Review and Synthesis of Manatee Data in Everglades National Park

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Executive Summary

We compiled and evaluated existing datasets on Florida manatees (*Trichechus manatus latirostris*) for Everglades National Park (ENP) for use in the Park's General Management Planning (GMP) effort, including aerial survey, radio telemetry, and carcass recovery data. The analyses and summaries of datasets contained herein describe how manatees make use of the waters of ENP. We discuss the relative importance of different areas to manatees within the park, and evaluate how these areas might be affected by ecosystem management, park operations and management, and park visitor use. Gaps in available information are identified, and recommendations are made for future research to address these gaps.

Everglades National Park provides habitat for a substantial population of manatees. Scientists have studied this population intermittently since Joseph Moore collected information from park wardens and other observers in the area and began observing manatees in May 1949 (Moore 1951a). Aerial surveys were conducted intermittently on a monthly basis from December 1979 – September 1981, and again from October 1990 – September 1993. Winter synoptic surveys, coordinated by the Florida Fish and Wildlife Conservation Commission (FWC) and flown just after severe cold fronts, have been conducted annually since 1991. These and other aerial surveys conducted in and around the northwest portion of ENP have provided useful information about manatee distribution in ENP. Additional data available from the region include those from radio-tagged animals and recovered manatee carcasses.

The principal study area was the south and southwest coast of Florida from Barnes Sound, throughout the coastal waters of ENP, and extending north through the Ten Thousand Islands to Marco Island (Fig. 1). Publicly owned areas within the study area include ENP, Big Cypress National Preserve, Fakahatchee Strand Preserve State Park, Ten Thousand Islands National Wildlife Refuge (TTINWR), Collier Seminole State Park, Deltona Lands, and Rookery Bay National Estuarine Research Reserve (RBNERR). Additionally, areas important to manatees but not currently within publicly-owned lands include the Port of the Islands basin, and areas around Everglades City and Chokoloskee.

Summary of Methods

The following datasets were compiled and analyzed for this report:

Environmental data from multiple agencies, including water temperature and salinity readings, and monthly "snapshots" of water quality.
Monthly fixed-wing distributional aerial survey data from December 1979 – September 1981 conducted by ENP staff.
Monthly fixed-wing distributional aerial survey data from Collier County conducted from late 1980's through early 1990's by FWC staff.
Fixed-wing distributional aerial survey data from Ten Thousand Islands area conducted from 1999 through 2005 by TTINWR staff.
Monthly fixed-wing distributional aerial survey data from March 1990 through February 1993 conducted by ENP staff.
Statewide, interagency synoptic aerial survey data conducted annually during winter from January through March of 1991 – 2004.
Carcass salvage data compiled by FWC from 1974 – 2004.

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Radio tracking data from FWC and USGS tagged manatees that utilized ENP or TTI waters.
Maps of submerged aquatic vegetation from Collier County, FWC, and RBNERR.
ENP aerial survey data for boats from October 1983 – September 1984.

We defined seasons using a simple 3-month or quarterly format—winter: December – February; spring: March – May; summer: June – August; fall: September – November. Two seasons were of special interest because manatees may have critical resource needs that are limited in availability. The first was winter, when cold water temperatures cause manatees to seek warm water refuges. The second was spring, which corresponds to the dry season, when availability of fresh water is limited.

We delineated large polygons to represent regional units (Fig. 2) based on previous delineations used by Snow (1991), Davis and Thue (1979), Whalen (1979), and Odell (1976). We also added additional polygons west of ENP to Marco Island.

We delineated small polygons to represent hydrologic basins, bays, channels, shoals, and other relatively discrete landscape features used by manatees throughout the study area (Figs. 3 – 12). Each polygon or "patch" has attributes such as geographic name of basin/location, and general habitat zone (offshore, travel corridors, inshore bays, and inland rivers). Data from aerial surveys and tagged manatees were overlaid with these polygons using a GIS to identify areas of high manatee use and to look for patterns in manatee use of different types of habitat.

Aerial survey data were analyzed using two approaches. The first used a kernel density function to generate relative densities across the surveyed region. The second used the number of manatees surveyed in each patch and the amount of habitat (water) available in each patch to calculate relative density per patch. Absolute densities could not be reliably calculated from these data because no estimates of detection probability, availability for detection, or observer bias could be calculated to account for unknown biases in the data that may vary spatially and temporally. We consider the output from these analyses to be useful only for qualitative comparisons, therefore all density maps are displayed on a log scale without numerical values to emphasize large qualitative differences only.

Manatee carcass salvage data were analyzed using binomial analyses to compare the relative proportions of different mortality categories across 11 broad regions (defined in Fig. 2), and also seasonal mortality by region. Prior to conducting these analyses, the distribution of undetermined-cause carcasses across the regions was examined, and these undetermined-cause carcasses were then removed from the dataset.

Home ranges were determined for each animal based on the Argos PTT data. We calculated a seasonal home range for each animal, combining data across years for individual animals tracked for multiple years. We summed the resulting home range grid files for all animals tracked during a given season, treating each animal as a single sampling unit. Wild-caught animals were analyzed separately from naïve, captive-raised animals released in the area. Animals with less than 2 weeks of data for a given season were excluded from the seasonal analysis.

Manatee travel corridors were determined from GPS data combined across all animals and all seasons. GPS locations were translated into travel segments, then processed using a kernel analysis to generate a surface representing areas of high use.

II
Summary

Additional data analyzed included aerial survey data for boats conducted across ENP Oct 1983 – September 1984, and data from water monitoring stations of water temperature and salinity.

Summary of Results

Water monitoring stations within ENP are located across the landscape, and emphasize inland areas, with no stations positioned offshore (Fig. 13). Gulf water temperatures near Naples (Fig. 14) fell below 20 degrees Celsius for several weeks at a time in December – February in every recorded year (Fig. 14). These cold-water conditions induce manatees to seek out thermal refuges, as evidenced by the aerial survey data. Recorded salinities in the Everglades and TTI bays and lower river systems were high during the dry season, and fell rapidly during the onset of the wet season that typically begins in June – July (Fig. 15). The salinity in the ENP system sometimes remained high as late as October (Fig. 16), so for much of each year, manatees in the Everglades area would have to travel inland to find water sources of <5 ppt salinity. All manatees that we tracked in the Gulf made regular, multi-kilometer movements inland, indicating a behavioral drive to access fresh water.

Aerial surveys flown from 1979 – 2004 were examined for patterns in spatial and temporal manatee distributions (Figs. 17 – 35; Tables 1 – 3). In the southern part of ENP, areas with consistent manatee sightings included Whitewater Bay (east side in general and Mud Bay on the west side), Watson River, Shark River, Wood River, Rogers River, Lostmans Creek, Broad River, and Tarpon Bay (Figs. 18, 21, 34). In the northern part of ENP, sightings were common in Chokoloskee Bay, Broad River, Turner River, East River, Fakahatchee River, House Hammock Bay, Rabbit Key, and Demijohn Key (Figs. 18, 21, 34). In the TTI area, POI basin (POI) and the Faka Union Canal, Barron River, Wootens and Big Cypress basins, White Horse Key, Round Key, and the waters off Cape Romano showed high counts (Fig. 28). Marco Island in general also had high relative densities (Fig. 31).

Summer and fall sightings were prevalent in the offshore seagrass beds and Chokoloskee Bay (Figs. 24 – 25), while relative densities in winter and spring were greater in inshore riverine systems and basins, where warm or fresh water would be available (Figs. 22 – 23). The winter synoptic surveys flown from 1991 – 2004 showed heavy use of the inland areas, similar to those seen in the cold season distributional aerial surveys, such as Mud Bay, Wootens and Big Cypress basins, and POI. Other winter use areas included Tarpon Bay, Broad River Bay, Fakahatchee River, Marco Island canals, and the Glades canal system (just north of Manatee Bay) (Fig. 34).

Salvage records documented 520 carcasses from 1977 – 2004 that were in the area of this study (Fig. 36) and for various causes (Figs. 37 – 44). The cause of mortality could not be determined for 45% of the carcasses recovered in the Everglades area (Fig. 37). In cases where the mortality cause was known, over 40% were from watercraft collisions (Fig. 38). Red tide and other natural causes accounted for 27%, and perinatal mortality was the cause in 20% (Fig. 39) of the known cases. Inland sites were overrepresented in the carcass database (and offshore areas were underrepresented), possibly because the carcass of a manatee that dies offshore might drift inland and be found, or float out to sea and be lost, depending on currents and tides. The Everglades City – Chokoloskee area showed very high numbers of manatees killed by watercraft relative to the entire Everglades region (Fig. 38). Marco Island and Whitewater Bay had high numbers of perinatal deaths (Fig. 39), and Marco Island also had high numbers of manatees killed by red tide (Fig. 42). The relatively few cases of mortality due to cold stress were found in disproportionately high numbers in the POI and Whitewater Bay areas (Fig. 40). A disproportionately high number of carcasses with unknown mortality cause occurred during the winter, suggesting that mortality from cold stress could be higher than the data showed (Fig. 45). There is large annual variation in carcass counts for various mortatility categories (Fig. 46). In interpreting these results, caution must be exercised because skewed results may be caused by spatially varying, unidentified biases in the rates of carcass recovery.

Composite home ranges for the wild-caught animals were mostly within the TTI area and northwest portion of ENP (Figs. 47 – 57). The winter range of 16 of 21 manatees tagged at POI was within 10 – 20 km of POI, but the other five animals made a winter movement to Whitewater Bay. For other seasons, all of the tagged manatees had home ranges that were within 30 – 40 km of POI. Telemetry data also supported the general pattern of more inshore use during the winter months, with more offshore visits to feeding areas in summer and fall. Cape Romano Shoals was a core feeding area for the majority of the animals that were radio-tagged at POI. Telemetry data from captive-raised manatees released near Coot Bay showed strong fidelity to the eastern portion of Whitewater Bay, with some movement north into the TTI area in the fall and winter.

Movement and home ranges of tagged animals varied seasonally (examples in Figs. 47 – 56), but most individuals showed a regular pattern of movement alternating between offshore seagrass beds and river systems or canals providing access to freshwater (Fig. 57).

Information on submerged aquatic vegetation (SAV) available to manatees in ENP is very limited. Two statewide spatial datasets for seagrasses showed several seagrass beds in the ENP boundaries north of Cape Sable, with only one additional bed west of the Park off Cape Romano (Fig. 64). The seagrass beds in the two datasets showed limited overlap in the western ENP region, suggesting that both surveys were incomplete. East of Cape Sable, nearly all of Florida Bay was mapped as a single, large seagrass bed (Fig. 65). In comparison to seagrass beds, even less spatial information is available for SAV in the bays and river systems used by manatees in ENP.

Summary of Conclusions, Possible Management Strategies and Future Research Needs

The aerial survey and telemetry data showed concordant patterns of how manatees use the landscape within ENP. Throughout the year, manatees were present within most coastal-accessible waters in ENP. Although offshore seagrass foraging areas were used throughout the year, manatee distribution shifted inland during the winter and spring. During summer and fall, the distribution shifted toward offshore areas. The inland focus during winter is likely associated with manatees seeking thermal refuges, whereas during the spring this inland focus may be associated with access to fresh water. In summer and fall, fresh water is more readily available, allowing the manatees to shift to offshore areas.

Vulnerability to cold stress – Manatees in this region of Florida may be vulnerable to cold stress, especially during severe winters, due to the absence of significant springs or industrial warm water effluents. Several passively-warmed winter aggregation sites have been documented in this region outside of ENP, but little is known about the characteristics of aggregation sites within ENP. Analysis of the 1991 – 2004 winter synoptic surveys indicated that Whitewater Bay, including adjacent areas such as Mud Bay, Joe River, Rogers River, and North River, had the highest counts of manatees in winter in ENP (Figs. 34, 35). Several other inland sites north of Whitewater Bay also were important, including Upper Broad River, Broad River Bay, Wood River Bay, Rogers River Bay, and Lostmans Creek. Usage of these sites tended to vary considerably from year to year and among surveys (Fig. 35), presumably depending in part on the severity of cold winter weather. During cold weather, large numbers of manatees use the canals outside of ENP at POI, Wooten's boat basin, and Big Cypress headquarters. Further south, the lack of sites with high counts belies the fact that large numbers of manatees overwinter in ENP, but they are scattered across the landscape in smaller aggregations.

Boaters or canoeists can disturb manatees that are thermoregulating in small winter refuges, causing manatees to flee from an aggregation site and be exposed to cold stress. Protecting such sites may therefore be particularly important. One mitigation strategy is to create temporary seasonal sanctuaries where entry by any vessel is prohibited during the winter. The system of temporary seasonal sanctuaries used at Crystal River National Wildlife Refuge has been used successfully for many years, allowing manatees to thermoregulate without disturbance, while boaters are still able to use the open waters adjacent to the sanctuaries. The boat density data suggest that relatively few boaters use many of the small aggregation sites in ENP (e.g. Mud Bay; Fig. 66), so the impact of seasonal sanctuaries on boaters may be minimal.

Access to freshwater – Several lines of evidence indicate that manatees need regular access to freshwater, presumably for drinking and osmoregulation (Ortiz et al. 1999; Stith et al. 2004). Aerial survey data showed that manatees were present in rivers and inland areas year-round, but especially during the dry season (Fig. 23). The availability of freshwater changed dramatically with season (Fig. 15 – 16), and during the dry season more manatees were seen inland than during the wet season (compare Fig. 23 and 24). During the dry season, Turner River, Sunday Bay, and Broad River Bay showed high relative densities (Fig. 23). Seasonal patterns developed from the telemetry data were very similar to the aerial survey patterns (compare Fig. 53 and 54), and analysis of tagged individuals showed that all manatees made frequent trips up rivers and creeks, apparently to access freshwater (Figures 56 – 58).

Frequent movements of individual manatees between offshore and inland areas suggest that manatees are using relatively narrow rivers and creeks (Figs. 59 – 63), especially during the cold and dry season. Manatees seeking fresh water may travel far upstream into narrow, shallow areas where they are especially vulnerable to boats. Speed restrictions for boats may be warranted in those areas where manatees are restricted in movement and cannot easily avoid collisions, especially during the winter and spring when manatee use of these areas is higher.

Corridor Use – Carcass data indicated that the Chokoloskee region had disproportionately high watercraft mortality (Fig. 37). The boat density data also showed that this area was heavily used by boats (Fig. 66). Several major manatee travel corridors cross this region from the offshore grass beds, through the inshore bays and passes, and up into river systems. These include Chokoloskee Pass and Rabbit Key Pass (Fig. 61), Chokoloskee Bay, Baron River, Turner River, Cross Bays, and Lopez River (Figs. 61 – 62). Speed zones in the inland bay portion of ENP from Gate Bay to Chokoloskee Bay are generally less restrictive (or non-existent) compared to adjacent portions of Collier County, where speed limits typically are 30 mph in channels and 20 mph outside of channels (Fig. 67). Implementation of the Collier County speed restrictions throughout the inland bay portions of ENP, so that the entire bay section from Gate Bay through Chokoloskee Bay has consistent, more restrictive speed zones, might reduce watercraft mortality in this region.

Offshore foraging areas – Throughout the year, but especially during the summer and fall, high relative densities of manatees were found in offshore seagrass beds (Figs. 24 – 25, 54 – 55). The aerial survey and telemetry data showed that relative use of these offshore areas was non-uniform, with some areas showing high use and others showing no use (Figs. 18 – 36, 52 – 55). In general, aerial survey data showed that during the winter and dry seasons, relative densities in offshore areas of ENP were concentrated in the seagrass beds near the seasonal high-use areas of Lostmans and Broad River (Fig. 22 – 23). During the summer and fall, offshore use was more widely distributed and extensive, shifting into the more northerly portions of ENP (Figs. 24 – 25). Manatees feeding in these offshore seagrass beds would often be in shallow water and thus vulnerable to boat strike. Speed restrictions in shallow, high-use foraging areas may be appropriate, especially in the offshore areas of Chokoloskee region where boat density (Fig. 66) and apparent watercraft mortality is high (Fig. 38).

Inshore bays – Large numbers of manatees were seen during aerial surveys in several of the larger inshore bays. Chokoloskee Bay had high counts in all seasons (Figs. 22 – 24), while eastern Whitewater Bay, was occupied year-round, but had high counts only during winter. Smaller bays were also seasonally important, especially in the cold and dry season. Analysis of telemetry data suggested that some manatees remained within inshore bays, although the majority of use by tagged animals occurred in offshore seagrass beds (Figs. 53 – 55; winter being the exception Fig. 52). As an example of a tagged animal that spent a large proportion of time in inshore bays, Santina spent most of the time feeding in Chokoloskee Bay during the wet seasons of 2001 and 2002 (Fig. 57).

Insights from telemetry data – Analysis of the telemetry data showed an important pattern that was not evident from aerial survey or carcass data. All tagged individuals showed regular movement between access points for freshwater and areas with preferred forage (example – Fig. 58). When these two resources are close together, manatee movements may be relatively small, but all of the wild-caught animals tracked for significant periods in the study area showed regular, multi-kilometer movements between these different habitat zones. This behavior has implications for managing the population. For example, establishing individual sanctuaries at high use areas such as Pavilion Key would not completely protect any individual, since the telemetry data showed that manatees regularly move in and out of these high use areas. This suggests that strategies for protecting manatees in ENP will require a network approach that considers inshore and offshore high-use areas, and their connecting corridors. For example, the aerial survey data showed that Upper and Broad River Bay had consistently high relative densities, as did the offshore zones near the mouth of the Broad River (Figs. 22 – 25). Manatees with home ranges in this area likely were traveling regularly between these offshore and inland zones.

There is a major gap in information about food resources available to manatees in this region (Figs. 64, 65). Manatees likely forage on a wide variety of resources, and these resources differ among landscape zones. Field observations while following tagged animals in the region have anecdotally documented the occurrence of several species of SAV and their use as forage by manatees within inland bays. Almost no spatial information is available for SAV in ENP, and the existing seagrass maps almost certainly underestimate the extent of seagrass available for this region.

A network view of manatees in ENP – Resources used by manatees in ENP can be viewed as occurring on a seasonally changing network, where the network consists of warm water sites, sources of fresh water, and foraging areas. On a broad scale, some manatees migrate into ENP from the north during the winter, while others migrate north out of the region. The limited telemetry data suggest that the majority of manatees in the region are year-round residents. The network for these year-round residents appears to be smaller in winter than during other seasons, consisting of warm-water nodes in inland canals, rivers, creeks and bays, all connected to nearby foraging areas by corridors formed by rivers or tidal channels.

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Warm-water sites in ENP may be deserving of special protection during the winter because manatees using these critical resources can be disrupted by very minor human disturbance. An example of such a site is Mud Bay (Fig. 7), which appears to be a relatively small but important winter aggregation site (Fig. 22, 34) that has low use during other seasons. These sites are tabulated in Table 3 (see also Fig. 35).

As water temperatures climb with the approach of spring, these warm-water nodes may become less important, and nodes providing increasingly scarce freshwater may become more important. However, there is considerable overlap in the winter and dry season inland sites (compare Figs. 22 and 23). These nodes commonly are located up narrow creeks and shallow marshes where manatees have difficulty evading fast-moving powerboats. Examples of tagged manatee movements in such restricted areas can be seen in Figures 59 – 63, and in the aerial survey data (Fig. 23) where the Upper Broad River appeared to have especially high relative densities. Although boat densities may be low in such areas (Fig. 66), speed restrictions may still be warranted due to the narrow, shallow water conditions for both manatees and boaters. During the spring, the high use nodes increasingly extend into offshore areas where good forage is available.

With the advent of the summer wet season, freshwater nodes become less important, and manatees make more use of offshore areas or inshore bays that provide good forage (Fig. 24). During summer and fall, manatee and boat densities showed the highest overlap, generally in the offshore seagrass beds or inshore bays, especially in the Chokoloskee region (compare Figs. 24 – 25 versus Fig. 66). Speed restrictions may be appropriate within these shallow, high-use foraging areas, particularly where boat traffic is high or where manatee movement is highly restricted, such as small passages between offshore islands. Viewing manatee use in ENP as a changing network of feeding areas, travel corridors, and inland sources of warm water or freshwater will allow managers to provide more comprehensive protection for the local population.

Data gaps and future research needs – There are several areas where improved data collection would enhance our understanding of manatee habitat use and potential impacts of human activities within the region. Remote tracking with GPS satellite-linked technology, building on previous telemetry work in the TTI and surrounding areas, will provide more detailed information about seasonal use of microhabitats in and around Whitewater Bay, the inland waterways and corridors, and potential areas of increased human/manatee conflict. The locations and characteristics of warm-water sites are poorly understood, with the possible exception of POI, the largest winter aggregation site in the region. It is unclear how similar the natural sites in ENP are to deeper canal sites such as POI, where warm water seems to be associated with haloclines. Aerial surveys have been useful indicators of manatee distribution and relative densities over wide-ranging areas, at reasonable cost, but there are several known biases to aerial surveys. New survey methodologies are needed to estimate and compensate for these biases, to give a more accurate picture of manatee distribution and abundance in the region. Improved population parameter estimates, such as adult survival and fecundity, are also needed for this region, but photo-identification data needed to conduct the appropriate analyses are lacking. Additional monitoring efforts are needed in this region to acquire photographs of individual manatees. Current information on boat usage within ENP is also lacking, although new surveys are underway. Finally, research is needed on how restoration projects in ENP may affect manatees.

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Introduction

Historical Studies

An important population of Florida manatees (*Trichechus manatus latirostris*) occurs within Everglades National Park (ENP). Scientists have studied this population intermittently for many decades. The earliest attempt to collate data and assess the status of manatees in ENP apparently was that of Joseph Moore, who collected information from park wardens and other observers in the area, and began observations himself in May 1949 (see Moore 1951a). At the time of publication, he reported 53 sighting records for the Park area, and he provided a map of these records. Moore noted that manatees had been hunted extensively in the area, and were virtually exterminated from Florida Bay. He noted, "Numbers of manatees in the Park area appear to be inversely proportional to their accessibility to the fishing villages of Chokoloskee and Flamingo." In describing ENP, he claimed, "The twelve named rivers with their interconnections and tributaries, and many shallow bays…constitute what appears to be the greatest concentration of manatee habitat in the United States." He concluded that "the Everglades National Park contains considerable concentrations of manatee habitat, and that the animals, although they have been persecuted as a source of meat, are widely if thinly scattered over large areas of the Park."

In a separate paper on the range of the manatee, Moore (1951b) described the locations of 54 sightings for the Park: "Whitewater Bay, mostly eastern part, and rivers emptying into it, 25; Shark River system, 11; Broad and Rogers rivers system, 14; and Lostmans River system, 4. Since patrolling of these extensive and intricate waterways has been much more intensive in the Shark, Broad, Rogers, and Lostmans Rivers area than in eastern Whitewater Bay and its attendant rivers, it is apparent that manatees are much more abundant in the latter area." He also noted, "The manatees in the area of the newly established Everglades National Park reflect their recent unlawful persecution by meat-hungry commercial fishermen by being very shy", and "the Chatham Bend River and Houston River are good places to look for sea cows, whereas in the Lopez and Turner Rivers just north of them the animal is rarely known to occur. This latter scarcity relates to the proximity of the mouth of the Lopez and Turner Rivers to the island of Chokoloskee which has been inhabited by several generations of low subsistence fishermen."

In a later paper, Moore (1956) commented on the difficulty of observing manatees in the Park, and noted that during 6 1/2 years of boating in the Park, having traveled 5,028 nautical miles, he only encountered manatees 13 times. Writing about winter aggregations, he noted that the severe freeze of January 15, 1956 lead to reports of three dead manatees, one each in Lostmans River, Cabbage Bay, and Tarpon Bay. He also reported, "Large aggregations form during cold snaps in the more tropical waters of the Everglades National Park *where there is no special warming feature evident to attract them*" (italics in original).

Peterson (1974) reported to Jack Stark (Superintendent of the Everglades National Park) in February 1974, "There is a winter-time growth in the manatee population of the Everglades National Park from one hundred to several hundred animals. This occurrence suggests a seasonal movement of manatees along the Gulf coast" (pg. 8).

Irvine and Campbell (1978) (U.S. Fish and Wildlife Service (USFWS) Sirenia Project, now U.S. Geological Survey, Florida Integrated Science Center (USGS-FISC) Sirenia Project) conducted a winter and summer aerial survey of Florida and adjacent areas in 1976. Of the 738 manatees sighted in the survey, 131 were found in ENP, indicating the importance of this area to the total population. They suggested that, "The extreme southern areas of Florida may be a warm water refuge. Temperatures at the mouth of the Shark River in the Everglades National Park averaged 25C annually from 1968 to 1971 and never dropped below 19C. Increased availability of new warm water sources in northern Florida during the last 25 years may have altered winter distribution patterns for manatees by diverting animals from southward winter migrations" (p. 615).

Bass (1989) summarized data from aerial surveys that he conducted in the park from December 1979 through September 1981. Highest numbers were seen in the winter months (165 in January 1981), lowest numbers in spring and fall (four in April 1981). Of the three zones delineated, Whitewater Bay and vicinity had the largest percentage of sightings (67%), followed by inland waters (25%), and Gulf (8%). Mean group size was 2.1. Calf sightings were 11% of total.

Snow (1991) described the distribution and relative abundance of manatees in ENP based on 35 aerial surveys conducted over a 12 month period from March 1990 through February 1991. Four hundred and twenty-four groups (769 individuals) were observed during 73.9 survey hours. The surveys indicated that manatees are present year-round in ENP, and Snow suggested that as much as 15 – 20 % of the west coast population and 7 – 9% of the state-wide population may occur in the Park (based on a total count of 652 and 1465 respectively for the west coast and entire state). Counts were highest during winter and summer, and appeared to be more concentrated in the southerly areas of the park in the winter and more northerly during the summer. Also, during the winter the distribution was shifted toward more protected waters (inland river, creeks, and bays) compared to the summer when the distribution was shifted toward more open waters (such as offshore shoals and river mouths).

Snow also reported results from 2 more years of surveys in the park for 1991 and 1992. Results were similar to the previous surveys.

Objectives

The primary objective of this report is to compile and evaluate existing datasets on manatees for Everglades National Park for use in the park's General Management Planning (GMP) effort. The databases to be analyzed include aerial surveys, radio and satellite telemetry data, carcass recovery data, and boat survey data (described in more detail in Methods section).

Analyses and summaries of datasets describe how manatees make use of the waters of ENP. Management-related issues are discussed regarding the relative importance of different areas to manatees within the park. Qualitative evaluations are made on how these areas might be affected by ecosystem management, park operations and management, and park visitor use. Gaps in available information are identified and recommendations are made for future research to address these gaps.

Study Area

The principal study area is the southwest coast of Florida within the boundaries of ENP, and extending north to Marco Island (Fig. 1). Manatees are known to use habitat directly west or north of the western portion of ENP, so we describe data from these areas also. Publicly owned areas outside of ENP include Big Cypress National Preserve, Fakahatchee Strand Preserve State Park, Ten Thousand Islands National

Wildlife Refuge (TTINWR), Collier Seminole State Park, Deltona Lands, and Rookery Bay National Estuarine Research Reserve. Additionally, areas important to manatees but not currently within publicly-owned lands include the Faka Union Canal, which is connected to the Picayune Strand State Forest to the north, and areas around Everglades City and Chokoloskee.

East and West Coast Manatee Populations

The primary study area within Everglades National Park follows the southwest coastline from the northwest corner of the Park near Everglades City south to Cape Sable and east to Barnes Sound (Fig. 1). Extensive shoals and shallow water east of Flamingo apparently restrict movement of manatees between Flamingo and the northeast portion of Florida Bay (Madeira Bay to Barnes Sound). Evidence from radio-tagged manatees suggests that movement between these two areas of Florida Bay may occur by individuals that traverse shallow boat or tidal channels, either through northern Florida Bay from Flamingo to Joe Bay, or along the southwest edge of the Park boundary between Cape Sable and the vicinity of Long Key in the Florida Keys. Manatees in the Keys should be considered part of the Atlantic coast population, because travel northward along the Florida Keys to the Atlantic coast is common and relatively unimpeded.

Data and Methods

The following tasks were identified in the scope of work for this project.

