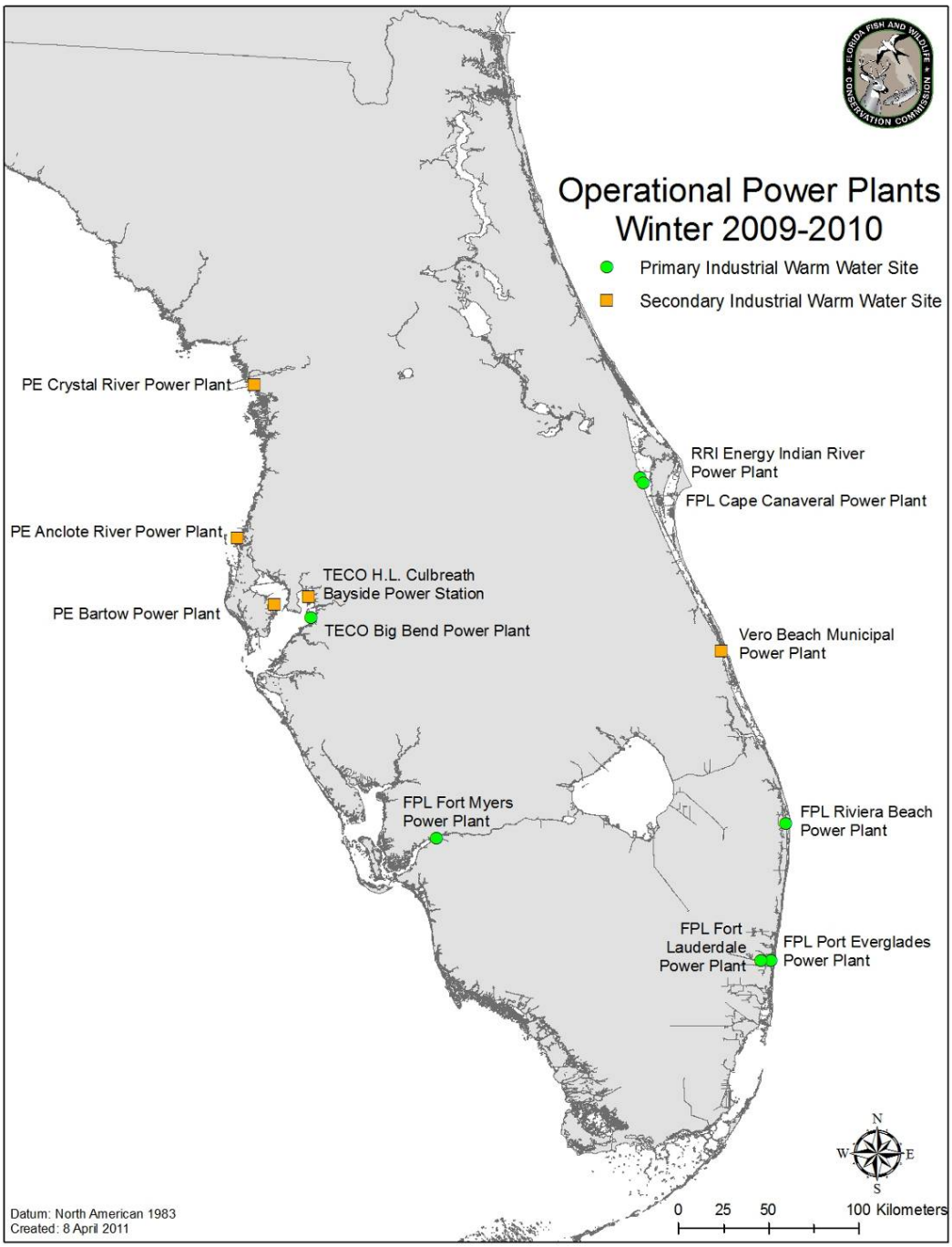


Figure 2. Locations of operational power plants during winter 2009-2010 with thermal effluents used by manatees. The primary power plants operate with a Manatee Protection Plan that is part of their National Pollution Discharge Elimination System (NPDES) permit that requires these plants to discharge waters to at least 20°C (68°F) when ambient water temperatures reach 16.1°C (61°F). Manatees frequently use these sites during the winter due to the consistent warm-water discharge. The secondary plants have discharges that are inconsistent in their operation resulting in fewer manatees using these sites on an infrequent basis.

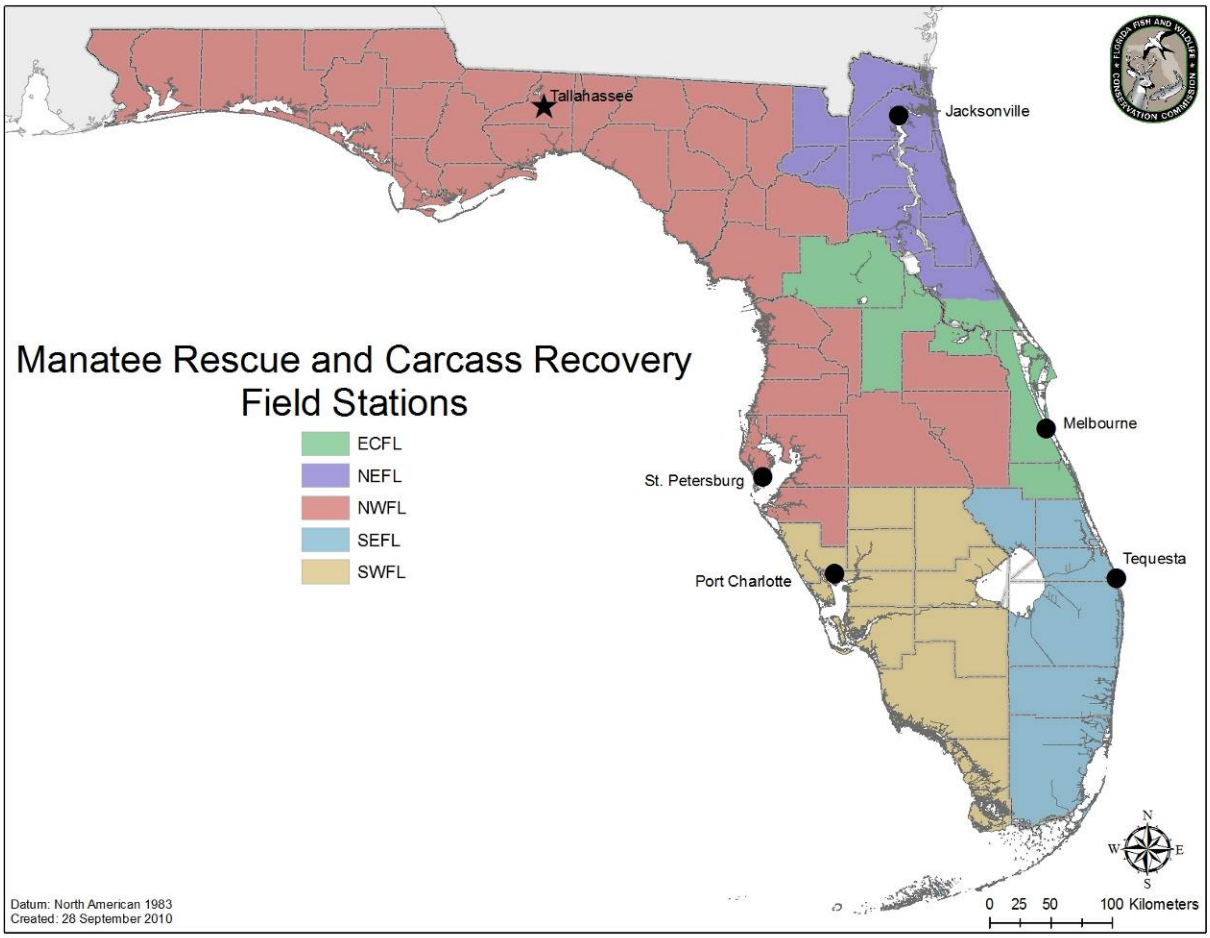


Figure 3. Locations of Florida Fish and Wildlife Conservation Commission (FWC) Fish and Wildlife Research Institute (FWRI) Manatee Rescue and Carcass Recovery field stations (black dots) and FWC headquarters (star). FWRI headquarters and the Marine Mammal Pathobiology Laboratory (MMPL) are both located in St. Petersburg.

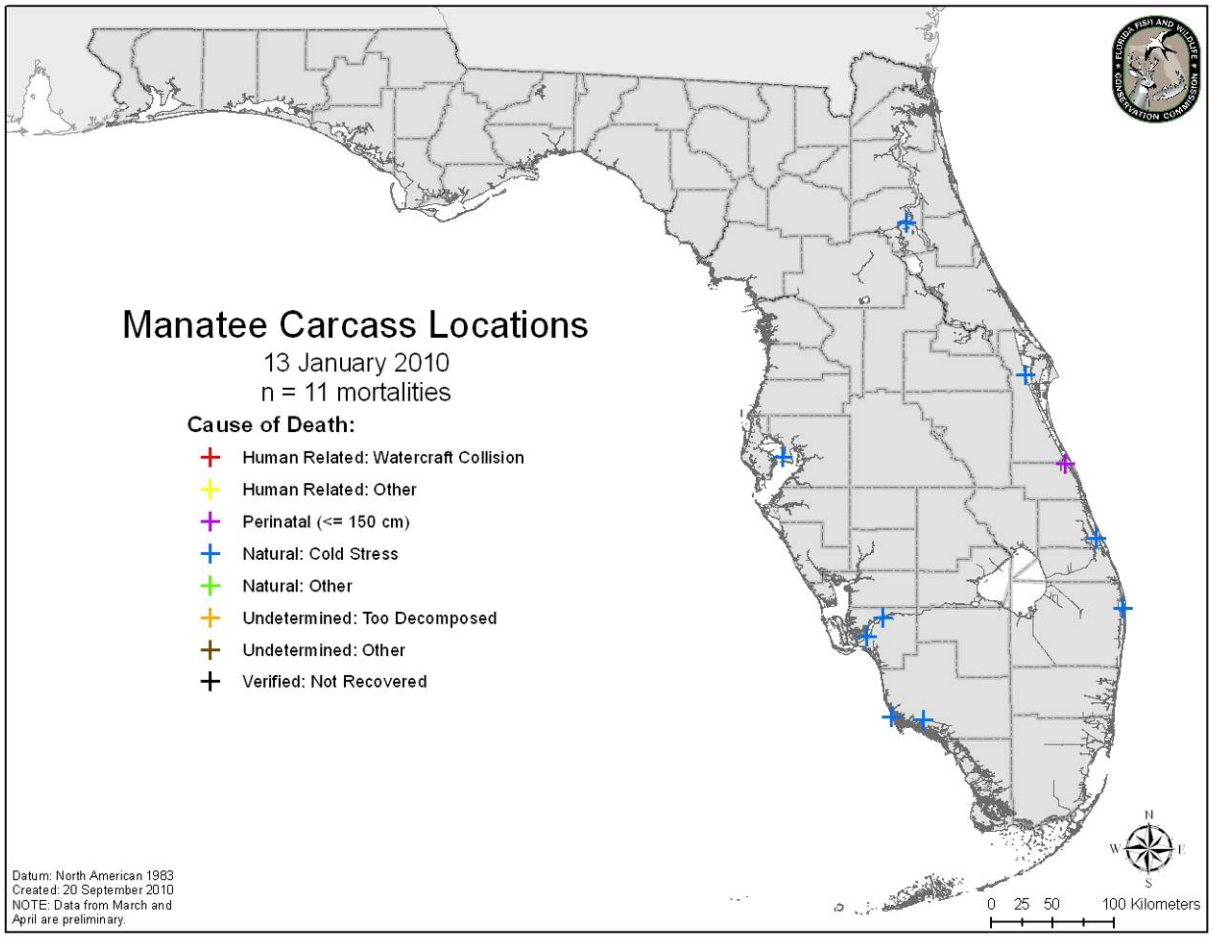


Figure 4. Distribution of eleven manatee carcasses reported in the state of Florida on January 13, 2010 with a cause of death attributed to cold stress. These carcasses, along with three carcasses recovered in Brevard County on January 11, 2010, marked the beginning of the 2010 cold-related manatee mortality event.

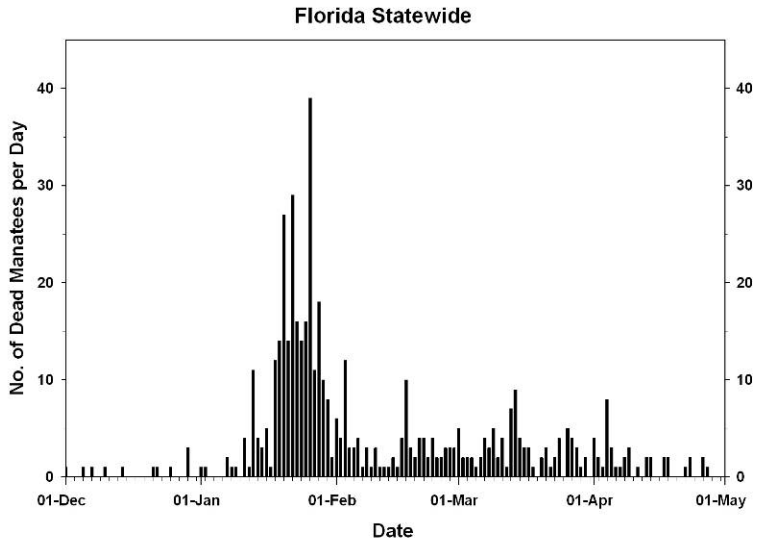


Figure 5. Number of manatee carcasses reported per day in the state of Florida during the winter of 2009-2010, excluding those with known human-related causes of death. Note that several of the single-day spikes in reported carcasses at the height of the mortality event were associated with reports from aerial carcass surveys over the Everglades.

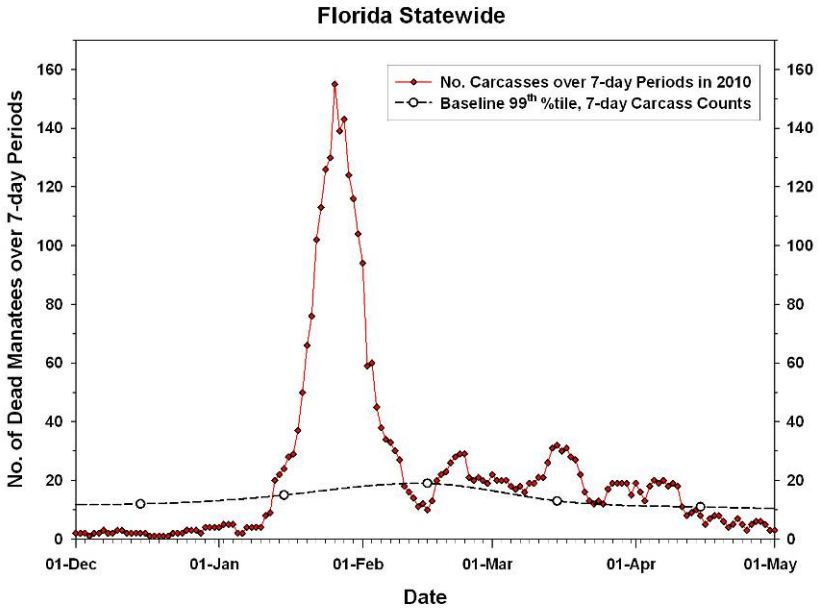


Figure 6. Number of manatee carcasses reported over 7-day periods in the state of Florida during winter 2009-2010, excluding those with known human-related causes of death. The dashed line represents the 99th-percentile of 7-day carcass counts for each month over the previous 5-year period, excluding known unusual mortality events during this reference period. The statewide cold-stress related unusual mortality event began January 11, 2010 and ended April 9, 2010, with a brief dip below threshold levels in mid-February.

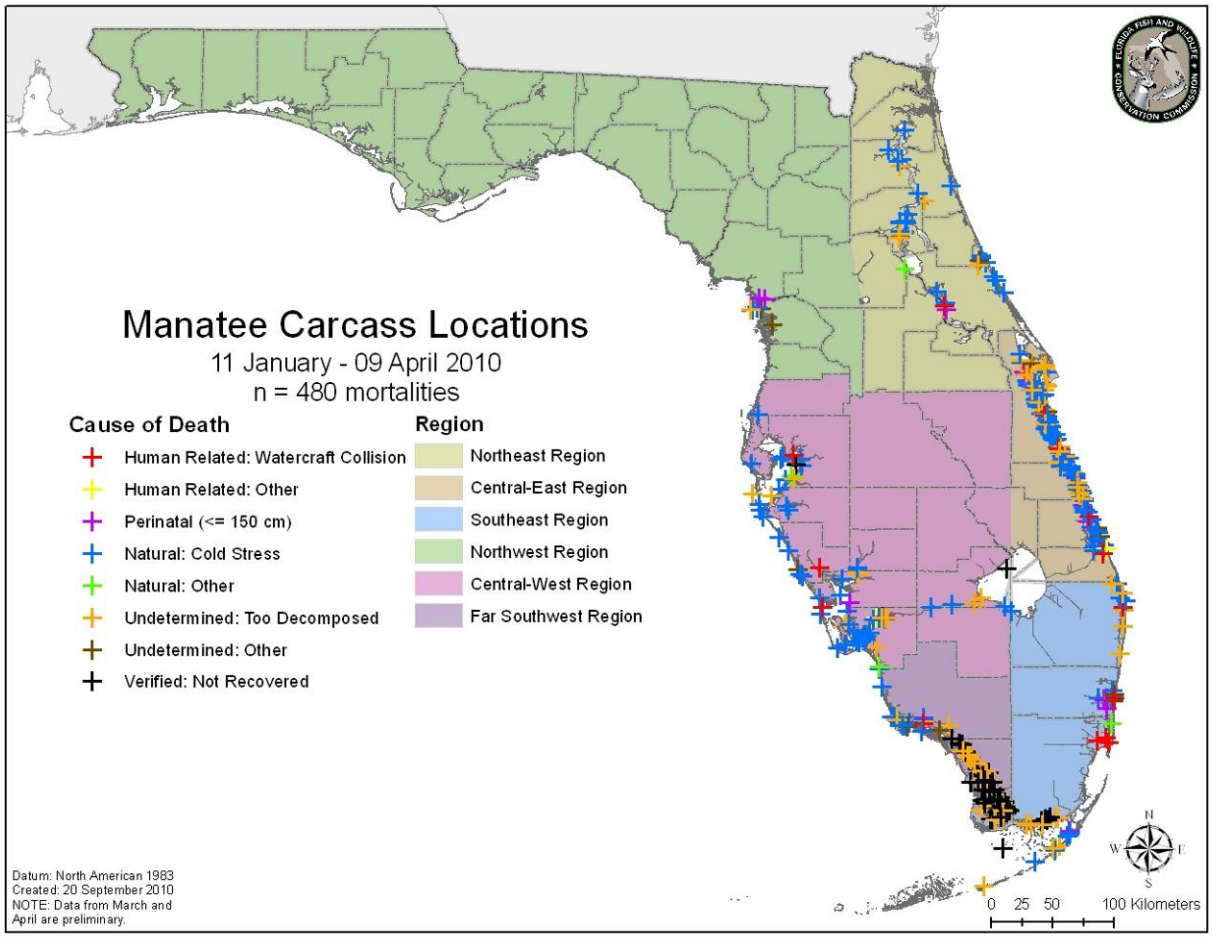


Figure 7. Distribution of manatee carcasses reported in the state of Florida from January 11 – April 9, 2010. Cause of death and regions delineated for analyses are shown. These dates mark the beginning and end of the 2010 cold-related manatee mortality event. Manatees in all regions, except in the northwest region, suffered unusually high mortality.

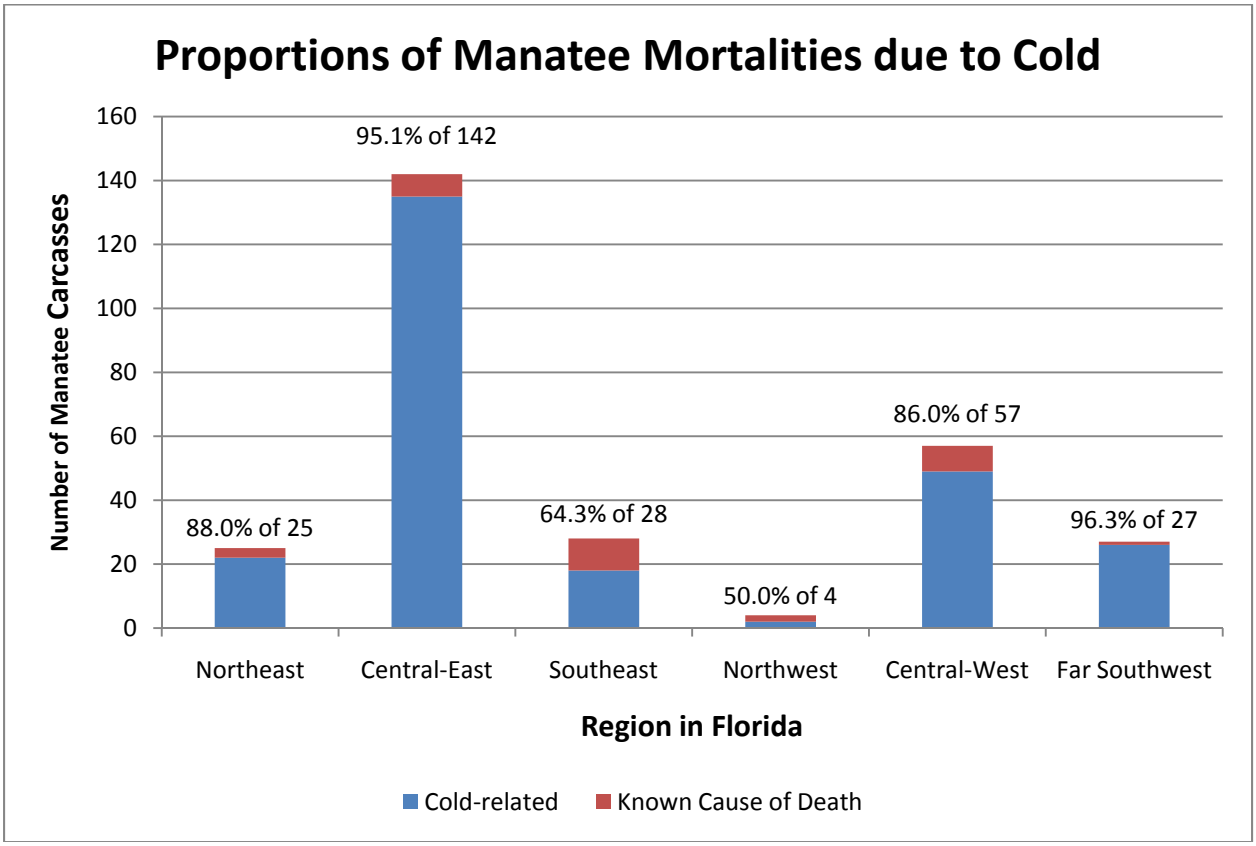


Figure 8. Numbers of manatee deaths attributed to cold versus other known causes by region during the 2010 unusual mortality event. Figures above each bar indicate the percentage of carcasses with a known cause of death that were attributed to cold stress for each region. Regions are defined in Appendix D and shown in Figure 7.

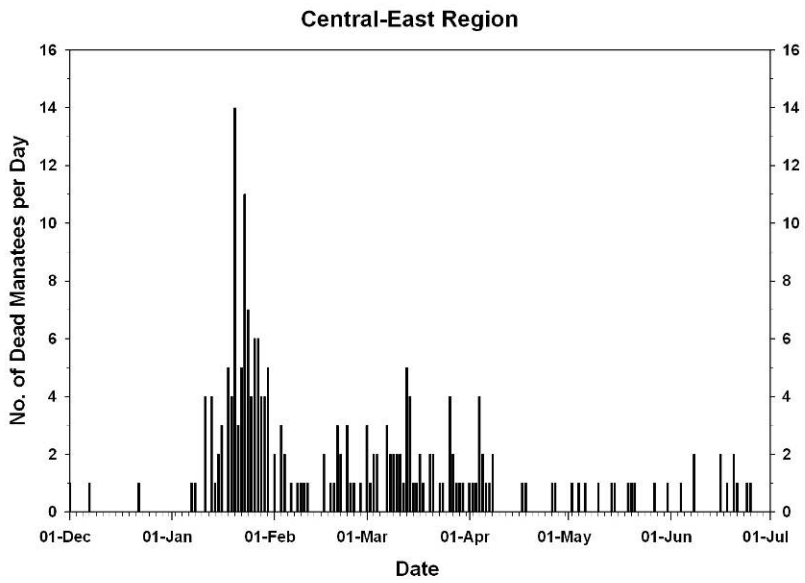


Figure 9a. Number of manatee carcasses reported per day in the central-east region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death.