Assemble existing electronic datasets relating to manatee distribution, abundance, and habitat. Area of interest extends from Cape Romano and TTINWR through the near-shore waters of ENP to Barnes Sound. Provide a narrative description of data type and methodology.
Evaluate the compiled data and data products to develop insights on manatee use patterns in ENP, including the relative importance of different areas within the park regarding their contribution to manatee recovery.
Identify gaps in available information needed for sound manatee protection and recommend future research required to address species recovery.
Produce graphical displays (maps, charts, tables, etc.) that best illustrate patterns of manatee use within ENP; provide these in an extensive appendix and in a standardized electronic GIS format where possible.
Work with ENP staff to evaluate whether data suggest how ecosystem management and park visitor use/operations may be affecting manatee habitat and species health. If data show possible effects on species recovery, identify potential future management options.

Pursuant to task 1, the following datasets were compiled and analyzed:

Environmental data from multiple agencies, including water temperature and salinity readings, and monthly "snapshots" of water quality.
Monthly fixed-wing distributional aerial survey data from December 1979 – September 1981 conducted by ENP staff.
Monthly fixed-wing distributional aerial survey data from Collier County conducted from late 1980's through early 1990's by Florida Fish and Wildlife Conservation Commission (FWC) staff.
Fixed-wing distributional aerial survey data from Ten Thousand Islands area conducted from 1999 through 2005 by TTINWR staff.
Monthly fixed-wing distributional aerial survey data from March 1990 through February 1993 conducted by ENP staff.
Statewide synoptic aerial survey data conducted annually during winter from January through March of 1991 – 2004.
Carcass salvage data compiled by FWC from 1974 – 2004.
Radio tracking data from manatees tagged by FWC or USGS Florida Integrated Science Center (FISC) in ENP or TTI waters.
Maps of submerged aquatic vegetation from Collier County, FWC, and Rookery Bay National Estuarine Research Reserve (RBNERR)
ENP aerial survey data for boats from October 1983 – September 1984

For these datasets, we obtained, produced, or had produced GIS layers of the raw data, then transformed the layers where necessary to conform to the standard projection of NAD83, UTM zone 17N. We then analyzed the data (specific methodology is explained in each section), and developed maps, graphs, and tables summarizing 1) overall spatial distribution of manatee data, 2) specific localities with high relative densities of manatee data, and 3) seasonal patterns in distribution.

Environmental data

The primary environmental data relevant to manatees that are readily available for ENP are salinity and water temperature. These data are collected at water monitoring stations within ENP and nearby areas by several agencies, including the Park Service, USGS-FISC, South Florida Water Management District (SFWMD), and Rookery Bay National Estuarine Research Reserve (RBNERR). Additionally, monthly "snapshots" of water quality are available from the Southeast Environmental Research Center (SERC) through the Florida International University South Florida Estuarine Water Quality Monitoring Network (Boyer and Jones 2002). This extensive boat-based sampling network has much more thorough spatial coverage of the entire study area compared to the coverage of permanent monitoring stations, but the monthly temporal resolution is much coarser.

Water temperature data

The current distribution of monitoring stations that provide water temperature is shown in Figure 13 (note: not all stations provide water temperature). Gulf water temperature is especially useful for analyzing winter distributions and movements of manatees, because manatees tend to shift their centers of activity out of Gulf waters and into inland waters and specific warm water refuges when Gulf waters fall below 20 degrees Celsius.

Salinity data

The current distribution of monitoring stations that provide salinity (or conductivity) is shown in Figure 13 (note: not all stations provide salinity). Some stations measure salinities at two levels of the water column (one near the surface and another near the bottom) whereas others provide a single measurement. Most stations are located at the mouths of rivers or further offshore, while only a couple are located in upstream areas frequented by manatees.

Definition of seasons

We defined seasons using a simple 3-month or quarterly format – winter: December – February; spring: March – May; summer: June – August; fall: September – November. Two seasons were of special interest because manatees may have critical needs that may be limited in availability. The first was winter, when cold water temperatures cause manatees to seek warm water refuges. The second was spring, which corresponds to the dry season, when availability of freshwater is limited.

Cold season

Manatees cannot survive for prolonged periods in cold water below about 20 degrees C (68 degrees F). Gulf temperatures in the study area routinely fell below this threshold during the measured winters (e.g. Naples; Fig. 14), with annual variation in the timing of the onset and end of the cold season. Manatees typically respond to drops in Gulf water temperature by seeking warmer inland sites. To investigate potential changes in the distribution or movements of manatees during periods when Gulf temperatures fall below 20 degrees C, we defined the cold period as the winter season.

Dry season

We qualitatively evaluated salinity data from various monitoring stations to look for trends and for periods when salinity was sufficiently low to provide drinking water to manatees (5 ppt or less). To investigate potential changes in the distribution or movements of manatees during periods when manatees can or cannot obtain freshwater at or near the mouths of inland rivers, we defined the dry period as the spring season.

Delineation of regional units

We delineated large polygons that represent regional units (Fig. 2) based on six previous delineations used by Snow (1991), Davis and Thue (1979), Whalen (1979), and Odell (1976). We also delineated five new regions representing wildlife refuges (Ten Thousand Islands NWR and Big Cypress NWR) and relevant geophysical areas (Marco Island, POI (POI) basin, and the Florida Keys) (Fig. 2).

Delineation of basin/patch units

We delineated 235 small polygons that represent hydrologic basins, bays, channels, shoals, and other relatively discrete landscape features used by manatees throughout the study area (Fig. 3). Each polygon was attributed features such as geographic name of basin/location, and general habitat zone (inland, offshore, bay, channel).

Characterization of general habitat zones

Each patch was assigned to one of four habitat zones within the TTI/ENP landscape: 1) offshore foraging areas, 2) travel corridors, 3) inshore bays, and 4) inland rivers, canals, and lakes (Fig. 3). These zones were used to characterize shifts in seasonal use of zones along a gradient from offshore to inland.

Fixed-wing distributional aerial survey data

Several distributional surveys have been conducted in the study area dating back to 1979. During the years they were flown, these surveys were generally conducted on roughly a monthly basis. Survey data, metadata and other information about the first three survey groups was obtained from FLDEP (1998), and the fourth group of surveys was obtained from T.J. Doyle at Ten Thousand Islands National Wildlife Refuge. Methodology for all surveys was similar to the methods described in Irvine et al. (1981), though the flight paths differed among groups. The following aerial surveys were analyzed for this project (flight paths are available on CD):

ENP (monthly): December 1979 – September 1981

This was the first systematic set of aerial surveys conducted for the Park. Twenty one surveys were conducted by ENP staff between December 1979 and September 1981. The flight path for these surveys followed the outer islands and inner bays of the entire ENP.

ENP (monthly): March 1990 – Feb 1993

Manatee distribution surveys were flown by ENP staff approximately monthly from March 1990 to March 1993. The flight path for these surveys covered more area than the previous ENP surveys, adding several passages from the inner bays to offshore areas in northwest ENP, and east of the park boundary to the north shore of Key Largo.

Collier County (monthly): 1991 – 1993

Manatee distribution surveys were flown by FWC staff approximately monthly from January 1991 to November 1993. The flight path of these surveys covered most manatee-accessible waters from Coon Key (close to Cape Romano) down to Rabbit Key and the Lopez River.

Ten Thousand Islands: 1999 – 2005

Manatee distribution surveys were flown by TTINWR staff approximately monthly for Ten Thousand Islands National Wildlife Refuge from August 1999 to January 2005. The flight path for these surveys overlapped the northern area of the earlier Collier County surveys, from the northeast shore of Marco Island down to Indian Key.

Statewide synoptic aerial survey data

The statewide synoptic survey is a simultaneous count of manatees across the state at key winter aggregation sites (Ackerman (1995). This statewide, interagency survey has been conducted annually since 1991 during the coldest winter weather during January through March. At that time, manatees move to warm-water sites such as natural springs, thermal discharges from power and industrial plants, and deep canals. We selected the survey results along the section of coast from the north shore of Marco Island down to the Florida Keys and east to Card Sound for this report.

Aerial survey general density

We used a kernel density routine (ESRI ArcMap Spatial Analyst, Kernel Density with cell size of 50m and search radius of 4000m) to indicate the areas of highest manatee kernel density regardless of available habitat for each survey dataset. This routine smoothed the raw counts into a visible surface showing areas of high and low local density. One issue for this analysis was due to the inclusion of non-habitat (land) in the density calculation, which resulted in lower densities than would be calculated if the non-habitat were removed. Densities calculated in small water bodies such as narrow rivers, bays, or corridors had potentially negative biases compared to more open water, but these biases likely were small because of the heavy weighting placed on nearby points. Absolute densities could not be reliably calculated from these data because no estimates of detection probability, availability for detection, or observer bias could be calculated to account for unknown biases in the data that may vary spatially and temporally. We therefore consider the output from this analysis to be useful only for qualitative comparisons. Data were displayed without numbers, and with a quantile distribution, producing visualizations similar to a log-transform of population density data. This transformation emphasized large differences in kernel densities that presumably were substantially greater than errors introduced by unknown biases. With the log-scale visualizations that we chose for these displays, the kernel density more than doubled for each color change. The survey biases would have to differ by more than 100% across adjacent color zones for the relative density colors to reflect equivalent values. Because all but one of these surveys were multi-year, repeat samples that were aggregated across years, random spatial errors likely were smoothed out and the remaining large-scale patterns were not likely due to random error associated with small sample size. Nevertheless, we recommend consulting graphs of the raw counts when interpreting the associated maps. We also recommend relying only on the largest relative differences when interpreting the results of these analyses, again because of the substantial biases that are known to exist during aerial surveys.

Aerial survey density by available habitat per patch

Calculation of available habitat

Digitized aerial survey flightlines were obtained and projected onto a model of the Florida coastline (BTHEVG, BTHBIS, BTHKEY combined; FLDEP 1998). All water within 1km of the flight line was located and saved as a separate shape file. This file was subdivided by habitat patch and the available water in each patch was measured. A distance of 1km was used to encompass a typical sight distance from a plane, plus the area observed during small displacements made by the plane when investigating suspected sightings. Though the observer would be surveying only from the right side of the plane, there were enough observations recorded from the left side of each flight path to consider both sides as the area surveyed.

Density per patch

The manatees located within each habitat patch during each aerial survey were summed, and the total number was divided by the area of habitat (water) available in each patch to estimate the local density of manatees. The entire patch was used for counting manatees because many individuals were located well outside the 1km buffer zone, presumably because the actual flight path deviated from the published flight line. Because this analysis relies on the same raw-count data used in the aerial survey general density approach described previously, the same caveats apply to this analysis. Due to unknown biases in aerial surveys, density data were displayed on a log-transformed scale with at least double the density difference between colors, to compress the extreme low and high values, make the charts more visually intuitive, and to mask the effect of inaccurate counts in each patch. The density per patch visual output contrasts with overall manatee density in that a small group of manatees would display a high density in the patch if the available water habitat in that patch were very small, such as in a narrow river. Conversely, even a large aggregation of animals would show a relatively low density in a patch with a large surface area of water, such as a large bay, or an offshore area. This type of analysis is as accurate as the water area polygon file it is based on (see “Calculation of available habitat”, above), and can show serious errors in interpretation, especially in the smaller areas found in inland waters, if the calculated water area differs from what is found in the landscape. Examples of polygon errors included the C-111 canal, which was not represented at all on the polygon layer, so it had a water area of “0”, and the POI area in the 1979 – 1981 aerial surveys, which was not on the official aerial survey route, so manatees found there were not counted in the polygon density map.

Colors found on the patch maps were based on the relative densities found during that particular aerial survey, and so cannot be visually compared across maps. Their purpose is to direct the viewer toward the watersheds with relatively higher or lower manatee densities found on that particular survey. The calculated density found in each patch was not included on the maps, because unknown availability and observer biases inherent in all aerial surveys may have caused systematic error within each survey. Provided the differences in density exceeds the imprecision introduced by various biases, this color-based density estimation can be used qualitatively to identify areas of high relative manatee density with that which might overlap with, for example, areas with high boat use.

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Carcass salvage data

Data for recovered manatee carcasses from 1974 – 2004 were downloaded from the FWC internet map server website (http://ocean.floridamarine.org/mrgis/viewer.htm) (note: popup blocker must be disabled in web browser to download). The carcass salvage data classify manatee deaths into nine categories based on gross, histological, and microbiological findings (Ackerman et al. 1995). These categories include:

1) Watercraft – deaths resulting from propeller wounds, impact, crushing, or any combination of the three due to hits by boats, barges, or any type of watercraft.
2) Flood gate or canal lock – death by crushing or asphyxiation in flood gates and canal locks.
3) Other human-related causes – deaths caused by vandalism, poaching, entrapment in pipes and culverts, complications due to entanglement in ropes, lines, and nets, or ingestion of fishing gear or debris.
4) Perinatal – manatees less than 150 cm (5 ft.) in total length where death was determined to be not due to human-related causes.
5) Cold stress – death resulting from exposure to prolonged cold weather. Animals usually show signs of emaciation or malnutrition. This category was not added until 1986.
6) Other natural – deaths resulting from infectious and non-infectious diseases, birth complications, natural accidents, and natural catastrophes (such as red tide poisoning).
7) Undetermined – deaths in which the cause of death could not be determined.
8) Verified/Not Recovered – deaths that were reported and verified, but the carcass was not available.
9) Undetermined – other.

Binomial mortality analysis

We segregated carcass recovery data from Marco Island south to the Florida Keys for analysis. We then performed a two-part binomial analysis for each mortality type by region, and then a similar binomial analysis was performed for seasonal mortality by region. This analysis provided insight into the relative importance of each mortality type in each region or season. Large regions (Fig. 2) were used to divide the spatial extent because locating the carcasses at a much finer scale would be inappropriate. Injured animals may have swum, or carcasses drifted from the area where the mortality agent affected the animal, to the area where the carcass would eventually be recovered.

The first part of the analysis separated all carcasses with known mortality causes from those where the mortality cause was undetermined. Based on the overall rate of undetermined cause of carcass recovery, a binomial analysis was performed on each region, where the probability of each region's undetermined proportion being similar to the overall proportion was calculated. In other words, if a statistically lower or greater proportion of undetermined-mortality carcasses were found in a certain region compared to the proportion of undetermined-mortality carcasses found in the Everglades study area as a whole, it was noted on the map display.

After the data from undetermined cause carcasses were removed from the data set, similar binomial analyses were performed for each type of mortality, calculating the probability of the proportion of each type in each region being similar to that type for the overall data.

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Charts of carcass recovery per region were prepared, and each region was labeled according to the probability that the proportion of carcasses recovered in that region for each mortality type was similar to the number of carcasses of that type recovered over the entire study area. The labels in the chart are:

Chart Label	Probability that proportions were similar
Very Low	$p < 0.05$ (region was lower than overall study area)
Low	$p < 0.20$ (region was lower than overall study area)
Medium	$p > 0.20$ (region was similar to overall study area)
High	$p < 0.20$ (region was higher than overall study area)
Very High	$p < 0.05$ (region was higher than overall study area)

Regions that are found to be "Very Low" or "Very High" should be investigated for causative factors (or lack thereof) that might explain the relative disproportion in the type of mortality seen in recovered carcasses from that region. These two extreme categories correspond to a p-value of < 0.05 that any differences in mortality were due to random fluctuations in mortality factors or random errors in the recovery data; a level generally held to be statistically significant. In interpreting these results, caution must be exercised because skewed results may have been caused by spatially varying, unidentified biases in the rates of carcass recovery.

Radio tracking data

Satellite-based radio tracking provided by Service Argos, Inc. has been used as a research tool for manatees since 1984 (Deutsch et al. 1998; Weigle et al. 2001; Reid et al. 1995; Lefebvre and Frohlich 1986). Performance of Argos tags on manatees is generally better than on other marine mammals because manatees spend much more time at or near the surface, thus greatly increasing the number of satellite uplinks compared to species that frequently dive for extended periods (Reid et al. 1995).

Locations derived from Service Argos-monitored transmitters (known as PTTs) were used to provide information on the movements, home range, and habitat use of individual manatees. These tracking methods have been successfully applied in other portions of the manatee's range (Rathbun et al. 1990, Reid et al. 1995, Deutsch et al. 1998).

Argos satellite telemetry data were obtained from USGS and FWC (the latter included some data collected by Mote Marine Laboratory). The available USGS data were from 33 animals tracked from August 2000 – July 2005 for a study in the Ten Thousand Islands area. Nearly all of the manatees tracked by USGS were free-ranging, captured, and tagged during winter at POI in Collier County; several others were rescued/rehabilitated manatees tagged and released within the study area. The USGS data were filtered to obtain the highest quality fix within any 2-hour interval, resulting in a maximum of four fixes per day. The data set was further filtered to keep only the locations with high location reliability (location classes 2 and 3). The FWC data were from 19 animals tracked between 1992 and 2005. We included USGS and FWC data from young, naïve captive manatees tagged at release, but we analyzed their locations separately from the wild-caught animals. Combined, the USGS and FWC data for 43 animals (USGS 24; FWC 19) contained 24,360 Argos fixes collected over 8,024 tracking days (Table 5). In addition to PTT data, some animals were fitted with GPS transmitters. In contrast to the PTT location error that was often hundreds of meters, the GPS transmitters gave locations with accuracies of <5 meters every 15 – 30 minutes.

Seasonal Home Range Analysis

Home ranges were estimated for each animal based on the Argos PTT data. We calculated a seasonal home range for each animal, combining data across years for animals that were tracked for multiple years. We used the Home Range Extension for ArcView (Rodgers and Carr 1998) with a fixed kernel for the utilization distribution (Worton 1989), and least square cross validation for the smoothing parameter (Silverman 1986). We summed the resulting home range grid files for all animals tracked during a given season, treating each animal as a single sampling unit. Animals with less than 2 weeks of data for a given season were excluded from the seasonal home range analysis, leaving 28 animals in the database. The analysis was performed on two categories of animals: 1) experienced, wild-caught, and 2) naïve, captive-raised. The naïve, captive-raised animals were defined as either captive born or captive-raised calves taken from the wild at less than 225 cm in length (less than 2 years old and presumably naïve about habitats and resources within the release area). Of the nine animals categorized as naïve, captive-raised and used in the home range analysis, four were captive-born, four were orphaned and rescued at less than 170 cm in length, and one was a subadult captured at 226 cm and kept in captivity for over 8 years. Experienced, wild-caught animals were defined as larger subadults or adults that were caught, tagged, and released immediately, or were brought into captivity for rehabilitation and released near the capture site. Only two adults that were brought into captivity for rehabilitation were included in the category of experienced, wild-caught animals.

Corridor Analysis

We computed travel corridors using GPS data only, since the Argos PTT data had insufficient spatial accuracy and temporal resolution to identify pathways at the corridor scale. Due to the relatively small sample size of 16 animals, GPS data were combined across all seasons. The GPS points were used to generate a “polyline” file of segments between points. Segments longer than 1200 meters were removed from the database, because they did not adequately represent movement pathways. The remaining segments were processed using a kernel analysis to generate a gridded surface representing areas of high use.

Seagrasses

Submerged aquatic vegetation (SAV) in the TTI/ENP region includes both marine seagrasses (primarily *Thalassia testudinum*, *Syringodium filiforme*, and *Halodule wrightii*) and macroalgae beds along the gulf coast, and freshwater tolerant vascular pants and algae periodically occurring among the inner bays and rivers (*Ruppia maritime*, *Potemogeton sp.*, *Chara sp*., etc.). Although there appears to be preferential use among areas, all of these species are used by manatees as forage in the greater Everglades. Manatees are also known to occasionally feed on mangrove leaves, and mangroves have been mapped throughout the region (http://gapanalysis.nbii.gov). Manatees also have opportunities to access floating plants and bank grasses as forage.

Information on SAV available to manatees in ENP is very limited. Two statewide spatial datasets for seagrasses were obtained from FMRI. One data set contained seagrass bed locations mapped from aerial photographs taken from 1987 – 1999, and was obtained from the MRGIS website of FMRI (http://ocean.floridamarine.org/mrgis/viewer.htm). A more recent dataset was obtained from an FMRI study on scarring of Florida seagrasses (Sargent et al. 1995). Two additional GIS datasets were provided to FMRI by Collier County and Rookery Bay NERR. The Collier County dataset was mapped opportunistically during marine mammal surveys. The RBNERR data focused on Fakahatchee Bay and Faka Union Bay only. The shallow waters of Florida Bay have been extensively studied, but much of this region is too shallow and too far from freshwater sources to be used extensively by manatees.

Very little information is available on submerged aquatic vegetation in the rivers and bays used by manatees in the western portion of ENP. A few site-specific studies of benthic vegetation in select bays and rivers (e.g. Whitewater Bay, North River) have been made in association with fisheries or ecology studies (e.g. Tabb et al. 1974; Davis and Hilsenbeck 1974). In comparison to seagrass beds, even less spatial information is available for SAV in the bays and river systems used by manatees in ENP.

Boat surveys

We analyzed ENP aerial survey data from October 1983 – September 1984 (four flights per month; alternating weekday and weekend), using a kernel density function to identify areas of high boat use. Canoes and sail boats were separated from motorboats, and records with no boat type information were deleted. Actual numbers of boats found in the surveys are not shown, because of unknown availability and observer biases inherent in all aerial surveys.

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Results

Environmental data

Water Temperature data

Figure 14 shows variation in Gulf water temperature for Naples. Every recorded year showed that in December through February, water temperatures in the Gulf fell below 20 degrees Celsius for several weeks at a time. These cold-water conditions can be fatal or debilitating to manatees (Bossart et al. 2003), and induce them to seek out small-scale thermal refuges that are found throughout the inshore portion of the study area.

Salinity data

Hydrologic monitoring stations located at the mouths of rivers indicated that the arrival of low water salinity after the start of the wet season varied throughout the study area. Figures 15 – 16 show salinity variation for several monitoring stations in the ENP and TTI area. Salinities in ENP area may remain high for several months after the start of the wet season. The onset of low salinities in eastern Whitewater Bay occurred with considerable annual variability, sometimes arriving as late as October (Fig. 16), even though the wet season typically begins in June – July. Low salinities in the TTI area typically begin in July – August, showing much less variability reflecting the high discharge rates associated with the Faka Union canal drainage. Manatees in the TTI and ENP region would have to travel inland to find water sources of <5 ppt salinity for a significant proportion of each year.

Fixed-wing distributional aerial survey data

Careful consideration is needed when interpreting these aerial survey results. There is strong consensus that absolute population size or absolute densities cannot be reliably calculated from these data because no estimates of detection probability, availability for detection, or observer bias can be calculated to account for unknown biases in the data that may vary systematically both spatially and temporally. For this reason, presentation of map results was limited to qualitative patterns, and graphs and tables of the raw counts were provided to give a sense of sample size issues, and should not be used to infer temporal trends.

ENP (monthly): December 1979 – September 1981

Twenty one surveys were conducted between December 1979 and September 1981. Figure 17 shows a map of manatee sightings for these surveys. Figure 18 shows a kernel density map of relative density for all surveys combined. Figure 19 shows the seasonal variation in counts. Table 1 shows total counts of manatees for these surveys. This data set was the smallest time series with the fewest counts among all the aerial surveys, and extra caution should be used in interpreting these results.

The kernel density map (Fig. 18, top) shows high relative densities of manatees mainly at inland sites, with offshore feeding areas also showing high concentrations. The largest and densest area was along the east and southeast section of Whitewater Bay and more inland areas including Coot Bay, Hells Bay, Pearl

Bay, Lane Bay, Roberts River, and North River. Other areas of high relative density included the Rogers River/Rocky Creek area and POI.

ENP (monthly): March 1990 – Feb 1993

Thirty six monthly surveys were flown between March 1990 and March 1993 (August 1992, the month following hurricane Andrew, was not flown). Recorded manatee locations from these surveys are shown in Figure 20, showing manatee sightings along all of the flightline on the southwestern shore and within Whitewater Bay, but sparser sightings along the southern coastline. A summary of counts from each habitat zone is shown in Table 2.

Seasonal habitat use patterns are shown in Figures 22 – 26. Winter use (December – February, Fig. 22) was characterized by concentrations of animals in the inland waters, especially the areas around Wood River, Tarpon Bay, Broad River, and Lostmans Creek. Offshore areas proximate to those inland waters also showed large concentrations of manatees. Whitewater Bay showed an overall low concentration of animals due to its large size, but the smaller Mud Bay and the eastern region of Whitewater Bay had high densities of manatees.

Spring (March – May, Fig. 23) also showed high concentrations of manatees in the Broad River region, along with associated corridors and offshore feeding areas. Several inland basins in the northwestern area of the park, including House Hammock Bay and Turner River, had high spring concentrations, along with associated corridors and feeding areas of Jack Daniels Key and Jewell Key.

Summer (June – August, Fig. 24) showed manatee use in Broad River, Rogers River, and Lostmans Creek, but an even higher use of the offshore feeding area nearby. Whitewater Bay and Mud Bay showed much lower concentrations relative to winter. Further north, Chokoloskee Bay, Lopez River, and House Hammock Bay showed intensive manatee use, along with the feeding areas of Rabbit Key and Demijohn Key.

Fall (September – November, Fig. 25) patterns were similar to those of the summer, with most manatees being found offshore all along the coast in the seagrass beds. There were also frequent sightings far inshore, especially in Broad River and Lostmans Creek to the south, and House Hammock Bay and Turner River to the north.

Collier County (monthly): 1991 – 1993

Manatee distribution surveys were flown approximately monthly from January 1991 to November 1993. Figure 27 shows a map of the manatee sightings for these surveys. The general population distribution and density in each associated basin patch is shown in Figure 28, and Figure 29 shows the variation in raw counts over time and in different habitat zones.

By far, the highest counts of animals and the highest relative density were found in the POI basin and the associated Faka Union Canal. The Fakahatchee River area showed high density with few manatees found in the region because of the limited water surface area in the area. Most other inland areas showed relatively high densities of manatees, as did the travel corridor of the Faka Union Pass, and associated offshore feeding areas. The Russell Key area and associated seagrass beds in the center part of the survey area showed relatively few manatees, but the southern end of the survey area showed high densities in the corridors of Sandfly Pass, Chokoloskee Pass, and Rabbit Key Pass, associated with the high population densities found in Chokoloskee Bay, Barron River, and Turner River.

Ten Thousand Islands: 1999 – 2005

Manatee distribution surveys were flown approximately monthly for Ten Thousand Islands National Wildlife Refuge from November 1999 to January 2005. Figure 30 shows a map of the manatee sightings for these surveys. The general population distribution and density in each associated basin patch is shown in Figure 31, and Figure 32 shows the seasonal variation in counts and habitat use.

This later survey of the Ten Thousand Islands covered a more northern range than the previous Collier County survey, covering from Marco Island in the north to Russell Key in the south. The previous Collier County surveys covered down past Chokoloskee Bay. Similar to the earlier surveys, POI and the Faka Union Canal showed very high raw counts and relative densities. Round Key, and offshore from Cape Romano, also showed high local population levels. The waters between these locations (Coon Key, Brush Island, and Turtle Key) showed low numbers and densities of manatees, indicating that they spent relatively little time traveling through those locations.

Statewide synoptic aerial survey data

Manatee sightings in the study area from the statewide synoptic surveys for the winters of 1991 – 2004 are shown in Figure 33. Manatees were sighted along almost all sections of the flight line, but the kernel density analysis (Fig. 34) showed strong overrepresentation in the inshore rivers and bays relative to the offshore areas. There were three primary areas of high relative density: Mud Bay, Wootens and Big Cypress basins, and POI. The polygon analysis, which accounted for area, showed high-density sites in addition to the preceding three sites, including: Tarpon Bay, Broad River Bay, Fakahatchee River, Marco Island canals, and the Glades canal system (just north of Manatee Bay). Figure 35 shows basins that contained at least 10 manatees during a survey. The same data are shown in Table 3 with associated variability, showing that the minimum values for all sites except POI was zero, reflecting large year-to-year variability. The POI basin and canal complex produced the largest number of raw counts, followed by Whitewater Bay, Marco Island Canals, Wootens Basin, Big Cypress Basin, Fakahatchee River, Mud Bay, and Wood River Bay. Some winter-use sites were not warm water refuges, but represented travel corridors (e.g. Faka Union Canal) or feeding areas (e.g. Round Key).

Carcass salvage data

Salvage records documented 532 carcasses from 1977 – 2004 that were in the area of this study (Table 4; Fig. 36). The cause of mortality could not be determined for 45% of the carcasses recovered in the Everglades area. Of the carcasses where the mortality cause was known, over 40% were from watercraft collisions. Red tide and other natural causes claimed 27%, and perinatal mortality caused 20%. Watercraft collisions were the cause of nearly all human-related mortality: only 2% were caused by other human-related means, and no manatees were known to have been killed by flood gates or canal locks in the area. After analysis for spatial variability in the numbers of undetermined versus known-cause carcasses, the data from undetermined-cause carcasses were separated from the database. All further binomial analyses and displays of carcass salvage numbers by cause were based on known types only.

Spatial patterns in carcass recovery

Carcasses were recovered or verified in 9 of the 11 identified regions in the Everglades study area. Only regions 2 and 3, the open water of Florida Bay and off Cape Sable had no carcasses recovered. These areas are remote, and other surveys (aerial, telemetry) indicated low use by manatees. The regions with the highest density of carcasses were POI, Marco Island, Chokoloskee – Everglades City area, and the east side of Whitewater Bay (Fig. 36). Inland sites were overrepresented in the carcass database, possibly because the carcass of a manatee that dies offshore might drift inland and be found, or float out to sea and be lost, depending on currents and tides.

Undetermined Cause – 234 of the 520 carcasses (45%) recorded in the study area were caused by an unknown mortality agent (Fig. 37). Regions 4 and 5 (Whitewater Bay) showed a significantly higher proportion of undetermined mortality carcasses, possibly due to the remoteness of the area and the low probability of finding a carcass before it decomposes. Conversely, the heavily-populated areas of Marco Island and POI, along with the Florida Keys areas (regions 9, 8a, 1, and K) showed significantly lower proportions of undetermined cause carcasses.

Watercraft mortality – 115 of the 286 carcasses (40%) that were recorded with known mortality agents were killed by watercraft collisions (Fig. 38). Regions 7 and 8, the Everglades City – Chokoloskee area, showed very high numbers of manatees killed by watercraft relative to the entire Everglades region, while POI (region 8a) and especially Marco Island (region 9) had disproportionately low numbers. The Florida Keys area (1 and K) showed high numbers of carcasses killed by watercraft.

Perinatal mortality – 56 of 286 manatee carcasses (20%) were perinatal (young, small manatees; Fig. 39). Marco Island (region 9) and Whitewater Bay (region 4) showed high numbers of perinatal carcasses, and the southern portion of Ten Thousand Islands plus Big Cypress showed low relative numbers of perinatal carcasses.

Cold stress mortality – 31 of 286 manatee carcasses (11%) died of cold stress (Fig. 40). Almost 2/3 of the manatees killed by cold stress were found at POI (region 8a). Whitewater Bay (region 4) also showed high numbers. The sample size of cold stress carcasses was relatively small, so the power of this test was limited.

Other human mortality – only six out of 286 manatee carcasses showed mortality due to human causes other than watercraft (Fig. 41). Several regions showed high relative numbers, but sample sizes were too small throughout the region for the binomial test to provide useful comparisons.

Other natural mortality – 78 of 286 manatees (27%) died of natural causes other than cold stress (Fig. 42). Marco Island (region 9) showed very high relative numbers, and many of these deaths may have been due to red tide. Of the relatively few known-cause deaths in the Lostmans River/Shark River area (region 5), more than half were from "other natural mortality". POI (region 8a) and the southern part of Ten Thousand Islands (region 6) showed low numbers of "other natural" carcasses.

Seasonal patterns in carcass recovery

Most carcasses (300 of 520; 58%) were recovered during the cold months of December, January, and February, and consisted mainly of cold stress and undetermined deaths. The undetermined deaths peaked during and just after the winter months (Fig. 45), and natural mortality, mostly red tide, was disproportionately high during March and April.

The spatial distribution of carcasses in the study area was non-uniform, with a large majority occurring in the northwest area, especially near Chokoloskee, Faka Union Canal, and Marco Island (Fig. 36) – all areas with a large human population. Watercraft deaths and natural deaths due mostly to red tide also were concentrated in this northwest area (Figs. 38, 42). The cause of death could not be determined for a large proportion of the carcasses in the middle and southern portion of the study area, and a large majority of these undetermined or decomposed deaths occurred during the winter (Fig. 45).

Figures 43 and 44 show quarterly spatial patterns in carcass recovery. During the winter quarter, high numbers of carcasses were recovered in the Whitewater Bay region (regions 4 and 5) and POI (region 8a; Fig. 43). This pattern mimicked that of the cold stress carcasses, though the statewide mortality database only started to list cold stress as a separate causative agent in 1986. During the spring quarter, in regions 8 and 9, west of Chokoloskee to Marco Island, high numbers of carcasses were recovered, showing high losses due to red tide in those areas (Fig. 43). During the summer and fall quarters, in region 6, the southern part of the Ten Thousand Islands to Lostmans River, high numbers of carcasses were recovered, all of which were either from watercraft collisions or undetermined causes (Fig. 44). On a yearly basis, the carcass count was rising, but variable, with large differences between years (Fig. 46). Large peaks in the yearly counts may be due to red tide events or cold stress in very cold years.

Radio tracking data

Seasonal movement patterns

Seasonal movement patterns were obtained from Argos PTT data. Composite home range maps for each season are shown in Figures 52 – 55 for the wild-caught animals, and in Figures 48 – 51 for the naïve, captive-raised animals.

Composite home ranges for the wild-caught animals were mostly within the TTI area and northwest portion of ENP. The winter range of 16 of 21 manatees tagged at POI was within 10 – 20 km of POI, but the other five animals made a winter movement to Whitewater Bay. For other seasons, all tagged manatees had home ranges that were within 30 – 40 km of POI (Fig. 52). Areas of high use during winter included the POI capture site (a major winter refuge), the mouth of the Fakahatchee River, and shoals near Cape Romano and Round Key. The other seasonal home ranges were all in or near the TTI area and northwest portion of ENP. Winter and spring (Fig. 53) were the only two quarters that included POI within a 50% quartile zone. During spring, areas of high use included the POI capture site, shoals off Cape Romano, and areas near Turtle Key and Round Key. Summer (Fig. 54) and fall (Fig. 55) home ranges were more dispersed, centering on offshore areas. The Cape Romano shoals were within the highest 25% quartile zone for all seasons, highlighting their importance to manatees as a feeding area. The Pavilion Key shoals were within the 50% quartile zone for summer and fall.

The seasonal changes in home range patterns represented in the composite maps were derived from the home ranges of individual animals, so examination of individual home range maps can reveal patterns in individual movements that contribute to the composite pattern. Figures 56 and 57 show the 2001 – 2002 wet and dry season home range maps for Santina. These maps show that during the dry season, Santina's home range included POI as a regular inland site. During the wet season, she shifted away from this inland site and her home range was focused more on the offshore areas or inland bays. Stith et al. (2004) noted this pattern of using inland sites more during the dry season, especially those that are the most reliable sources of fresh water such as POI. During the wet season, manatees spend more time offshore, foraging on seagrass beds.

GPS tag data showed a pattern similar to the Argos data, but due to the higher spatial and temporal resolution of GPS data, additional insights into the behavior of individuals can be made (Stith et al. 2004). Irrespective of season, most manatees showed a similar pattern of frequent, regular movement between offshore and inland zones (one animal is shown in Figure 58). Tagged manatees typically spent less than a day at inland sites, but often remained on offshore seagrass beds for several days or more. Nearly all manatees showed a similar pattern of alternating between the offshore and inshore zones at regular intervals ranging from 2 – 8 days throughout the year (Stith et al. 2004).

Habitat use patterns of captive-raised animals – Movements of captive-raised animals tend to be different from wild animals, and as such, tell us little about wild manatee usage of the area. Their information is included here for completeness. All but one of the naïve, captive-raised animals were released in Buttonwood Canal, ENP, and most of the releases (six of nine) occurred during the spring. The composite home range map for spring showed a single high use area at Coot Bay (at the release site), and a moderate use area in Coot Bay extending into a small portion of Whitewater Bay (Fig. 48). Low use areas included the eastern side of Whitewater Bay extending into Hells Bay, and an area encompassing Big Lostmans Bay and Lostmans Creek.

The summer pattern of naïve animals showed high use areas in Coot Bay, Joe River, Lane Bay, and the area between Roberts River and North River (Fig. 49). Moderate use areas included most of eastern Whitewater Bay and areas between Roberts River and Hells Bay. Low use areas were found surrounding the moderate-used area of eastern Whitewater Bay, and at the mouth of the Chatham and Huston Rivers.

The fall pattern of naïve animals showed a single high use area within Whitewater Bay, centered on the mouth of the North River, and a moderate use area extending from Watson River to Lane Bay (Fig. 50). Low use areas occurred at Coot Bay, the northeast portion of Whitewater bay, the mouth of the Chatham and Huston Rivers, and the adjacent bay complex from Oyster Bay south to Canon Bay.

The winter pattern of naïve animals showed a single high use area within Whitewater Bay near the mouth of the North River, with a moderate use area extending south to the Roberts River (Fig. 51). Additional areas of moderate and low use were centered at Tarpon Bay, the mouth of the Fakahatchee River, and Addison Bay.

Corridors

The GPS-based corridor analysis showed high use of areas that connected offshore feeding areas with inshore access points for fresh water (Figs. 59 – 63). Moving from west to east in Figure 60, corridors were evident in Snook Channel, Dismal Key Pass, Little Wood River, Faka Union Pass, West Pass, and Fakahatchee River. These corridors were all west of ENP. In Figure 61, additional corridors were evident in Barron River, Chokoloskee Pass, Rabbit Key Pass, Cross Bays, and Lopez River. All of these corridors except the Barron River were within ENP. In Figure 62, additional corridors included the

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Huston and Chatham Rivers, while in Figure 63, weaker corridors were found in Lostmans River into Lostmans Creek, and in the upper Wood River.

Seagrass

Figures 64 and 65 show seagrass beds and a few inshore SAV areas mapped from three separate sources (FMRI, RBNERR, and Collier County). These datasets showed roughly 15 seagrass beds in the ENP boundaries north of Cape Sable, with only one additional bed west of the Park off Cape Romano. There was only limited overlap in identified seagrass beds among the datasets, suggesting that even in combination, they missed a number of significant seagrass beds. Only the two FMRI seagrass datasets extended into the ENP boundaries. The RBNERR data provided information for Fakahatchee and Faka Union Bay, but little coverage of other bays and riverine systems that undoubtedly contain significant food resources for manatees in the region.

Boat surveys

The kernel analysis of boat survey data showed that the northwest region of ENP near Chokoloskee had the largest area of high relative boat density, especially along Chokoloskee Bay near Chokoloskee Pass, Sandfly Pass, and West Pass (Fig. 66). The offshore seagrass beds from Stop Keys south to Pavilion Key, and the mouth of the Chatham/Huston Rivers south to Plover Key also had high boat densities. Another high density area was located in Florida Bay near the Buttonwood and Snake Bight canals, with smaller areas in Coot Bay, Lake Ingraham, and Rankin Key. On the east side of Florida Bay, the area near Nest Keys and the Intracoastal Waterway between Buttonwood Sound and Blackwater Sound showed high densities.

Discussion and Potential Management Approaches

In this report we have tried to extract additional information from aerial survey data using two types of density analyses. Because the data and analyses could only support qualitative comparisons, maps were displayed without numbers. We also used a quantile or log distribution for the coloring scheme to emphasize large differences in relative densities that presumably were substantially greater than errors introduced by unknown biases. Because all but one of these surveys were multi-year, repeat samples that were aggregated across years, random spatial errors likely were smoothed out and the remaining large-scale patterns are not likely to be due to random error associated with small sample size. Nevertheless, we recommend consulting graphs of the raw counts when interpreting the associated maps. We also recommend relying only on the largest relative differences when interpreting the results of these analyses, since substantial biases are known to occur during aerial surveys.

The aerial survey and telemetry data showed similar patterns of manatee habitat use throughout the landscape within ENP. These two methodologies have complementary biases (single-observer aerial surveys have unknown availability and observation biases, but are thought to cover distribution well, while telemetry data show distribution biases limited to the tracked animals, but observability and availability is excellent), so having both survey types showing similar results increases our confidence that the biases were nominal. Because conditions, habitat, and aerial survey methodology and effort changed over the years covered by the various data sets, one would expect to see differences among the surveys. Notwithstanding biases found in single-observer aerial surveys, any similarities seen among years may indicate a robustness in spatial habitat use – a pattern predicted by the species' known high site fidelity.

Manatees are present within most accessible waters in ENP year-round, however their distribution shifts seasonally between the inland and offshore zones. During the winter and spring, manatee distribution is shifted inland, and during the summer and fall, their distribution is shifted offshore (compare Figs. 22 – 24; 52 – 55). During the winter, this inland focus likely is associated with manatees seeking out thermal refuges, whereas during the spring this inland focus may be associated with manatees accessing freshwater. During the summer and fall, freshwater is much more readily available, and manatee distribution shifts to more offshore areas.

Broad patterns in the seasonal home range maps indicate that individual animals change their high use areas seasonally. All four quarterly home range maps (Figs. 52 – 55) show that the Cape Romano Shoals is a high use area and is a strong candidate for additional year-round protection (this area is outside of ENP). Other areas of high or moderate use include within TTI, Caxambas Pass, and shoals near Turtle Key and Round Key. Within ENP, Demijohn Key and Pavilion Key are high use areas. These sites also had high numbers of manatees in the aerial survey data, except that the telemetry-based home ranges for wild-caught manatees did not generally extend into southern ENP (excluding winter). This northerly habitat usage in the telemetry home ranges is probably because nearly all wild-caught, tagged animals were caught at POI, a northern site. Animals caught in the southern Everglades would likely show a more southerly use pattern.

The telemetry data showed individual patterns and heterogeneous behavior of manatees that could not be discovered with aerial surveys or carcass data. For example, tagged, wild-caught animals showed substantial individual variation in winter behavior, with five individuals moving south to Whitewater Bay (Fig. 52) from TTI, six individuals moving north out of the study area, and the remainder wintering in the TTI area. Such behavioral heterogeneity is encouraging from a conservation standpoint, since it means that animals are employing different strategies when seeking out thermal refuges, making the population less vulnerable to a particular type of environmental change (e.g., plant shutdowns) than a population with a single migratory strategy. This heterogeneity is consistent with the well-documented migratory behavior on the east coast of Florida (Deutch et al. 2003).

Vulnerability to cold stress – Manatees in this region of Florida may be very vulnerable to cold stress, especially during severe winters, due to the absence of significant springs or warm water effluent. Anecdotal evidence for cold stress includes observations of dead manatees in the region following strong cold fronts (e.g. Moore 1951a). In some years, physical examination of manatees captured at POI during winter showed signs of acute cold stress (B. Bonde, USGS/Sirenia Project, pers. comm., Feb. 8, 2001). The carcass data analysis for cold stress (Fig. 40) shows that POI, which is the largest winter aggregation site in this region, had very high relative mortality during the winter. The undetermined mortalities are very high in regions 4 and 5 in the Whitewater Bay area (Fig. 37), and these numbers peak strongly during the winter (Fig. 45). While this is highly suggestive of cold stress, boater density also peaks in the winter, which may relate to more undocumented water craft mortalities, or carcasses being more likely to be discovered and reported.

Working under the precautionary assumption that cold stress is a problem for manatees in this region, the winter synoptic survey is probably the best source of data for identifying winter aggregation sites. Analysis of the 1991 – 2004 winter synoptic survey indicate that Whitewater Bay, including adjacent areas such as Mud Bay, Joe River, Rogers River, and North River, are important aggregation sites for manatees in ENP (Fig. 34). Several other inland sites north of Whitewater Bay also are important, including Broad River Bay, Wood River Bay, Rogers River Bay, and Lostmans Creek. The 1990 – 1993 aerial survey shows a similar spatial pattern for winter season densities (Fig. 22). Counts in these sites tend to vary considerably from year to year (Fig. 35), presumably depending in part on the severity of the winter and timing of surveys with cold front. The lack of large aggregations such as are seen in the TTI area belies the fact that large numbers of manatees overwinter in ENP, but they are scattered across the landscape in smaller aggregations. These surveys likely underestimate the use at identified sites, due to turbid conditions where manatees aggregate, and do not include some winter-use sites that may exist outside of the surveyed area.

The potential exists for boaters or even canoeists to disturb manatees that are thermoregulating in these small winter aggregation sites. The boat density data (Fig. 66) did not show a strong overlap between boats and winter aggregation sites. Nevertheless, a single boat or canoe can easily cause thermoregulating manatees to flee from an aggregation site, so protecting such sites may be especially beneficial to manatees (Sorice et al. 2003). One established approach to lessening the impact of boats in these sites is to create seasonal sanctuaries where entry by any vessel is prohibited during the winter (Buckingham 1999). The system of seasonal sanctuaries at Crystal River National Wildlife Refuge, as well as at most major warmwater aggregation sites state-wide, has been used successfully for many years, allowing manatees to thermoregulate without disturbance, while boaters are still able to use the open waters adjacent to the sanctuaries (50CFR 17.103; 62 Federal Register 63036-63038). This strategy may be most appropriate for the canals at POI, Wootens, and Big Cypress, where significant numbers of manatees overwinter in the TTI. The boat density data suggest that many of the small aggregation sites in

ENP (e.g. Mud Bay) are not often used by boaters, so establishing seasonal sanctuaries would have little impact on fishing or recreation.

Analysis of tracking data has revealed insights to manatee overwintering strategies in the TTI and ENP region. Winter aggregation sites north of ENP in the TTI area are mostly associated with deep, dredged canals. As cold fronts pass, temperatures in these deeper waters drop more slowly than in the adjacent shallow bays and gulf. These canals often have a pronounced thermocline/halocline with warmer, salty water on the bottom (USGS-FISC, unpub.). In ENP, few accessible canals exist; the Buttonwood canal has rather small winter aggregations compared to the deeper canal systems in the TTI region. Instead, manatees in ENP seem to be using small dead-end bays (e.g. Mud Bay) or deeper, bay-like sections of rivers (e.g. Broad River Bay, Tarpon Bay, and Wood River). The mechanisms that create the warmer water may vary among these sites. During strong cold fronts, shallow water cools rapidly, while deeper pockets of water may show a lag in cooling that allow manatees to bottom rest. The temperature of groundwater in this region is much warmer than the ambient water temperature during much of the winter, so areas with significant groundwater seepage may accumulate layers of warm water. If the groundwater beneath tidally-influenced rivers is saline, groundwater seepage may establish haloclines with heavier saline water on the bottom, which maintain temperature inversions such as those observed at POI (USGS, in prep.). Haloclines have recently been recorded in association with manatee sightings during the winter at Rogers River (B. Loftus, pers. obs.; information provided by R. Snow). Following the passage of cold fronts, shallow areas heat up rapidly due to solar radiation and become the focus of manatee use (J. Reid, pers. obs.). Also, soft sediments likely provide additional insulation and reduce heat loss for bottom resting manatees. There is speculation that bacterial decomposition of organic matter in the muddy substrate may provide additional warmth. Submerged and emergent aquatic vegetation also may have an effect on winter water temperature (R. Snow, pers. comm.). Further investigation of the mechanisms that produce the warm water sought out by manatees in ENP is underway by USGS-FISC.

Access to freshwater – Some evidence indicates that manatees need regular access to freshwater, presumably for drinking and osmoregulation (Ortiz et al. 1999; Stith et al. 2004). The availability of freshwater changes dramatically with season (e.g. Figs. 15 – 16), and aerial survey data showed that during the dry season (Fig. 23), more manatees were seen inland than during the wet season (Figs. 24 – 25). Seasonal patterns developed from the telemetry data for wild-caught individuals were very similar to the aerial survey patterns (compare Fig. 53 with 54 – 55).

Analysis of tagged individuals showed that all manatees made frequent trips up rivers and creeks (e.g. Fig. 56). The frequent movement of individual manatees between the offshore and inland areas means that all manatees are using relatively narrow rivers and creeks (Fig. 59 – 63), especially during the cold and dry season. Manatees seeking freshwater may travel far upstream into narrow, shallow areas where they are especially vulnerable to boats. Speed restrictions for boats may be warranted in those areas where manatees are restricted in movement and cannot easily avoid collisions, especially during the winter and spring when manatee use of these areas is higher.

Corridor Use – Carcass data indicate that the Chokoloskee region had disproportionately high watercraft mortality (Fig. 38). The boat density data also showed that this area had the largest area of high density boat use within ENP (Fig. 66). Several major travel corridors cross this region, including Chokoloskee Pass and Rabbit Key Pass (Fig. 61). These travel corridors connect offshore seagrass beds to Chokoloskee Bay and into the Baron River, Turner River, Cross Bays, and Lopez River (Figs. 24 – 25, 54 – 55). In contrast, two other regions outside of ENP with major corridors and high boat traffic, POI and Marco Island, have disproportionately low watercraft mortality. Possible explanations for Chokoloskee's high relative mortality include inadequate speed zones, poor boater compliance, insufficient enforcement, and low rates of other types of mortality compared to POI (with high cold stress) or Marco Island (with high red tide). The speed zones in the inland bay portion of ENP from Gate Bay to Chokoloskee Bay in general are less restrictive (or non-existent) than in adjacent portions of Collier county, where speed limits typically are 30 mph in channels and 20 mph outside channels (Fig. 67). To reduce watercraft strike mortality, it may be sensible to implement the Collier County speed restrictions throughout the inland bay portions of ENP, so that the entire bay section from Gate Bay through Chokoloskee Bay has consistent, more restrictive speed zones.

Offshore foraging areas – Throughout the year, and especially during the summer and fall, high relative densities of manatees were found in offshore seagrass beds (Figs. 24 – 25, 54 – 55). The aerial survey and telemetry data showed that relative use of these offshore areas was non-uniform, with some areas showing much higher use than others (Figs. 18 – 36, 52 – 55). In general, aerial survey data showed that during the winter and dry season, relative densities in offshore areas of ENP were highest near Lostmans and Broad Rivers, which are the seagrass beds closest to inshore hotspots for these two seasons (Figs. 22 – 23). During the summer and fall, offshore use was more widely distributed and extensive, shifting into the more northerly portions of ENP (Figs. 24 – 25). Manatees feeding in these offshore seagrass beds often are in very shallow water and are very vulnerable to boat strike. Speed restrictions in shallow, high-use foraging areas may be appropriate, especially in the offshore areas of Chokoloskee, Faka Union, and Marco Island regions where boat densities (Fig. 66) and watercraft mortalities are high (Fig. 38).

Inshore bays – Aerial survey data showed that several of the larger inshore bays in the region had relatively high manatee densities. Chokoloskee Bay had overall high densities for all seasons (Figs. 22 – 24), while eastern Whitewater Bay had high densities only in winter. Smaller bays are seasonally important, especially in the cold and dry season (see above). Telemetry data suggest that some manatees forage preferentially within inshore bays, although the majority of use by tagged animals occurred in offshore seagrass beds (Figs. 53 – 55; winter being the exception, Fig. 52).

Insights from telemetry data – Analysis of the telemetry data shows an important pattern that is not evident from aerial survey or carcass data. All tagged individuals showed regular movement between access points for freshwater and areas with preferred forage (example – Fig. 58). When these two resources are close together, manatee movements may be relatively small, but all of the wild-caught animals tracked for significant periods in the study area showed regular, multi-kilometer movements between different habitat zones. This behavior has implications for managing the population. For example, establishing individual sanctuaries at high use areas such as Pavilion Key will not offer complete protection, since the telemetry data show that they all regularly move in and out of these high use areas. This suggests that strategies for protecting manatees in ENP will require a network approach that considers high use areas in offshore and inshore areas and their connecting corridors. For example, the aerial survey data show that Upper and Broad River Bay have consistently high relative densities, as do the offshore zones near the mouth of the Broad River (Figs. 22 – 25). Manatees with home ranges in this area likely are traveling regularly between these offshore and inland zones, and any shallow water or narrow passage in each zone or connecting corridor may warrant reduced speed zones.

A network view of manatees in ENP – Resources used by manatees in ENP can be viewed as occurring on a seasonally changing network, where the network consists of warm water sites, sources of fresh water, and foraging areas. On a broad scale, some manatees migrate into ENP from the north during the winter, and others migrate north out of the region, while a very few migrate to or from the Atlantic population. The limited telemetry data for wild-caught individuals suggests that the majority of manatees in the region are year-round residents. The winter network for these year-round residents may be smaller than during other seasons, consisting of warm-water nodes in inland canals, rivers, creeks and bays (Table 3; Fig. 35), all connected to nearby foraging areas by corridors formed by rivers or tidal channels. These warm-water sites may be deserving of special protection during the winter since they may constitute a critical resource that can be disrupted by minor human disturbance. An example of such a site is Mud Bay (Fig. 7), which appears to be a relatively small but important winter aggregation site (Figs. 22, 34) that has low use during other seasons.

As water temperatures climb with the approach of spring, these warm-water nodes may become less important, and nodes providing increasingly scarce freshwater may become more important. However, there is considerable overlap in the winter and dry season inland sites (compare Figs. 22 and 23). These nodes commonly are located up narrow creeks and shallow marshes where manatees would have difficulty evading fast moving powerboats. Examples of tagged manatee movements in such restricted areas can be seen in Figures 59 – 63, and in the aerial survey data (Fig. 23), where the Upper Broad River appeared to have especially high relative densities. Although boat densities may be low in such areas (Fig. 66), speed restrictions may still be warranted due to the narrow, shallow water conditions for both manatees and boaters. During the spring, the high use nodes increasingly extend into offshore areas where good forage is available.

As summer approaches, freshwater nodes become less important, and high use areas shift increasingly towards offshore areas or inshore bays with good forage (Fig. 24). The advent of low salinities is generally delayed in the southern part of ENP relative to the TTI area, so the shift to offshore areas may be delayed in those areas as well. During summer and fall, manatee and boat densities show the highest overlap, generally in the offshore seagrass beds or inshore bays, especially in the Chokoloskee region (compare Figs. 24 – 25 versus Fig. 66). Speed restrictions may be appropriate within these shallow, high-use foraging areas, particularly where boat traffic is high or where manatee movement is highly restricted, such as small passages between offshore islands. Viewing manatee use in ENP as a changing network of feeding areas, travel corridors, and inland sources of warm water or freshwater will provide a more comprehensive, dynamic view of how to protect the local population.

There is a major gap in information about food resources available to manatees in this region. Manatees likely are foraging on a wide variety of resources, and these resources differ among landscape zones. Resources in the offshore zone are associated with seagrass beds consisting of *Thalassia testudinum* (turtle grass), *Halodule wrightii* (shoal grass), and *Syringodium filiforme* (manatee grass), all of which are likely to be abundant throughout the region (Zieman 1982; Sargent 1995). Researchers following radio tracked manatees in the TTI have documented the occurrence of these species and their use as forage by manatees. Seagrasses are almost certainly more extensive than is mapped from data available for this region (Figs. 64, 65). Little is known about long-term changes in these seagrass beds, and whether they change significantly in composition or extent seasonally. Florida Bay is the exception, where studies have documented major seagrass declines starting in the late 1980s (Hall et al. 1999).

Even less is known about the potential food resources within bays, river systems, or freshwater marshes used by manatees. The home range analysis and telemetry maps (Figs. 48 – 57) showed that the offshore zone was a major focus of activity for most individuals, but some individuals spent a substantial proportion of their time within inshore bays, rivers, and a few accessible marshes. The food resources available in these less saline ecozones may vary significantly both seasonally and annually, and the plant communities are likely to be much more dynamic compared to the offshore seagrass beds. For example, during the wet season, species that favor less saline conditions, such as *Ruppia* and *Chara*, may establish and grow rapidly in river mouths and nearby bays, only to die back during the dry season when conditions favor species such as *Halodule* that favor higher salinities. Human modifications to freshwater inflow into these bays may have greatly altered the composition and abundance of SAV in many of these bays, probably favoring more salt-tolerant species (Tabb et al. 1974; Davis and Hilsenbeck 1974). Restoration activities may favor the re-establishment and growth of new SAV communities in these bay and river systems through increased and more prolonged freshwater discharge. However, excessive freshwater discharge could potentially damage nearby seagrass beds, and might induce manatees to shift their home ranges and/or use of specific corridors.