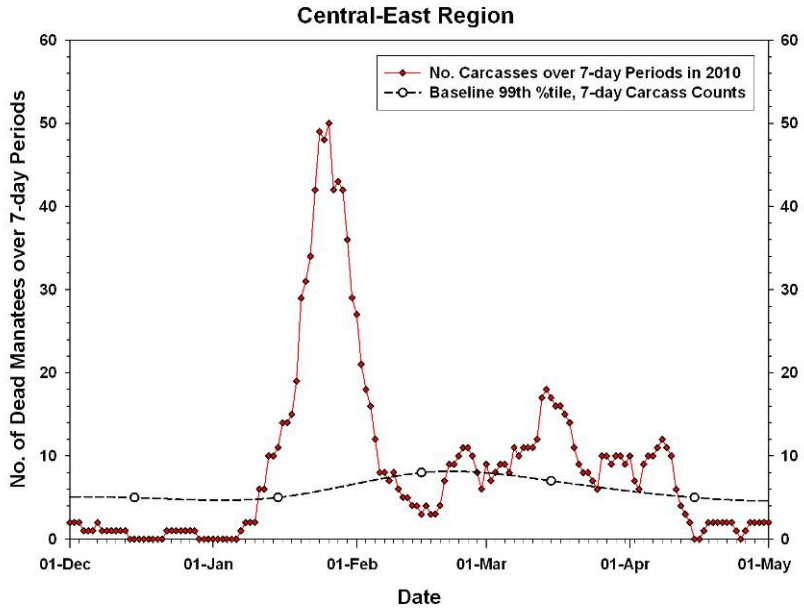


Figure 9b. Number of manatee carcasses reported over 7-day periods in the central-east region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death. This is shown in relation to the 99th-percentile of 7-day carcass counts for each month over the previous 5-year period in this region, excluding known unusual mortality events during that reference period. Carcass counts exceeded UME thresholds from January 11 through February 4, and on most days from February 21 through April 8.

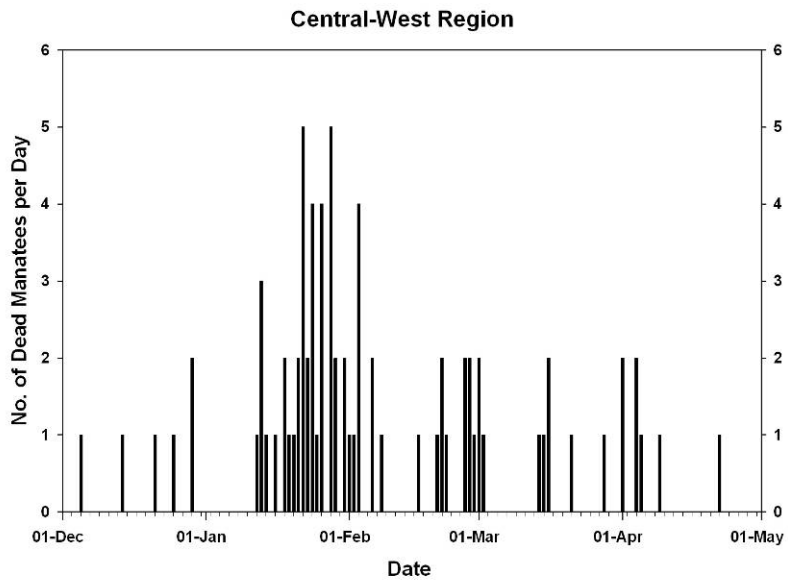


Figure 10a. Number of manatee carcasses reported per day in the central-west region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death.

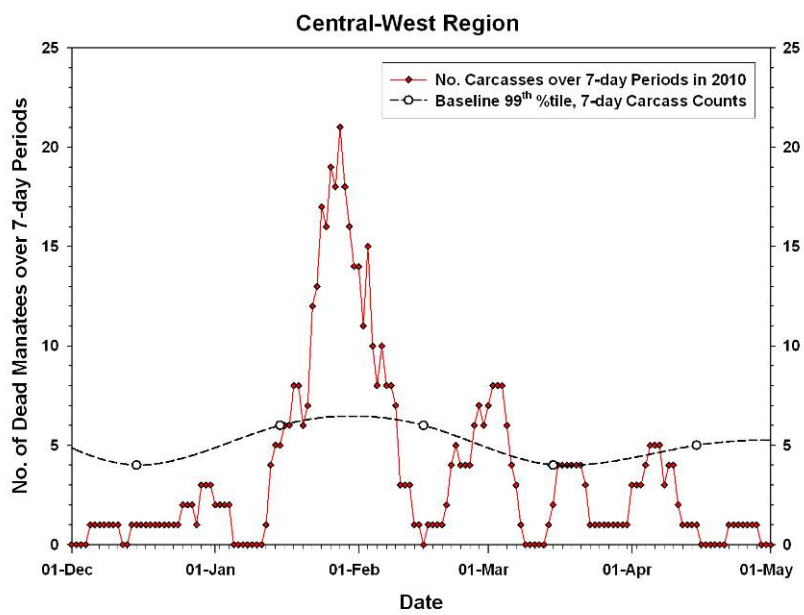


Figure 10b. Number of manatee carcasses reported over 7-day periods in the central-west region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death. This is shown in relation to the 99th-percentile of 7-day carcass counts for each month over the previous 5-year period in this region, excluding known unusual mortality events during that reference period. Carcass counts exceeded UME thresholds from January 18 through February 8, and from February 27 through March 2.

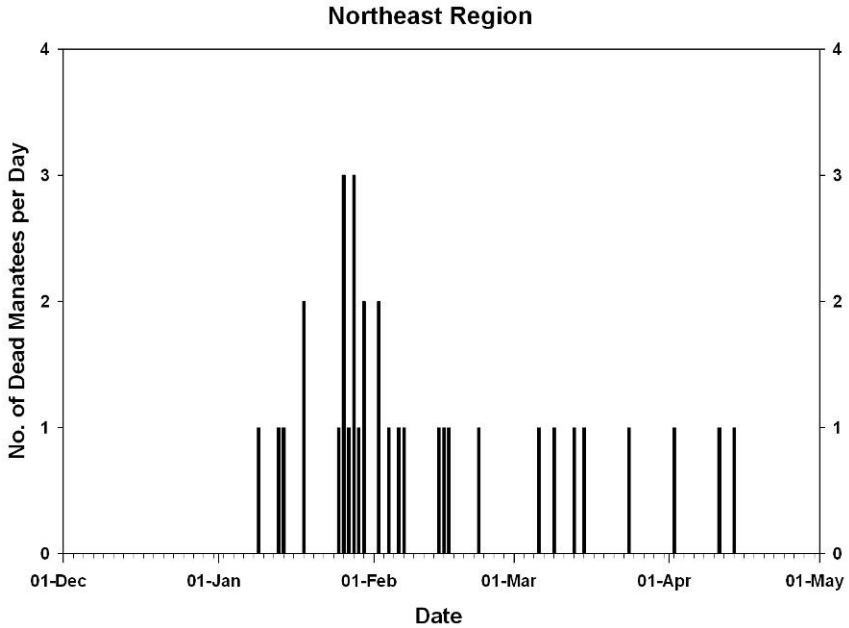


Figure 11a. Number of manatee carcasses reported per day in the northeast region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death.

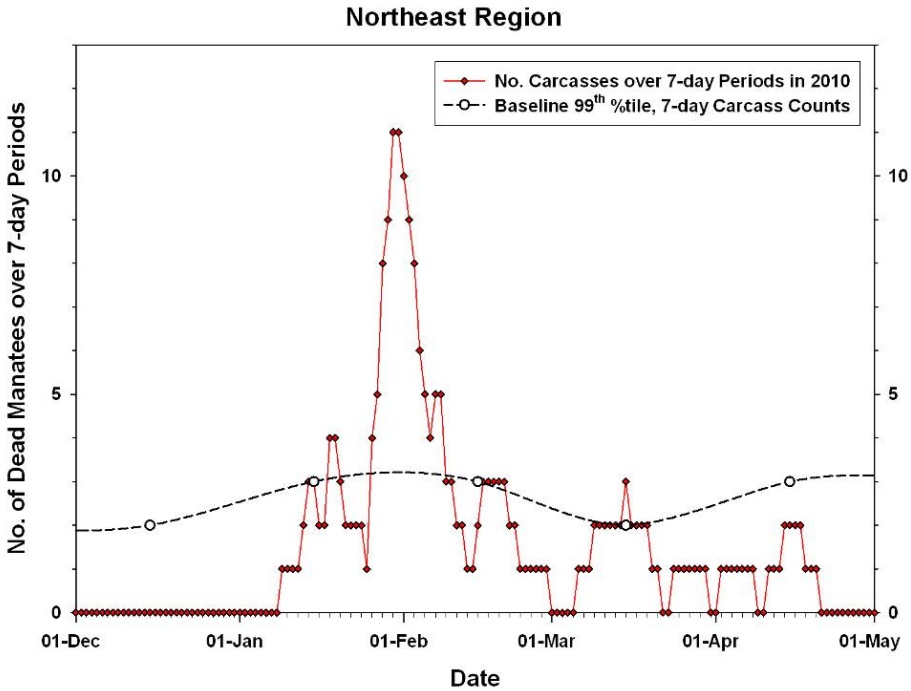


Figure 11b. Number of manatee carcasses reported over 7-day periods in the northeast region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death. This is shown in relation to the 99th-percentile of 7-day carcass counts for each month over the previous 5-year period in this region, excluding known unusual mortality events during that reference period. Carcass counts exceeded UME thresholds on January 18 and from January 26 through February 7.

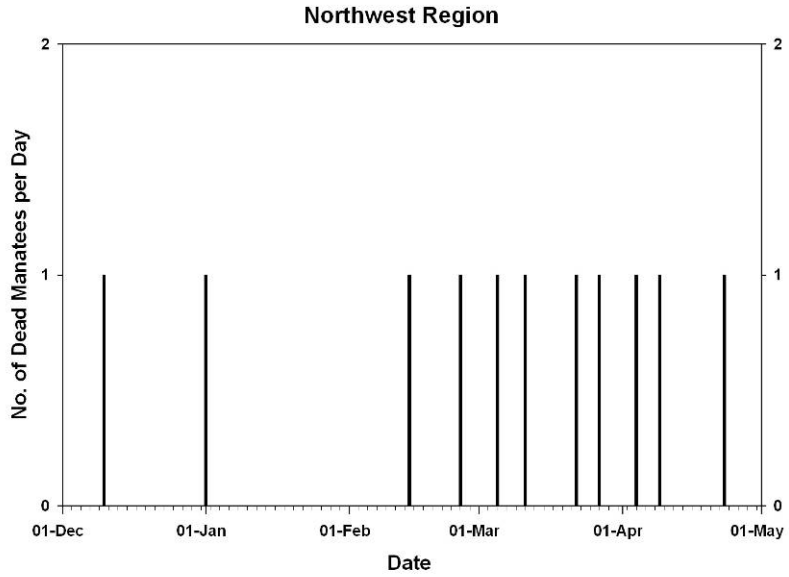


Figure 12a. Number of manatee carcasses reported per day in the northwest region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death.

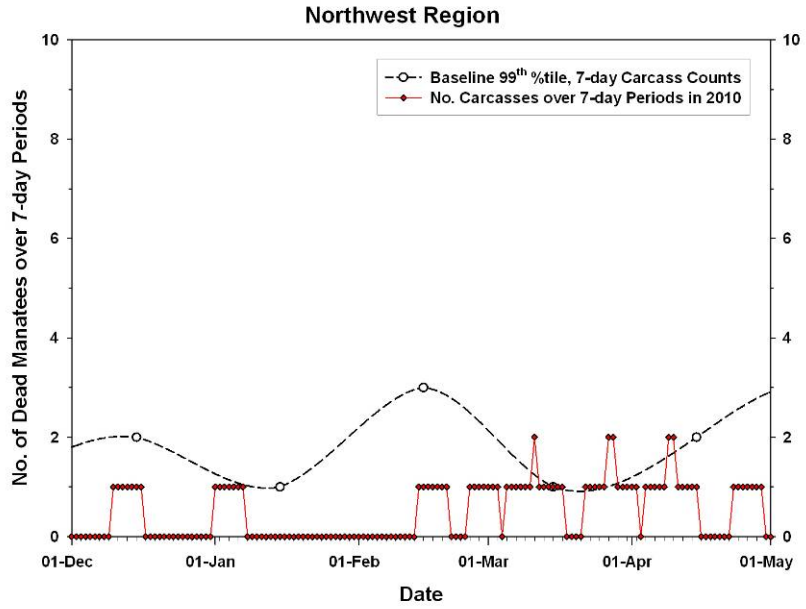


Figure 12b. Number of manatee carcasses reported over 7-day periods in the northwest region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death. This is shown in relation to the 99th-percentile of 7-day carcass counts for each month over the previous 5-year period in this region, excluding known unusual mortality events during that reference period. No UME was detected.

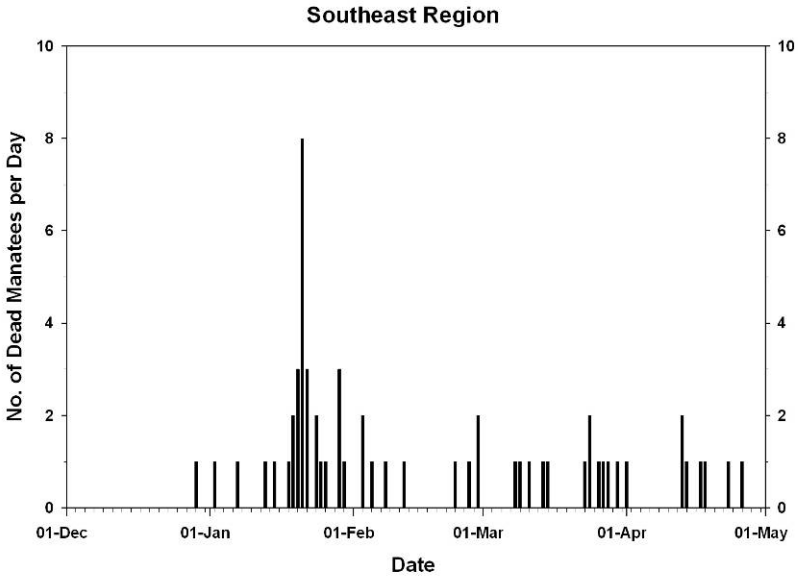


Figure 13a. Number of manatee carcasses reported per day in the southeast region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death.

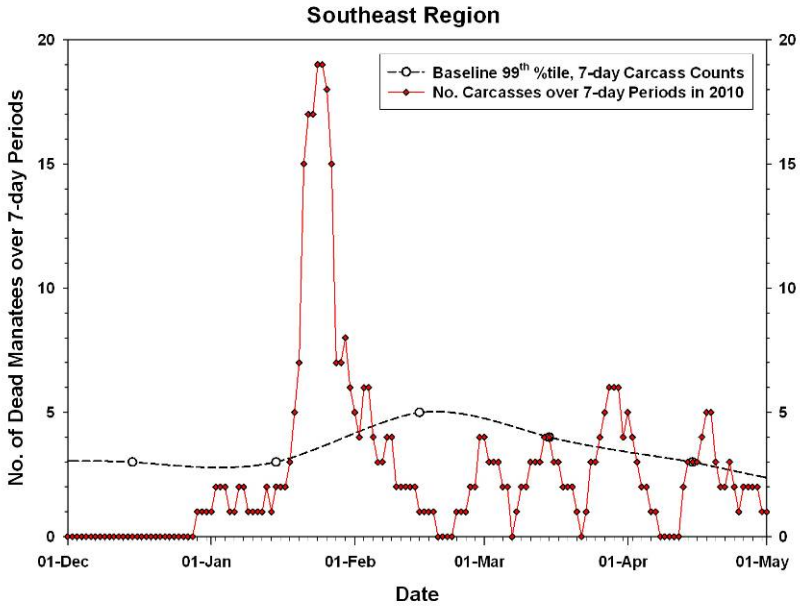


Figure 13b. Number of manatee carcasses reported over 7-day periods in the southeast region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death. This is shown in relation to the 99th-percentile of 7-day carcass counts for each month over the previous 5-year period in this region, excluding known unusual mortality events during that reference period. Carcass counts exceeded UME thresholds from January 19 through February 3, and briefly in late spring (March 27 - April 1, April 17-18).

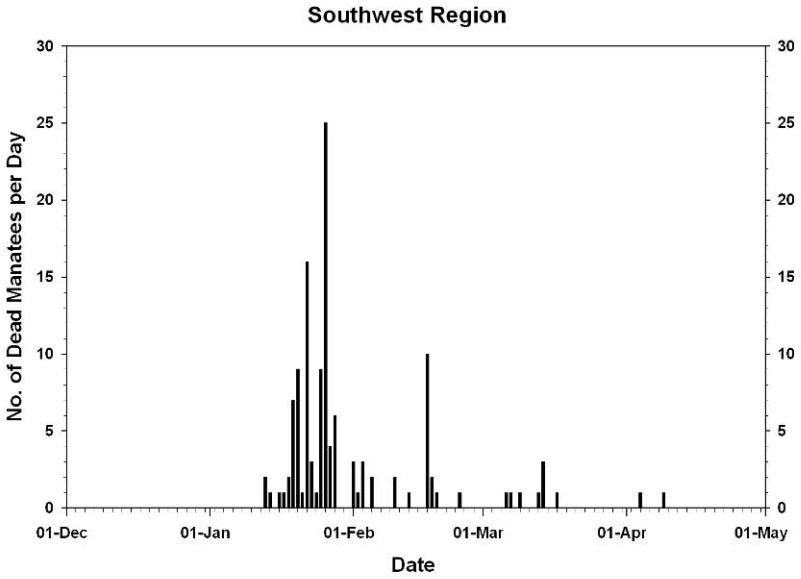


Figure 14a. Number of manatee carcasses reported per day in the far southwest region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death.

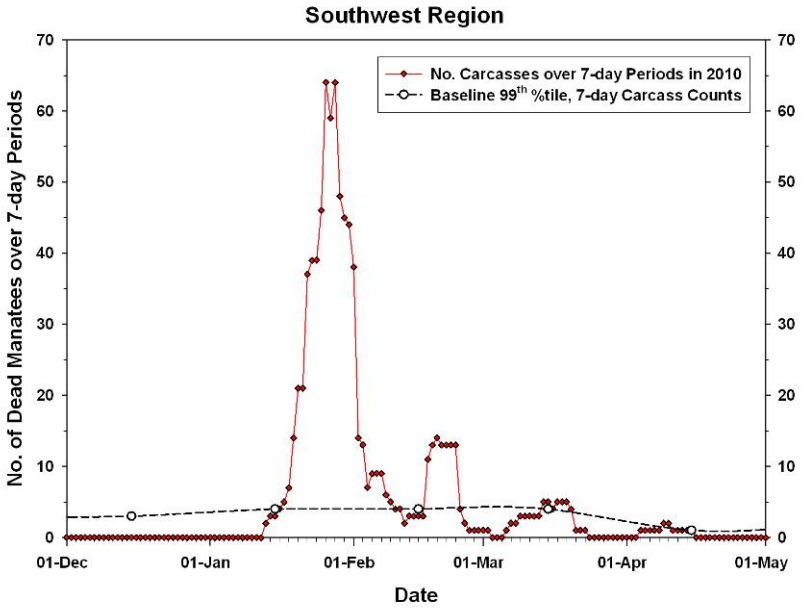


Figure 14b. Number of manatee carcasses reported over 7-day periods in the far southwest region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death. This is shown in relation to the 99th-percentile of 7-day carcass counts for each month over the previous 5-year period in this region, excluding known unusual mortality events during that reference period. Carcass counts exceeded UME thresholds from January 17 through February 5, and briefly in late winter (February 17-19, March 14-17).

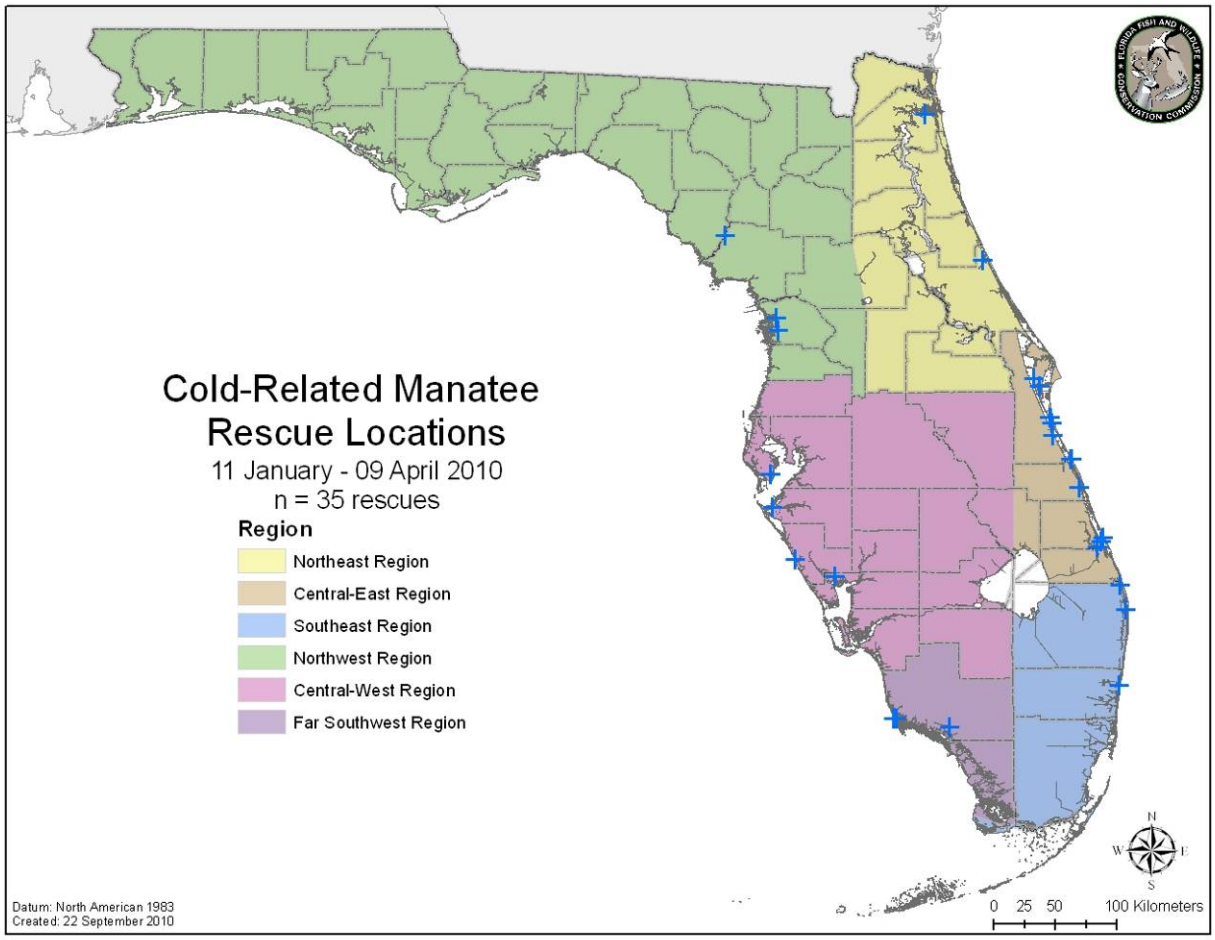


Figure 15. Distribution of manatees rescued in the state of Florida from January 11 – April 9, 2010 due to injuries related to cold stress.

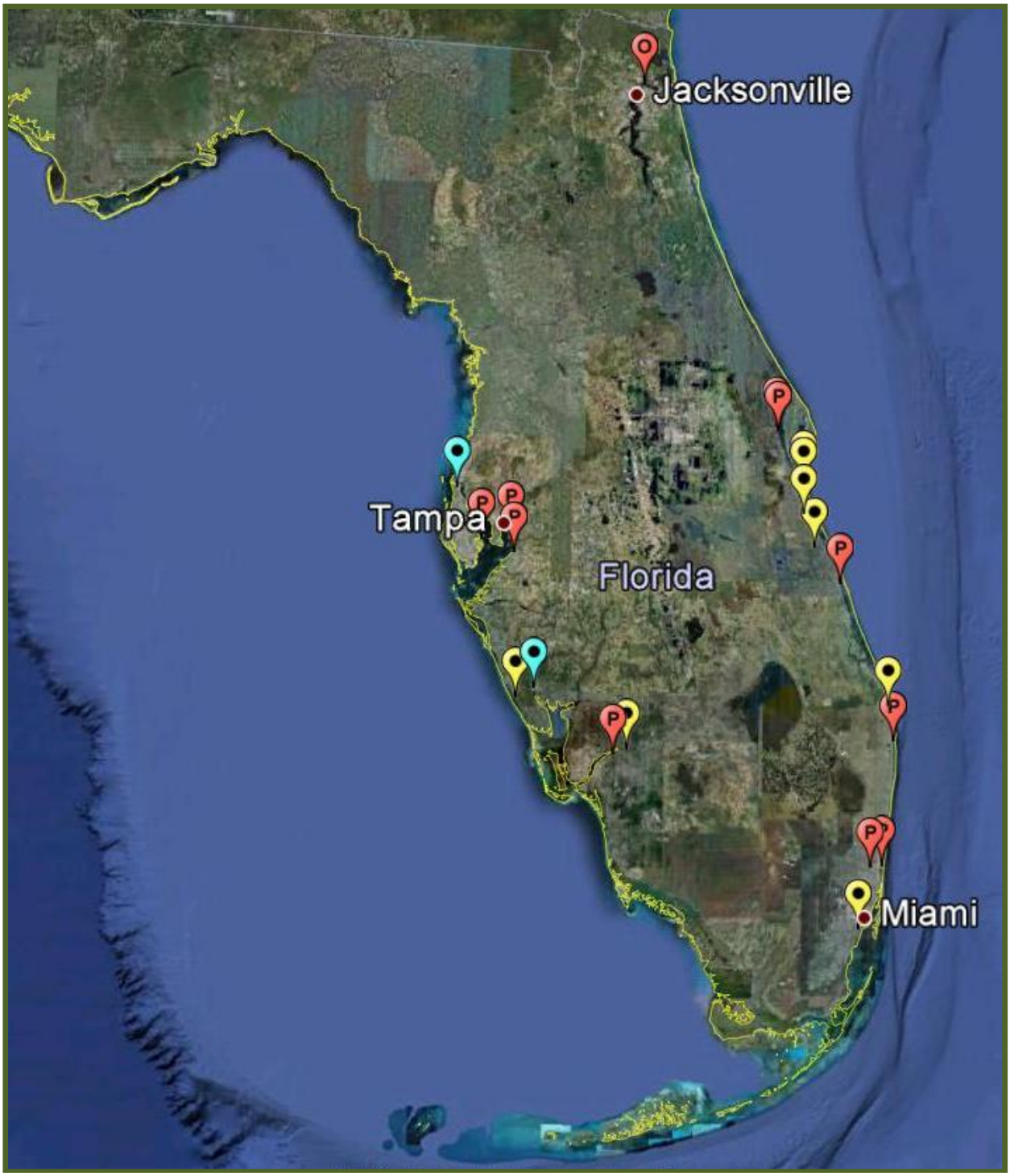


Figure 16. Locations of Florida Fish and Wildlife Research Institute (FWRI) temperature loggers at manatee warm-water aggregation sites in Florida during winter 2009-2010. One or more loggers were placed in the warm-water habitat at each site and also at a nearby ambient site. Symbols denote power plants (red "P"), other industrial sites (red "O"), thermal basins (yellow), and springs (blue).

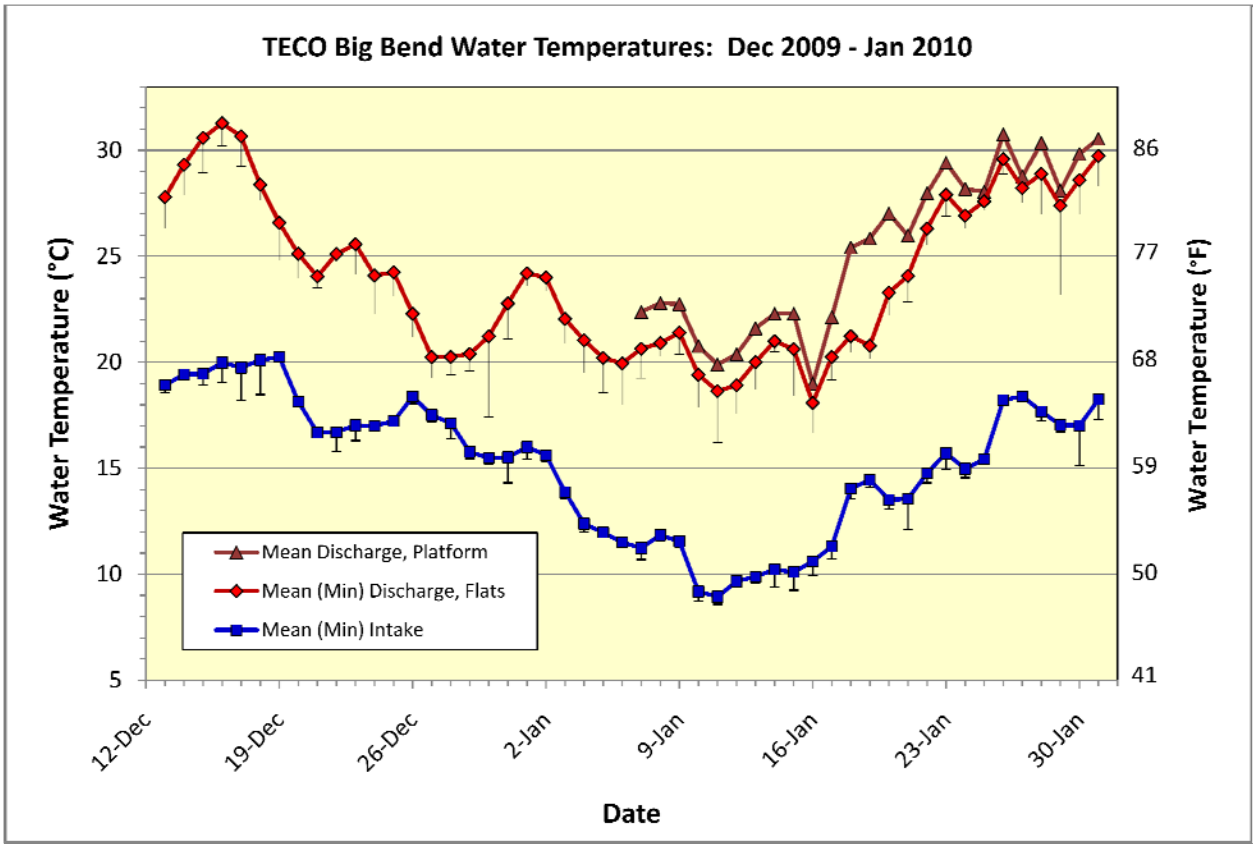


Figure 17. Mean daily water temperatures in the intake and discharge canals of the TECO Big Bend power plant (Apollo Beach, FL) during December 2009 and January 2010. The vertical bars denote the minimum daily temperatures.

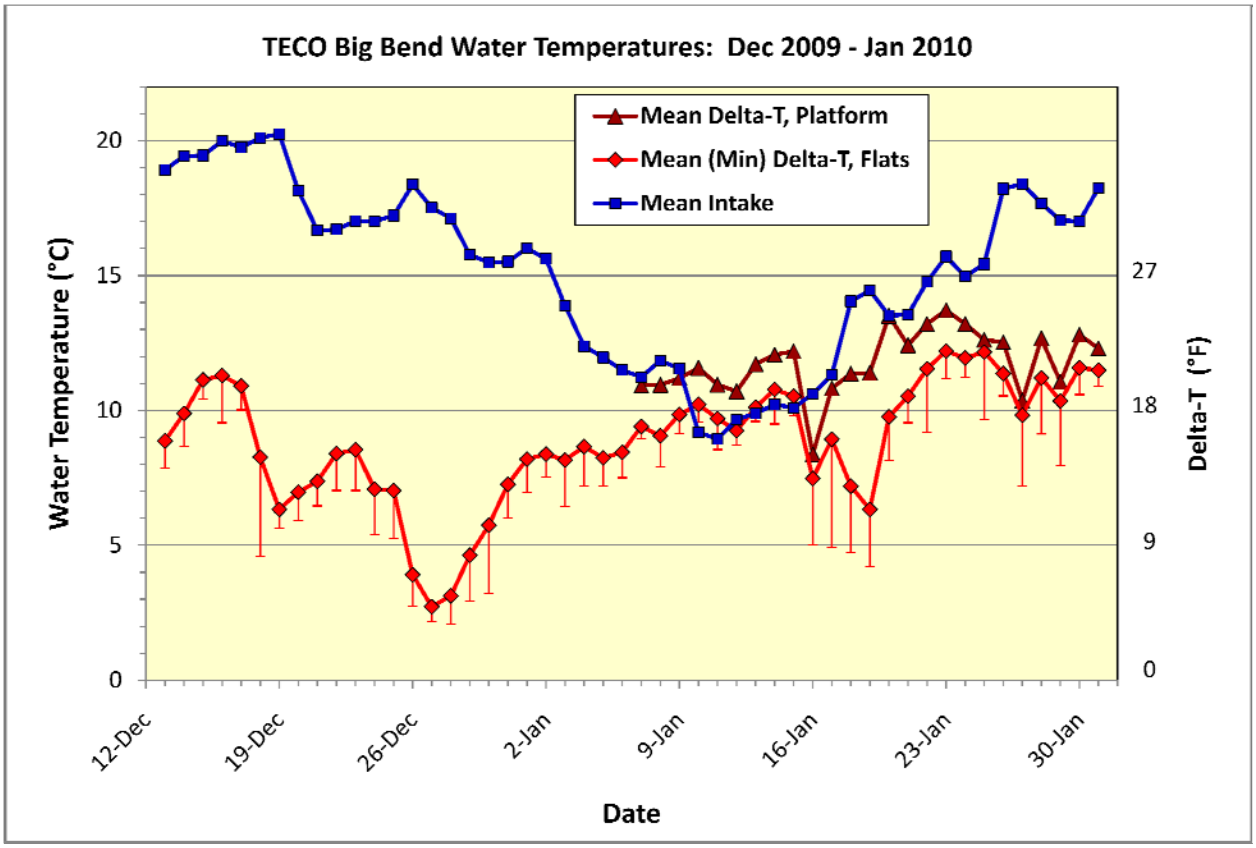


Figure 18. Mean daily delta-T (difference between discharge and intake canal water temperatures) and mean daily intake temperature at the TECO Big Bend power plant (Apollo Beach, FL) during December 2009 and January 2010. The vertical bars denote the minimum daily delta-T for the discharge flats site, which was cooler than the platform site.

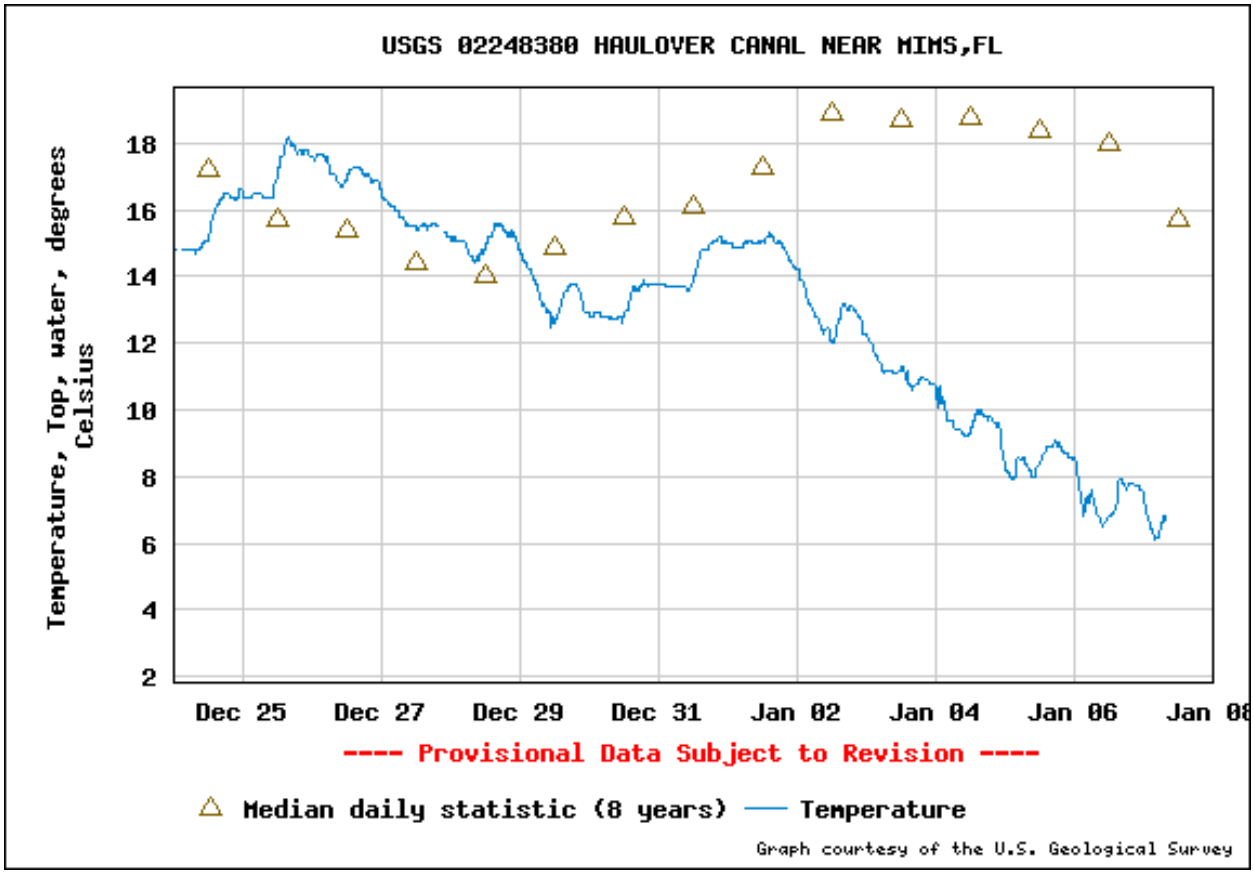


Figure 19. Surface water temperature at Haulover Canal near Mims in northern Brevard County, FL over a two-week period (24 Dec 2009 – 7 Jan 2010) obtained online from the U.S. Geological Survey on 7 January 2010 (http://waterdata.usgs.gov/nwis/uv?02248380).

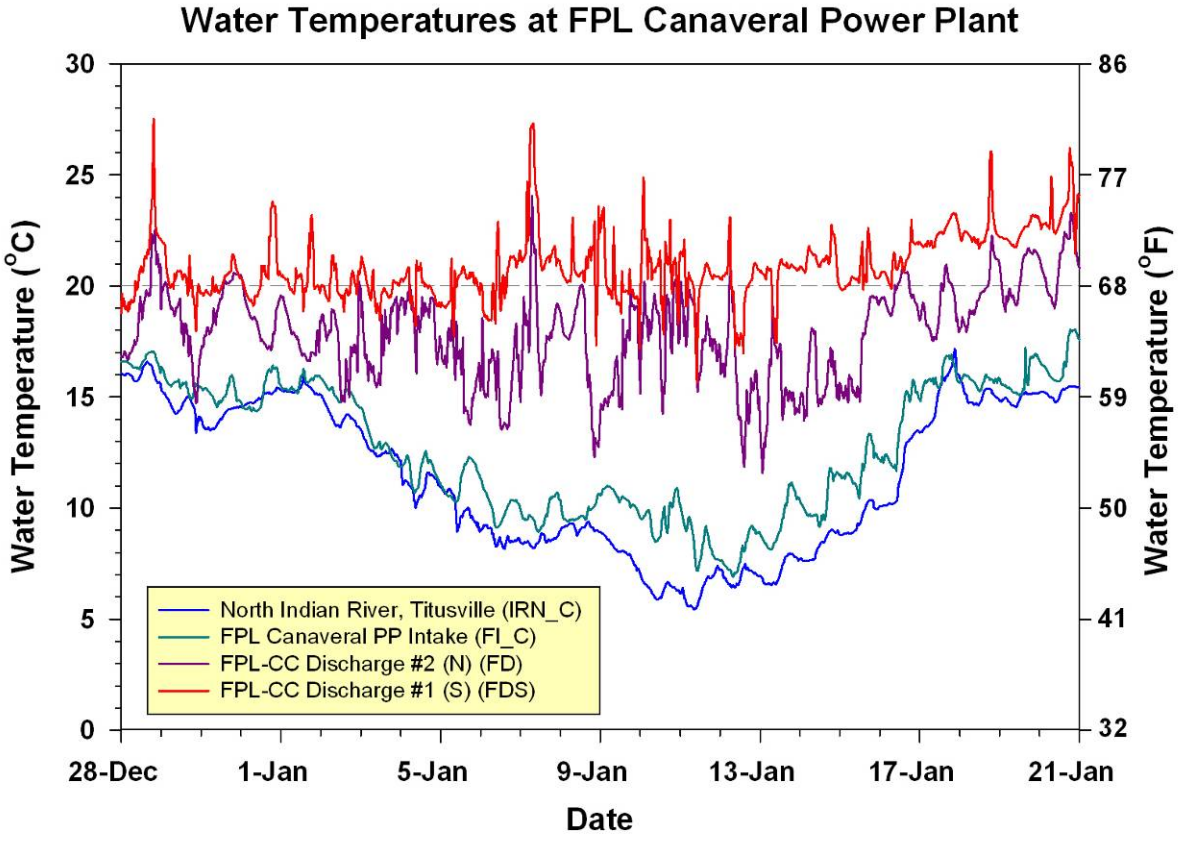


Figure 20. Water temperatures recorded at the FPL Cape Canaveral power plant intake and discharge areas, and nearby in the Indian River (NASA Causeway), during the extreme cold snap of early January 2010.

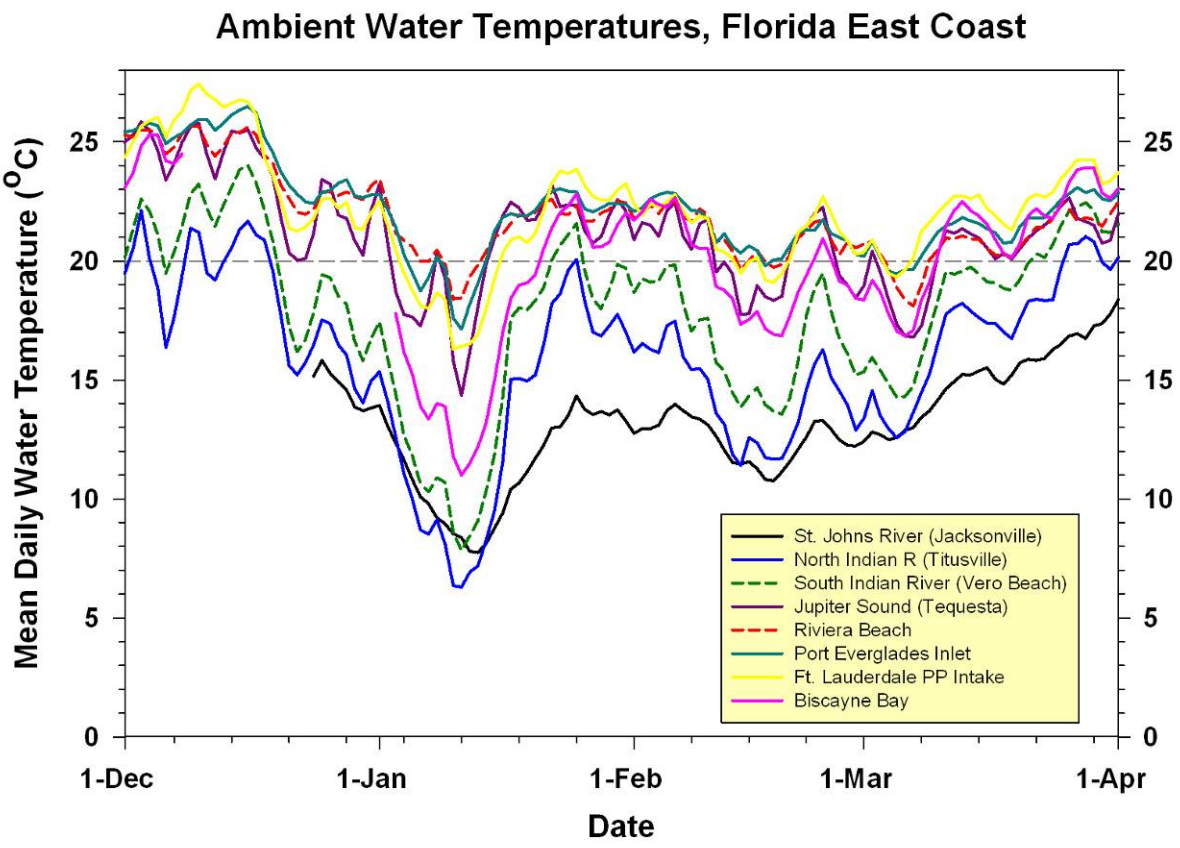


Figure 21. Seasonal change in mean daily temperature of ambient waters at eight sites in manatee habitat along the east coast of Florida, from Jacksonville to Biscayne Bay, during winter 2009-2010. Sites in the legend are ordered from north to south.

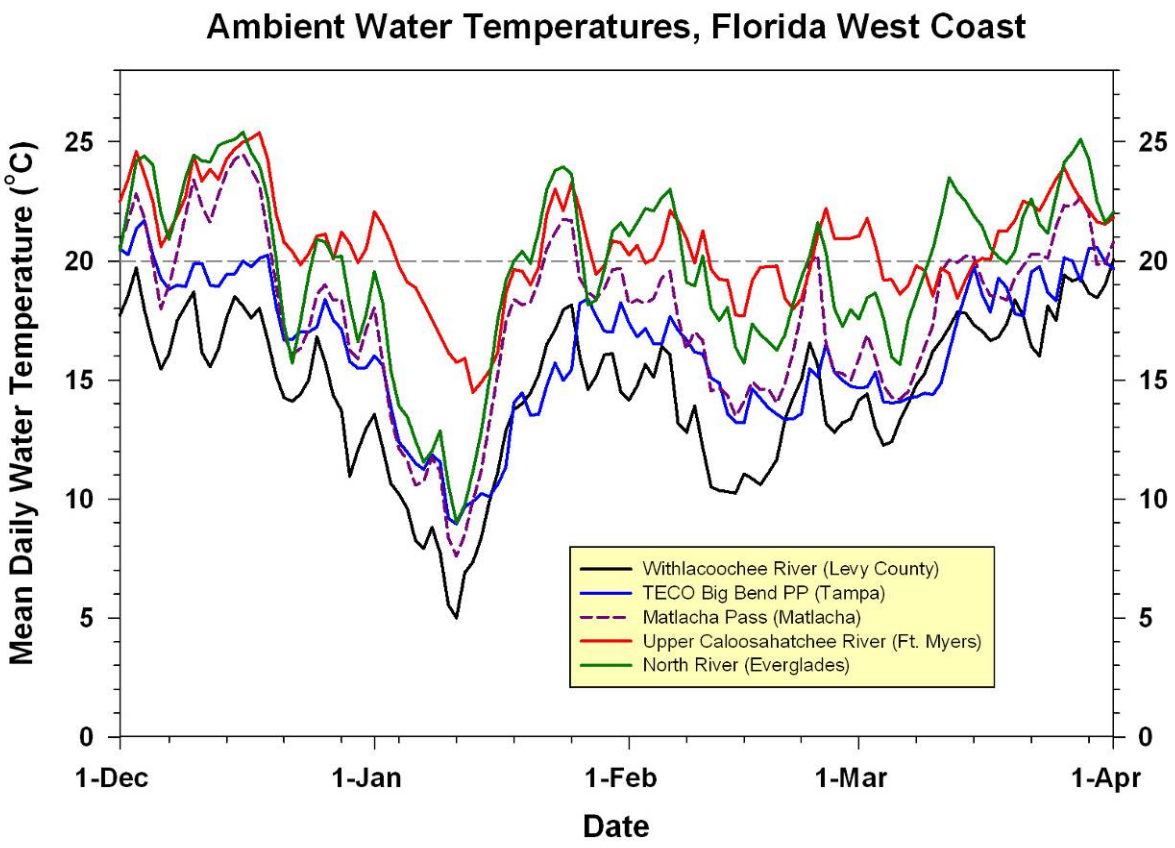


Figure 22. Seasonal change in mean daily temperature of ambient waters at five sites in manatee habitat along the west coast of Florida, from Levy County to the Everglades, during winter 2009-2010. Sites in the legend are ordered from north to south. Data from Withlacoochee and North Rivers were from USGS; data from Matlacha and the Caloosahatchee River were from Mote Marine Laboratory.