Future research needs

There are several areas where improved data collection would enhance our understanding of manatee habitat use and potential impacts of human activities within the study area. Satellite-based telemetry methods, especially with GPS technology, are needed in the southern part of the study area, because most existing telemetry data are from animals using the TTI and northern portion of ENP. More efforts in this direction are underway by the USGS, and will provide more detailed information about seasonal use of microhabitats in and around Whitewater Bay, and the inland waterways. Corridor use and potential areas of increased conflict with boats is another area where GPS technology will improve our knowledge.

Physical mechanisms that produce warm water used by manatees during the winter are poorly understood in this region. There are no artificially warmed water sources such as power plants in the entire study region. The largest winter aggregation site, the POI basin, is an artificial but passively warmed refuge. One mechanism by which the POI basin retains its warm water appears to be by a thermal inversion layer, where warm salt water is trapped under a layer of fresh water. The origin of this salt water layer is unknown, though possible mechanisms include trapping of warm tidal water, upwelling of salty groundwater, bacterial metabolic processes, or combinations of all of the above. It is unclear if the mechanisms operating in natural sites in ENP are similar to those of deeper canal sites, where warm water attraction seems to be associated with haloclines. More research in this area is being performed by USGS-FISC under an FY06 CESI/PES study.

A third area where better research and methodology would be useful is aerial surveys. In the past, these surveys have been useful for locating aggregation sites and as indicators of manatee distribution over wide ranging areas, but have unresolved problems for estimating abundance. Known biases to aerial surveys include availability bias, where the animal may or may not be visible when the plane flies overhead, operator bias, where the observer may not recognize a visible manatee, and location bias, where the plane may not be flying in the right place to see a manatee. These problems prevent us from analyzing aerial survey data in more detail than the gross analyses that were displayed here, and even these simple relative-abundance maps have been questioned by some researchers as being beyond the scope of the data. New survey methodologies, including double observer, reflight methods, removal sampling, and more comprehensive flight lines, are being investigated. These improved methods should be encouraged and continued, because they provide mechanisms by which biases can be estimated and compensated for, giving a more accurate picture of manatee distribution and abundance in the region. This research need is also being addressed by USGS-FISC in an FY06 CESI/PES study.

A fourth area where additional data collection is needed is photo-identification of manatees for estimation of population parameters such as survival rates and fecundity. Scar patterns and other unique markings of individual manatees are photographed underwater or while manatees are at the surface. These patterns of unique marks allow researchers to track individual animals over time, and can be analyzed using sophisticated techniques to generate population parameter estimates. The southwest region is the only part of Florida that has virtually no data useful for conducting these important analyses, which are crucial for monitoring the status of the manatees in the region (see Runge et al. 2004; Langtimm et al. 2004; Kendall et al. 2004). Limited access and poor water visibility in this area have hampered efforts in the past.

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Another area of research concerns the potential impacts of the Everglades restoration on manatees. Restoration will alter the distribution, timing, and quantity of freshwater discharge throughout the region, potentially changing the availability of warm water and freshwater. Collaborative efforts between USGS-FISC hydrological and ecological modelers are being initiated to address this issue. Newer information is needed on boat usage across ENP, and surveys are now underway to address this need. Current boating information collected by TTINWR and Mote Marine should also be incorporated into boat usage analyses. These data will be very useful to identify areas of potential conflict between boats and manatees.

Although limited information is available on seagrasses and SAV in the region, new seagrass mapping efforts are underway based on aerial photography obtained during spring 2006. Such efforts should not be restricted to offshore seagrass beds only, and should include mapping of SAV communities in the bays, river systems, and accessible marshes. Comprehensive spatial information is important 1) for analyses of resource use by manatees in all habitat zones across the region, 2) to provide a baseline for comparison of pre- and post-restoration conditions, and 3) to model the potential impacts of restoration on seagrasses and manatee distribution and abundance. Ecologists and biologists from USGS-FISC are also pursuing seagrass mapping using manatee telemetry tracking data from the Everglades and TTI regions.

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Signature Page

Supervisory approval:

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Appendix 1 – Data files and metadata.

All data files are provided on a CD. The contents of the CD with a brief description of the data file names, locations, and contents are provided below and on the root directory of the CD in a file called "Files.doc".
All GIS files are in ESRI Shape format.
All data were projected to UTM zone 17, NAD 1983, map units in meters.
Metadata descriptions are provided with data files in .xml format. The metadata files are too long to include in this report.

1979 – 1981 ENP Aerial surveys

File Name	Directory	Contents
bass_survey	AerialSurveys\1979-1981 ENP	Flightline
1979_1981manatee_UTMNAD83.shp	AerialSurveys\1979-1981 ENP	Manatee count data from 1979 – 1981 survey in ENP

1986 – 1993 Collier County Aerial Surveys

File Name	Directory	Contents
z_collier1986-1993.shp	AerialSurveys\1986-1993 Collier County	Manatee count data from 1986 – 1993 survey in Collier County
FLTMC90_UTMNAD83.shp; FLTPRT_UTMNAD83.shp; FLTTEN_UTMNAD83.shp	AerialSurveys\1986-1993 Collier County	Flight lines for 1986 – 1993 survey in Collier County

1990 – 1993 ENP Aerial Surveys

File Name	Directory	Contents
z_man90-93mrg.shp	AerialSurveys\1990-1993 ENP	Manatee count data from 1990 – 1993 survey in ENP
man_flt_path_UTMNAD83.shp	AerialSurveys\1990-1993 ENP	Flight line for 1990 – 1993 survey in ENP

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1991 – 2003 Statewide Synoptic Aerial Surveys

File Name	Directory	Contents
z_syn_1991to2003utm_nad83.shp	AerialSurveys\1991-2003 Statewide Synoptic	Manatee count data from 1991 – 2003 Statewide surveys
2004_Synoptic_flight_path_UTMNAD83.shp	AerialSurveys\1991-2003 Statewide Synoptic	Flight line for 1991 – 2003 Statewide surveys

1999 – 2005 TTI Distributional Aerial Surveys

File Name	Directory	Contents
distrib_zones_mar05.shp	AerialSurveys\1999-2005 TTI Distributional	Manatee count data from 1999 – 2005 Ten Thousand Islands surveys
flightline_UTM_NAD83.shp	AerialSurveys\1999-2005 TTI Distributional	Flight line for 1999 – 2005 Ten Thousand Islands surveys

Polygon files for patches and regions

File Name	Directory	Contents
zones_sirenia.shp	Basin	Basin/habitat zones for region

Manatee Carcass data

File Name	Directory	Contents
mort_1976_2004_enp.shp	Carcass	Carcass data from 1976 – 2004 for region
ENP_Zones	Carcass	Polygons showing proportional differences among regions for each mortality type

Telemetry data from Argos PTT and GPS

File Name	Directory	Contents
Individual-kernel-crossref.doc	Telemetry\FWC\PTT\IndividualData\Grids	File showing indexing scheme to cross-reference manatee-season by kernel# for home range for FWC tagged animals
kernel1, kernel2…kernel105	Telemetry\FWC\PTT\IndividualData\Grids	Arcview home range grids for 44 manatee-season combinations from Argos PTT data obtained from FWC

.
Telemetry data from Argos PTT and GPS (Continued)

File Name	Directory	Contents
1kernel_95, 2kernel_95, …105kernel_95	Telemetry\FWC\PTT\IndividualData\ShapeFiles	Arcview home range shapefiles with 95% and 50% contours for 44 manatee-season combinations from Argos PTT data obtained from FWC
OverlayCalc.doc	Telemetry\FWC\PTT\OverlayData\Grids	File showing map calculator commands to create overlay grids for select FWC tagged animals
Winter, spring, summer, fall	Telemetry\FWC\PTT\OverlayData\Grids	Overlay of ArcView home range grids by season from Argos PTT data obtained from FWC
Individual-kernel-crossref.xls	Telemetry\USGS\PTT\IndividualData\Grids	File showing indexing scheme to cross-reference manatee-season by kernel# for home range for USGS tagged animals
kernel1, kernel2…kernel104	Telemetry\USGS\PTT\IndividualData\Grids	Arcview home range grids for 86 manatee-season combinations from Argos PTT data obtained from USGS
1kernel_95, 2kernel_95, …104kernel_95	Telemetry\USGS\PTT\IndividualData\ShapeFiles	Arcview home range shapefiles with 95% and 50% contours for 86 manatee-season combinations from Argos PTT data obtained from USGS
OverlayCalc.doc	Telemetry\USGS\PTT\OverlayData\Grids	File showing map calculator commands to create overlay grids for select USGS tagged animals
Winter, spring, summer, fall	Telemetry\USGS\PTT\OverlayData\Grids	Overlay of ArcView home range grids by season from Argos PTT data obtained from USGS

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Report

File Name	Directory	Contents
FinalReport.doc	root	Final report with all maps and graphics

Background Landscape Files

File Name	Directory	Contents
Gap_sf_nad83.rrd	GISBackground	Landsat Classification modified from GAP project
SFL_shoreline_24k.shp	GISBackground	Shoreline file

Zones

File Name	Directory	Contents
Swfl_patches_manatee	Zones\Patch	Polygon file of patches representing river basins, bays, shoals, etc.
ENP_Zones	Zones\Regional	Polygon file of regions

Seagrasses

File Name	Directory	Contents
FMRI_seagrass_swcoast_fl_1987_poly	SeaGrass	Polygon file of seagrass beds, FMRI 1987 survey
FMRI_seagrass_scars_1991to1994	SeaGrass	Polygon file of seagrass beds, FMRI scar surveys
collierseagrass	SeaGrass	Polygon file of seagrass beds, Collier County
10-40_sav	SeaGrass	Polygon file of seagrass beds, RBNRR survey, Cape Romano, low density
40-100_SAV	SeaGrass	Polygon file of seagrass beds, RBNRR survey, Cape Romano, high density
Export_10-40SAV	SeaGrass	Polygon file of seagrass beds, RBNRR survey, Fakahatchee, low density
Export_40SAV	SeaGrass	Polygon file of seagrass beds, RBNRR survey, Fakahatchee, high density

.

Table 1. Total counts of manatees sited during distributional aerial surveys conducted in ENP from December 1979 to September 1981.

Survey Date	Fall	Spring	Summer	Winter	Grand Total
12/31/79				91	91
1/31/80				45	45
2/27/80				30	30
4/29/80		23			23
5/22/80		30			30
6/25/80			25		25
7/29/80			40		40
8/28/80			48		48
9/30/80	47				47
10/22/80	11				11
11/24/80	32				32
1/2/81				5	5
1/22/81				166	166
3/5/81		23			23
3/25/81		79			79
4/30/81		9			9
5/28/81		17			17
7/1/81			12		12
8/6/81			13		13
9/3/81	21				21
9/24/81	12				12
Grand Total	123	181	138	337	779

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Table 2. Total counts of manatees sited during distributional aerial surveys conducted in ENP from October 1990 to March 1993.

Year-Month	Bay	Channel	Inland	Offshore	Total
1990-10	5	2	11	13	31
1990-11		1	14	9	24
1990-12	2		20	1	23
1990-3	1	1	12	4	18
1990-4		1	9	2	12
1990-5	2		7	5	14
1990-6	4	1	22	16	43
1990-7	10	2	22	40	74
1990-8	6	3	13	20	42
1990-9	4	1	9	10	24
1991-1	4	1	42	5	52
1991-10	10	7	29	32	78
1991-11	14	2	31	25	72
1991-12	10	2	25	23	60
1991-2	8	1	79	6	94
1991-3	5	1	34	7	47
1991-4	5	1	26	4	36
1991-5	4	1	27	18	50
1991-6	8	9	38	37	92
1991-7	16	2	21	28	67
1991-8	12	6	32	44	94
1991-9	10	7	19	28	64
1992-1	6		35	6	47
1992-10	8	1	12	57	78
1992-11	5	3	29	23	60
1992-12	10	2	36	31	79
1992-2	8		56	5	69
1992-3	2	2	40	9	53
1992-4	6	5	42	28	81
1992-5	8	5	46	40	99
1992-6	10		44	21	75
1992-7	14	5	22	29	70
1992-9	9	1	27	57	94
1993-1	5	1	39	7	52
1993-2	9	2	38	21	70
1993-3	3	1	25	17	46

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Table 3. Winter use sites with at least 10 manatees recorded during at least one synoptic survey. Note that some of these heavily used winter sites are travel corridors or feeding sites rather than thermal refuges.

Place	max	min	mean	st. dev.
Faka Union Basin (POI)	192	30	88.80952	50.30668
Whitewater Bay	93	0	16.14286	20.58953
Marco Is. Canals	55	0	13.66667	13.73074
Faka Union Canal	41	0	6.809524	9.887462
Wootens Basin	40	0	10.7619	8.543446
Big Cypress Basin	38	0	17.14286	9.593152
Fakahatchee River	34	0	6.333333	8.21178
Fakahatchee Bay	31	0	4	7.98749
Round Key	30	0	1.666667	6.521758
Mud Bay (WB)	28	0	10.47619	8.225686
Broad River Bay	27	0	2.47619	6.368823
Wood River Bay	27	0	1.285714	5.891883
Panther Key	25	0	1.952381	5.426566
Cape Romano	25	0	1.190476	5.455447
Joe River	24	0	4.714286	6.380775
Chokoloskee Bay - East	20	0	2.761905	5.476356
Blackwater Sound	19	0	6.619048	5.783392
White Horse Key	19	0	1.190476	4.226335
Faka Union Pass	17	0	1.190476	3.723158
Chevelier Bay	15	0	1.714286	3.976718
Rogers River Bay	14	0	2.47619	4.032605
Lostmans Second Bay	14	0	1.571429	3.075247
House Hammock Bay	13	0	1.47619	3.059723
North River	12	0	2.952381	3.528118
Shark River	12	0	2.52381	3.429563
Upper Broad River	12	0	2.142857	3.539572
Big Lostmans Bay	12	0	1.285714	2.968886
Tarpon Bay	11	0	3.857143	3.070598
Faka Union Bay	11	0	2.52381	3.444112
Lostmans Creek	11	0	2.285714	3.393271

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Table 4. Carcass data for the study area (1979 – 2004) by death category for each month. Data obtained from FMRI.

Month	Watercraft	Other Human	Perinatal	Cold Stress	Other Natural	Verified / Not recovered	Undetermined / Decomposed	Undetermined / Other	Grand Total
1	12	1	6	12	11	1	18	16	77
2	10		2	9	2	6	26	17	72
3	15	1	7	2	18	5	27	9	84
4	8		5		22	1	17	4	57
5	11		9		2	4	7	3	36
6	9		8		2		3	6	28
7	8	2	3			1	13	2	29
8	11		2		2	1	6	1	23
9	5		5		2	4	1	3	20
10	10	1	1		1	1	3	5	22
11	2				8	1	8	2	21
12	19	2	4	8	10	4	9	7	63
Grand Total	120	7	52	31	80	29	138	75	532

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Table 5. Argos telemetry summary data (ALL CAPS names from USGS and Initial Caps names from FWC).

NAME	PTT Id	Tag start date	Tag end date	#days tracked	# days w/fixes	Total # fixes	Mean # daily fixes
ACTUAL	TNP-18	1/24/2002	1/22/2003	364	310	991	3.20
ADDISON	TNP-05	2/7/2001	3/30/2002	417	411	1,238	3.01
ALBERT	TNP-16	1/23/2002	4/25/2002	93	89	281	3.16
Andrea	TTB040	8/17/1994	9/11/1994	26	20	31	1.55
ANNA	TNP-11	3/21/2001	2/28/2003	710	609	1,808	2.97
April	TSW024	3/16/2000	3/24/2000	9	8	17	2.13
Aurora	TSW012	5/19/1998	8/20/1998	94	94	568	6.04
CHUCK	TNP-22	12/8/2002	2/26/2003	81	43	115	2.67
CUPID	TNP-13	8/16/2001	10/17/2001	63	63	186	2.95
D.Dahoon	TSW015	3/18/1999	8/3/1999	139	137	475	3.47
DEANO	TNP-15	1/24/2002	3/27/2002	63	61	143	2.34
Debbie	TTB034	8/6/1994	8/20/1994	15	12	15	1.25
Demi	TTB018	10/8/1992	5/14/1993	219	169	440	2.60
Easter	TTB019	10/26/1992	10/31/1992	6	6	14	2.33
Foster	TSW013	5/19/1998	12/16/1998	212	211	1,189	5.64
GRACE	TNP-09	2/8/2001	5/31/2002	478	445	1,217	2.73
Grahm	TTB053	9/7/1995	12/17/1996	468	432	1,088	2.52
GULLIVER	TNP-19	12/7/2002	2/28/2003	84	74	196	2.65
Jemp	TTB049	12/28/1996	12/25/1997	363	58	167	2.88
LEECH	TSW-19	8/29/2001	11/13/2001	77	76	239	3.14
LESLIE	TNP-10	3/21/2001	11/18/2002	608	582	1,660	2.85
Lynda	TSW025	3/16/2000	10/3/2000	202	124	257	2.07
Marjorie	TTB051	9/7/1995	10/5/1995	29	27	62	2.30
MEGAN	TNP-04	2/7/2001	4/23/2002	441	423	1,171	2.77
MITZIE	TNP-17	1/25/2002	2/26/2003	398	175	507	2.90
Mystic	TSW026	3/16/2000	4/25/2001	406	346	1,149	3.32
Naples	TTB039	8/15/1994	5/23/1996	648	454	868	1.91
NINA	TNP-06	2/8/2001	9/20/2001	225	223	723	3.24
Noah	TSW014	5/20/1998	10/6/1998	140	134	720	5.37
NOEL	TNP-08	2/8/2001	2/16/2001	9	9	27	3.00
PEGGY LEE	TNP-14	1/23/2002	3/23/2002	60	56	164	2.93
PIPE	TSW-34	8/31/2001	10/29/2001	60	60	166	2.77
POI	TNP-01	8/1/2000	8/6/2001	371	39	101	2.59
PORTER	TNP-20	12/9/2002	12/31/2002	23	16	27	1.69
Roca	TSW016	3/18/1999	4/29/1999	43	40	101	2.53
ROUNDER	TNP-12	3/21/2001	7/4/2001	106	104	300	2.88
SANTINA	TNP-07	2/7/2001	1/22/2003	715	683	2,123	3.11

.
Table 5 (Continued). Argos telemetry summary data (from USGS and FWC).

NAME	PTT Id	Tag start date	Tag end date	#days tracked	# days w/fixes	Total # fixes	Mean # daily fixes
SURFER	TNP-02	8/1/2000	10/4/2001	430	425	1,278	3.01
Sweetpea	TTB058	11/11/1996	11/14/1996	4	2	3	1.50
THUMPER	TNP-21	12/8/2002	2/27/2003	82	50	116	2.32
TIPPER	TNP-23	12/11/2002	2/8/2003	60	50	125	2.50
Valentine	TTB052	9/7/1995	3/16/1998	922	628	2,157	3.43
Zephyr	TTB013	7/28/1992	9/27/1992	62	46	137	2.98
Totals				10025	8,024	24,360	

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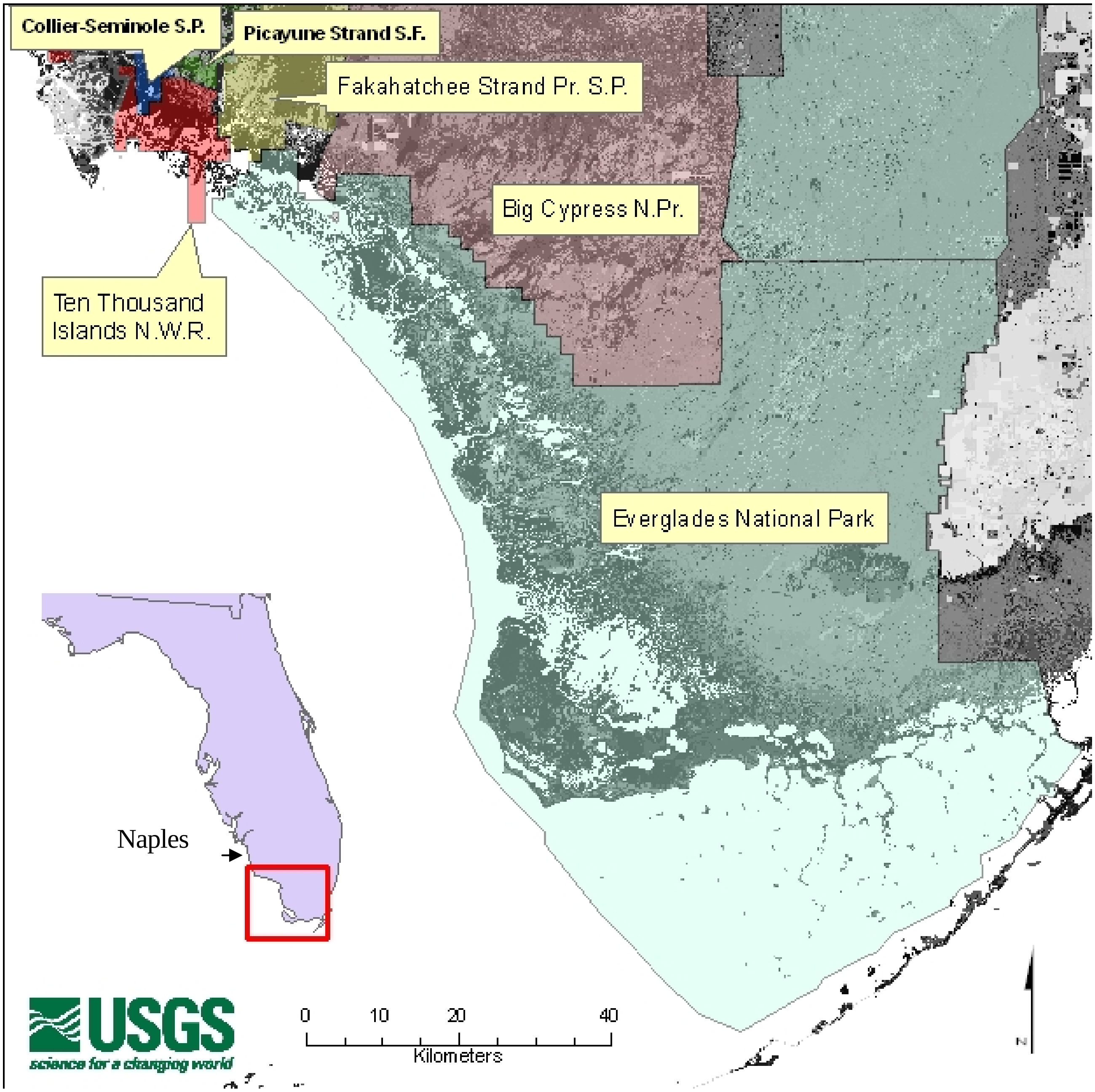

Figure 1. Map of study area showing major protected areas.

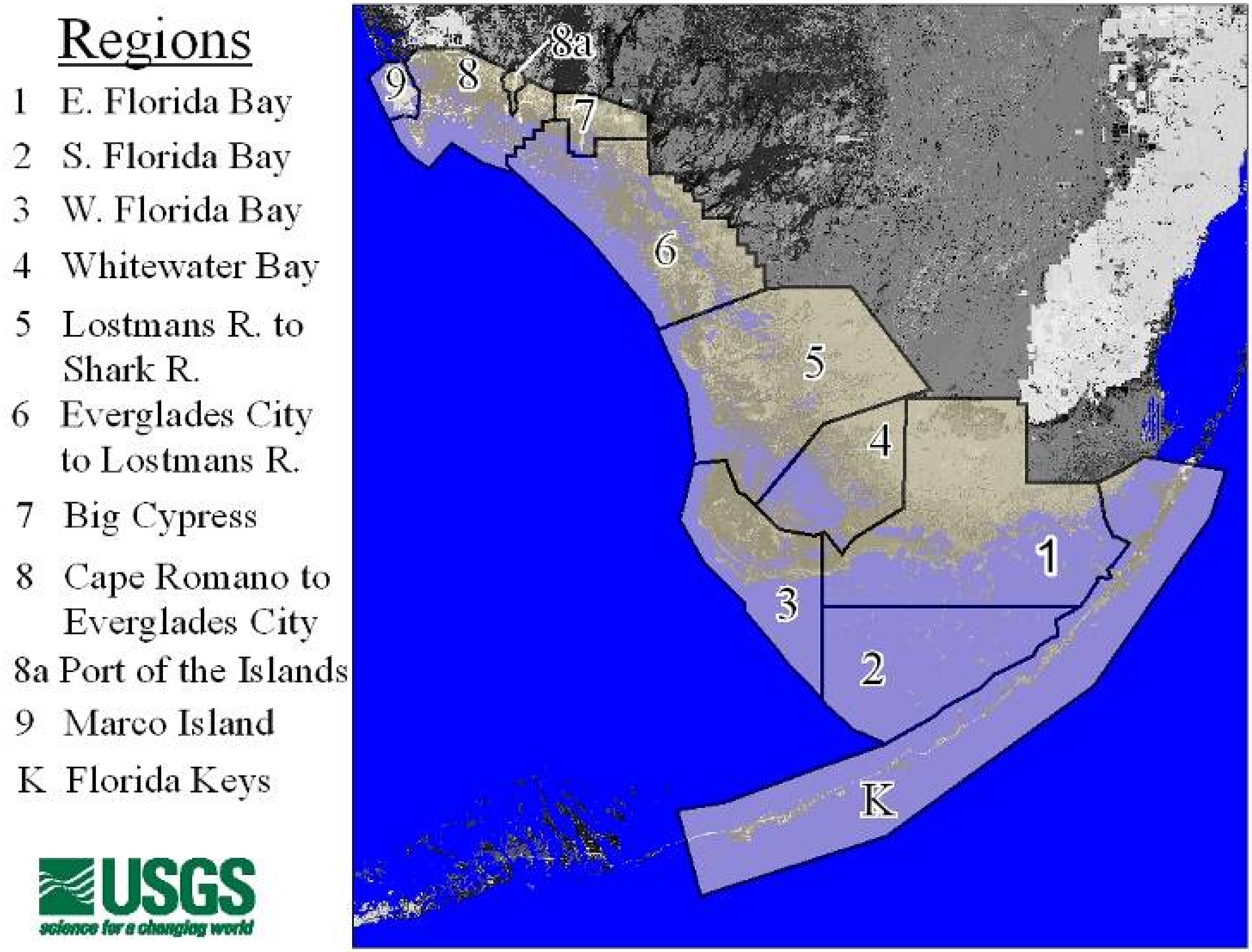

Figure 2. Map of the major regions of the Study area, including six regions within Everglades National Park (1 – 6) and five newly-delineated regions in the surrounding area (K, 7 – 9)

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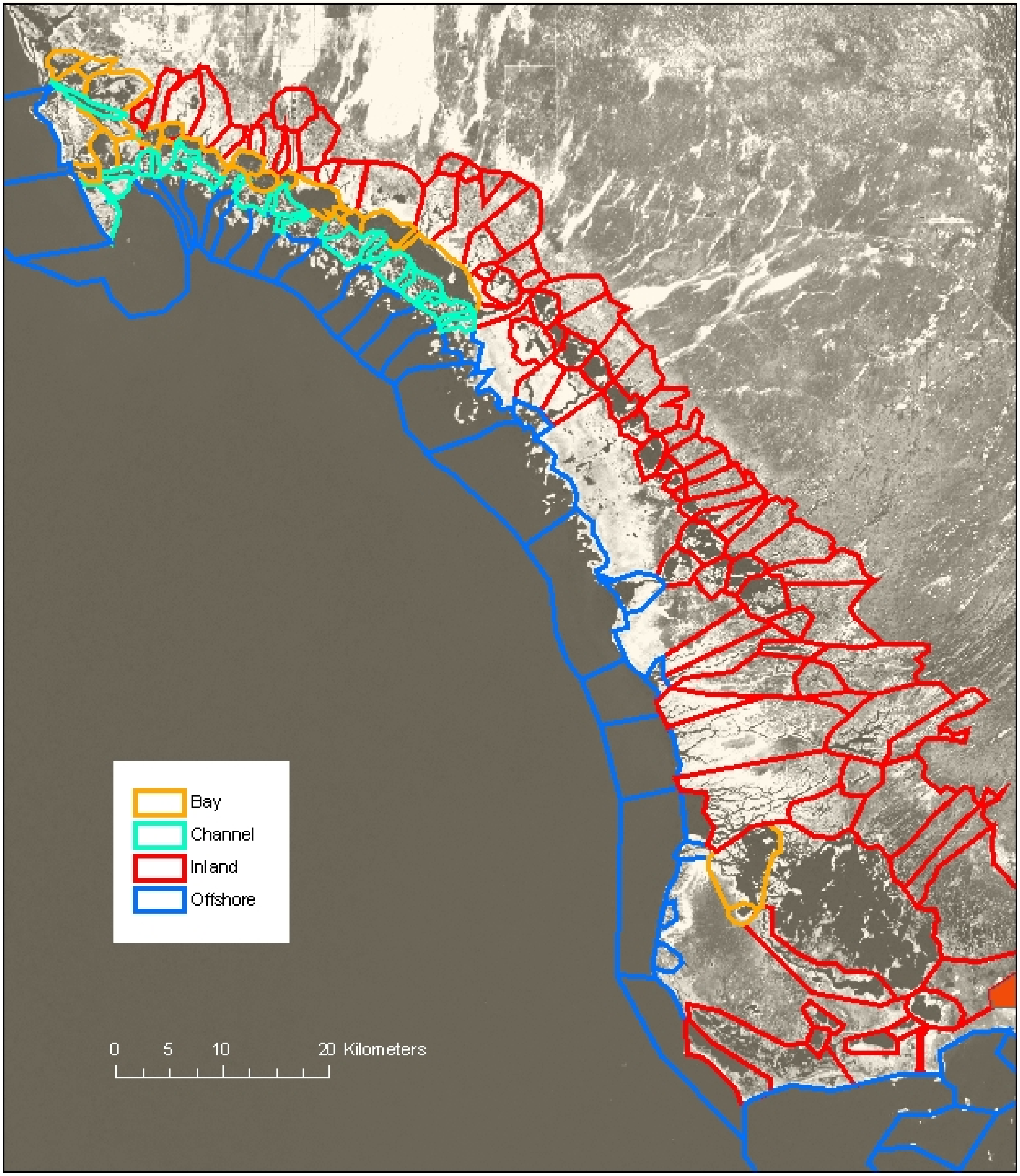

Figure 3. Map of polygonal zones showing simple coding for habitat type. Each polygon has an associated place name and other attributes used in various analyses.