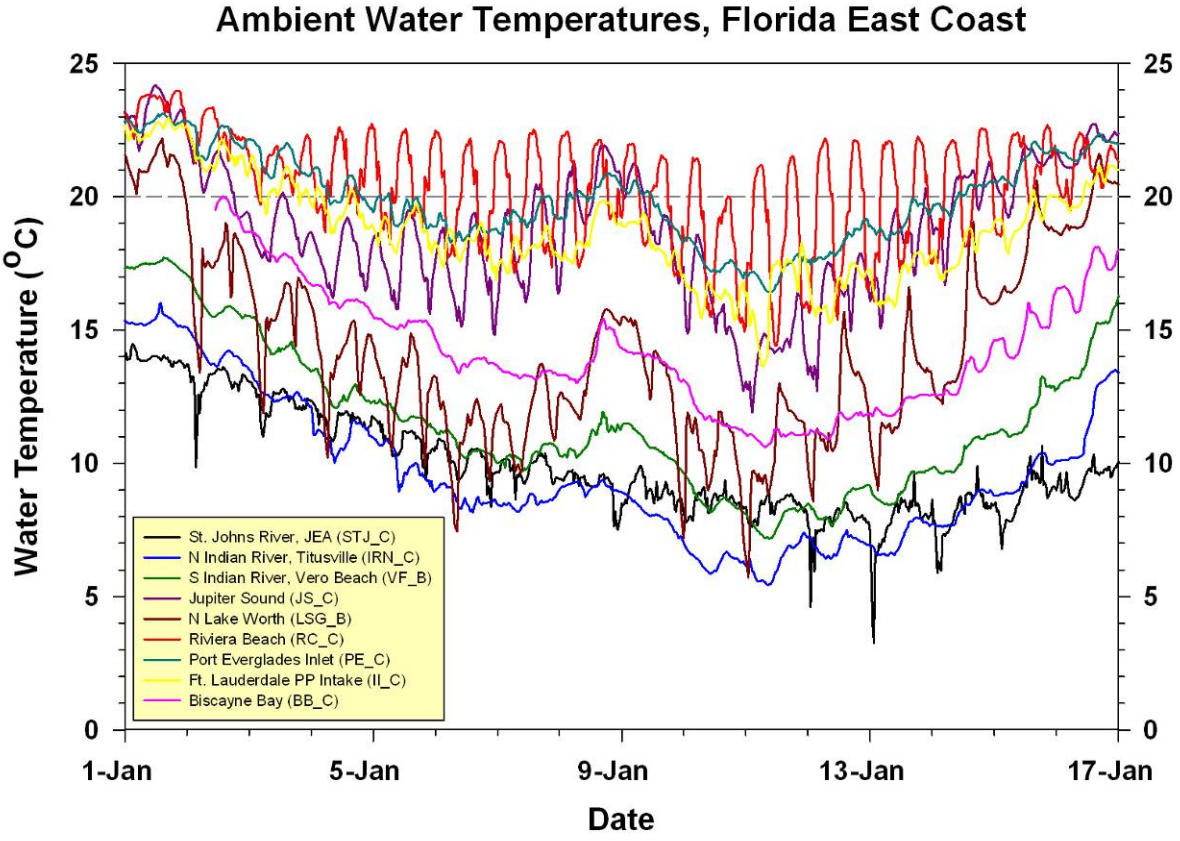


Figure 23. Temperature of ambient waters at nine sites in manatee habitat along the east coast of Florida, from Jacksonville to Biscayne Bay, during the extreme cold snap of early January 2010. Sites in the legend are ordered from north to south.

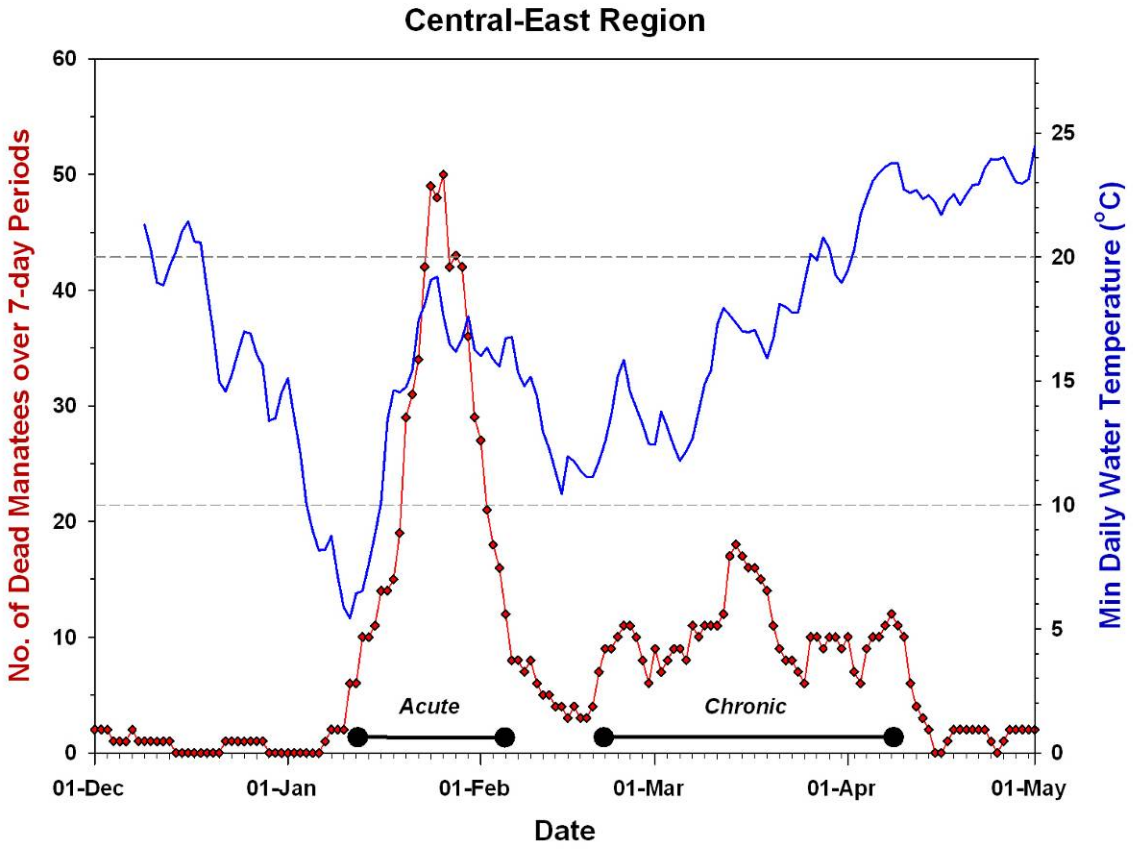


Figure 24. Number of reported carcasses over 7-day periods in the central-east region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death, in relation to minimum daily water temperature in the northern Indian River near Titusville, FL.

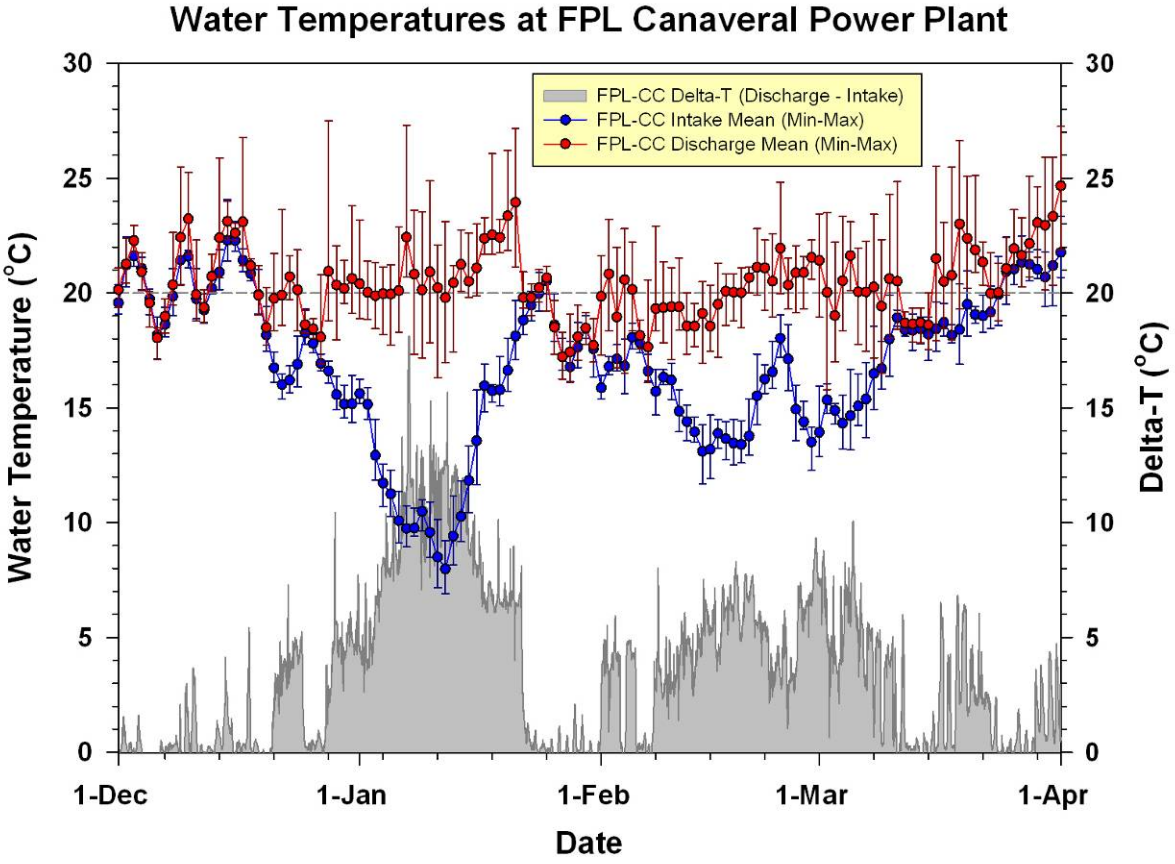


Figure 25. Mean daily water temperatures in the intake and discharge areas at the FPL Cape Canaveral power plant (Port St. John, FL) during winter 2009-2010. The vertical bars denote the daily maximum and minimum temperatures. Delta-T (difference between discharge and intake water temperatures) is shown as an area plot below. Note the periods (e.g., late January) when the plant was not operating.

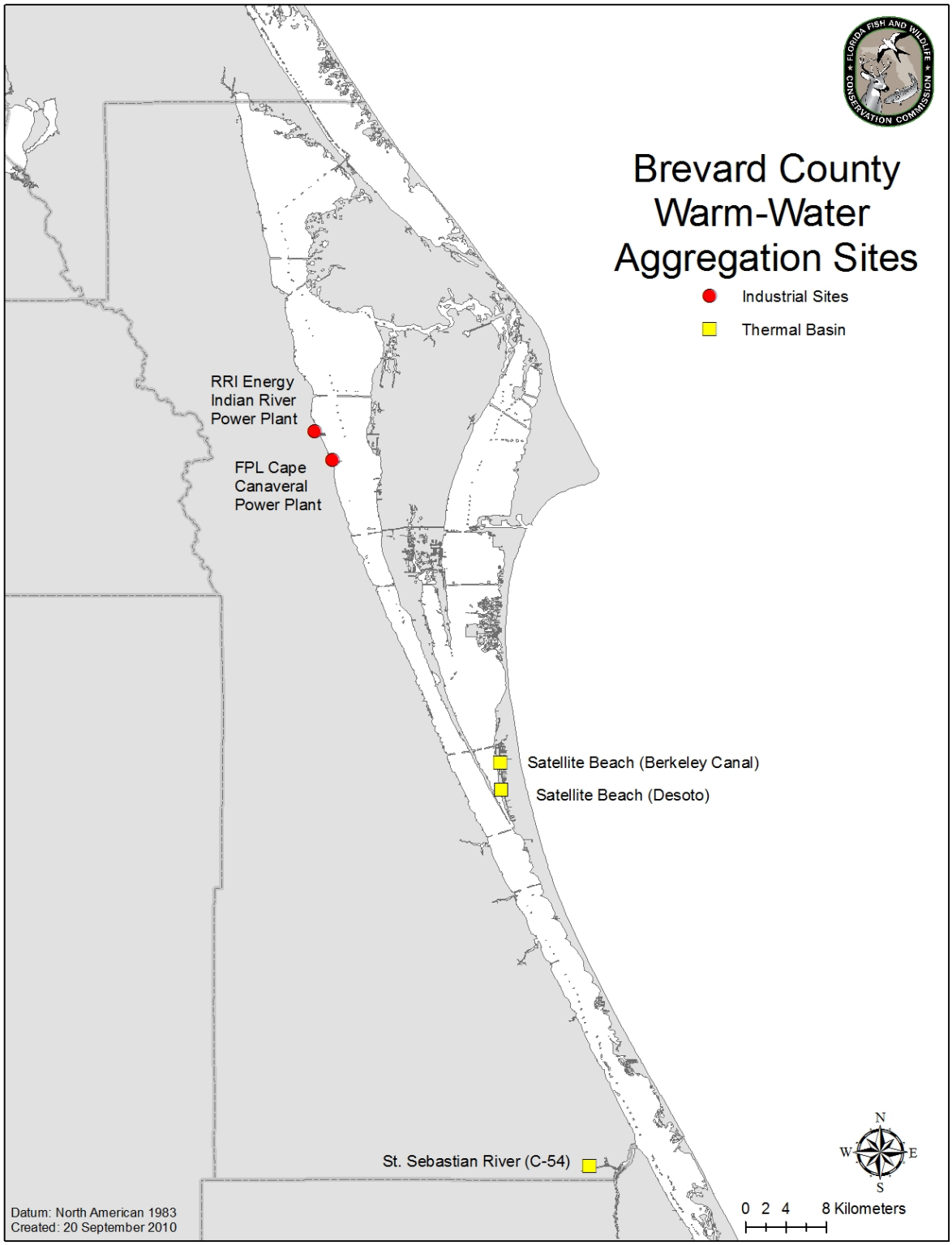


Figure 26. Locations of important warm-water manatee aggregation sites in Brevard County, Florida.

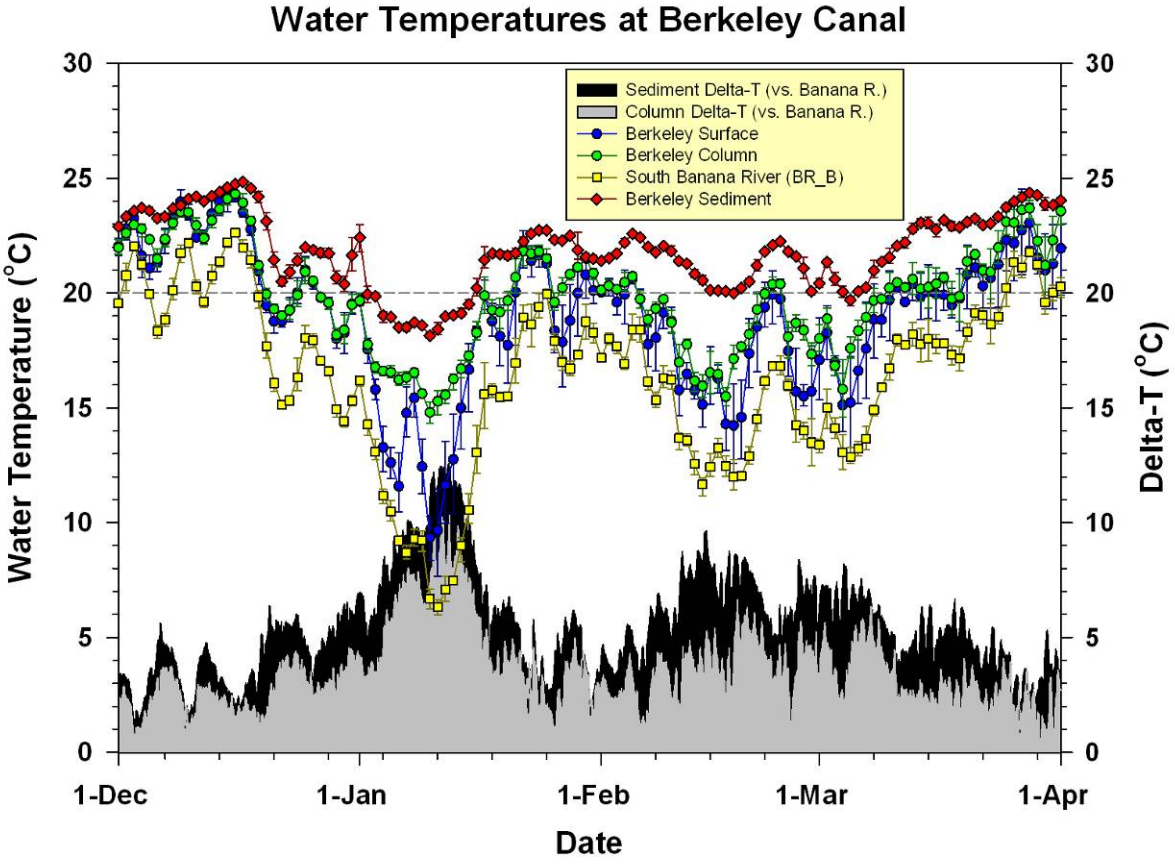


Figure 27. Mean daily water temperatures recorded at a vertical array of loggers at Berkeley canal (Satellite Beach, FL) and a nearby ambient site in the southern Banana River during winter 2009-2010. The vertical bars denote the daily interquartile range of temperatures. The temperature difference (i.e., delta-T) between Berkeley canal and the Banana River is shown as a multiple area plot below.

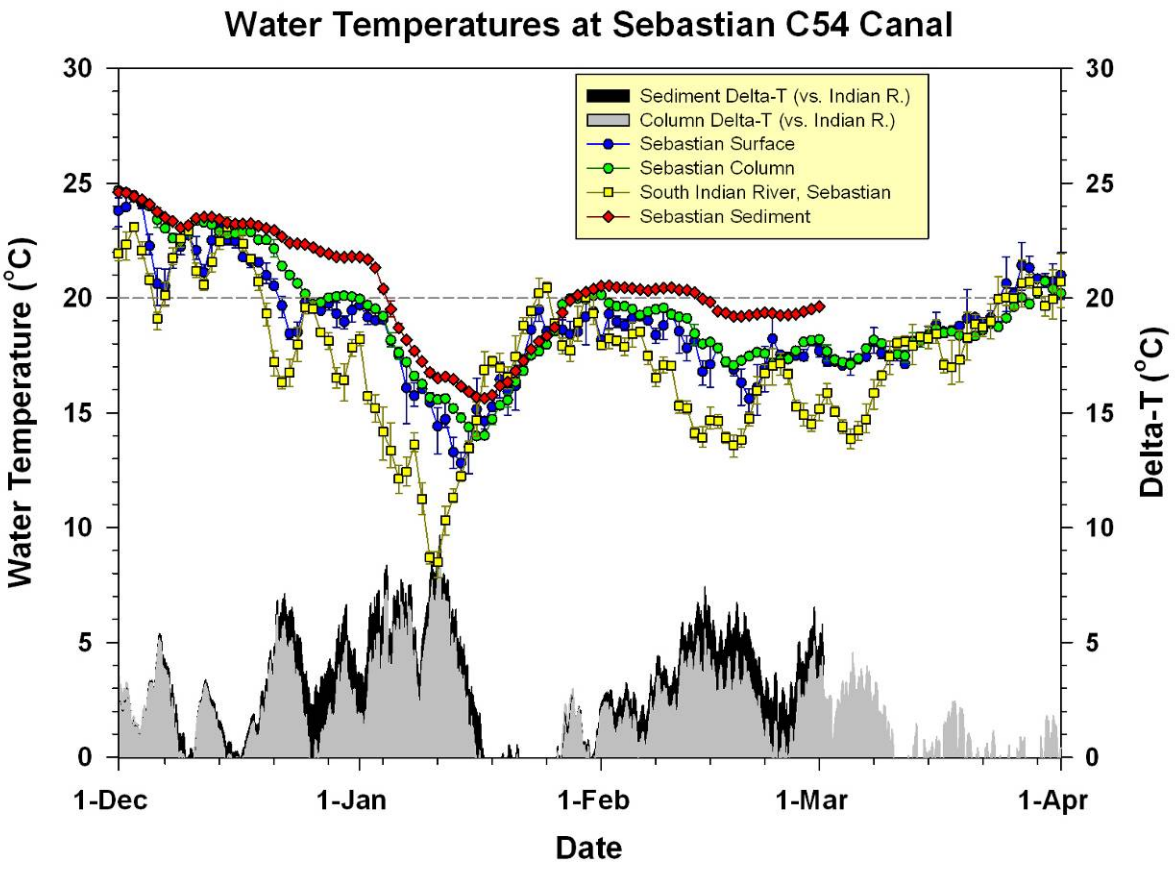


Figure 28. Mean daily water temperatures recorded at a vertical array of loggers at Sebastian River C-54 canal (Roseland, FL) and a nearby ambient site in the southern Indian River during winter 2009-2010. The vertical bars denote the daily interquartile range of temperatures. The temperature difference (i.e., delta-T) between Sebastian canal and the Indian River is shown as a multiple area plot below.

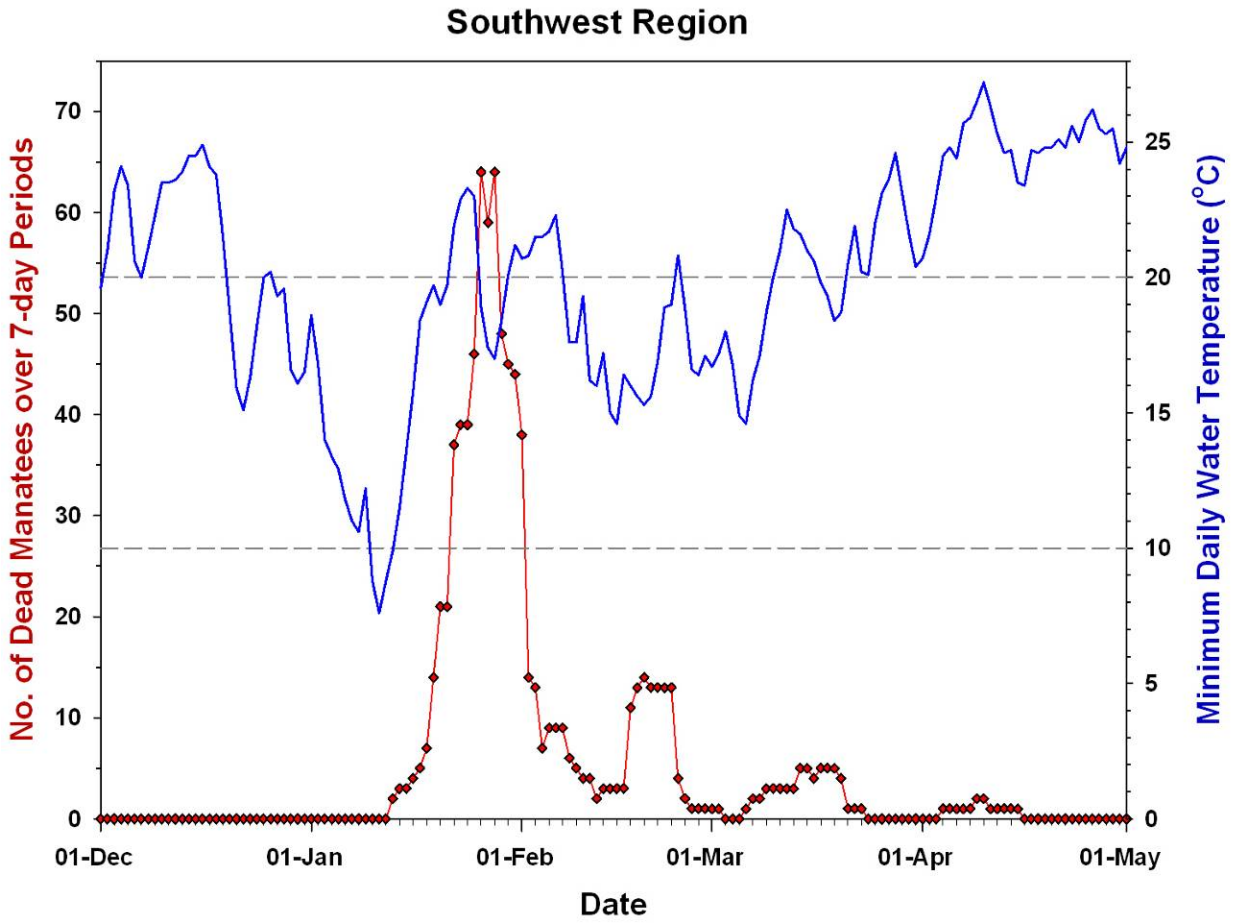


Figure 29. Number of reported carcasses over 7-day periods in the far southwest region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death, in relation to minimum daily water temperature in the North River, Everglades National Park (USGS provisional data).

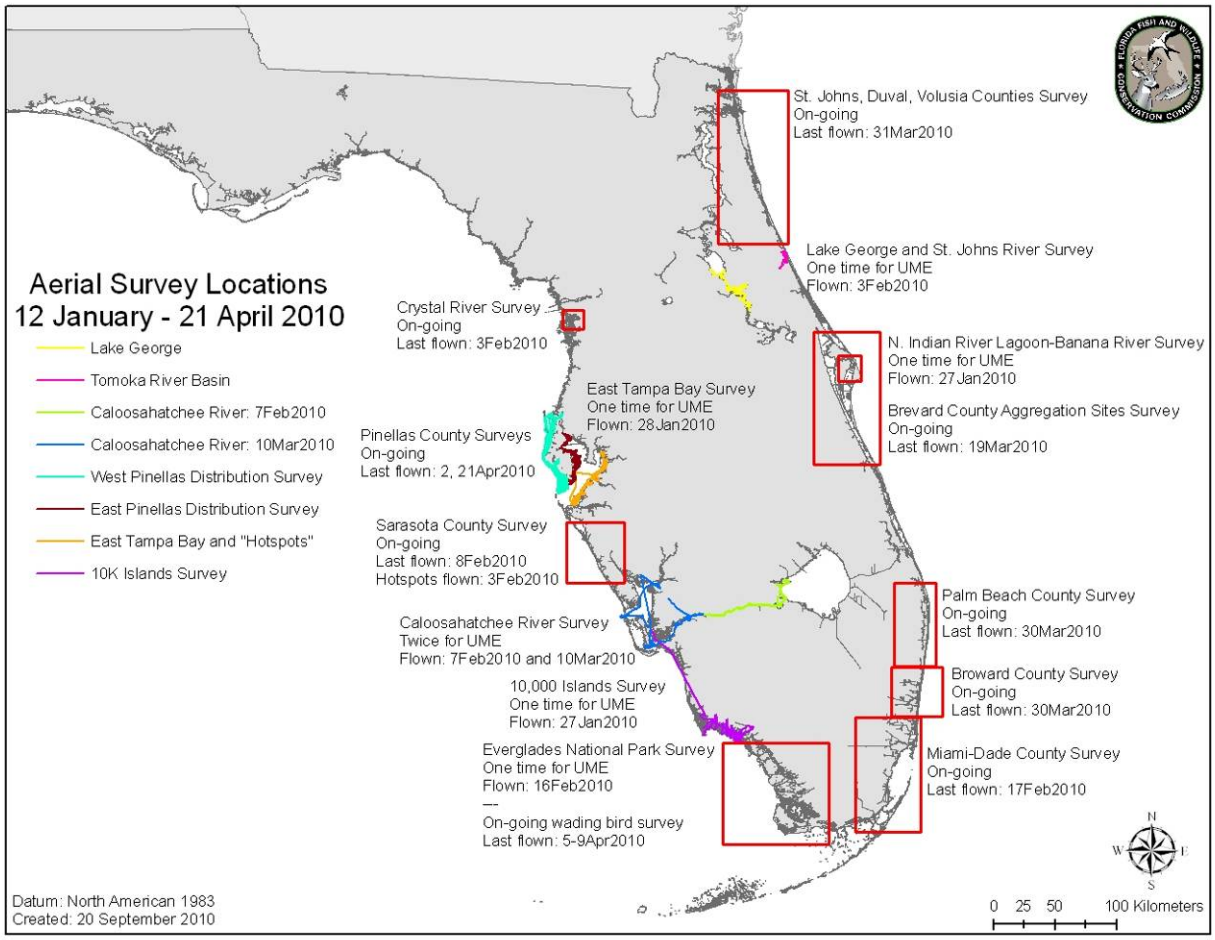


Figure 30. Locations of aerial surveys conducted in peninsular Florida during the 2010 cold-related manatee mortality event. Red boxes indicate general areas surveyed (where specific flight routes were unavailable); colored lines show flight paths. The majority of the peninsular Florida shoreline was surveyed from the air at some point during the event.

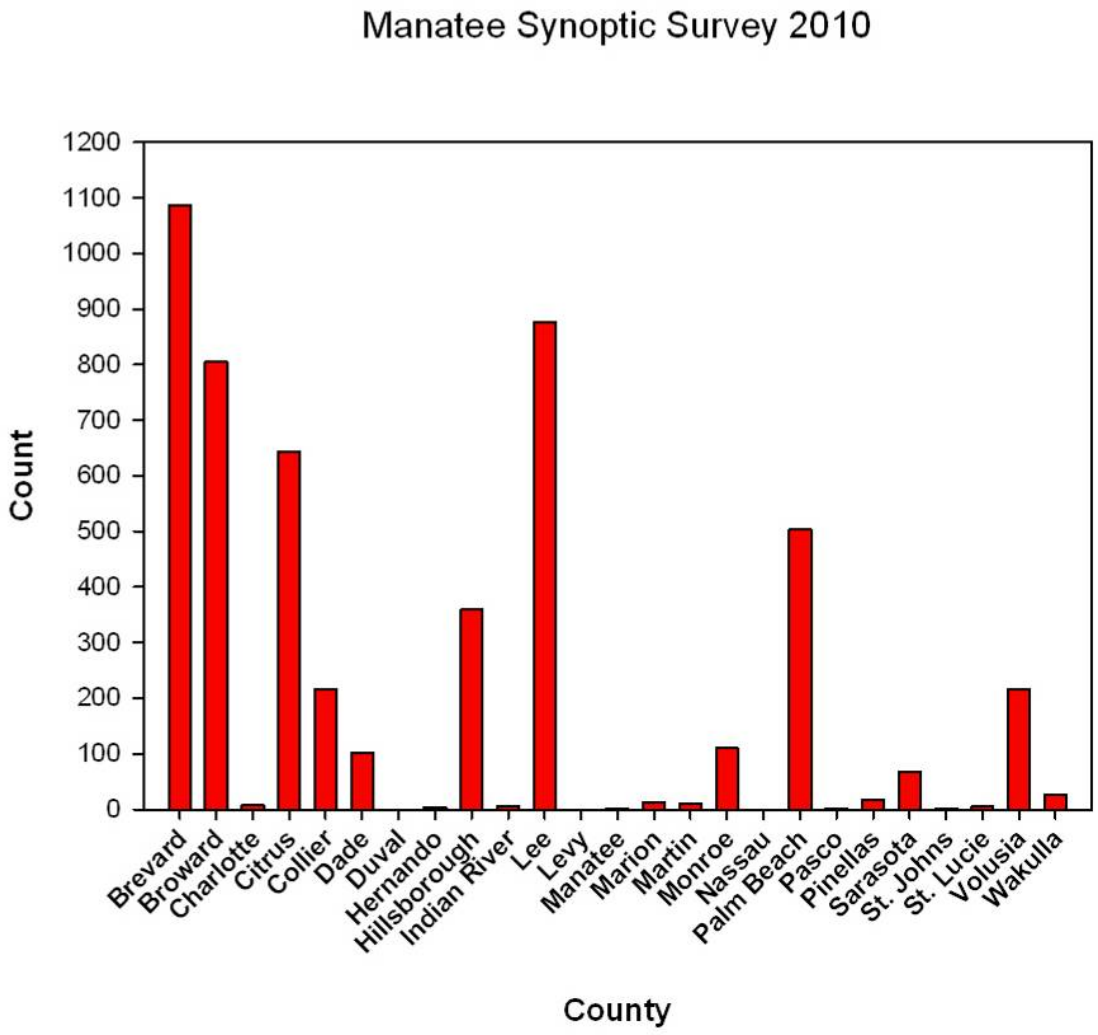


Figure 31. Number of manatee sightings by county during the 2010 statewide manatee synoptic survey conducted from January 12-15, 2010. Counts are considered to be minimum counts since some manatees go undetected during the survey.

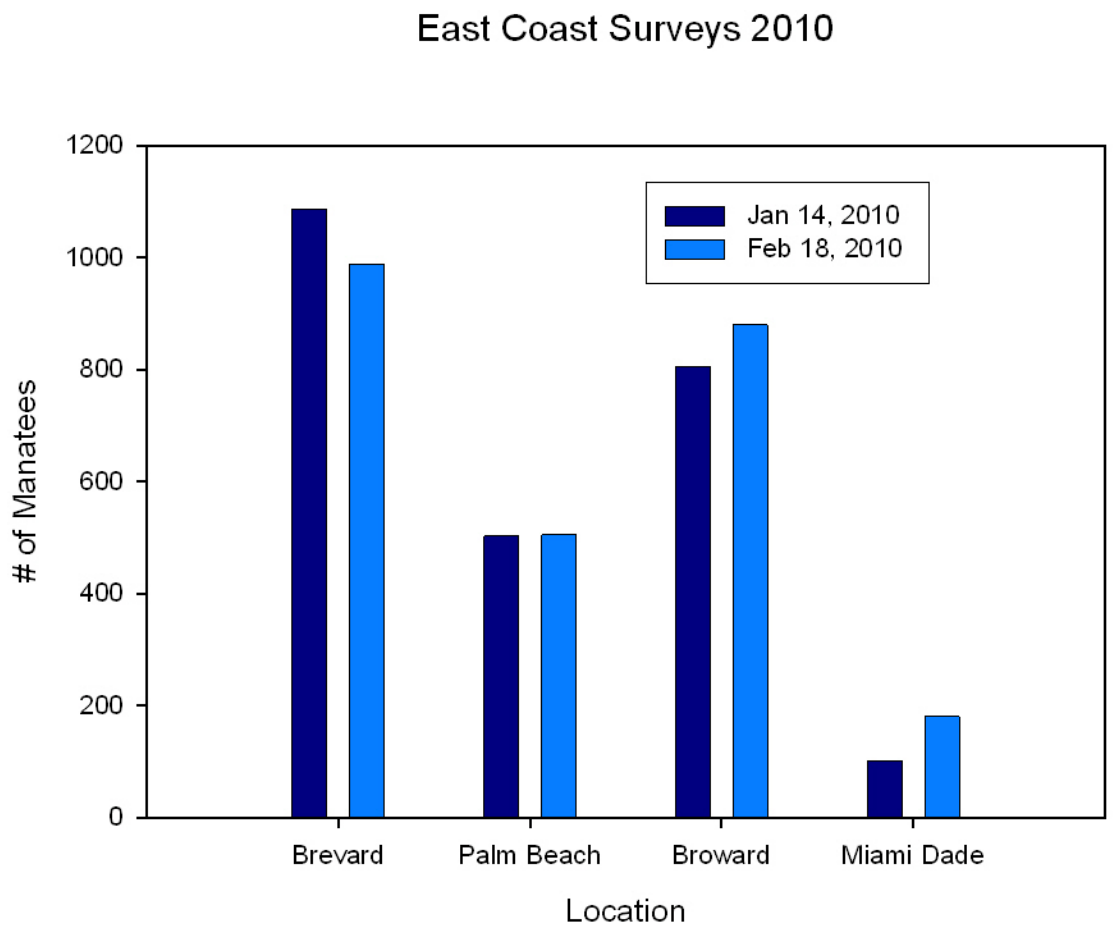


Figure 32. Counts of manatees from aerial surveys in Brevard, Palm Beach, Broward and Miami-Dade Counties, FL on January 14, 2010 and February 18, 2010.

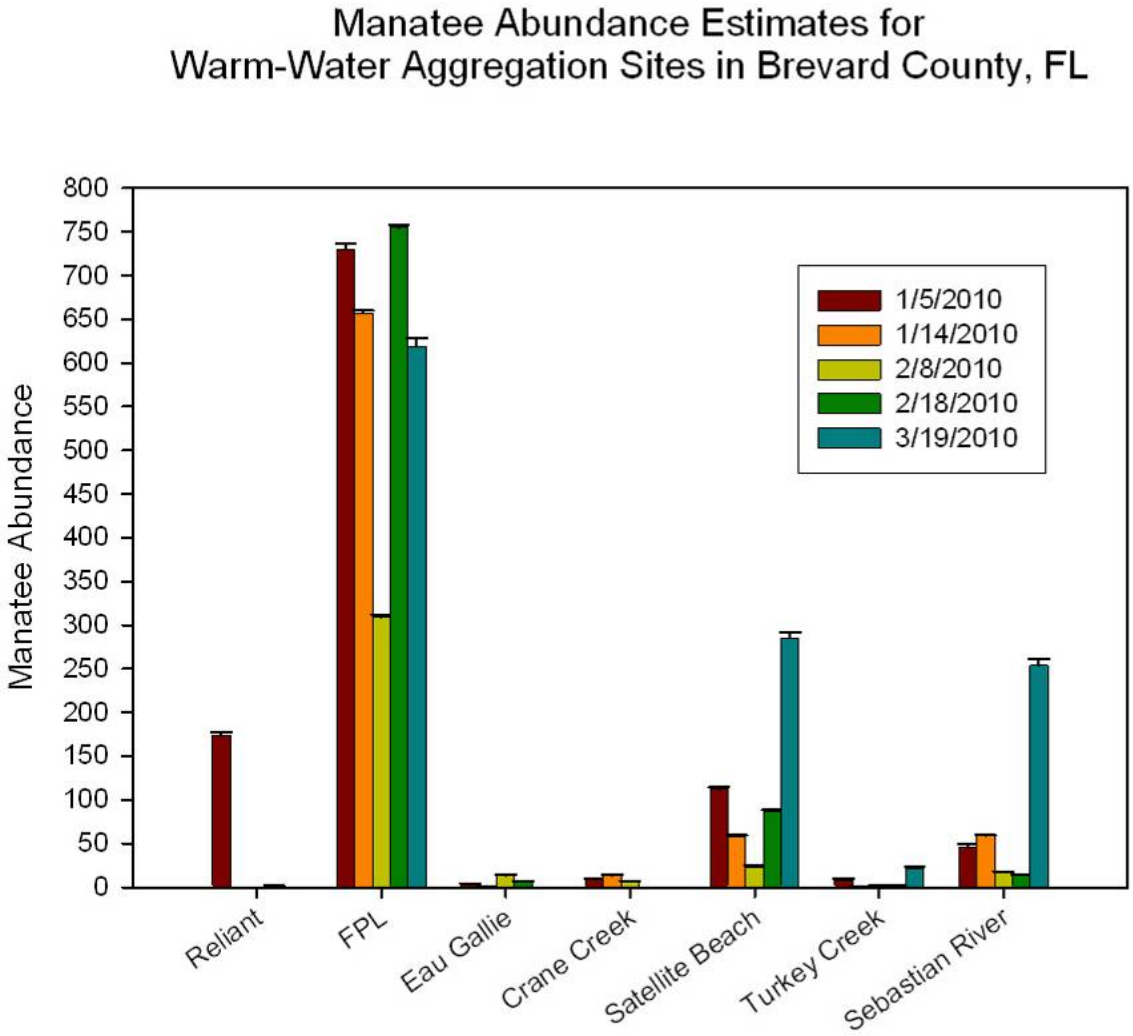


Figure 33. Manatee abundance estimates with standard deviations for warm-water aggregation sites in Brevard County, FL. The counts used to make these abundance estimates were obtained by aerial replicate-count surveys conducted on five days in winter 2010. Reliant= RRI Energy Indian River power plant; FPL= FPL Cape Canaveral power plant; Sebastian River= Sebastian River C-54 canal.

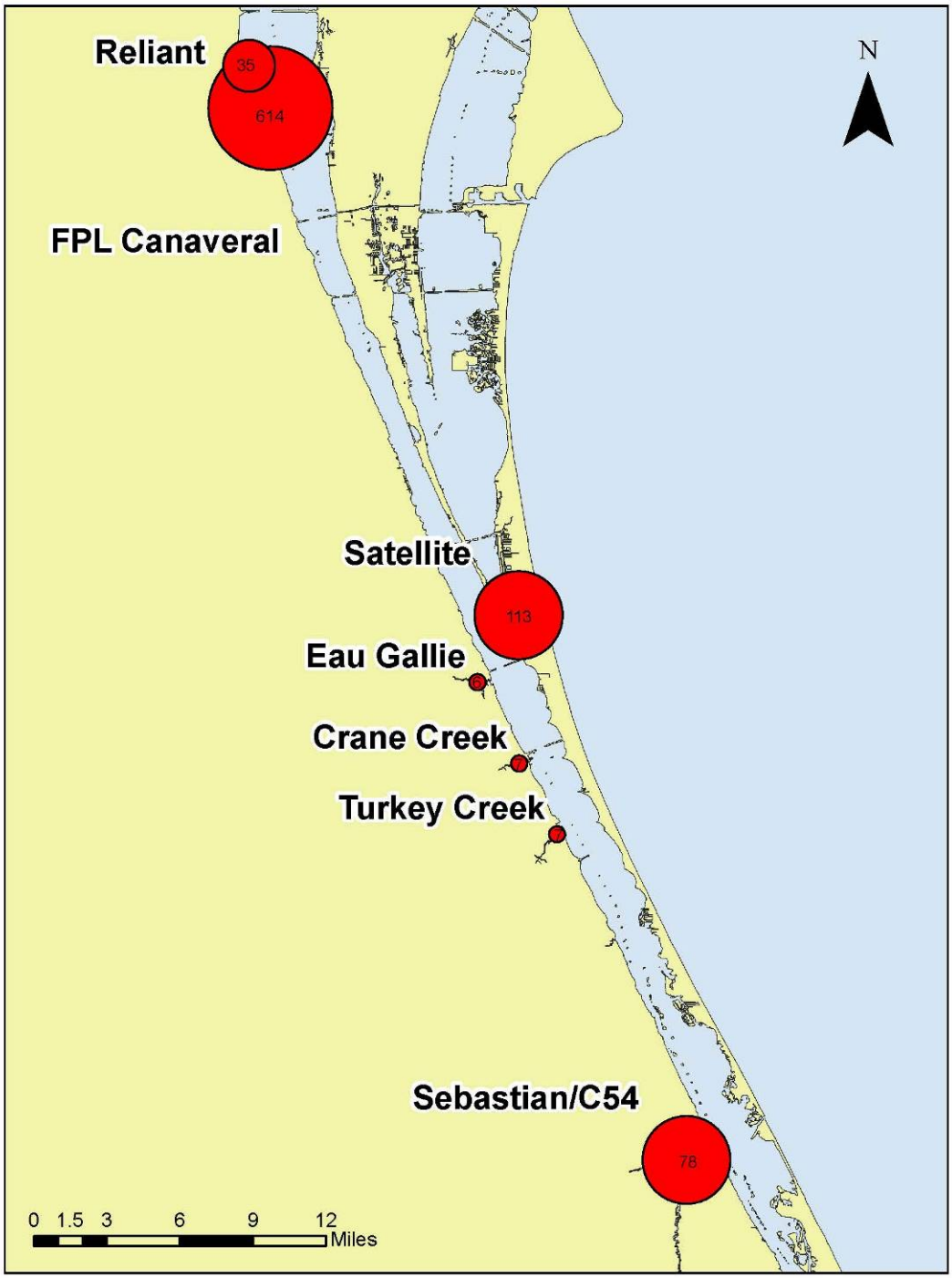


Figure 34. Overall distribution of manatees in Brevard County, FL among several aggregation sites surveyed by air on five dates in winter 2009-2010 (see Figure 33). Mean abundance estimates from the five surveys are shown in the red circles. Reliant= RRI Energy Indian River power plant; FPL Canaveral= FPL Cape Canaveral power plant.

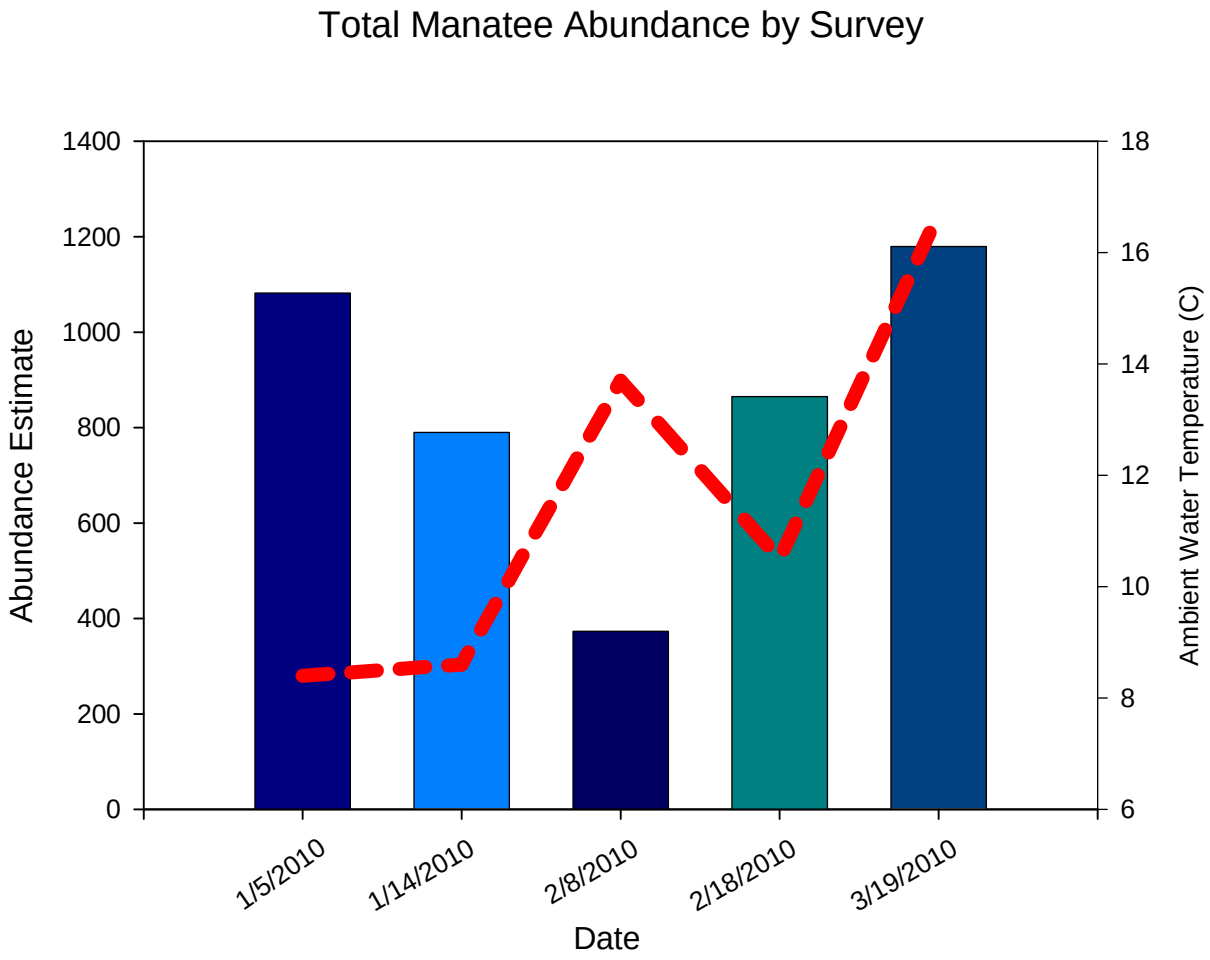


Figure 35. Estimated manatee abundance at several aggregation sites surveyed by plane using replicate-count methodology in Brevard County, FL during winter 2009-2010 in relation to ambient water temperature (USGS real-time water monitoring station at Haulover Canal near Mims, FL).

Figure 36. Desoto canal (Satellite Beach, FL) drainage ditch used heavily by manatees during winter 2009-2010.

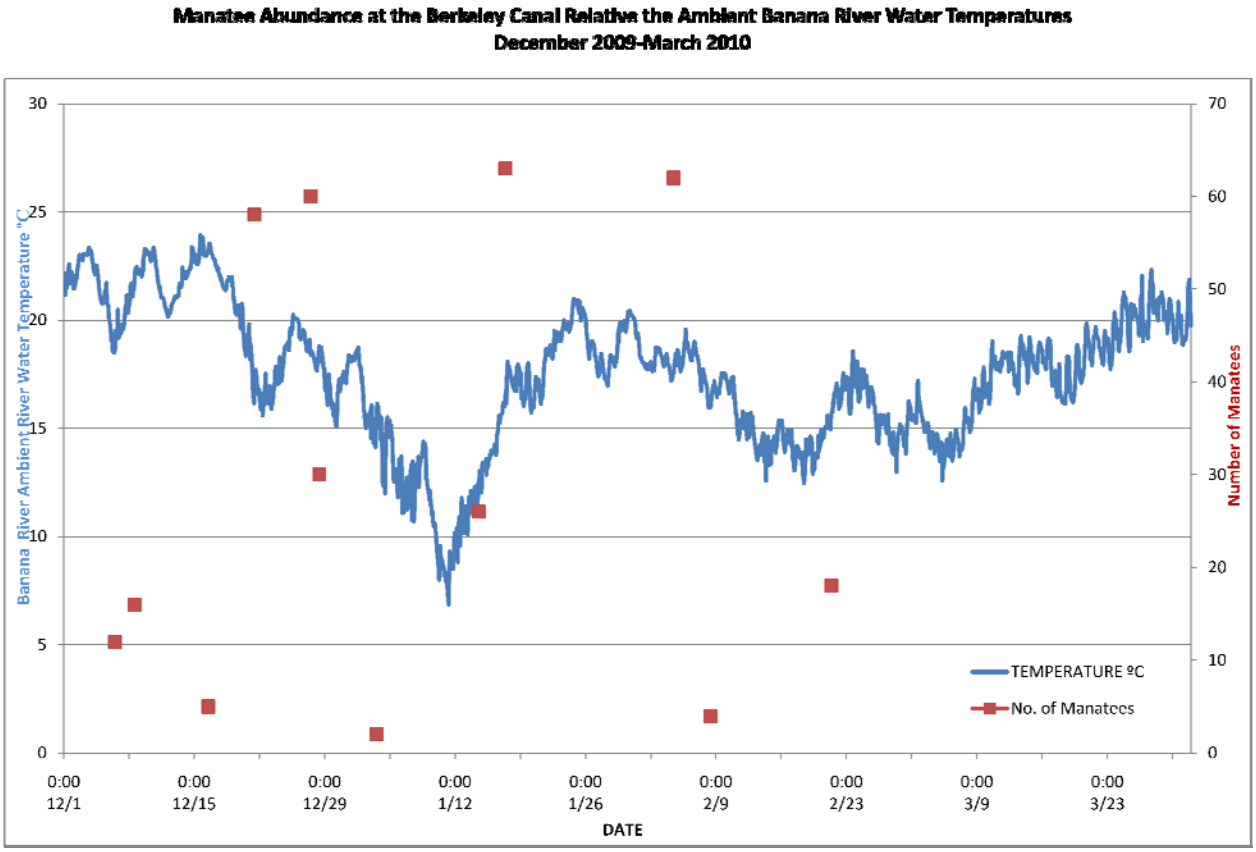


Figure 37. Ground counts of manatees at Berkeley Canal (Satellite Beach, FL) in relation to nearby ambient water temperatures in the southern Banana River from December 1, 2009 – April 1, 2010.