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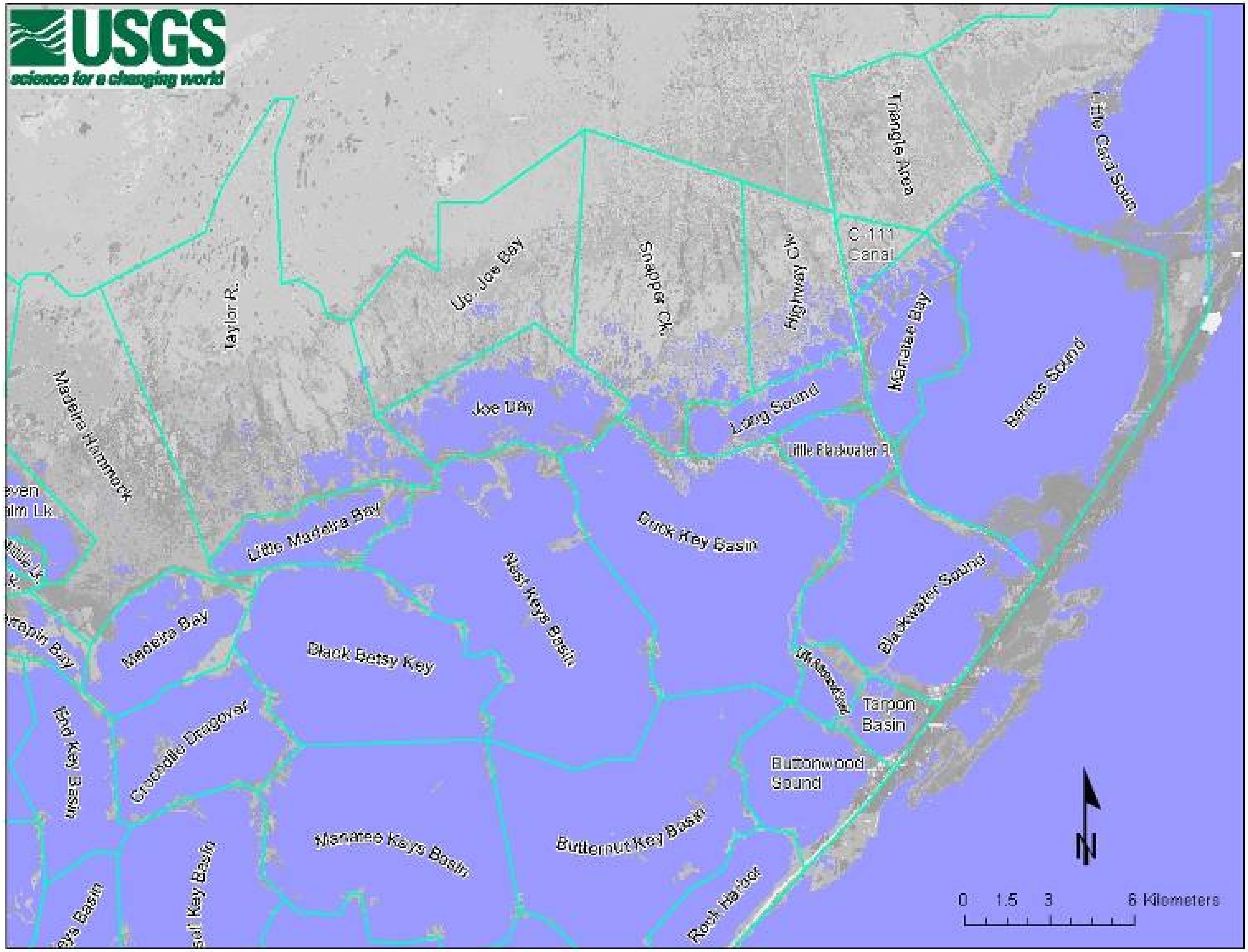

Figure 4. Map of the polygonal zones contained within ENP Bioregion 1.

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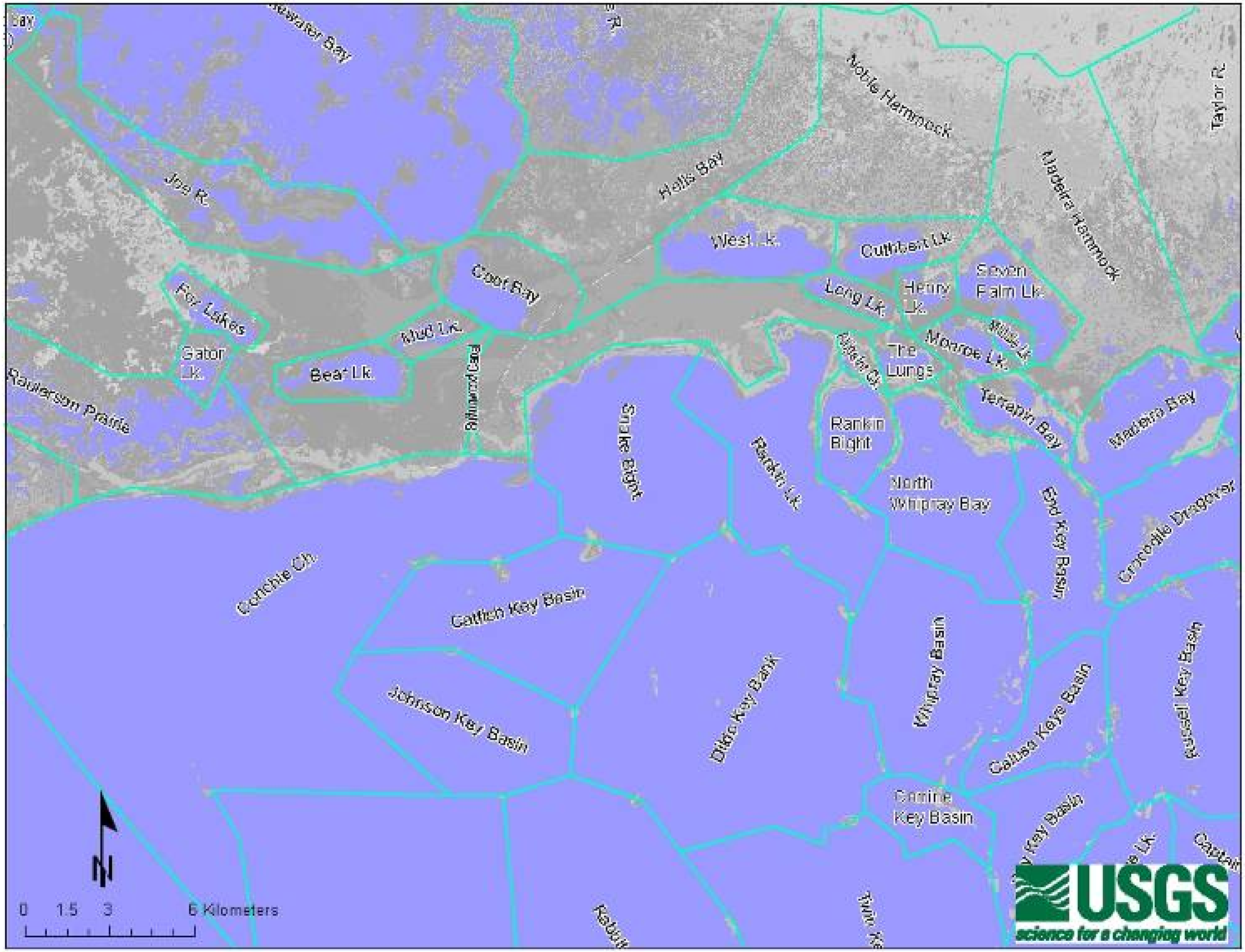

Figure 5. Map of the polygonal zones contained within ENP Bioregions 1 and 4.

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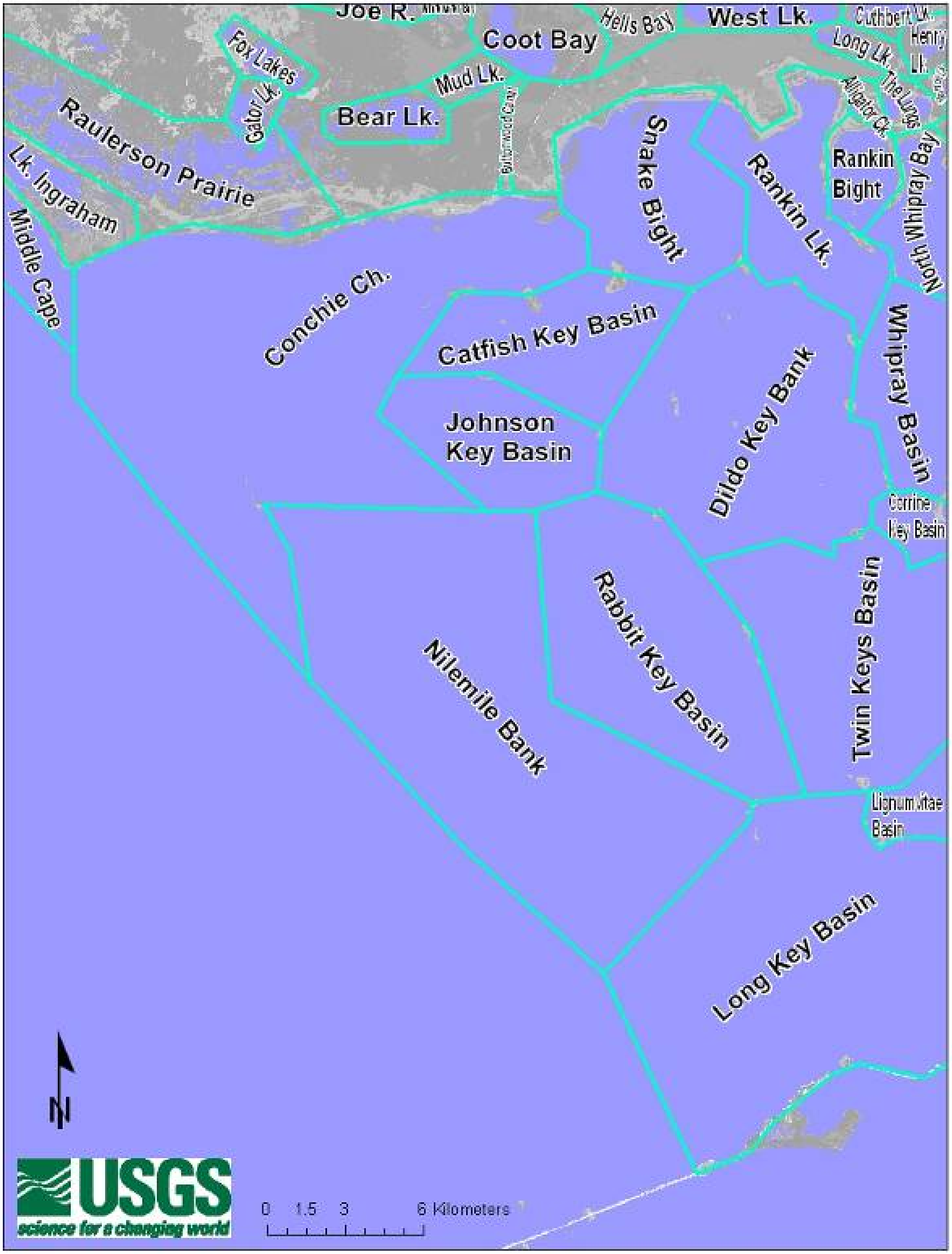

Figure 6. Map of the polygonal zones contained within ENP Bioregion 3.

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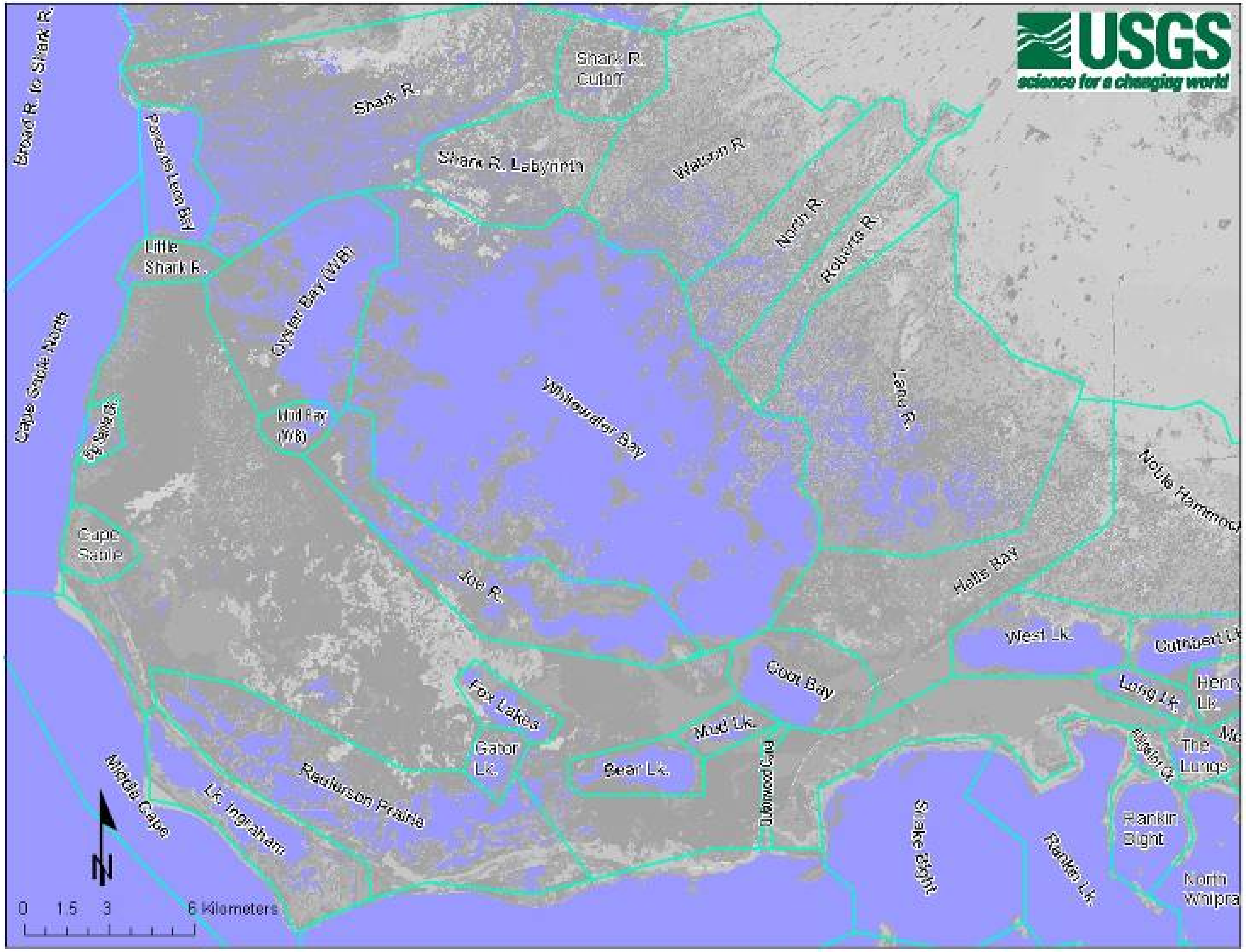

Figure 7. Map of the polygonal zones contained within ENP Bioregions 3, 4 and 5.

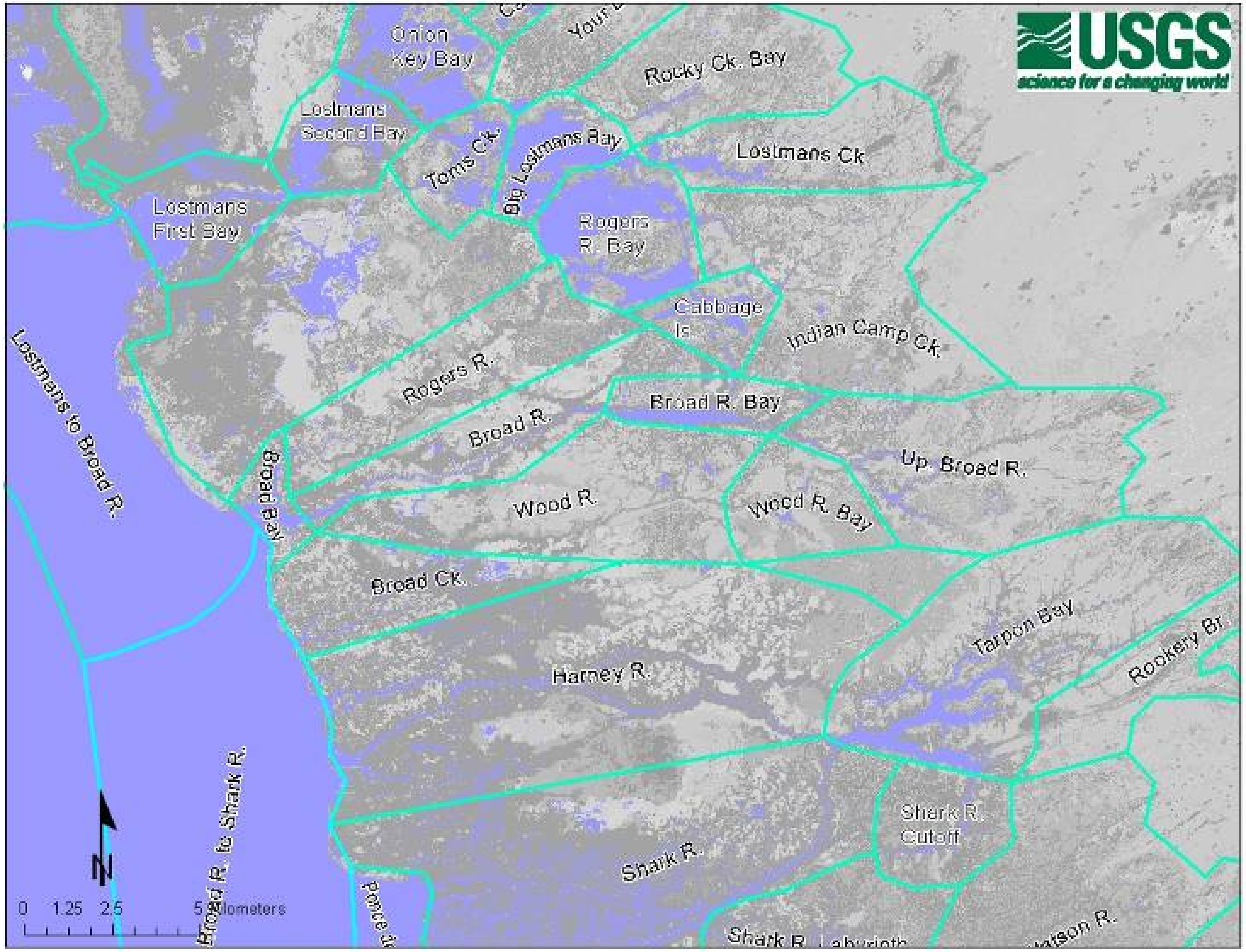

Figure 8. Map of the polygonal zones contained within ENP Bioregion 5.

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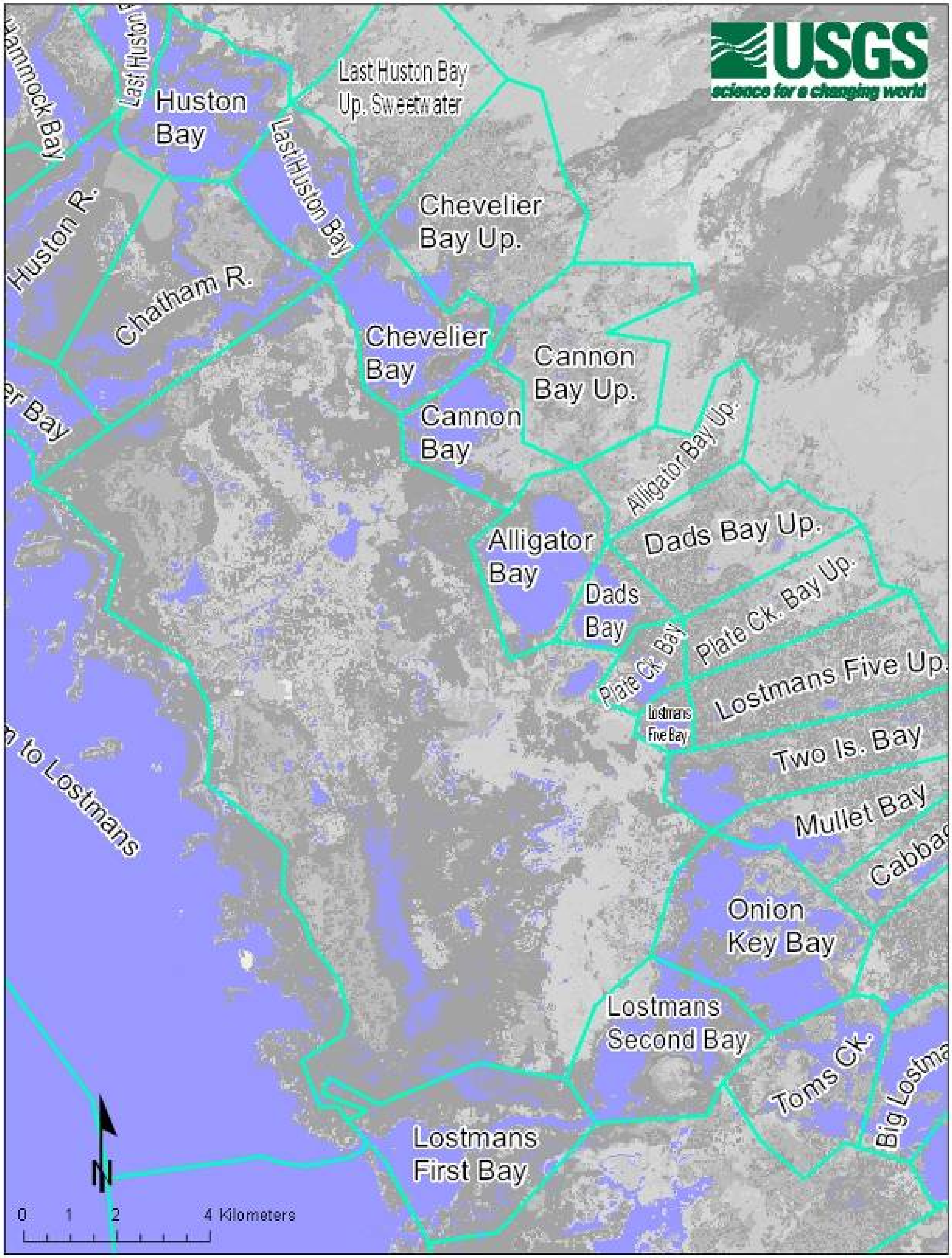

Figure 9. Map of the polygonal zones contained within ENP Bioregion 6.

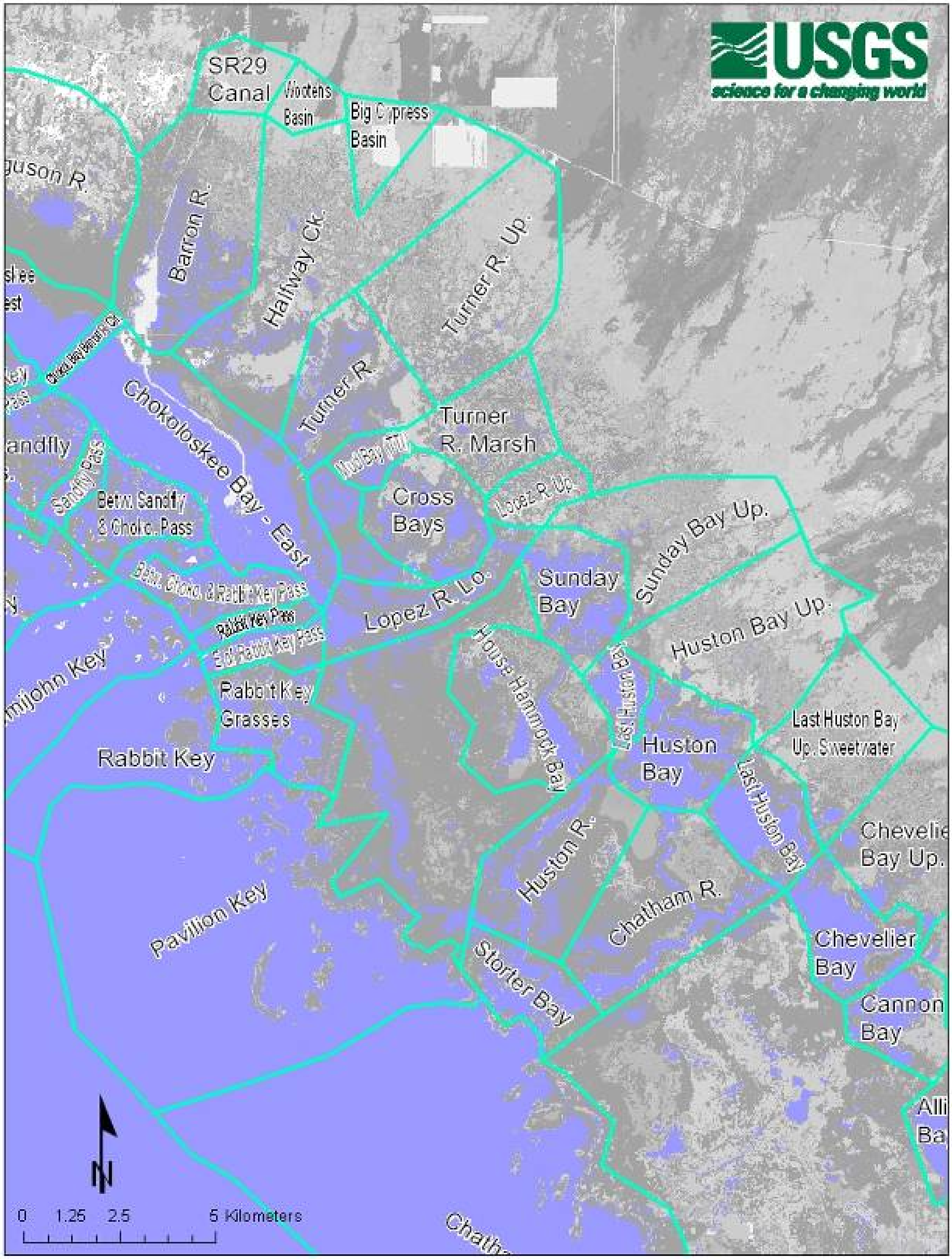

Figure 10. Map of the polygonal zones contained within ENP Bioregions 6 and 7.