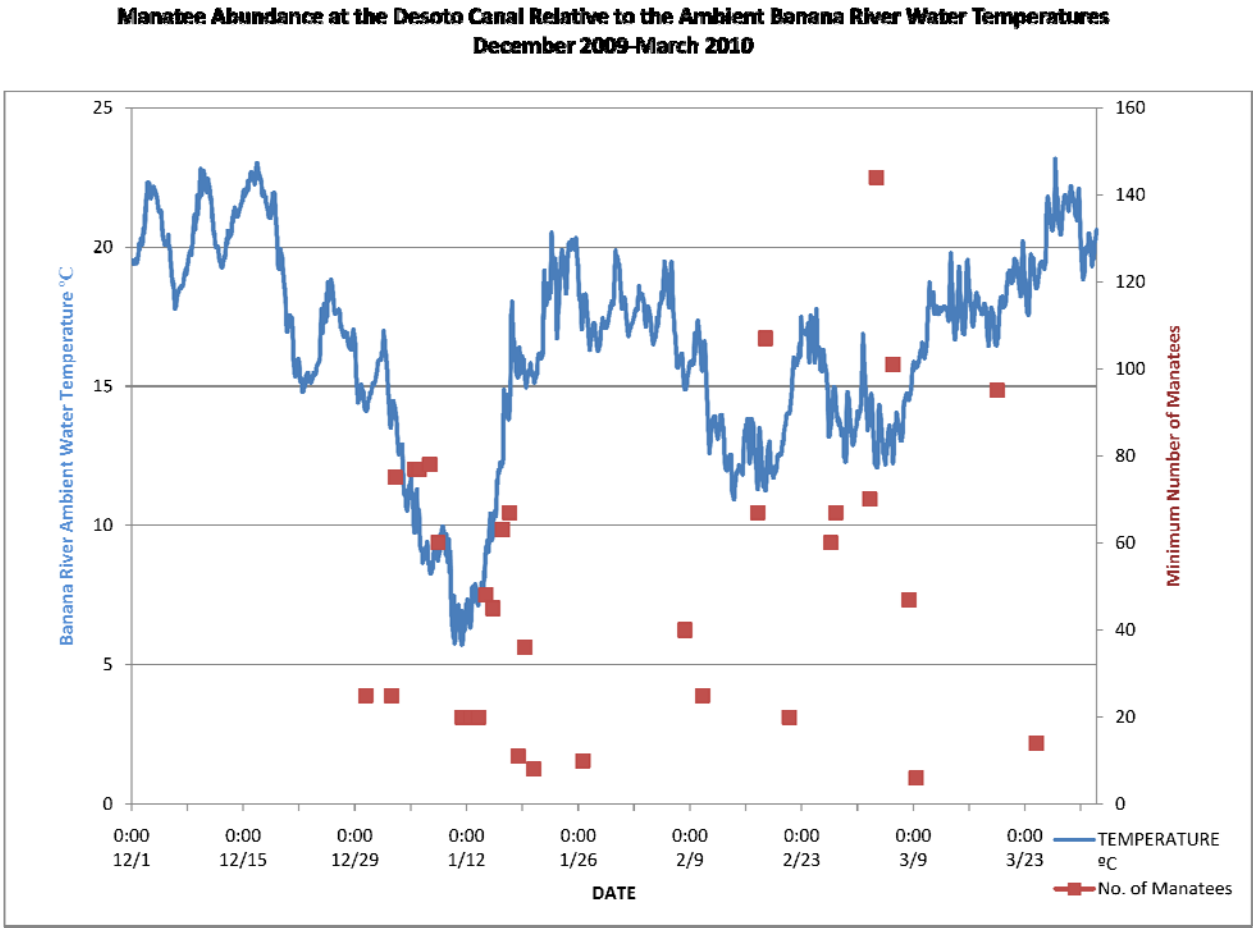


Figure 38. Ground counts of manatees at Desoto Canal (Satellite Beach, FL) in relation to nearby ambient water temperatures in the southern Banana River from December 1, 2009 – April 1, 2010.

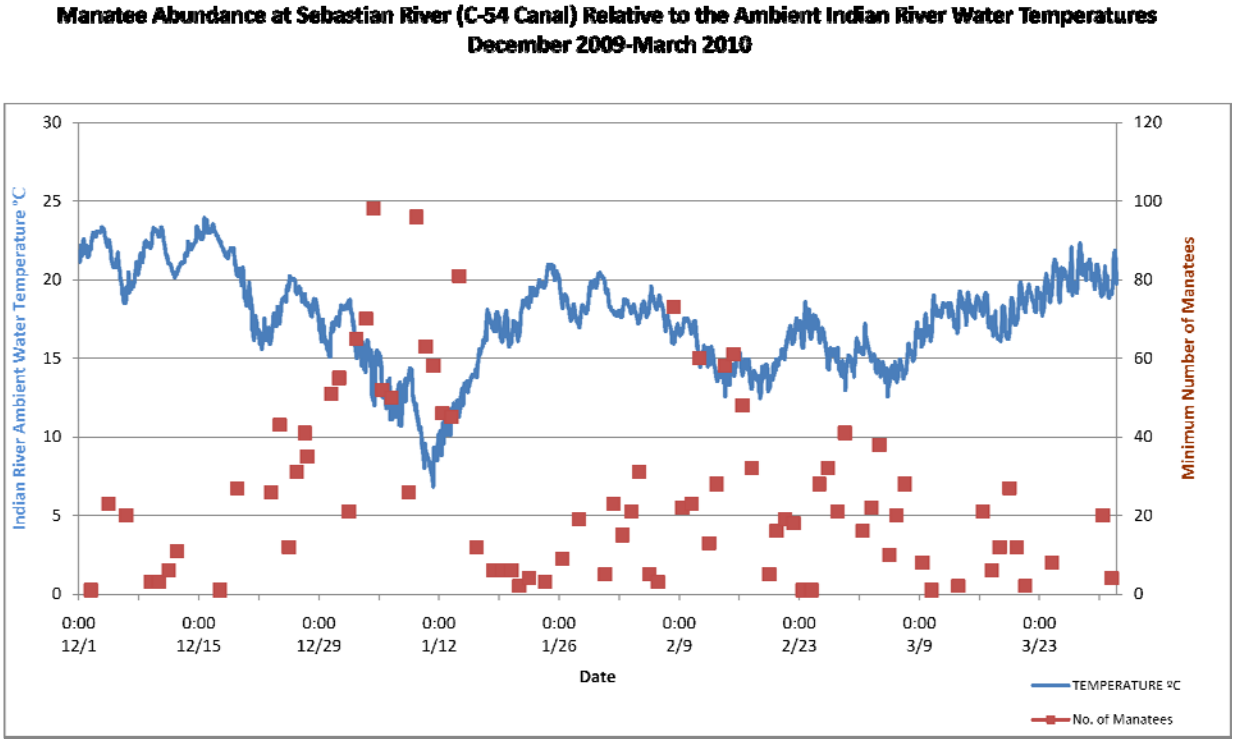


Figure 39. Ground counts of manatees at Sebastian River C-54 canal (Roseland, FL) in relation to nearby ambient water temperatures in the Indian River from December 1, 2009 – April 1, 2010.

Figure 40. Most commonly observed cold stress lesions in manatees during the 2010 cold-related manatee mortality event included whitish or gray mottling of the snout.

Figure 41. Most commonly observed cold stress lesions in manatees during the 2010 cold-related manatee mortality event included a whitish or gray halo around the margin of the tail.

Figure 42. Most commonly observed cold stress lesions in manatees during the 2010 cold-related manatee mortality event included small, usually circular lesions that varied from superficial to deeper erosions of the skin.

Figure 43. Most commonly observed cold stress lesions in manatees during the 2010 cold-related manatee mortality event included "bald" patches where large areas of the skin had sloughed off, leaving patches of clear skin amongst an otherwise algae-covered dermis.

Figure 44. Less common, but notable, observations of cold stress in manatees during the 2010 cold-related manatee mortality event included extensively white faces (mostly snout).

Figure 45. Less common, but notable, observations of cold stress in manatees during the 2010 cold-related manatee mortality event included extensively white heads with blotches extending back over the manatee's shoulders.

Figure 46. Less common, but notable, observations of cold stress in manatees during the 2010 cold-related manatee mortality event included ulcerating white lesions protruding above the skin.

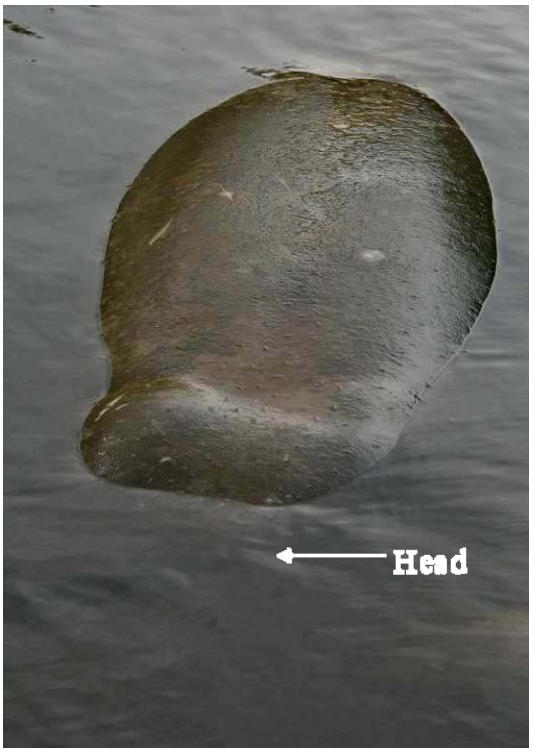


Figure 47. Individuals at the Desoto canal (Satellite Beach, FL) drainage ditch appeared thin during the 2010 cold-related manatee mortality event. Depressions between the scapulas were obvious in some animals.

Figure 48. Variations of external signs of cold stress were observed among individual manatees during the 2010 cold-related manatee mortality event, regardless of whether they aggregated at the same or different thermal refuges. This image was taken at Desoto canal (Satellite Beach, FL) on February 19, 2010.

Figure 49. The same individual manatee was photographed a month apart in January and February 2010 at FPL Cape Canaveral (Port St. John, FL), permitting an evaluation of changes in the extent of cold-induced whitening of the skin in the head region. In this particular manatee, no major changes were evident.

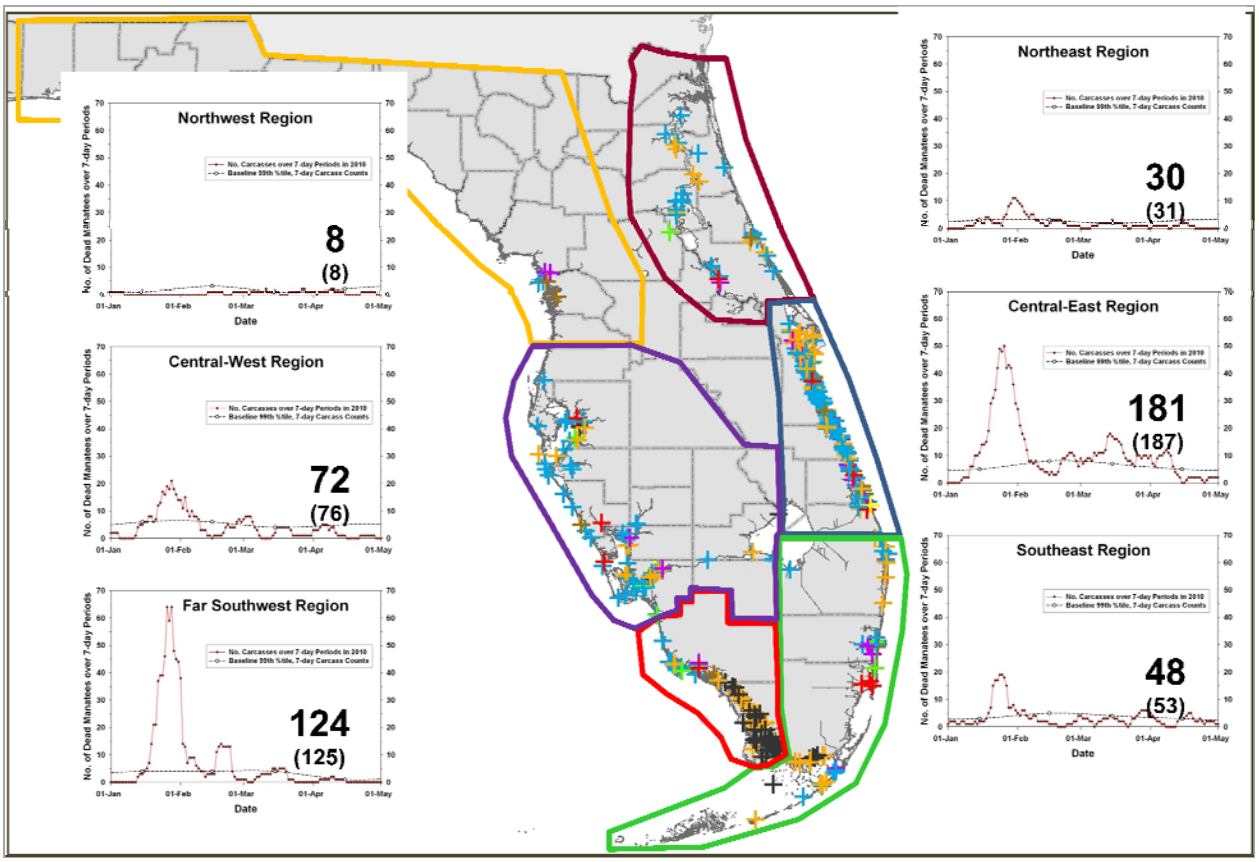


Figure 50. Graphs show the number of reported carcasses over 7-day periods in each region of Florida during the winter of 2009-2010, excluding those with known human-related causes of death. The same scales are used for regional comparisons. This is shown in relation to the 99th-percentile of 7-day regional carcass counts for each month over the previous 5-year period, excluding known UMEs during that reference period. The number of carcasses, excluding known human-related causes, for the UME timeframe (January 11 to April 9) is shown for each region (463 statewide); the total number of carcasses for each region is shown in parentheses. See Figure 7 for cause of death legend symbols.

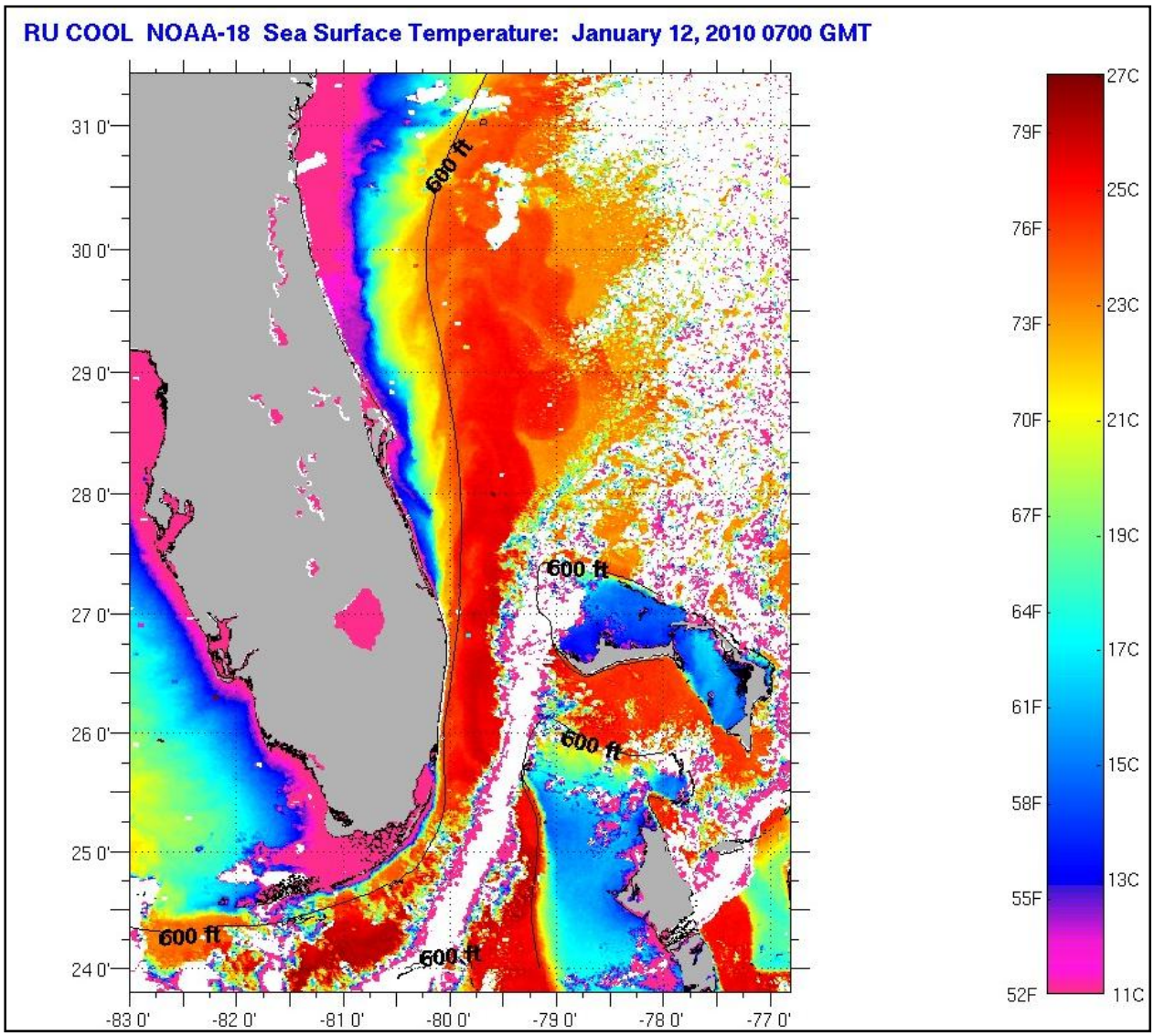


Figure 51. Sea surface temperature in Florida waters from NOAA satellite imagery taken on January 12, 2010 at 0200 EST. Note the warm (red) Gulf Stream coursing through the Florida Straits and along the southeastern coast, and the cold waters (violet) along Florida's west coast, including Florida Bay. Source: Rutgers University Coastal Ocean Observation Lab.

Tables

Table 1. Number of manatee carcasses reported within each region in the state of Florida from January 11 – April 9, 2010 categorized by cause of death. The numbers in parentheses indicate carcasses with a cause of death also attributed to Natural: Cold Stress. Regions are defined in Appendix D and shown in Figure 7.

Cause of Death by Region	**Northeast**	**Central-East**	**Southeast**	**Northwest**	**Central-West**	**Far Southwest**	**TOTAL**
Human Related: Watercraft Collision	1	5	5	0	3	1	**15**
Human Related: Other	0	1	0	0	1	0	**2**
Perinatal (<=150 cm)	1	11 (10)	4(1)	2	2	2 (2)	**22 (13)**
Natural: Cold Stress	22	125	17	2	49	24	**239**
Natural: Other	1	0	2	0	2	0	**5**
Verified: Not Recovered	0	0	5	0	3	55	**63**
Undetermined: Too Decomposed	5	40	18	2	15	39	**119**
Undetermined: Other	1	5	2	2	1	4	**15**
TOTAL	**31**	**187**	**53**	**8**	**76**	**125**	**480**

Table 2. Number of manatee carcasses reported in the state of Florida from January 11 – April 9, 2010 categorized by cause of death and by size class. Perinatal carcasses with a cause of death attributed to cold stress are represented in the Natural: Cold Stress category. The numbers in red indicate the percent of cold-stress related mortalities by size class. The numbers in blue indicate the percent of each cause of death attributed to carcasses for the 2010 cold-related mortality event.

Cause of Death by Size Class	**Perinatal** (<= 150 cm)	**Calf** (151-235 cm)	**Subadult** (236-265 cm)	**Adult** (>265 cm)	**Unknown**	**TOTAL**
Human Related: Watercraft Collision	0	2	6	7	0	**15** 3.12%
Human Related: Other	0	1	1	0	0	**2** 0.42%
Perinatal (<=150 cm)	9	0	0	0	0	**9** 1.88%
Natural: Cold Stress	13 5.2%	133 52.8%	51 20.2%	55 21.8%	0	**252** 52.50%
Natural: Other	0	1	1	3	0	**5** 1.04%
Verified: Not Recovered	2	15	10	9	27	**63** 13.13%
Undetermined: Too Decomposed	0	58	22	39	0	**119** 24.79%
Undetermined: Other	0	6	4	5	0	**15** 3.12%
TOTAL	**24**	**216**	**95**	**118**	**27**	**480**

Table 3. Number of manatee carcasses reported in the state of Florida from January 11 – April 9, 2010 categorized by cause of death and by sex. The numbers in parentheses indicate carcasses with a cause of death also attributed to Natural: Cold Stress.

Cause of Death by Sex	Male	Female	Unknown
Human Related: Watercraft Collision	9	6	0
Human Related: Other	1	1	0
Perinatal (<=150 cm)	12 (8)	10 (5)	0
Natural: Cold Stress	127	112	0
Natural: Other	5	0	0
Verified: Not Recovered	7	9	47
Undetermined: Too Decomposed	60	49	10
Undetermined: Other	4	10	1
TOTAL	**225**	**197**	**58**

Table 4. Start and end dates of the 2010 cold-related manatee mortality event for the state of Florida and each region. These dates are based on the 7-window in the UME algorithm with a 5-year reference period of 2005-2009, excluding periods with known UMEs. End dates were truncated to the date of last carcasses reported within the time window. Counts briefly dipped to or below the 99th percentile threshold during some periods below. Regions are defined in Appendix D and shown in Figure 7.

Region	Acute Phase		Chronic Phase	
	Start Date	End Date	Start Date	End Date
Florida Statewide	January 13	February 9	February 17	April 9
Northeast	January 18*, 26	February 7	None**	None
Central-East	January 11	February 4	February 21	April 8
Southeast	January 19	February 3	March 27	April 1
Northwest	None	None	None	None
Central-West	January 18	February 8	February 27	March 2
Far Southwest	January 17	February 5	a. February 17 b. March 14	a. February 19 b. March 17

*Cumulative carcass count exceeded UME threshold for one day on January 18.
**Cumulative carcass count exceeded UME threshold for one day on March 15.

Table 5. Number of carcasses reported within each region in the state of Florida for each phase of the 2010 cold-related manatee mortality event; this includes all causes of death. Numbers in red indicate the percent of carcasses reported in the acute versus the chronic phases for each region. Numbers in blue indicate the percent of carcasses reported across regions for each of the phases. Regions are defined in Appendix D and shown in Figure 7.

Region	**Acute Phase** (January 11 - February 9)	**Chronic Phase** (February 10 – April 9)	**TOTAL**
Florida Statewide	299 62.3%	181 37.7%	**480**
Northeast	20 64.5% 6.7%	11 35.5% 6.1%	**31** 6.5%
Central-East	103 55.1% 34.4%	84 44.9% 46.4%	**187** 39.0%
Southeast	31 58.5% 10.4%	22 41.5% 12.1%	**53** 11.0%
Northwest	0	8 100% 4.4%	**8** 1.7%
Central-West	48 63.2% 16.1%	28 36.8% 15.5%	**76** 15.8%
Far Southwest	97 77.6% 32.4%	28 22.4% 15.5%	**125** 26.0%

Table 6. Number of manatee carcasses reported in the state of Florida by cause of death for each phase of the 2010 cold-related mortality event. Numbers in parentheses indicate carcasses with a cause of death also attributed to Natural: Cold Stress.

Cause of Death by Mortality Phase	**Acute Phase** (January 11 - February 9)	**Chronic Phase** (February 10 – April 9)	**TOTAL**
Human Related: Watercraft Collision	2	13	**15**
Human Related: Other	1	1	**2**
Perinatal (<=150 cm)	12 (10)	10 (3)	**22 (13)**
Natural: Cold Stress	162	77	**239**
Natural: Other	1	4	**5**
Verified: Not Recovered	23	13	**36**
Undetermined: Too Decomposed	65	54	**119**
Undetermined: Other	33	9	**42**
TOTAL	**299**	**181**	**480**

Table 7. Number of manatee carcasses with a cause of death attributed to cold stress reported in the state of Florida by size class for each phase of the 2010 cold-related mortality event. The numbers in red indicate the percent of each size class within each phase, and the numbers in blue indicate the percent of carcasses reported in the acute versus the chronic phases for each size class.

Natural: Cold Stress by Size Class	**Perinatal** (<= 150 cm)	**Calf** (151-235 cm)	**Subadult** (236-265 cm)	**Adult** (>265 cm)	**TOTAL**
Acute Phase (January 11 – February 9)	10 5.8% 76.9%	78 45.3% 58.6%	35 20.3% 68.6%	49 28.5% 89.1%	**172** 68.3%
Chronic Phase (February 10 – April 9)	3 3.8% 23.1%	55 68.8% 41.4%	16 20.0% 31.4%	6 7.5% 10.9%	**80** 31.7%
TOTAL	**13** 5.2%	**133** 52.8%	**51** 20.2%	**55** 21.8%	**252**

Table 8. Number of manatee carcasses with a cause of death attributed to cold stress reported in the state of Florida by sex for each phase of the 2010 cold-related mortality event. The numbers in red are the percent of each sex within each phase, and the numbers in blue indicate the percent of carcasses reported in the acute versus the chronic phase for each sex. These numbers include the 13 manatee carcasses also categorized as perinatal deaths.

Natural: Cold Stress By Sex	**Male**	**Female**	**TOTAL**
Acute Phase (January 11 – February 9)	87 50.6% 64.4%	85 49.4% 72.6%	**172** 68.3%
Chronic Phase (February 10 – April 9)	48 60.0% 35.6%	32 40.0% 27.4%	**80** 31.7%
TOTAL	**135** 53.6%	**117** 46.4%	**252**

Table 9. Number of manatees rescued in the state of Florida from January 11 – April 9, 2010 categorized by cause for rescue and region. The numbers in red indicate the percent of cold-related rescues within each region, and the numbers in blue indicate the percent of each cause for rescue for manatees rescued during the 2010 cold-related mortality event. Regions are defined in Appendix D and shown in Figure 7.

Cause for Rescue by Region	**Northeast**	**Central-East**	**Southeast**	**Northwest**	**Central-West**	**Far Southwest**	**TOTAL**
Human Related: Watercraft Collision	0	1	2	0	2	0	**5** 10.2%
Human Related: Other (Entanglement)	0	0	0	1	0	0	**1** 2.0%
Entrapment	0	2	0	2	0	0	**4** 8.2%
Natural: Cold Stress	3 8.6%	19 54.3%	3 8.6%	3 8.6%	4 11.4%	3 8.6%	**35** 71.4%
Natural: Other	0	1	0	3	0	0	**4** 8.2%
TOTAL	**3**	**23**	**5**	**9**	**6**	**3**	**49**

Table 10. Number of manatees rescued due to injuries related to cold stress in the state of Florida by size class for each phase of the 2010 cold-related manatee mortality event. The numbers in red indicate the percent of each size class within each phase, and the numbers in blue indicate the percent of rescues in the acute versus the chronic phases for each size class.

Natural: Cold Stress by Size Class	**Perinatal** (<= 150 cm)	**Calf** (151-235 cm)	**Subadult** (236-265 cm)	**Adult** (>265 cm)	**TOTAL**
Acute Phase (January 11 – February 9)	2 20.0% 66.7%	4 40.0% 23.5%	2 20.0% 18.2%	2 20.0% 50.0%	**10** 28.6%
Chronic Phase (February 10 – April 9)	1 4.0% 33.3%	13 52.0% 76.5%	9 36.0% 81.8%	2 8.0% 50.0%	**25** 71.4%
TOTAL	**3** 8.6%	**17** 48.6%	**11** 31.4%	**4** 11.4%	**35**

Table 11. Number of manatees rescued due to injuries related to cold stress in the state of Florida by sex for each phase of the 2010 cold-related mortality event. The number in red is the percent of each sex within each phase, and the numbers in blue indicate the percent of rescues in the acute versus the chronic phases for each sex and throughout the entire event.

Natural: Cold Stress By Sex	**Male**	**Female**	**TOTAL**
Acute Phase (January 11 – February 9)	1 10.0% 6.7%	9 90.0% 45.0%	**10** 28.6%
Chronic Phase (February 10 – April 9)	14 56.0% 93.3%	11 44.0% 55.5%	**25** 71.4%
TOTAL	**15** 42.9%	**20** 57.1%	**35**

Table 12. Number of primary abnormal clinical findings for 31 of the 35 manatees rescued due to cold stress in the state of Florida from January 11 – April 9, 2010.

Clinical Signs*	**Number**
Cold Stress Lesions	14
Blood	9
Eating disorder	9
Respiratory Compromise	7
Paresis	4
Trauma	3
Vascular compromise	2
Positive Buoyancy	1

**Cold stress lesions*: lesions fulfilling the criteria outlined by Bossart et al. (2002). Pathological features of the Florida manatee cold stress syndrome *Aquatic Mammals*, 29: 9–17

Blood: abnormal blood results found on preliminary blood work performed at presentation to the rehabilitation facility, as determined by the primary clinician and recorded on the USFWS/FWC Captive Manatee Database.

Eating disorder: Gastrointestinal anomalies and disinterest in eating.

Respiratory compromise: breathing difficulties encompassing increased physical effort required to breathe and/or clinical changes noted on radiographs.

Paresis: loss of function to at least part of the body, limbs or fluke.

Trauma: evidence of acute, chronic or non-healing physical injury such as monofilament or boat strike injury.

Vascular compromise: noted poor perfusion of extremities presenting as devitalization of tissues or edema due to lymph or blood congestion.

Positive buoyancy: inability to dive or submerge.

Table 13. Summary of manatee counts from aerial surveys in Brevard, Palm Beach, Broward and Miami-Dade Counties, FL on January 14, 2010 and February 18, 2010.

County	**Synoptic Survey** (January 14, 2010)	**East Coast Survey** (February 18, 2010)	**% Change in Count**
Brevard	1087 (39%)	989	-9.0
Palm Beach	503 (18%)	505	0.4
Broward	805 (29%)	880	9.3
Miami Dade	101 (4%)	181	79.2
TOTAL	**2496**	**2455**	

Number in parentheses is the % Total of the 2010 East Coast Synoptic Count (N=2780)

Table 14. Unadjusted aerial survey counts from manatee abundance surveys of warm-water aggregation sites in Brevard County, FL. The counts were obtained by aerial replicate-count surveys (3 to 5 consecutive surveys) conducted on five days in winter 2010. Entries of -999 indicate no count for that location on that date.

Aggregation Site	Date	Survey #1	Survey #2	Survey #3	Survey #4	Survey #5
RRI Energy Indian River Power Plant	1/5/2010	80	128	165	-999	-999
	1/14/2010	0	0	0	-999	-999
	2/8/2010	0	0	0	0	0
	2/18/2010	1	1	1	-999	-999
	3/19/2010	0	0	0	-999	-999
FPL Cape Canaveral Power Plant	1/5/2010	550	695	620	-999	-999
	1/14/2010	635	618	650	-999	-999
	2/8/2010	300	250	244	220	230
	2/18/2010	750	690	700	-999	-999
	3/19/2010	529	461	563	-999	-999
Eau Gallie	1/5/2010	1	1	0	-999	-999
	1/14/2010	1	1	0	-999	-999
	2/8/2010	5	9	11	12	9
	2/18/2010	3	2	6	-999	-999
	3/19/2010	29	-999	-999	-999	-999
Crane Creek	1/5/2010	4	2	6	-999	-999
	1/14/2010	12	11	13	-999	-999
	2/8/2010	2	3	1	4	7
	2/18/2010	0	0	0	-999	-999
	3/19/2010	-999	-999	-999	-999	-999
Satellite Beach	1/5/2010	61	60	106	-999	-999
	1/14/2010	55	51	57	-999	-999
	2/8/2010	21	15	17	15	17
	2/18/2010	80	85	75	-999	-999
	3/19/2010	182	240	249	-999	-999
Turkey Creek	1/5/2010	1	4	5	-999	-999
	1/14/2010	0	1	1	-999	-999
	2/8/2010	0	2	3	1	1
	2/18/2100	1	1	1	-999	-999
	3/19/2010	13	8	13	-999	-999
Sebastian River C-54 Canal	1/5/2010	31	35	31	-999	-999
	1/14/2010	41	46	59	-999	-999
	2/8/2010	6	14	14	-999	-999
	2/18/2010	8	14	9	-999	-999
	3/19/2010	176	220	203	-999	-999

Table 15. Maximum total counts of manatees in Brevard County based on unadjusted highest counts at each aggregation site surveyed on that date. Maximum counts at the aggregation sites were obtained from aerial photographs and aerial replicate-count surveys.

Date	Maximum Count (all aggregation sites)
1/5/2010	1068
1/14/2010	1087
2/8/2010	357*
2/18/2010	989
3/19/2010	1074*

* Counts where no aerial photographs were used.

Table 16. Frequency of cold stress signs by warm-water site and body region for manatees observed during winter 2009-2010. Percentages are of individuals scored (N shown in parentheses) with signs of cold stress in that particular body region.

Location	Date	Total N	Head	Trunk	Tail	Observer
FPL Cape Canaveral Power Plant	January 20	47	66% (35)	10% (40)	29% (28)	Deutsch, Barlas
FPL Cape Canaveral Power Plant	February 20	80	86% (66)	58% (71)	89% (71)	Deutsch, Barlas
Desoto Canal	February 19	26	55% (22)	58% (24)	86% (14)	Deutsch
TECO Big Bend Power Plant	February 11	120	28% (116)	21% (119)	44% (86)	Barlas, Rood

Table 17. Severity of cold stress signs by warm-water site for manatees observed during winter 2009-2010. Percentages are of individuals observed with cold stress at that site on that date. Number of individuals with stage 2 cold stress is shown in parentheses.

Location	Date	Cold Stress N	Stage 1	Stage 2	Stage 3	Observer
FPL Cape Canaveral Power Plant	January 20	25	96%	4% (1)	0%	Deutsch, Barlas
FPL Cape Canaveral Power Plant	February 20	76	91%	9% (7)	0%	Deutsch, Barlas
Desoto Canal	February 19	21	86%	14% (3)	0%	Deutsch
TECO Big Bend Power Plant	February 11	71	97%	3% (2)	0%	Barlas, Rood

Table 18. Estimated number of carcasses recovered in Florida by age class and sex. Manatees of unknown sex but with known size were split among sex classes based on the proportion of male and female carcasses for each age class during the UME. Manatees of unknown sex and unknown size (i.e., verified, not recovered) were split among age-sex classes based on the proportion of each age-sex class in the rest of the carcasses recovered during the UME.

Carcasses by Age Class and Sex	Male	Female	TOTAL
Adult	52.7 (11.0%)	72.2 (15.0%)	125.0 (26.0%)
Immature	203.1 (42.3%)	152.0 (31.7%)	355.0 (74.0%)
TOTAL	255.8 (53.3%)	224.2 (46.7%)	480

Percentage of total is in parentheses.

Appendix A- List of Acronyms and Terms

Acronyms

BCNP	Big Cypress National Park
ECFL	FWC-East Coast Field Laboratory at Indian River
ENP	Everglades National Park
FPL	Florida Power and Light
FWC	Florida Fish and Wildlife Conservation Commission
FWC-LE	FWC-Law Enforcement
FWRI	FWC-Fish and Wildlife Research Institute
HSC	FWC-Habitat and Species Conservation Division
K	Carrying Capacity
MMPL	FWC-Marine Mammal Pathobiology Laboratory
MRP	Manatee Rehabilitation Partnership
NEFL	FWC-Northeast Field Laboratory at Jacksonville
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
POI	Port of the Islands
S2S	Sea To Shore Alliance
SEFL	FWC-Southeast Field Laboratory at Tequesta
SRC	State On-site Response Coordinator
SWFL	FWC-Southwest Field Laboratory at Charlotte Harbor
TECO	Tampa Electric Company
TTI	Ten Thousand Islands
UME	Unusual Mortality Event
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

USJ	Upper St. Johns River
WGMMUME	Working Group on Marine Mammal Unusual Mortality Events
WWK	Warm-water Carrying Capacity

Units of Measurement

ºC	Degrees Celsius or centigrade
ºF	Degrees Fahrenheit
cm	centimeter
hr	hour (s)
km	kilometer
mi	mile
ppt	parts per thousand

Terms

Amyloid	a waxy, translucent substance, composed primarily of protein fibers
Brevetoxin	potent neurotoxins produced naturally by a species of dinoflagellate known as *Karenia brevis*
Enteritis	inflammation of the intestines, especially the small intestine
Heterophilic	having an affinity for an antigen other than its specific antigen
Hyperkeratosis	a thickening or overgrowth of the outer layer of the skin
Hyperplasia	enlargement of a part due to abnormal numerical increase of its cells
Lymphocytolysis	the dissolution or degeneration of lymphatic cells
Rouleaux	a group of red blood corpuscles resembling a stack of coins
Vasculitis	inflammation of the blood vessels
Vasculopathy	disease of the blood vessels
Zymogen	any of various enzyme precursor molecules that may change into an enzyme as a result of catalytic change

Appendix B- Working Group on Marine Mammal Unusual Mortality Events Criteria for Determining an Unusual Marine Mammal Morbidity/ Mortality Event (*revised July 2004*[4])

1. A marked increase in the magnitude or a marked change in the nature of morbidity, mortality or strandings when compared with prior records.

2. A temporal change in morbidity, mortality or strandings is occurring.

3. A spatial change in morbidity, mortality or strandings is occurring.

4. The species, age, or sex composition of the affected animals is different than that of animals that are normally affected

5. Affected animals exhibit similar or unusual pathologic findings, behavior patterns, clinical signs, or general physical condition (e.g., blubber thickness).

6. Potentially significant morbidity, mortality or stranding is observed in species, stocks or populations that are particularly vulnerable (e.g., listed as depleted, threatened or endangered or declining). For example, stranding of three or four right whales may be cause for great concern whereas stranding of a similar number of fin whales may not.

7. Morbidity is observed concurrent with or as part of an unexplained continual decline of a marine mammal population, stock, or species.

The WGMMUME declared the event to be an official Unusual Mortality Event (UME) on February 26 because at least four of their criteria established for designating a UME were met: criterion 1, 4, 5, and 6.

[4] Revised at the 2004 Annual Meeting of the Working Group on Marine Mammal Unusual Mortality Events; published in the **Federal Register** 12/14.06. 71 FR 75234

Appendix C- Logistics of Primary Response

Thomas Reinert

The FWRI marine mammal research program is comprehensive and includes projects in the fields of behavior ecology, forensics and rescue, and population assessment and monitoring. While most research staff are centrally located in St. Petersburg at FWRI headquarters or at the Marine Mammal Pathobiology Laboratory (MMPL), there currently are nine full-time and three part-time field biologists located around the state in four regional field stations (Figure A1). Each field station oversees manatee rescues and carcass recoveries for a particular region of the state. The photo-identification, telemetry, aerial survey, and GIS programs, as well as administrative activities, primarily are conducted out of FWRI-St. Petersburg, while rescue and mortality operations are delegated to the MMPL and the regional field stations.

FWRI Manatee program field staff members respond to all reported manatee deaths, to recover and document each carcass, and to transport the carcass for necropsy at the MMPL or to necropsy the carcass in the field, as each case dictates. Nearly all reported manatee carcasses are recovered, and most are transported to the MMPL for full examination. Carcasses that are too decomposed for full necropsy or too remote to be recovered are examined in the field. The MMPL maintains a regularly updated database of statewide manatee mortalities. Mortality numbers are published once a week on the FWRI website (http://research.myfwc.com/features/category_sub.asp?id=2241). Additionally, the MMPL staff and field biologists periodically receive updated training at the MMPL during workshops or by attending normal necropsy sessions.

Field personnel are appropriately trained to respond to reports by the public of manatees in distress or out of habitat range. Rescues can be performed from specialized capture boats, be based from land with specialized nets, or be executed from other platforms (e.g., a law enforcement boat) using specially-designed hoop nets. The type of rescue and equipment used are often situation- and site-specific. Rescues from a capture boat require that the boat captain have specific skills attained through extra training and an apprenticeship. Currently, there are several rescue-boat captains within the FWC's manatee rescue program. When necessary, injured or ill manatees are transported to appropriate critical care facilities (currently: Lowry Park Zoo in Tampa, Sea World in Orlando, and Miami Seaquarium).

Field Station Locations

FWC has five field stations or labs (including MMPL), strategically placed around Florida that employ trained marine mammal response staff. Each region is covered by their respective staff with the assistance of FWC-Law Enforcement (FWC-LE) officers and dispatch, and a 24-hour alert system (Figure A1). Field stations are staffed by at least one biologist from 8:00 am until 5:00 pm, seven days a week. The lead biologist at each field station also participates in a rotating On-Call Biologist position to maintain coverage after-hours (5:00 pm until 8:00 am) and during holidays, effectively covering the state 24-hours a day, 365-days a year. Locally, at least one biologist is available (on-call) to respond to emergencies after-hours or on holidays as directed by the On-Call Biologist (if that biologist is located elsewhere in the state).

The Northeast Field Lab (NEFL) is located in Jacksonville (Duval County) and is staffed with two full-time biologists and one part-time biologist. Staff members respond to strandings reported in the waters of the nine counties in the northeastern part of Florida: Baker, Bradford, Clay, Duval, Flagler, Nassau, Putnam, Saint Johns, and Union. Additionally, the NEFL coverage area includes the part of Volusia County north of State Road 44. NEFL staff may assist with rescues and carcass recoveries in southern Georgia as far north as Savannah. Available equipment includes two trucks, two carcass transport trailers, a rescue boat, a research boat (22' Key West), and a specialized transport truck.

The East Coast Field Lab (ECFL) is located in Melbourne (Brevard County) and is staffed with two full-time biologists and one part-time biologist. Staff members respond to manatees reported in the waters of the five counties in along the central-eastern coast of Florida: Brevard, Indian River, Lake, Marion, and Seminole. Additionally, the ECFL coverage area includes the part of Volusia County south of State Road 44. Available equipment includes two trucks, two carcass transport trailers, and a research boat (22' Key West Bay Reef).

The Southeast Field Lab (SEFL) is located in Tequesta (Palm Beach County) and is staffed with two full-time biologists, one part-time biologist, and the Research Administrator responsible for managing field station staff statewide (excluding MMPL staff). Staff members respond to manatees in the waters of the six counties in the southeastern part of Florida: Broward, Martin, Miami-Dade, Palm Beach, Okeechobee, and Saint Lucie. Additionally, the SEFL coverage area includes the Florida Bay side of Monroe County and the Florida Keys. Available equipment includes two trucks, two carcass transport trailers, a rescue boat, a research boat (17' Mako) and a specialized transport truck.

The Southwest Field Lab (SWFL) is located in Port Charlotte (Charlotte County) and is staffed with three full-time biologists. Staff members respond to manatees in the waters of the nine counties in the southwestern part of Florida: Charlotte, Collier, Desoto, Hardee, Hendry, Highlands, Glades, Lee and Sarasota counties. Additionally, the SWFL coverage area includes the peninsular portion of Monroe County. Available equipment includes three trucks, two carcass transport trailers, a research boat (22' Key West Bay Reef), and a specialized transport truck.

The Marine Mammal Pathobiology Laboratory (MMPL) is located in St. Petersburg (Pinellas County). In addition to being the primary facility responsible for the necropsy of most manatee carcasses, the MMPL serves as a field station covering 36 counties in the northwestern part of Florida: Alachua, Bay, Calhoun, Citrus, Columbia, Dixie, Escambia, Franklin, Gadsden, Gilchrist, Gulf, Hamilton, Hernando, Hillsborough, Holmes, Jackson, Jefferson, Lafayette, Liberty, Leon, Levy, Madison, Manatee, Okaloosa, Orange, Osceola, Pasco, Pinellas, Polk, Santa Rosa, Sumter, Suwannee, Taylor, Wakulla, Walton, and Washington. It is staffed with four full-time biologists, one part-time biologist, the lead veterinarian, a Research Administrator, and an intern from the University of Florida Aquatic Animal Health Program (eight staff total). The MMPL is assisted with manatee carcass salvage and field necropsies in the Florida Panhandle region by FWC-Habitat and Species Coordination (FWC-HSC) section staff located at FWC headquarters in Tallahassee. Available equipment includes two trucks, two carcass transport trailers, a rescue boat, and two research boats (17' Mako, 22' Key West Bay Reef).

Methods of Coordination for Catastrophic Events

In 1996, a bloom of red tide (*Karenia brevis*) in southwest Florida was responsible for approximately 150 manatee mortalities over a relatively short period. In response to this catastrophic event, the U.S. Fish and Wildlife Service (USFWS) released a plan specific to manatee catastrophic events (USFWS 1998). Geraci and Lounsbury (1997) integrated the USFWS manatee-specific response plan and the National Marine Fisheries Service's basic contingency plan for responding to unusual marine mammal mortality events (Wilkinson 1996) with existing State of Florida protocols into the document, "The Florida Manatee: Contingency Plan for Health-Related Events." Over the last two years, the FWC has initiated work on an addendum to that document, one that attempts to further identify policies and protocols at the field level. This document is not intended to replace Geraci and Lounsbury (1997), but to update and enhance the information contained therein. Although in draft form at the onset of the 2010 UME and based on a scenario whereby an event, either acute or chronic, unfolded at a specific site or in a single region of the state (e.g., a catastrophic shutdown of a critical warm-water providing power plant; a localized red tide event), some of the procedures and protocols outlined in the draft were implemented.

In the draft contingency plan, flow charts were developed to help formalize a response to a catastrophic event based on Geraci and Lounsbury (1997) protocols and other procedures identified by FWC. These flow charts identified positions, responsibilities, and procedures for an acute event (short-lived) and a chronic event (long-term, i.e., two or more weeks in duration; Figure A2). The plan did not consider an event that encompassed nearly the entire state, thus impacting all regions simultaneously, as was the case during this UME. Conditions, procedural adaptations, and outcomes from the 2010 UME have provided useful information that will further enhance the development of the FWC's Manatee Catastrophic Contingency Plan. The FWC's response to the 2010 UME drew mostly from the Geraci and Lounsbury (1997) protocols with consideration of the draft contingency plan protocols and lessons learned during previous manatee UMEs (e.g. manatee-red tide related events in southwest Florida).

At the regional response level, field station biologists assumed the role of the regional response coordinators for their area. This responsibility included coordinating staff resources and volunteers to collect as many carcasses as efficiently as possible and to rescue manatees; tracking mortality and rescue identification numbers; coordinating reporting and mapping of carcass and rescue locations; and maintaining and identifying equipment needs. Nearly all carcasses were transported to the MMPL for necropsy (with the primary exception being those located in the Everglades National Park, see *Response to the Unusual Mortality Event—Efforts Related to Manatee Carcasses and Necropsy* in this report). Additionally, a biologist from each field station provided daily updates to the field-staff research administrator, who then updated other senior staff, including the Manatee Program section leader, MMPL research administrator, MMPL veterinarian, and state on-site coordinator. One particular challenge during the event was relaying important carcass recovery information from field stations to the Data Management and GIS Team leaders for compilation and circulation in daily or near-daily summaries. To address this challenge, EFCL staff developed and maintained an electronic spreadsheet listing carcass ID, general recovery location, recovery date and time, and staff involved (including field staff, law enforcement officers, and/or volunteers involved in verification and transport). This spreadsheet

was stored on a common drive available to manatee program staff statewide, including incident managers and the Data Management and GIS Team leaders, when a completed 'page one' (a datasheet that summarizes pertinent recovery and necropsy information) was not readily available.

At the state response level, response team leaders directed the course of the investigation. Other than the on-site coordination roles, teams included: Rescue and Salvage Logistics, Environmental Sampling, Aerial Survey, Data Management and GIS, Necropsy and Medical Investigations, and Media Relations. These team leaders maintained close communication with daily conference calls to update response efforts, identify resource and personnel needs, and coordinate staff response while thinking outside normal regional boundaries. Daily coordinating calls progressed to weekly, but daily email coordination continued throughout the event. Members of the response team worked with other FWC divisions (e.g., FWC-LE, FWC-HSC), FWRI sections (e.g., Marine Fisheries, Outreach Coordination), and partner agencies (e.g., USFWS, National Park Service) to assist with the ongoing event. Media specialists (as the Media Relations team) provided information to the public via press releases, as warranted. The Data Management and GIS team leaders created daily or near-daily summaries of rescue and carcass recovery locations (tables and maps) that were circulated to federal, state, and non-government partners. The state on-site coordinators submitted mortality analyses and other documentation to the federal response coordinator (USFWS) for consultation with the Working Group on Marine Mammal Unusual Mortality Events (WGMMUME), and provided the carcass and rescue summaries to all partners throughout the event.