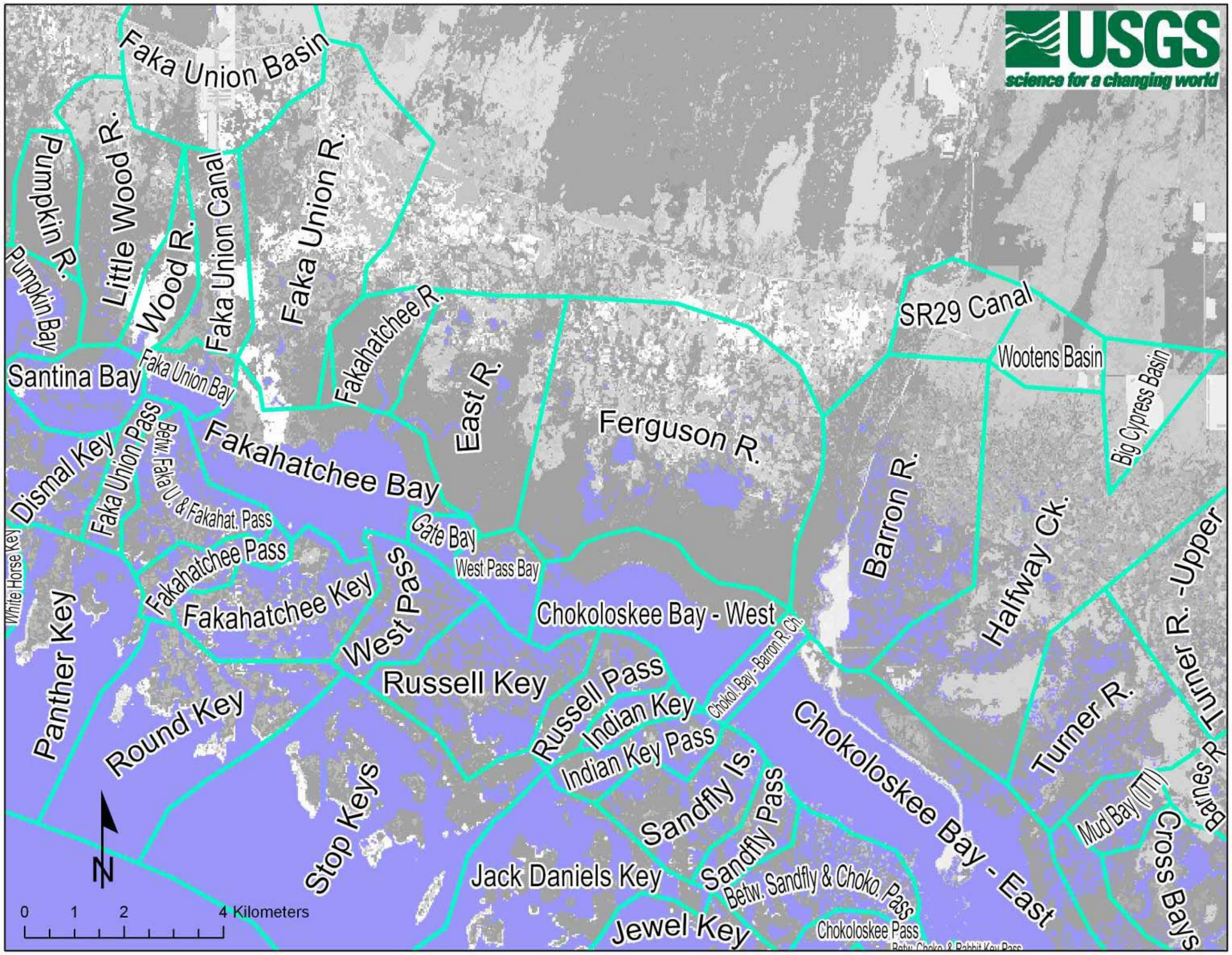

Figure 11. Map of the polygonal zones contained within ENP Bioregions 8 and 8a.

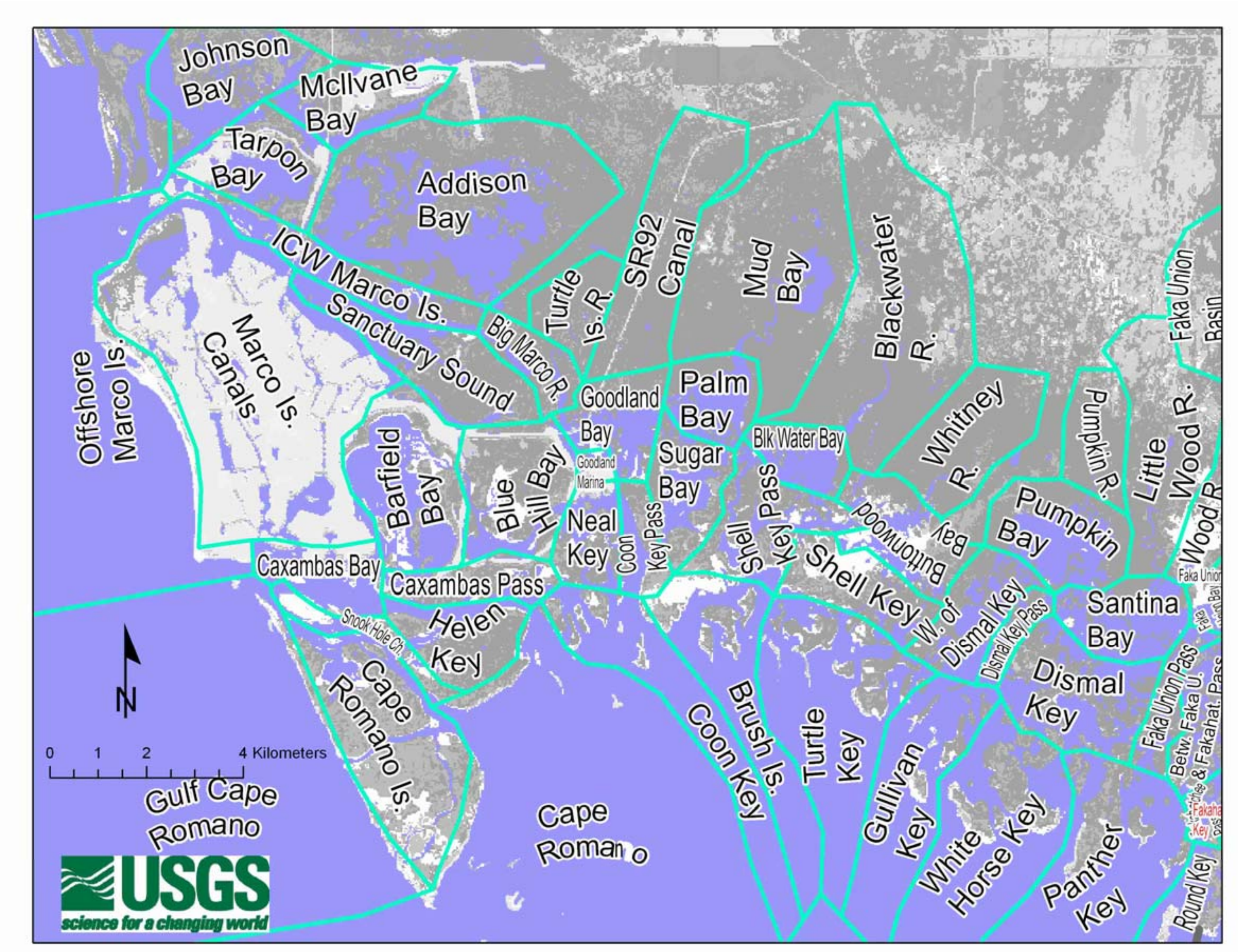

Figure 12. Map of the polygonal zones contained within ENP Bioregions 8 and 9.

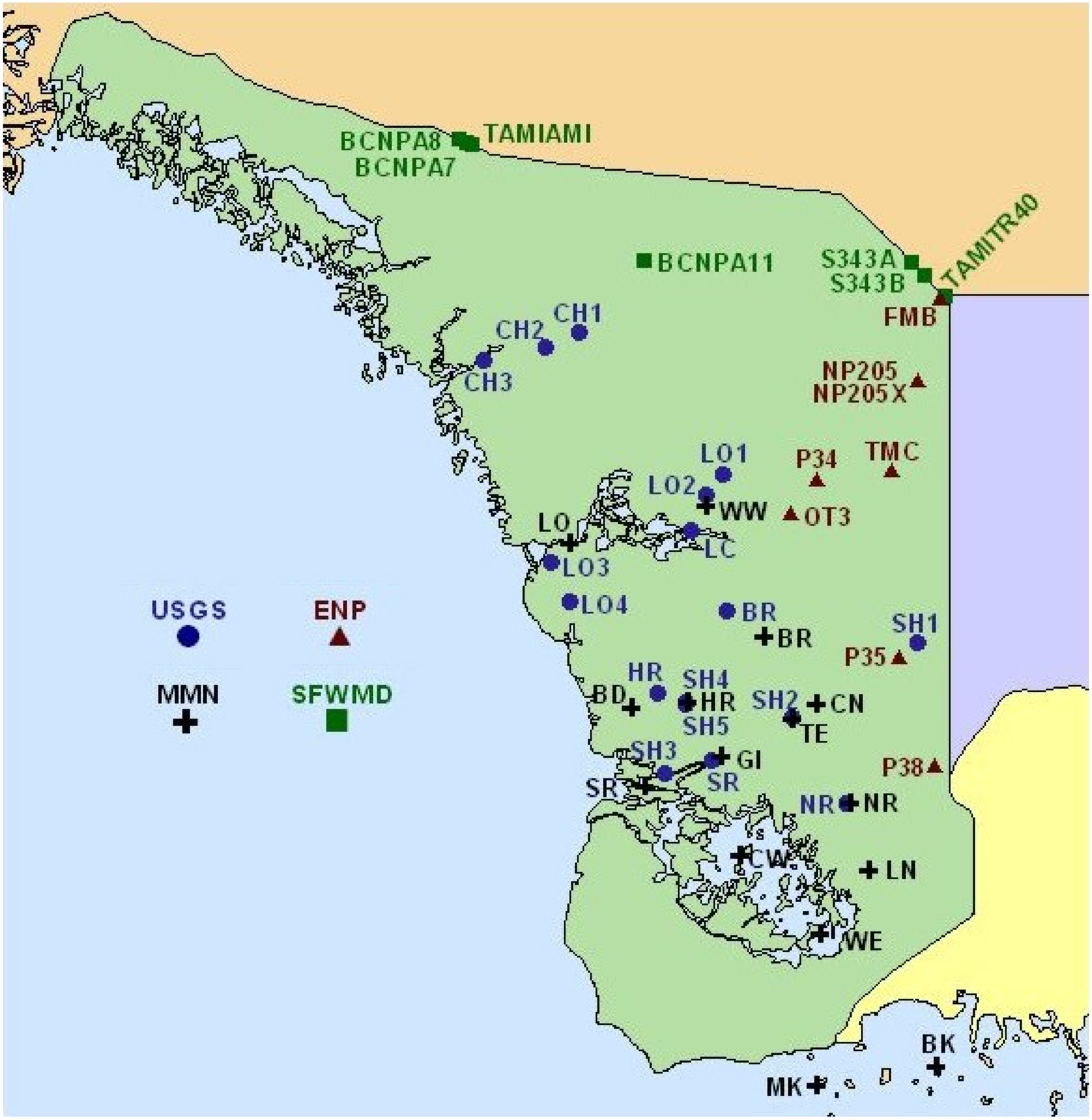

Figure 13. Water monitoring stations in the study area. Station ownership is indicated by symbol shape and color. (image from http://time.er.usgs.gov/TIME/).

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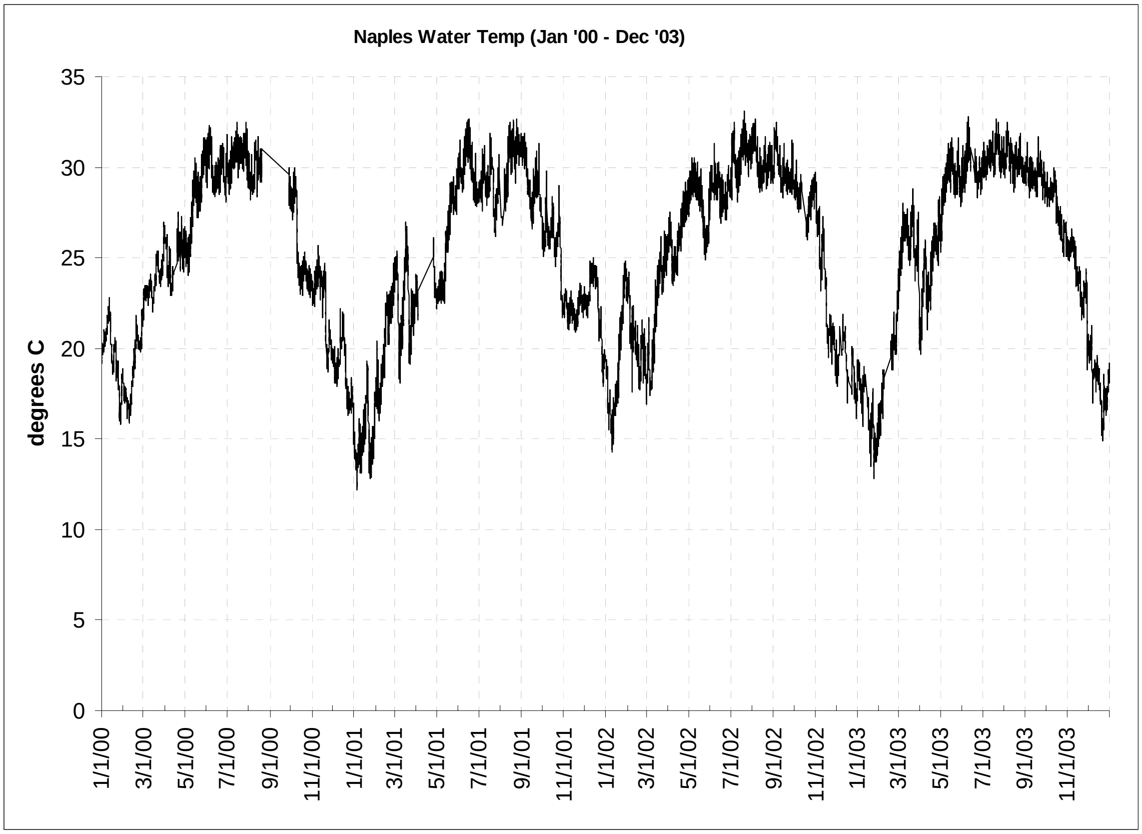

Figure 14. Gulf water temperature graph for years 2000 through 2003 at Naples, Florida.

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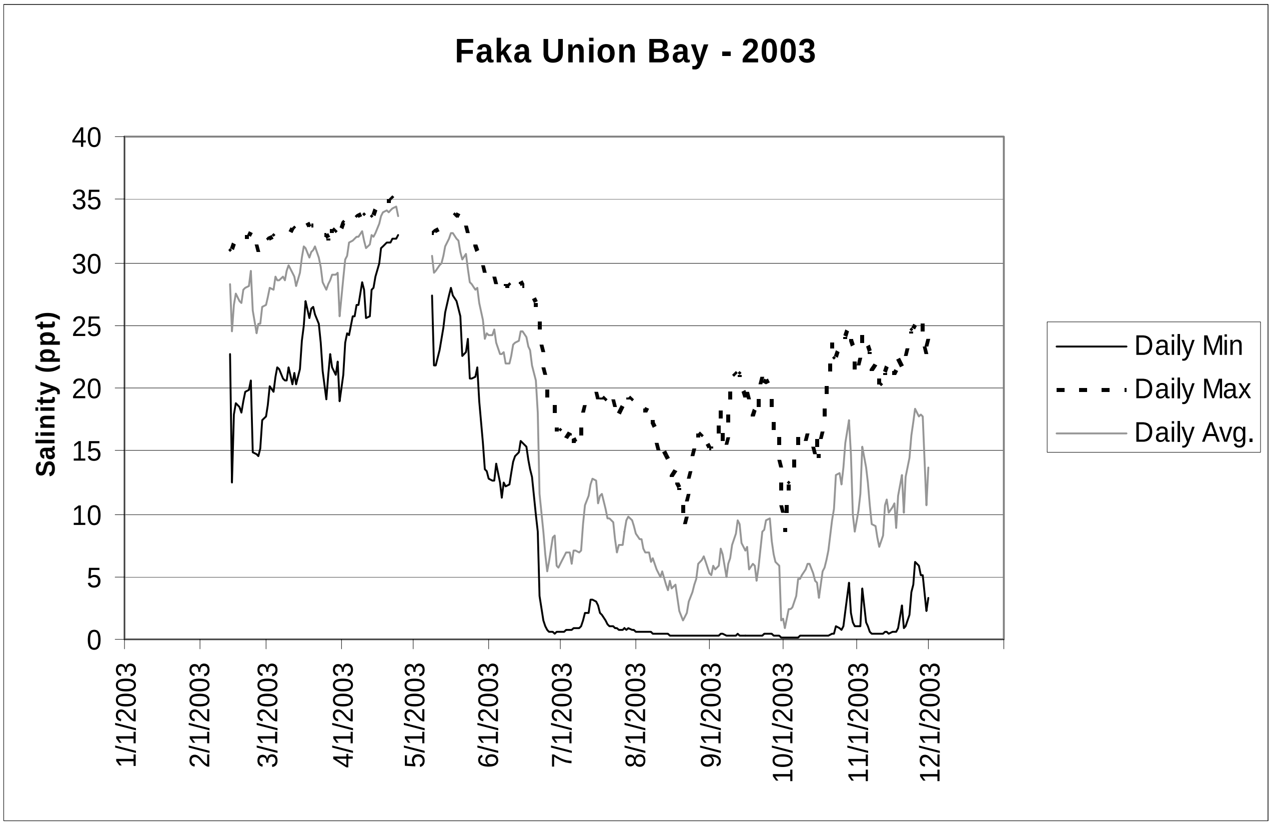

Figure 15. Salinity monitoring station data from the mouth of the Faka Union River, Ten Thousand Islands area from 2003, showing typical pattern of rapid fall in salinity in June. Data courtesy of Rookery Bay National Estuarine Research Reserve.

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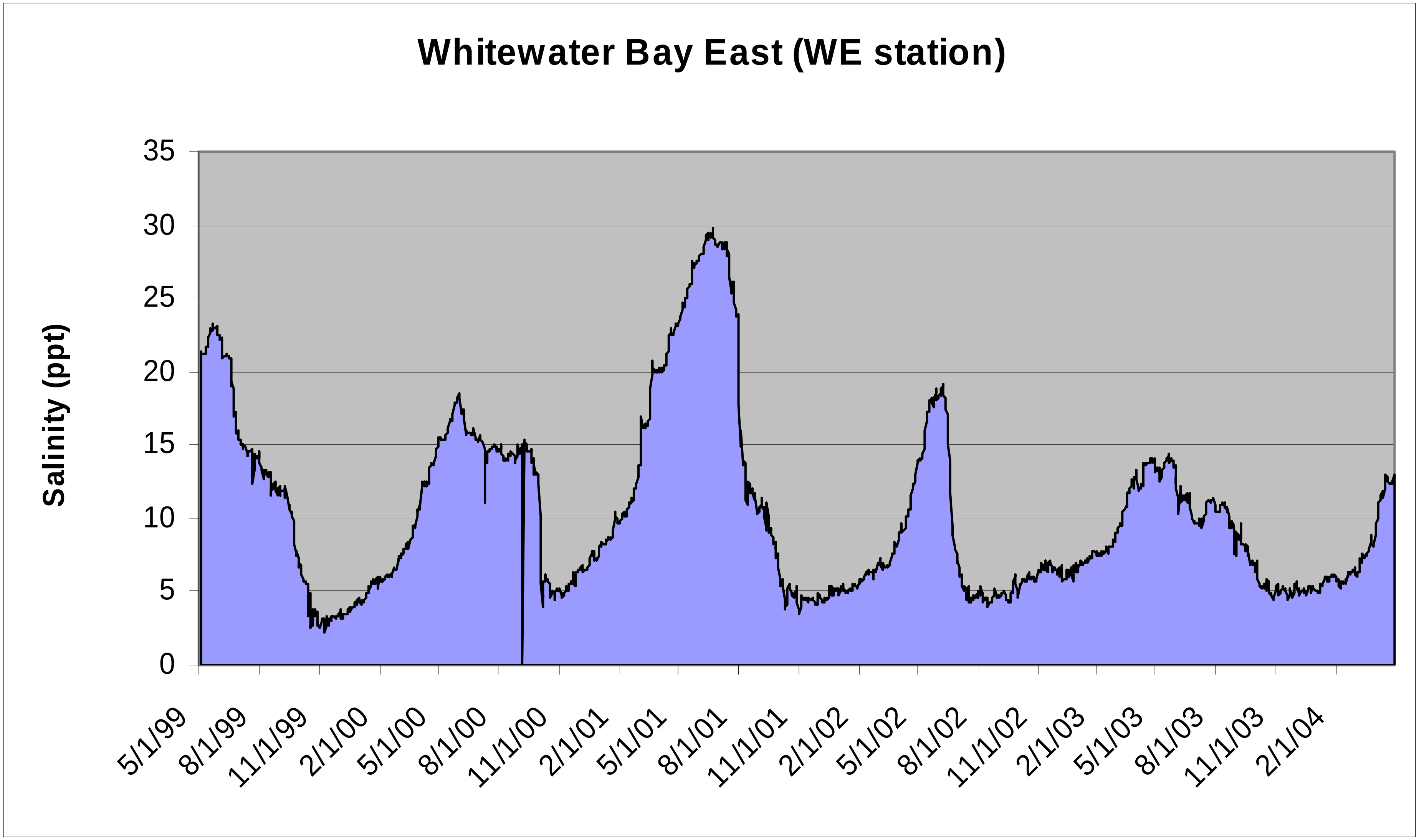

Figure 16. Minimum daily salinity graph at "WE" monitoring station (see Fig. 13 for location) in eastern Whitewater Bay (data courtesy of DataForever). The onset and duration of the period when salinity falls below 10 ppt shows ~3 mos. annual variation.

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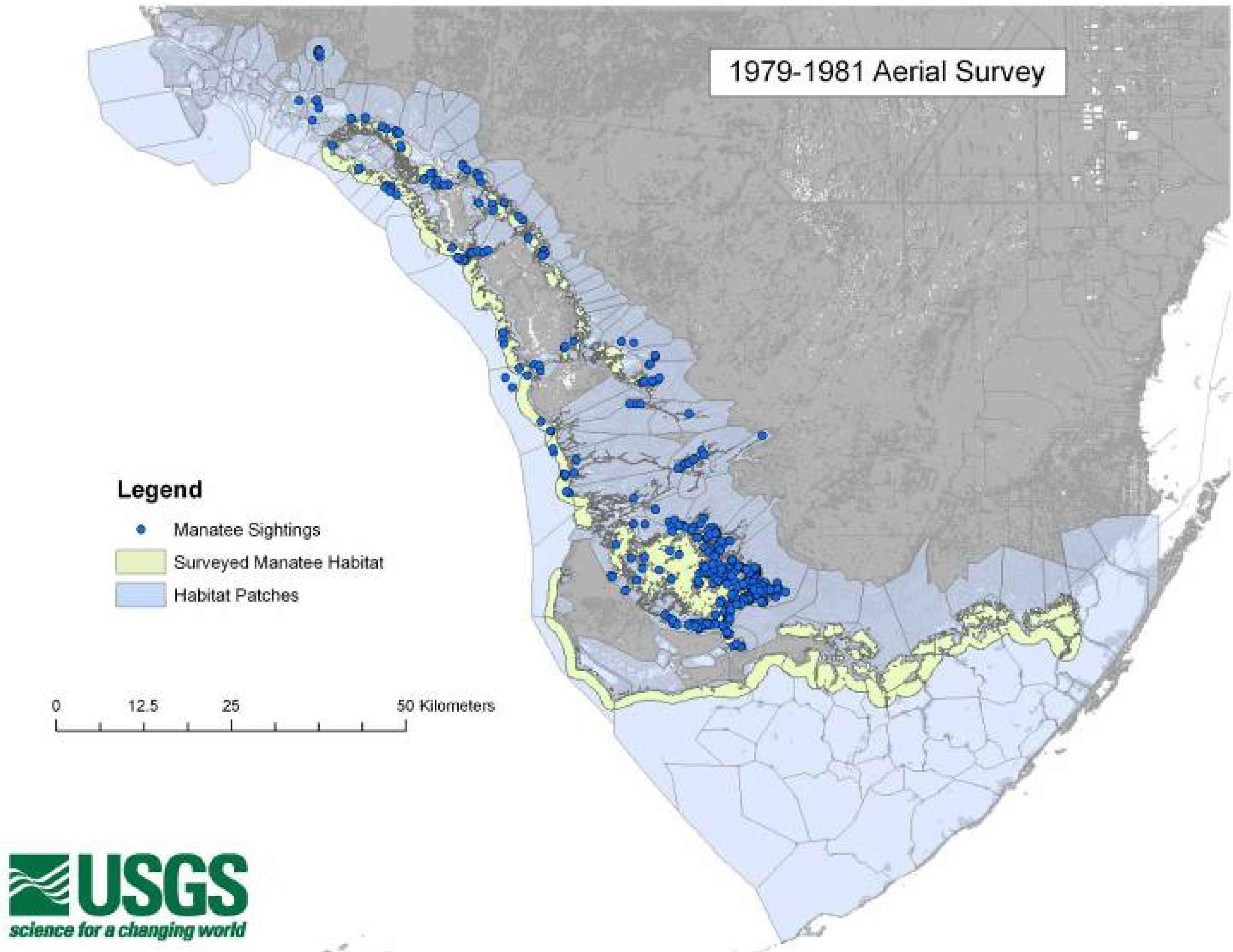

Figure 17. Map of distributional aerial survey data of manatee group sightings December 1979 – September 1981 (light-green and blue polygons represent surveyed and unsurveyed habitat patches, respectively).