Personnel and Resource Allocation

Staff, volunteers, and equipment were positioned or re-distributed based on conditions, need, and availability. The 2010 Unusual Mortality Event altered the daily job duties for every member of the FWRI marine mammal program. In addition, volunteers from USFWS and FWC-HSC section were deployed to the central-east coast and southwest Florida. These experienced volunteers primarily drove trailers with multiple carcasses from the response area to the MMPL. FWRI staff from the NEFL periodically relocated to the ECFL to assist and to provide time-off for ECFL staff. Various staff members assisted by meeting field staff half-way en route to the MMPL to ease the driving burden or by making the entire drive. Trucks and carcass transport trailers were swapped between field stations and MMPL, as needed. Additionally, staff from USGS-Sirenia Project and students and staff from the University of Florida and the University of North Carolina Wilmington assisted at the MMPL. FWC-LE on-water officers verified, retrieved, and towed carcasses daily. FWC-LE dispatch duty officers relayed reports of injured or dead manatees to field biologists. The FWC is very appreciative of the invaluable assistance of volunteers and conservation partners that helped to support this tremendous effort.

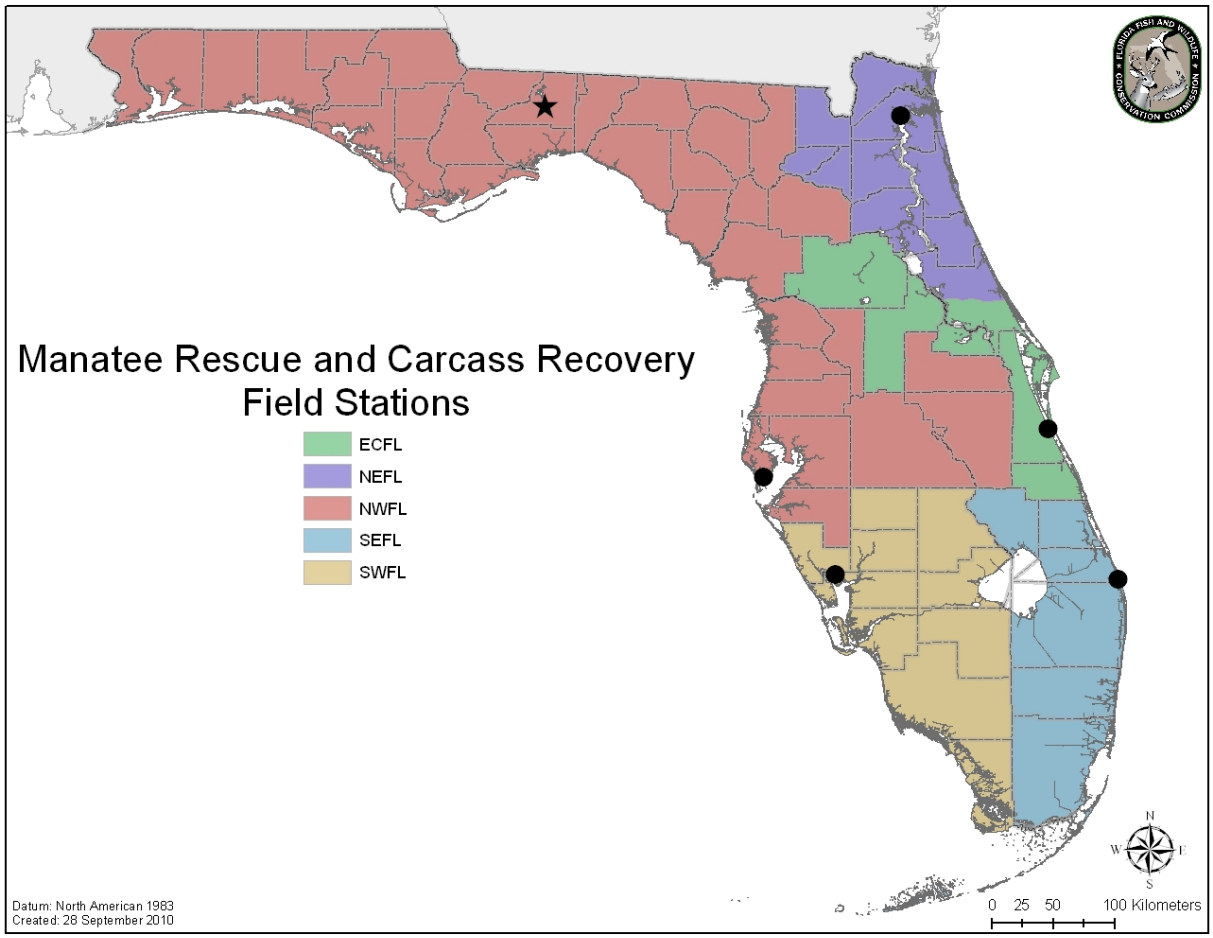


Figure A1. Locations of manatee rescue and carcass recovery field stations in the state of Florida. Florida Fish and Wildlife Conservation Commission (FWC) Fish and Wildlife Research Institute (FWRI) Manatee Rescue and Carcass Recovery field stations (black dots) and FWC headquarters (star). FWRI headquarters and the Marine Mammal Pathobiology Laboratory (MMPL) are both located in St. Petersburg, Pinellas County. Some staff located at FWC headquarters in Tallahassee assisted with rescue and field necropsies during the winter 2010 cold-related manatee mortality event.

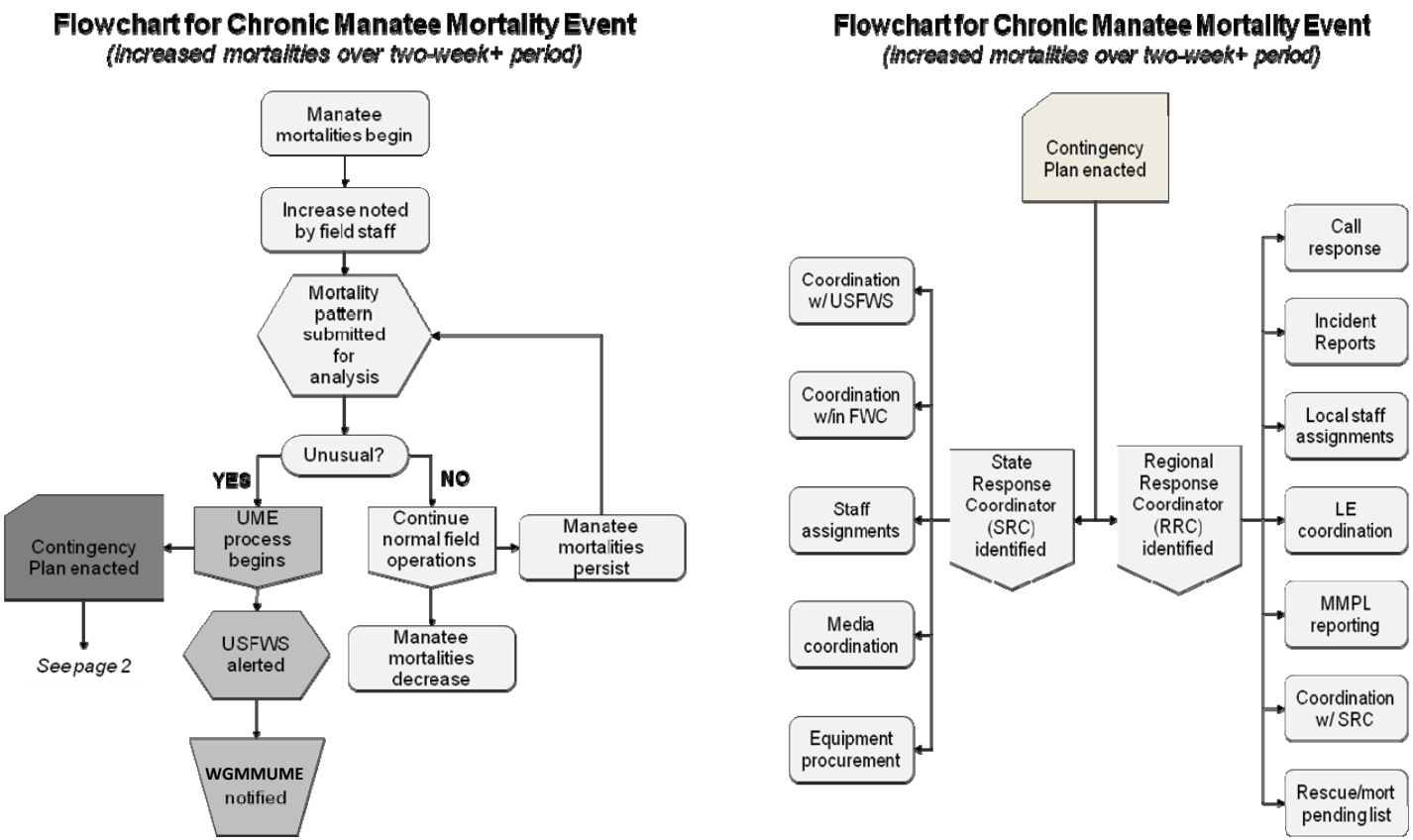


Figure A2. From the draft contingency plan, a flow chart of response for a chronic manatee mortality event. In the draft plan, a chronic event is defined as one that unfolds over a two-week period or longer. The winter 2010 cold-related manatee mortality event lasted from January 11 until April 9, 2010. Assessment and protocols leading to event declaration are shown on the left, and positions and responsibilities of Florida Fish and Wildlife Conservation Commission (FWC) staff responding to a chronic Unusual Mortality Event are shown on the right flowchart. Aspects of this chart were considered along with the Geraci and Lounsbury (1997) contingency plan when coordinating response to the 2010 UME. UME=Unusual Mortality Event; USFWS=U.S. Fish and Wildlife Service; WGMMUME=Working Group on Marine Mammal Unusual Mortality Events; LE=Law Enforcement; MMPL=FWC's Marine Mammal Pathobiology Laboratory.

Appendix D- Definitions of Regional Boundaries

Note that these boundaries are similar, but not identical, to the field station coverage areas noted in Appendix C.

Northeast Region: Nassau, Duval, Clay, St. Johns, Putnam, Flagler, the eastern half of Marion, Volusia, Lake, Seminole, and Orange counties.

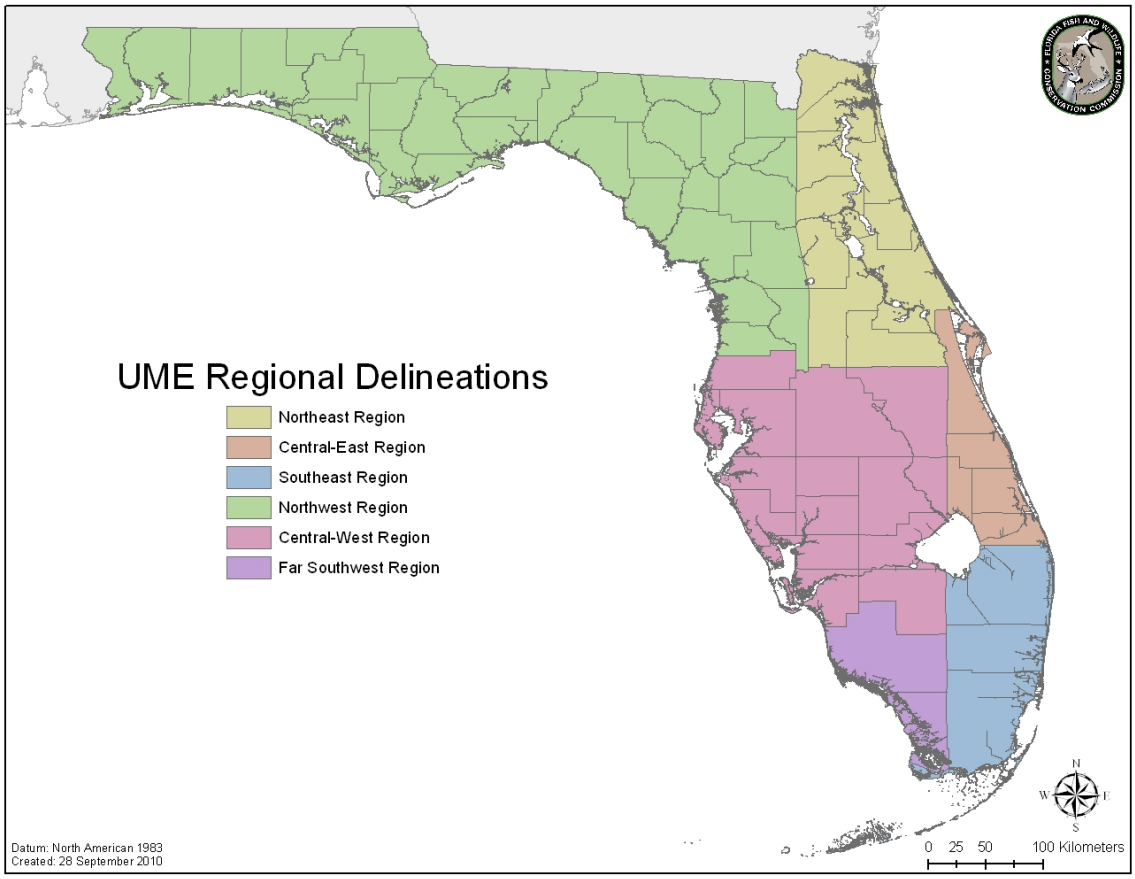
Central-East Region: Brevard, Indian River, the eastern half of Okeechobee, St. Lucie, and Martin counties.

Southeast Region: Palm Beach, Broward, Miami-Dade counties, and the Florida Bay side of Monroe County including the Florida Keys.

Northwest Region: Escambia, Santa Rosa, Okaloosa, Walton, Holmes, Washington, Bay, Jackson, Calhoun, Gulf, Gadsden, Liberty, Franklin, Leon, Wakulla, Jefferson, Madison, Taylor, Hamilton, Suwannee, Lafayette, Dixie, Columbia, Gilchrist, Levy, Baker, Union, Bradford, Alachua, the western half of Marion, Citrus, Sumter, and Hernando counties.

Central-West Region: Pasco, Pinellas, Hillsborough, Polk, Osceola, Manatee, Hardee, Desoto, Highlands, the western half of Okeechobee, Sarasota, Charlotte, Glades, Lee, and Hendry counties.

Far Southwest Region: Collier County and the Gulf of Mexico side of Monroe County.



Appendix E- Criteria to Assess External Signs of Exposure to Cold Temperatures

The following criteria were developed by an interagency team to assess external signs of exposure to cold temperatures in manatees gathered at warm-water sites. The information collected as part of these assessments will be recorded and analyzed in relation to weather and ambient water conditions over time to monitor trends in the proportion of cold-stressed manatees using the surveyed warm-water system. Actual cold stress syndrome is a complex multi-factorial disease process that involves metabolic, nutritional, and immunologic components.

The ranking system identified below is intended to aid in a quick visual assessment of external condition. It should be noted that additional factors, such as behavior, age/size, geography, weather, and time of year, have to be taken into consideration to determine actual cold stress disease. The stages identified below are therefore only indicative of severity of cold exposure by manatees, ranging from mild (stage 1) to moderate (stage 2) and severe (stage 3). Because a full body assessment may not always be possible, the lesion criteria should be ranked by the body part (head, trunk, tail) observed. In addition, body condition may be scored (see table at end of this appendix); however, it should be noted that the condition of cold-stressed animals may vary from obese to emaciated.

Categories for Ranking of Cold-Exposure-Related Skin Lesions:

STAGE 1: Mild Cold Exposure Signs

- Whitening/bleaching of skin on body extremities (on face, flippers, or "halo" of tail margin)

– Or –

- Scattered, small superficial cold-induced lesions (usually circular) on extremities and other parts of the body

<u>Example Images of Stage 1:</u>

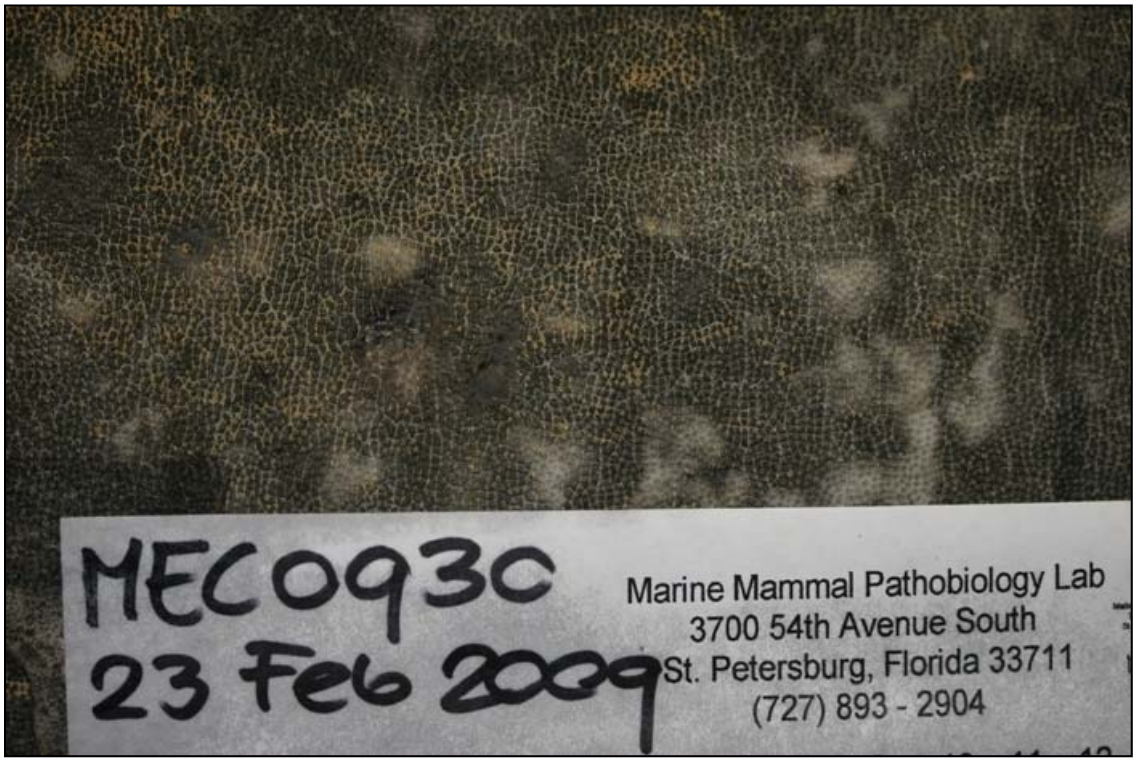
Scattered small circular lesions on the body along with whitening of the skin around the flippers and the tail (Photo Courtesy of USGS)

Scattered smaller lesions on the body along with whitening of the skin around the snout and the flippers (Photo Courtesy of USGS)

Small lesion of right nostril (Photo Courtesy of USGS)

Bleached spots on the body (manatee on right) and halo of the tail margin (both manatees) (Photo Courtesy of USGS)

Bleaching in the creases of the snout and superficial lesions on the head and the neck (Photo Courtesy of USGS)



Bleached skin (Photo Courtesy of FWC)

Bleaching in the creases of the head (Photo Courtesy of FWC)

Bleaching and scattered circular pitted lesions (Photo Courtesy of FWC)

Cobblestone-like skin on the ventrum of a manatee (Photo Courtesy of FWC)

STAGE 2: Moderate Cold Exposure Signs

- Wide spread blistering/ulcerating cold-induced lesions on extremities and other parts of the body

– Or –

- Scattered, larger (>quarter size), ulcerating cold stress lesion on extremities and other parts of the body

– Or –

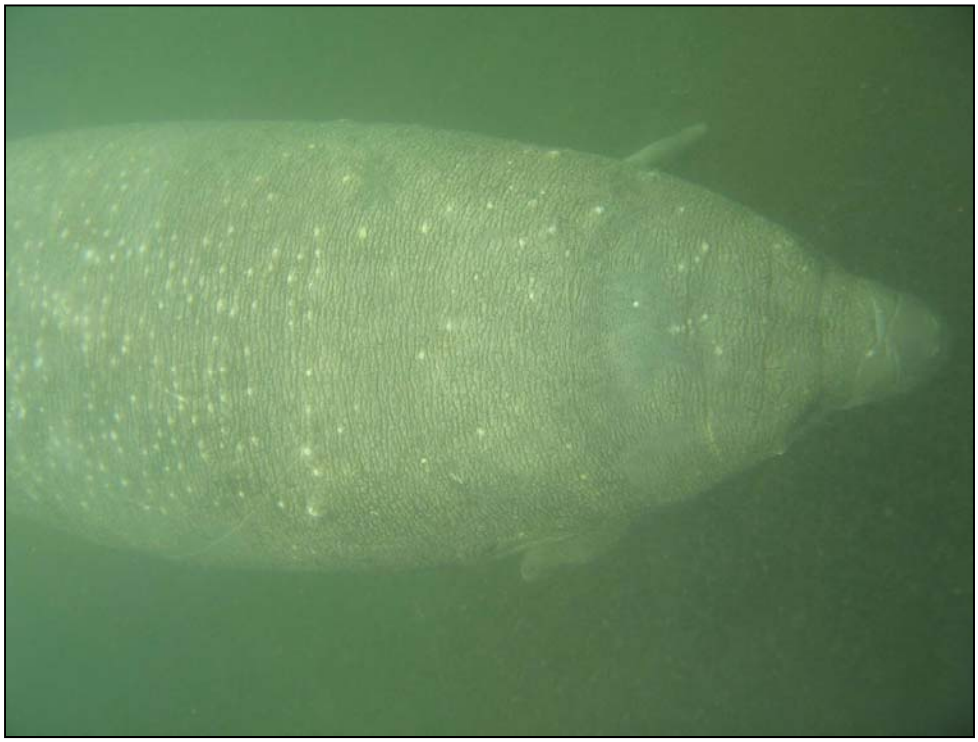
- Abscesses (large bulges filled with pus) on any part of the body

Example Images of Stage 2:

Larger ulcerating cold induced lesions on the head and the flippers, cobblestone epidermis on the body (Photo Courtesy of T. Calleson, FWC)

Halo around the tail margin and abscesses on the body (Photo Courtesy of Y. Zola, DEP)

Abscesses on the body (Photo Courtesy of T. Calleson, FWC)



Cold induced lesions more widespread over the body (note that nose is clean) and moderate cobblestone-like skin (Photo Courtesy of USGS)

Ulcerating lesions on the face and cobblestone-like skin (Photo Courtesy of T. Calleson, FWC)

STAGE 3: Severe Cold Exposure Signs

- Extensive areas of open cold-induced lesions

– Or –

- Sloughing epidermis

– Or –

- Blown out abscesses

<u>Example Images of Stage 3:</u>

Extensive, ulcerating cold induced lesions on the face and the flippers (Photo Courtesy of FWC)

Deep, ulcerating cold induced lesions on the nostrils and the head (Photo Courtesy of FWC)

Sloughing epidermis and extensive lesions on the fluke

Extensive ulcerating lesions

Deep ulcerating lesions on facial creases (Photo Courtesy of FWC)

Extensive, open cold induced lesions on fluke (mislabeled scale bar, should be MEC0892) (Photo Courtesy of FWC)

Manatee Body Condition Scoring
Created and last revised June 9, 2006 by M. Ross MS and B. Chittick DVM

Note: Body condition observations are generally based on clinical assessments, so determinations can be difficult to make from surface observations. Based on a 1-5 Scale:

Score	Description
1	**Emaciated**. Moderate to severe concavity of ventrum (midline depression "longitudinal skin fold" distinct with transverse skin folds), dorsum appears flattened, peanut-shaped head (hourglass shape of neck), bony structures such as ribs, scapula, or spine visually evident.
2	**Thin**. Flattened to mild concavity of ventrum (midline depression "longitudinal skin fold" without transverse skin folds), dorsum appears mildly flattened, +/- peanut-shaped head (mild hourglass shape of neck), ribs only visually evident with positional changes of body, overall body shape streamline (torpedo-like).
3	**Normal**. No concavity, mild convexity of ventrum, dorsum mildly rounded (gives "thicker" appearance of body from lateral view), slightly rounded neck, bony structures not visually evident, slightly oval overall body shape.
4	**Fat**. Rounded ventrum and dorsum, mild rolls of fatty tissue around neck, axillae, and peduncle, oval overall body shape.
5	**Obese**. Rounded ventrum, dorsal convexity with depression over dorsal midline (longitudinal depression along dorsal vertebral column), moderate to severe rolls of fatty tissue around neck, axillae, and peduncle, round overall body shape.