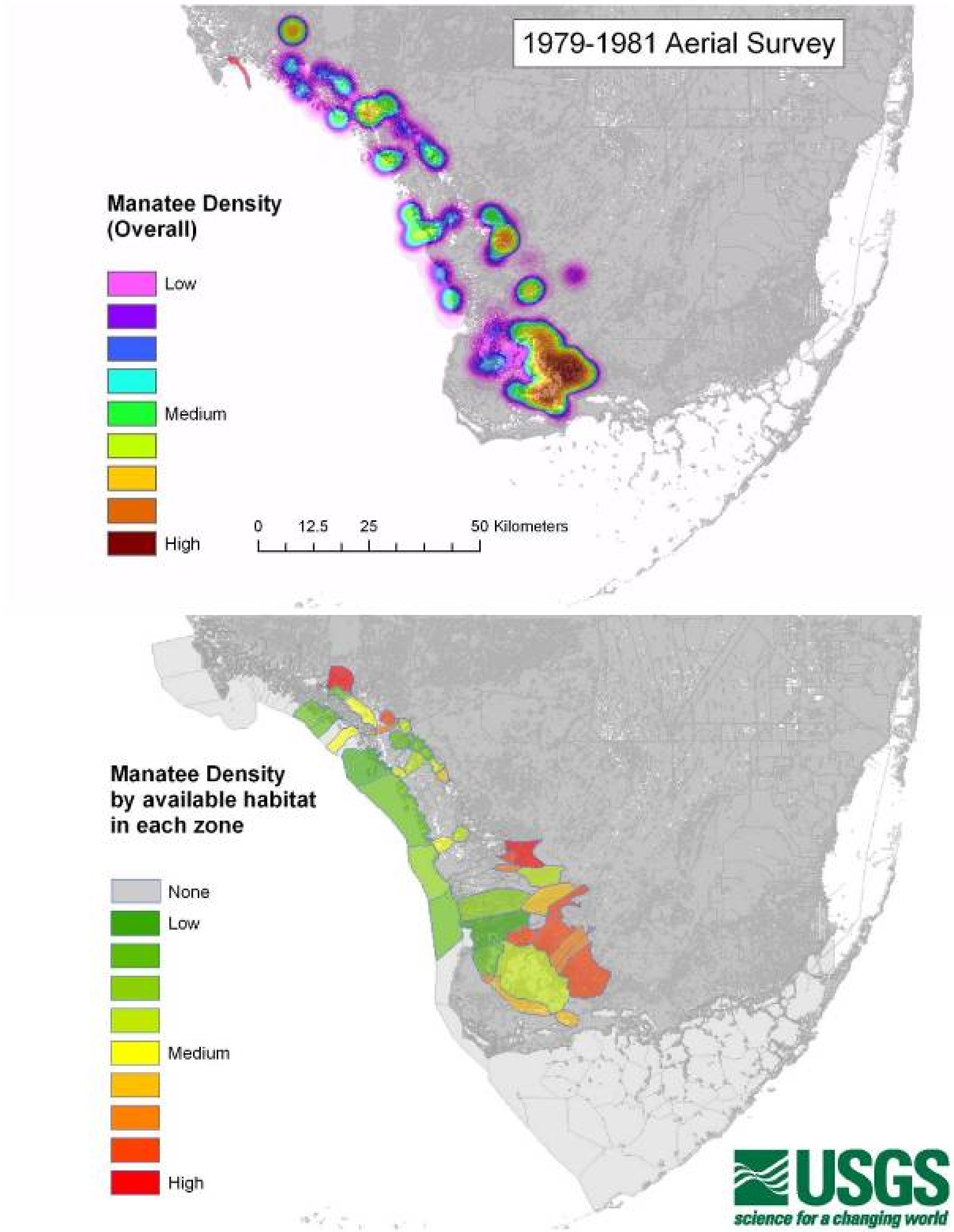

Figure 18. Kernel density map (top) and habitat polygon map (bottom) showing relative densities of manatee group sightings in Everglades National Park for surveys from December 1979 – September 1981.

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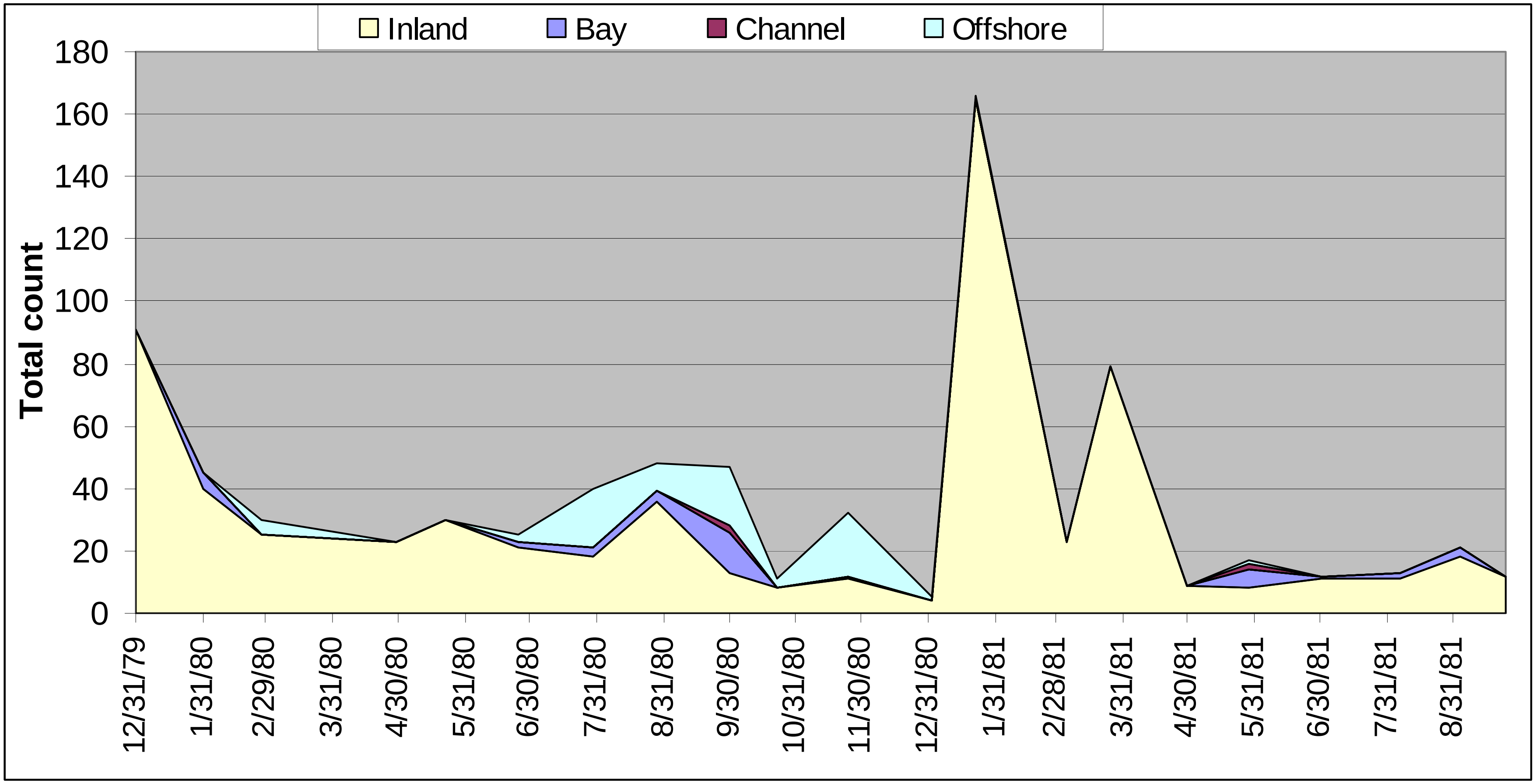

Figure 19. Total counts of manatees during distributional aerial survey data from Everglades National Park (1979 – 1981). Manatee counts peak in winter, when they aggregate in freshwater sites that provide thermal refuges.

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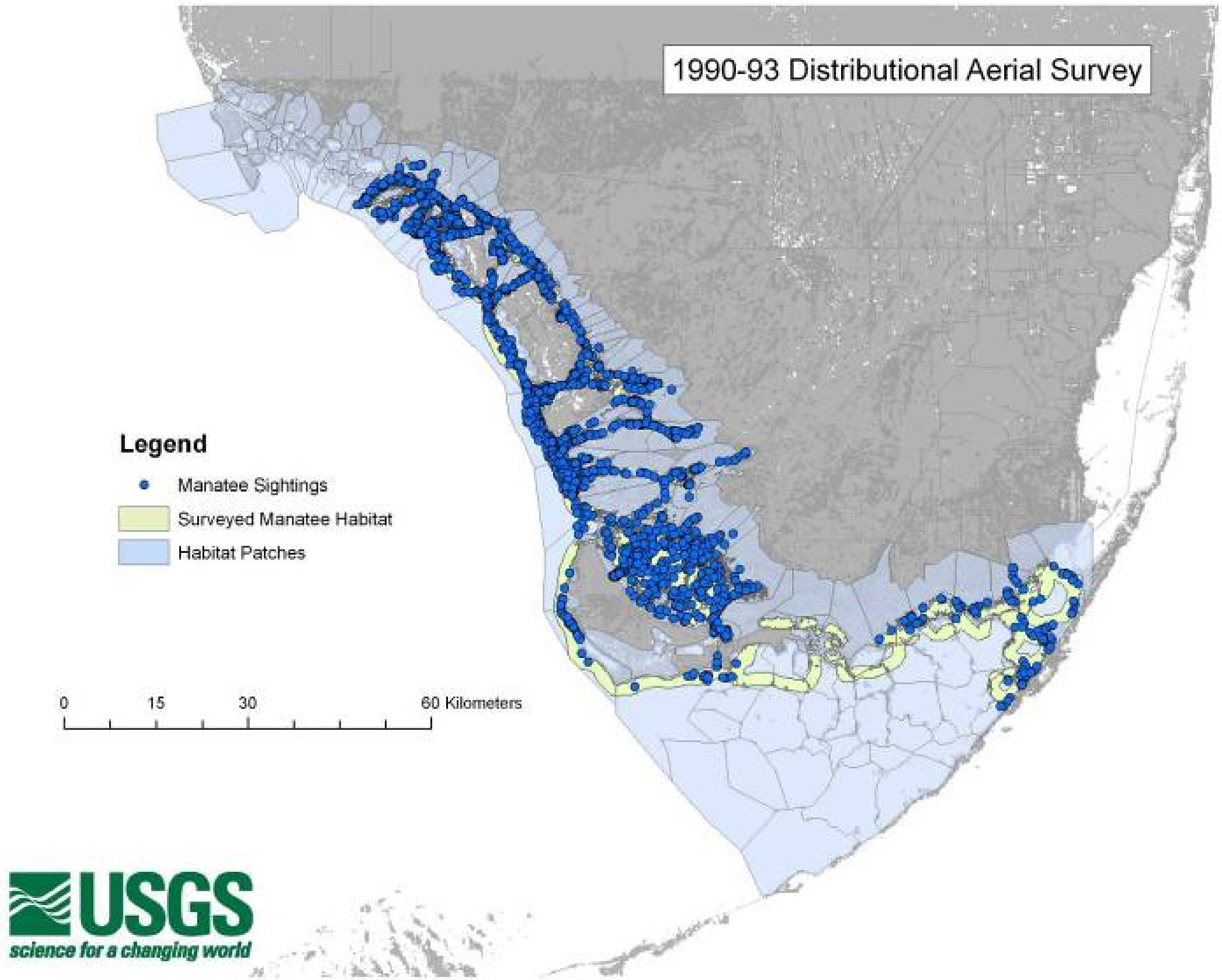

Figure 20. Map of manatee group sightings in Everglades National Park for surveys from March 1990 – March 1993 (light-green and blue polygons represent surveyed and unsurveyed habitat patches, respectively).

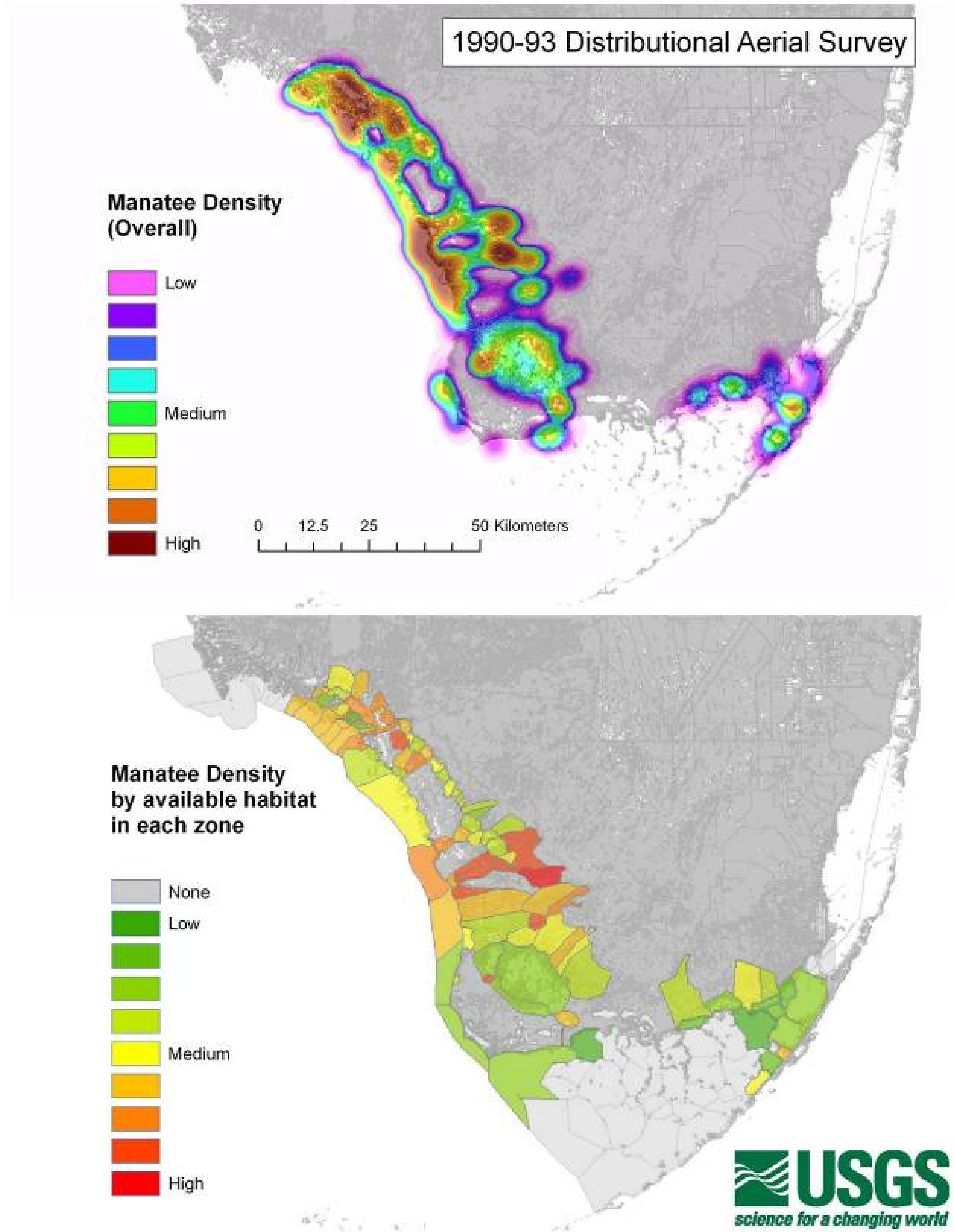

Figure 21. Kernel density map (top) and habitat polygon map (bottom) showing relative densities of manatee group sightings from 1990 – 1993 in Everglades National Park.

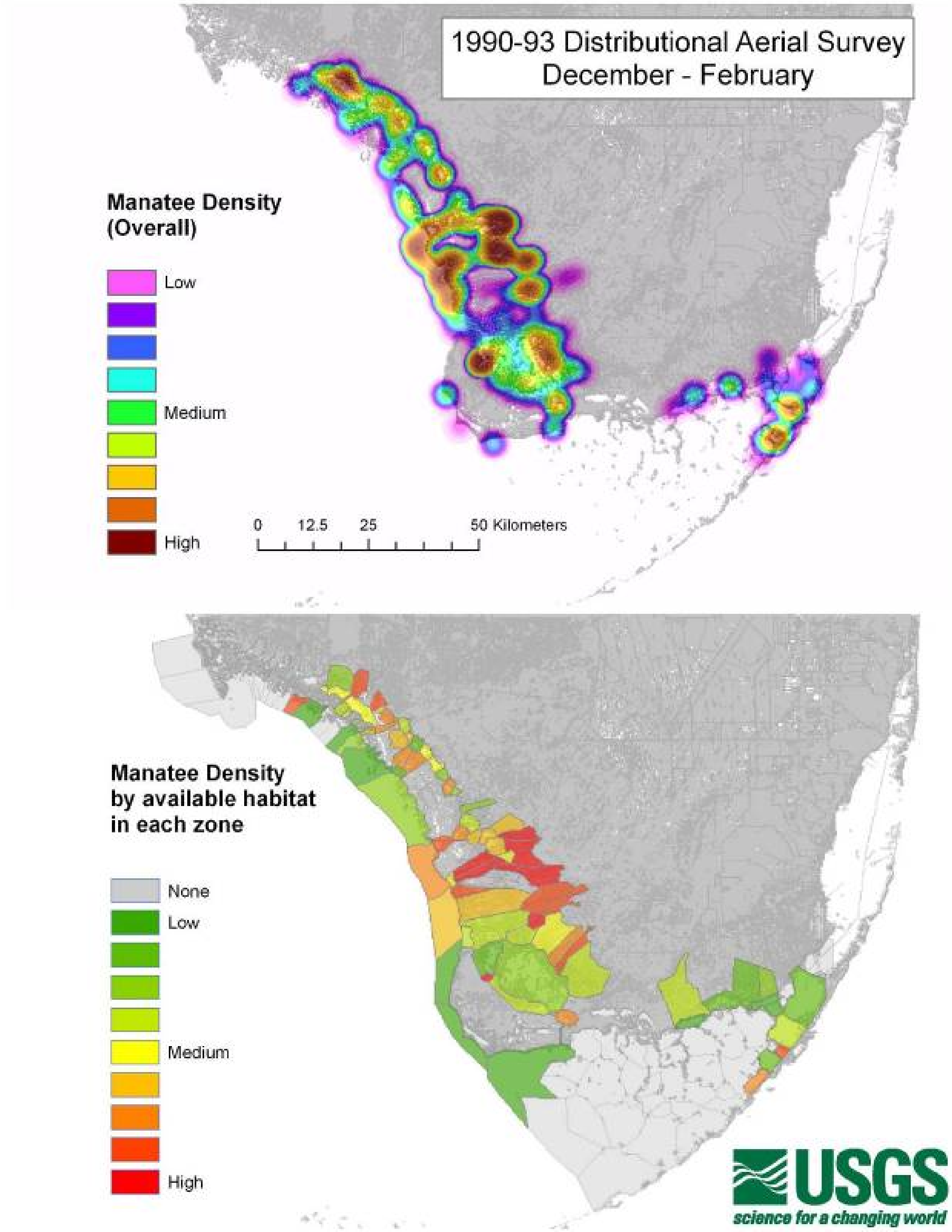

Figure 22. Kernel density map (top) and habitat polygon map (bottom) showing relative densities of manatee group sightings during winter months in Everglades National Park.

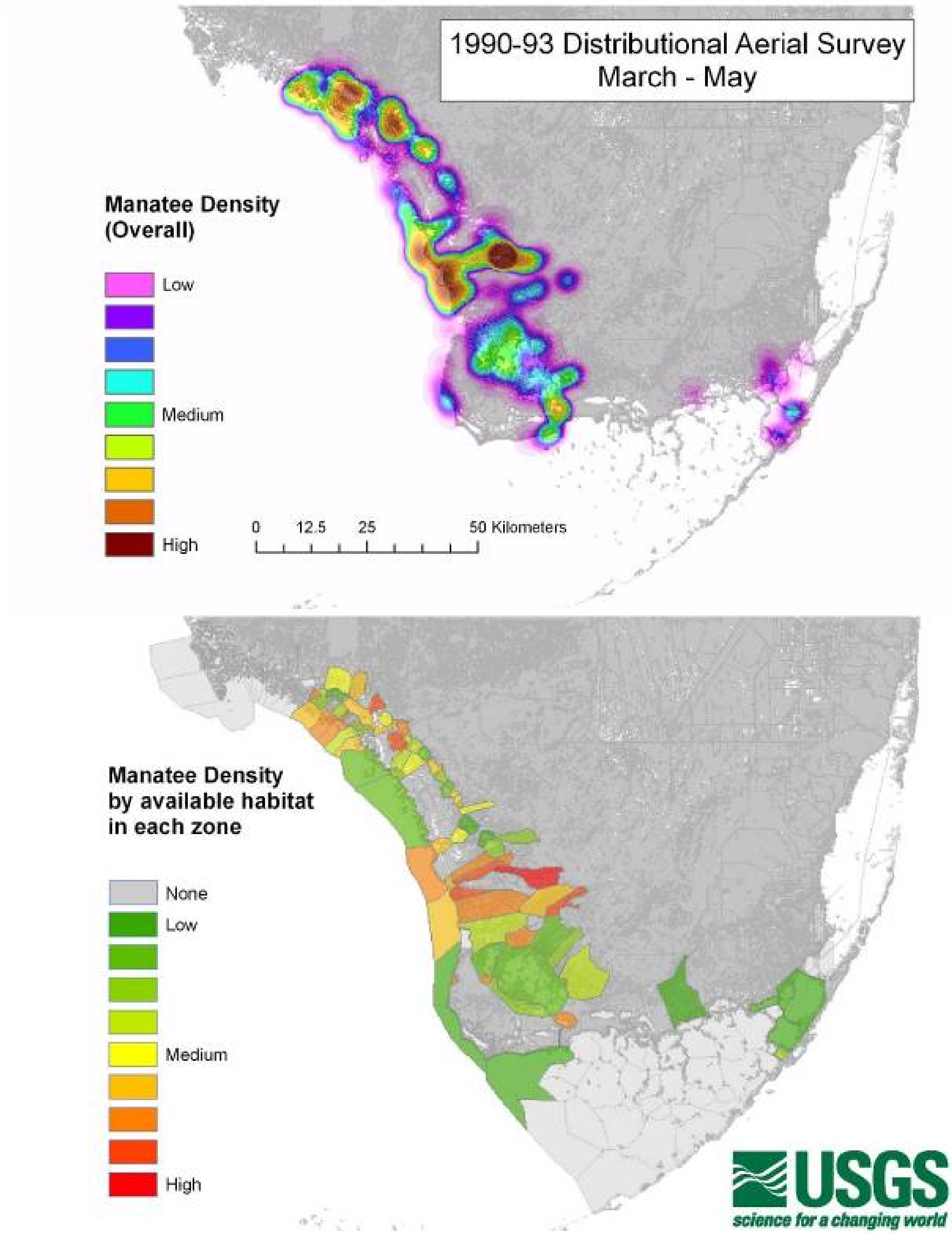

Figure 23. Kernel density map (top) and habitat polygon map (bottom) showing relative densities of manatee group sightings during spring months in Everglades National Park.

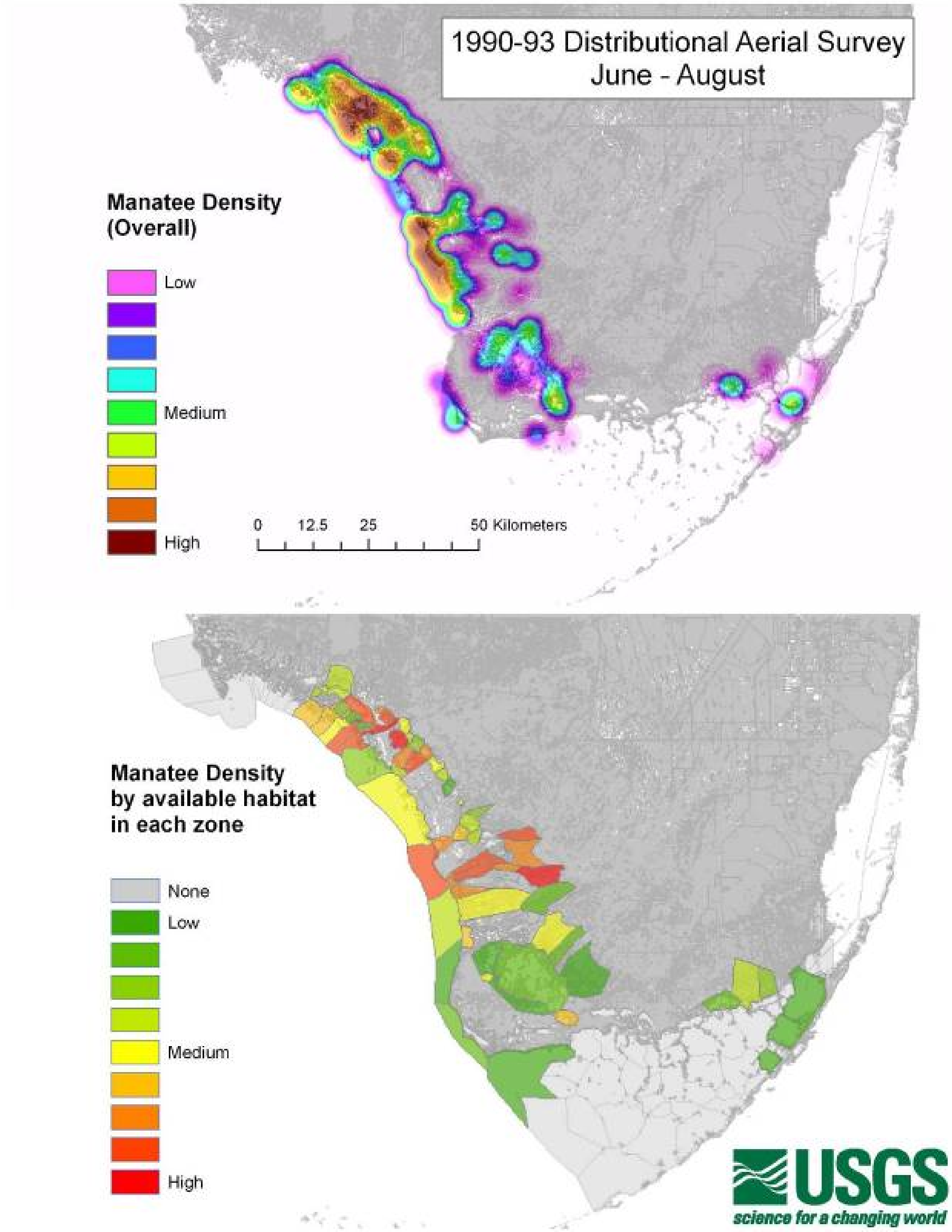

Figure 24. Kernel density map (top) and habitat polygon map (bottom) showing relative densities of manatee group sightings during summer months in Everglades National Park.

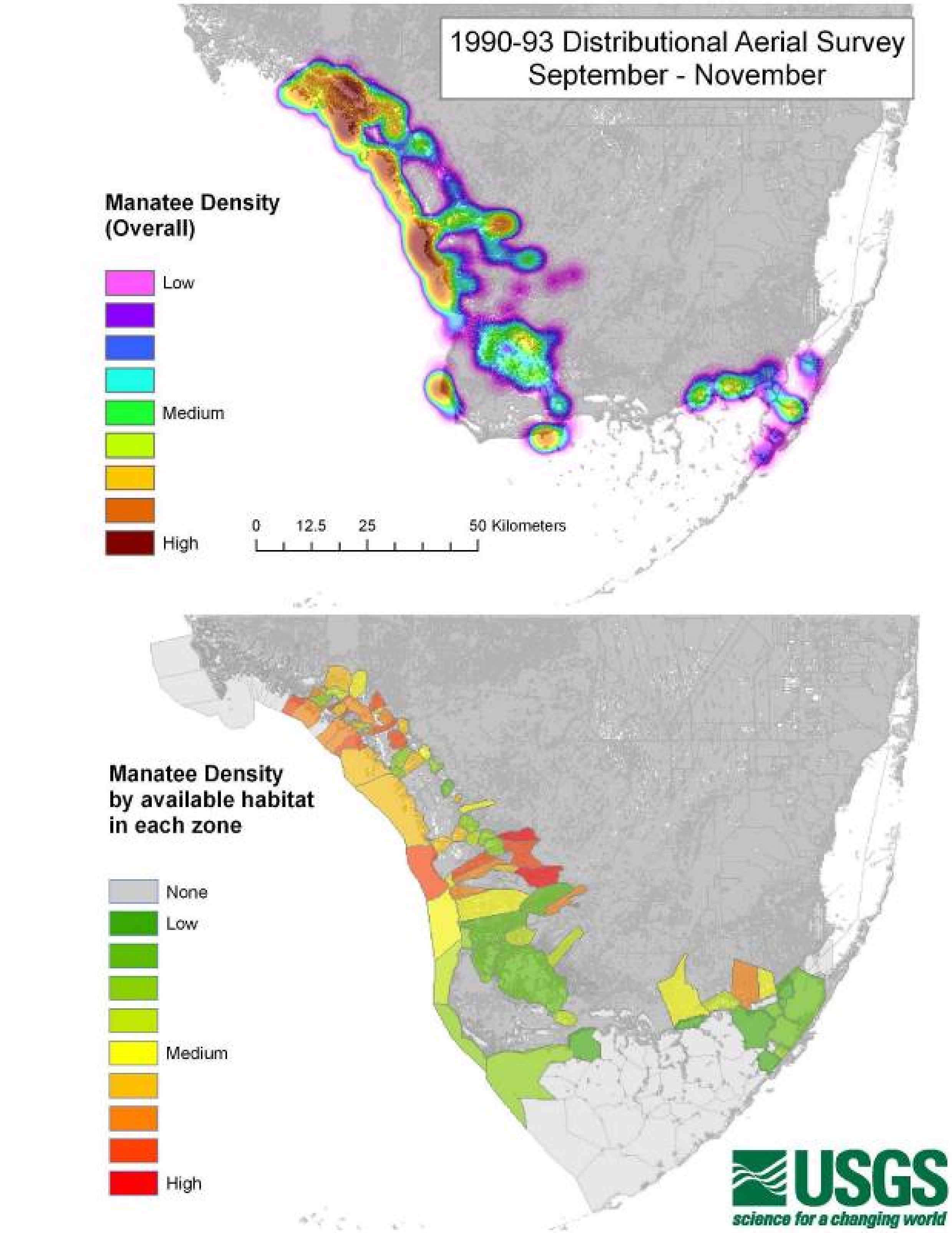

Figure 25. Kernel density map (top) and habitat polygon map (bottom) showing relative densities of manatee group sightings during fall months in Everglades National Park.

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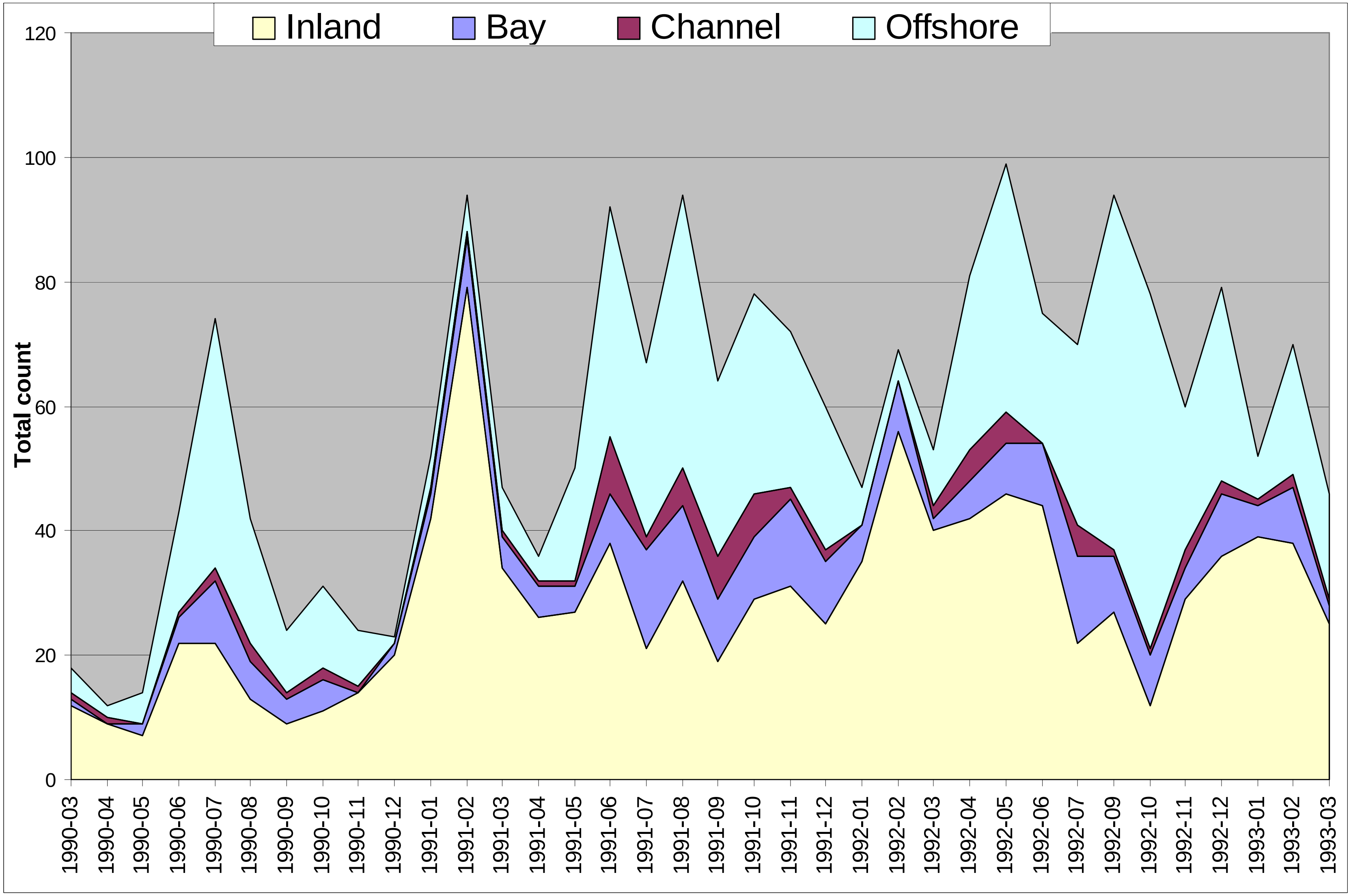

Figure 26. Seasonal use patterns of four habitat zones based on distributional aerial survey data from Everglades National Park (1990 – 1993). Inland manatee counts peak in winter, when they aggregate in sites that provide thermal refuges.

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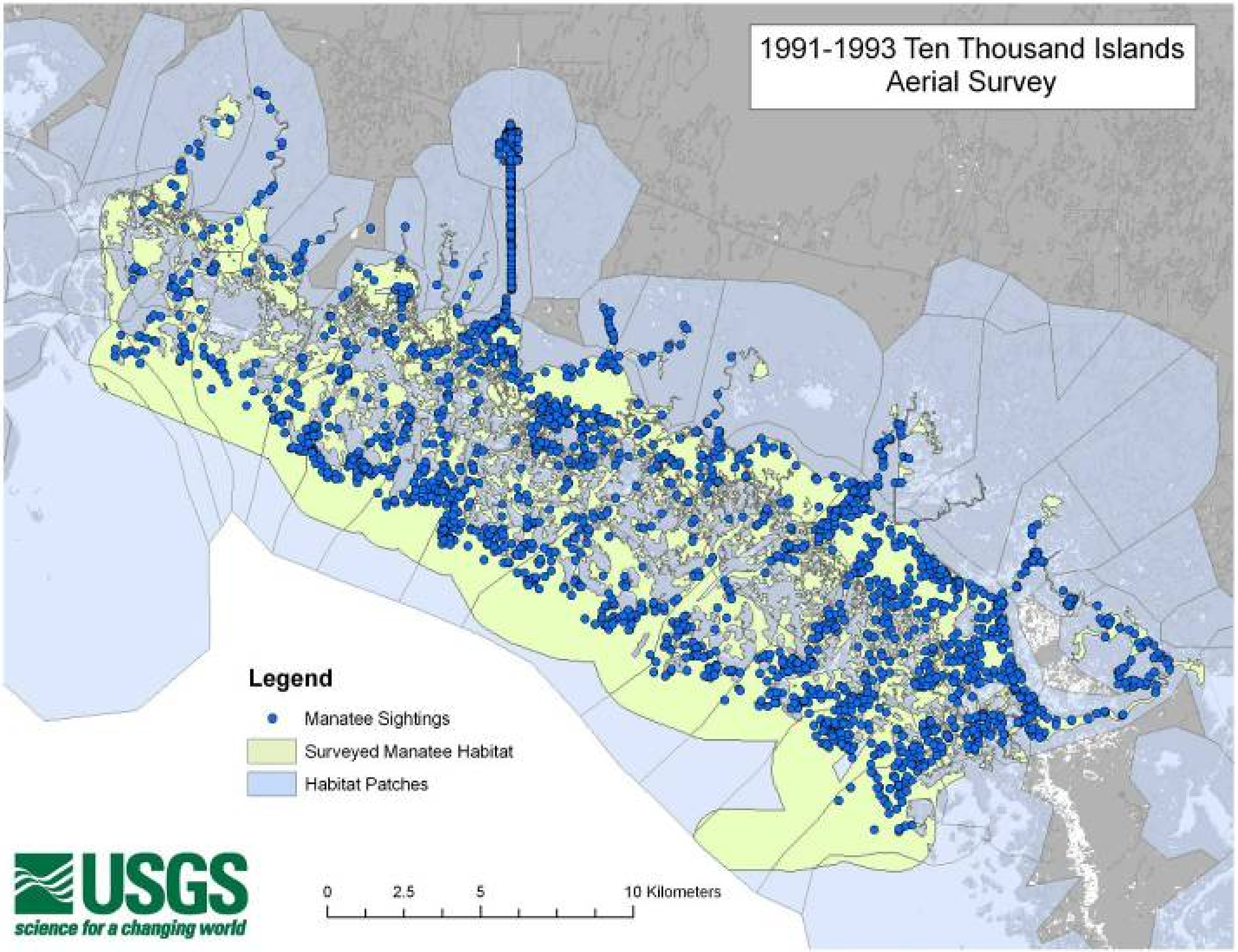

Figure 27. Map of manatee group sightings in Collier County from 1991 – 1993 (light-green and blue polygons represent surveyed and unsurveyed habitat patches, respectively).

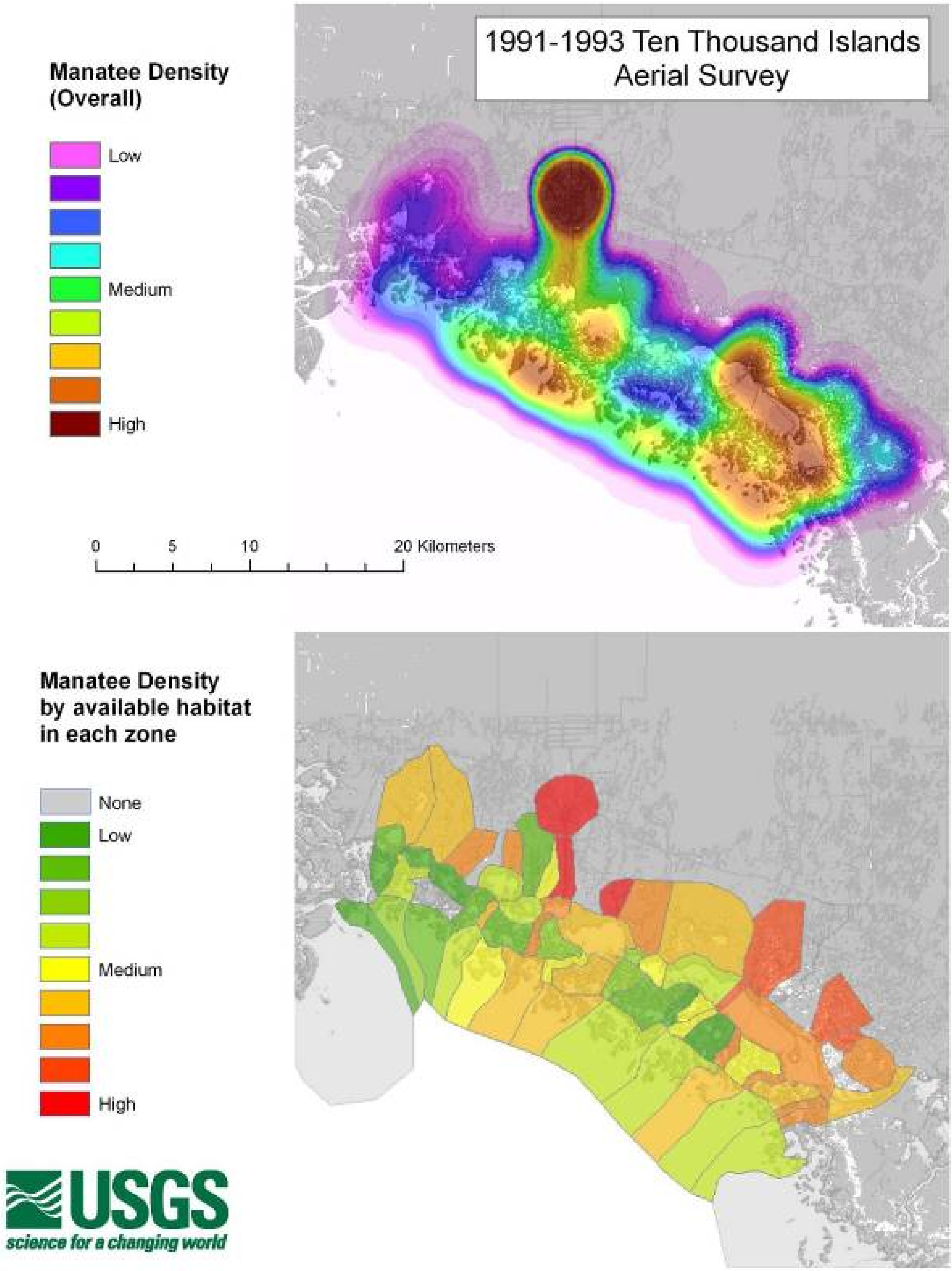

Figure 28. Kernel density map (top) and habitat polygon map (bottom) showing relative densities of manatee group sightings in Collier County from 1991 – 1993.

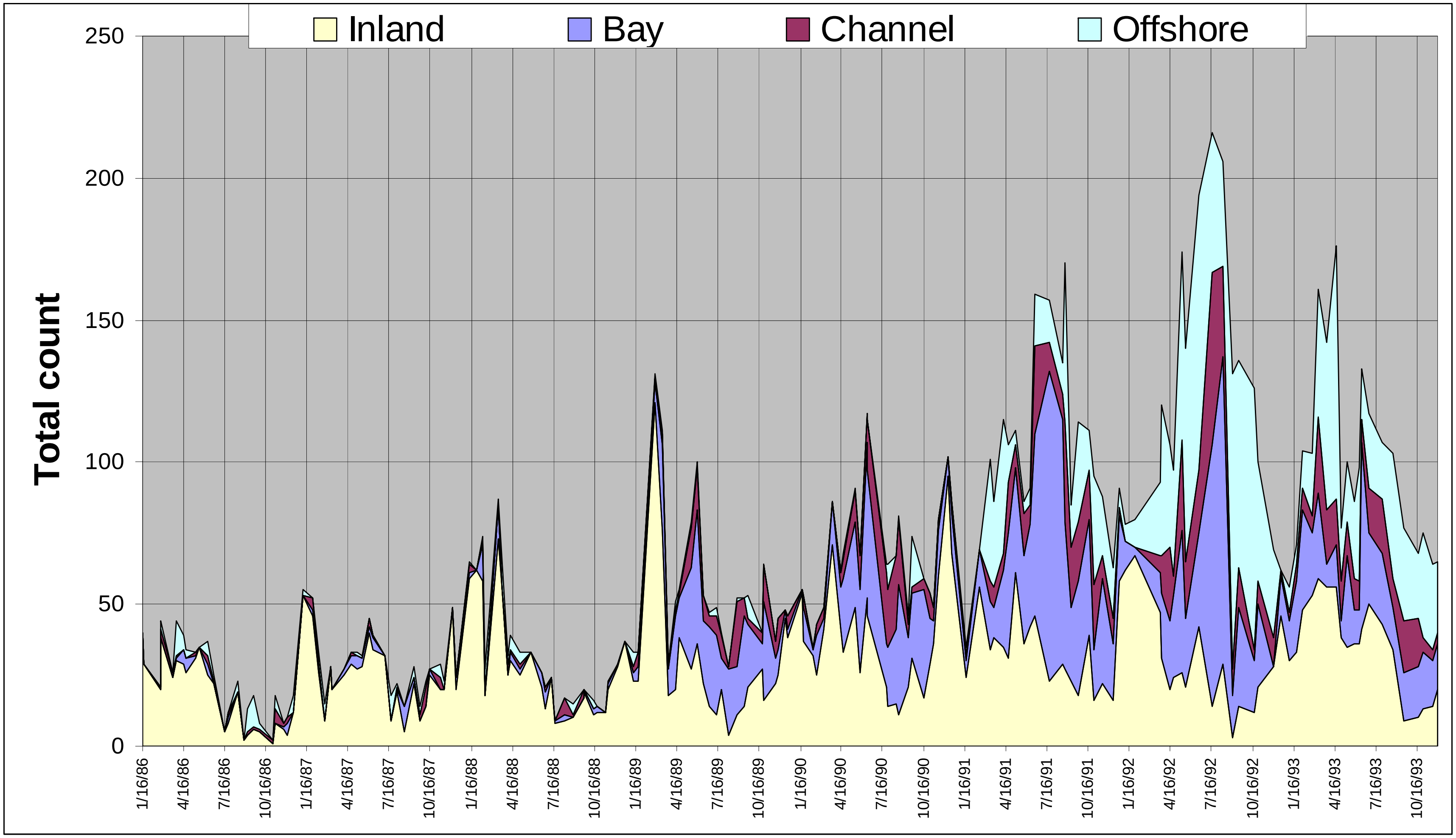

Figure 29. Total count and seasonal use patterns of four habitat zones based on distributional aerial survey data from Collier County (1986 – 1993). Inland manatee counts peak in winter, when they aggregate in freshwater sites that provide thermal refuges.

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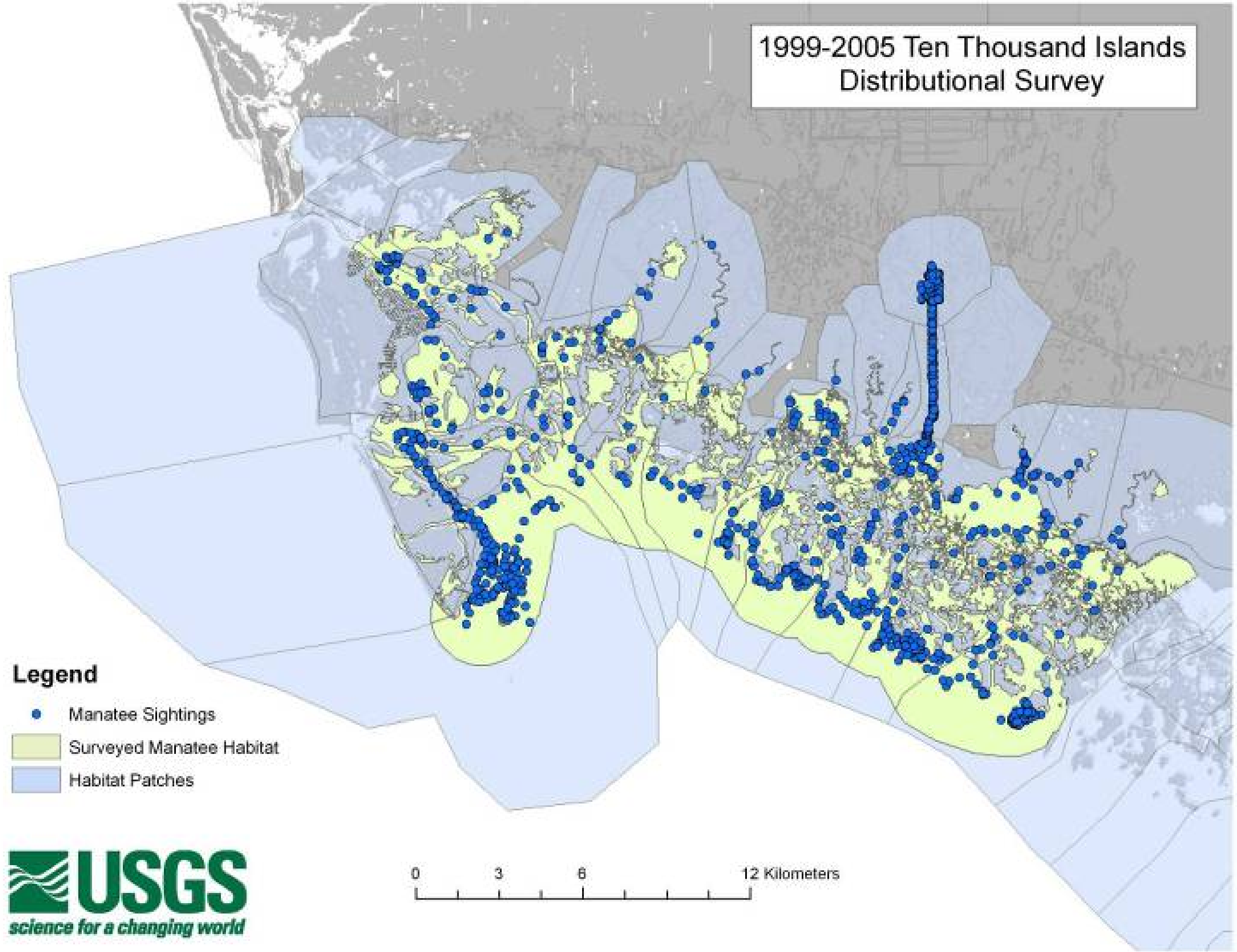

Figure 30. Map of manatee group sightings in Collier County from 1999 – 2005 (light-green and blue polygons represent surveyed and unsurveyed habitat patches, respectively).

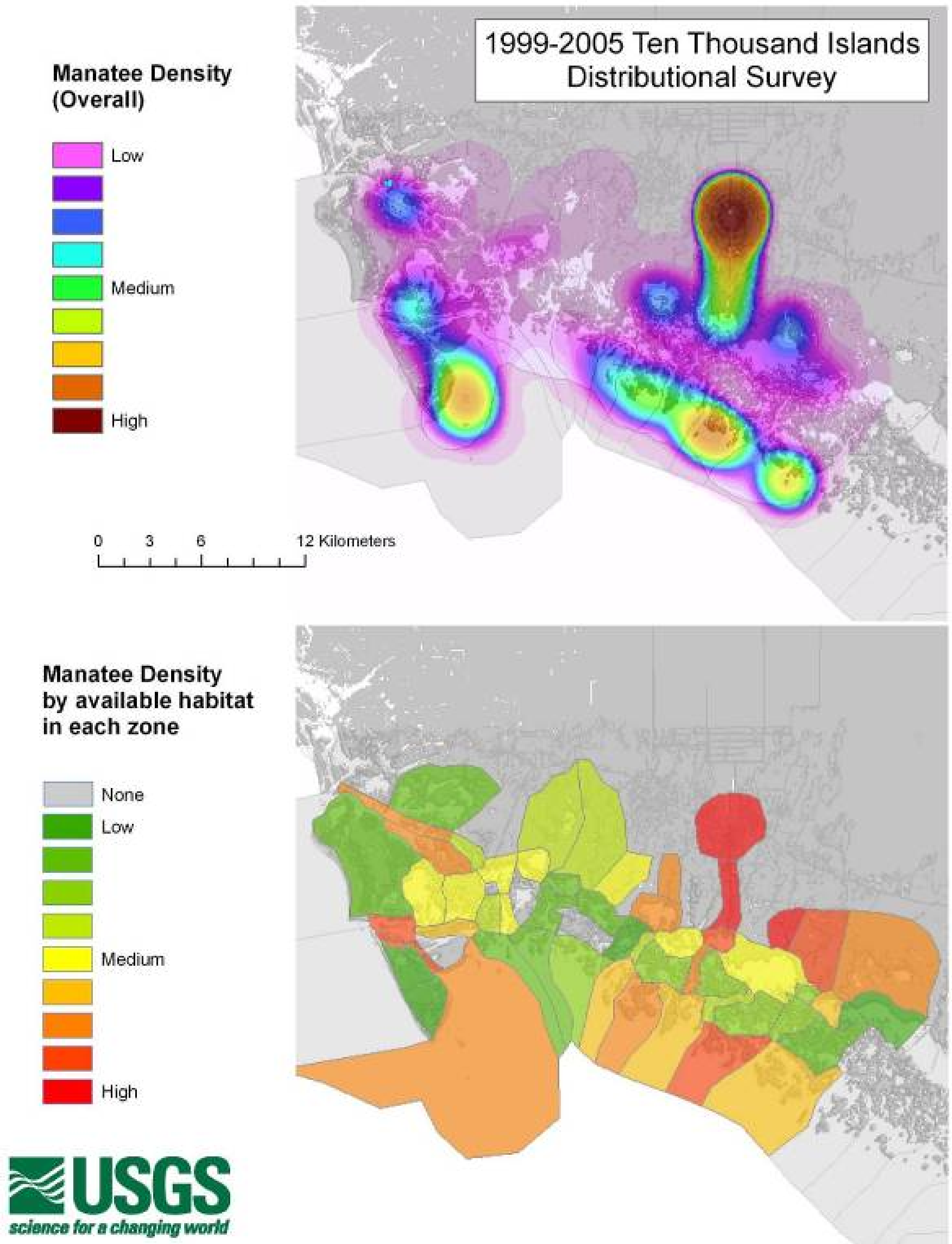

Figure 31. Kernel density map (top) and habitat polygon map (bottom) showing relative densities of manatee group sightings in the Ten Thousand Islands area from 1999 – 2005.

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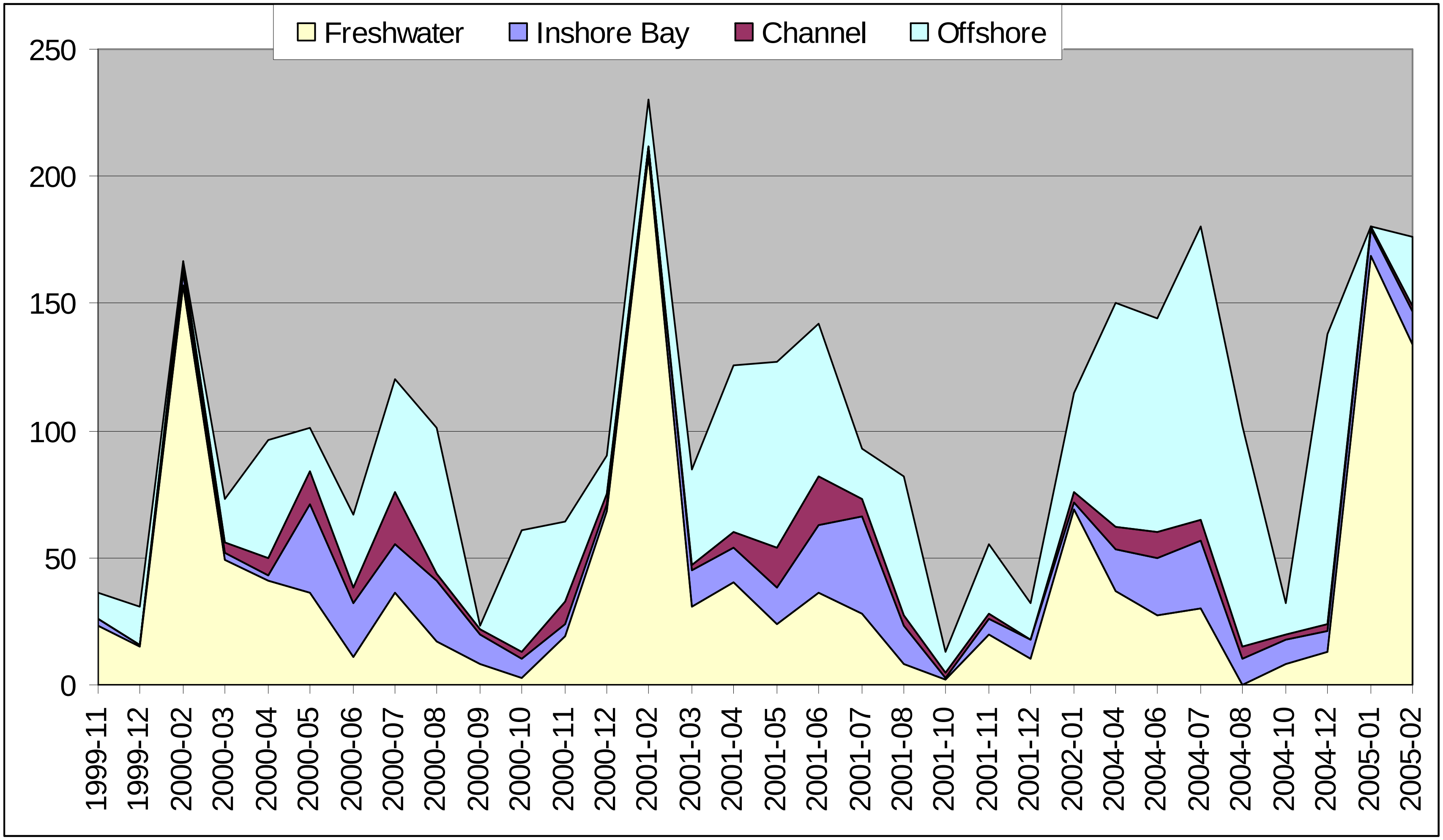

Figure 32. Seasonal use patterns of four habitat zones based on distributional aerial survey data from Ten Thousand Islands, Collier County November 1999 – February 2005. Manatee counts tend to peak in winter, when they aggregate in inland sites that provide thermal refuges.

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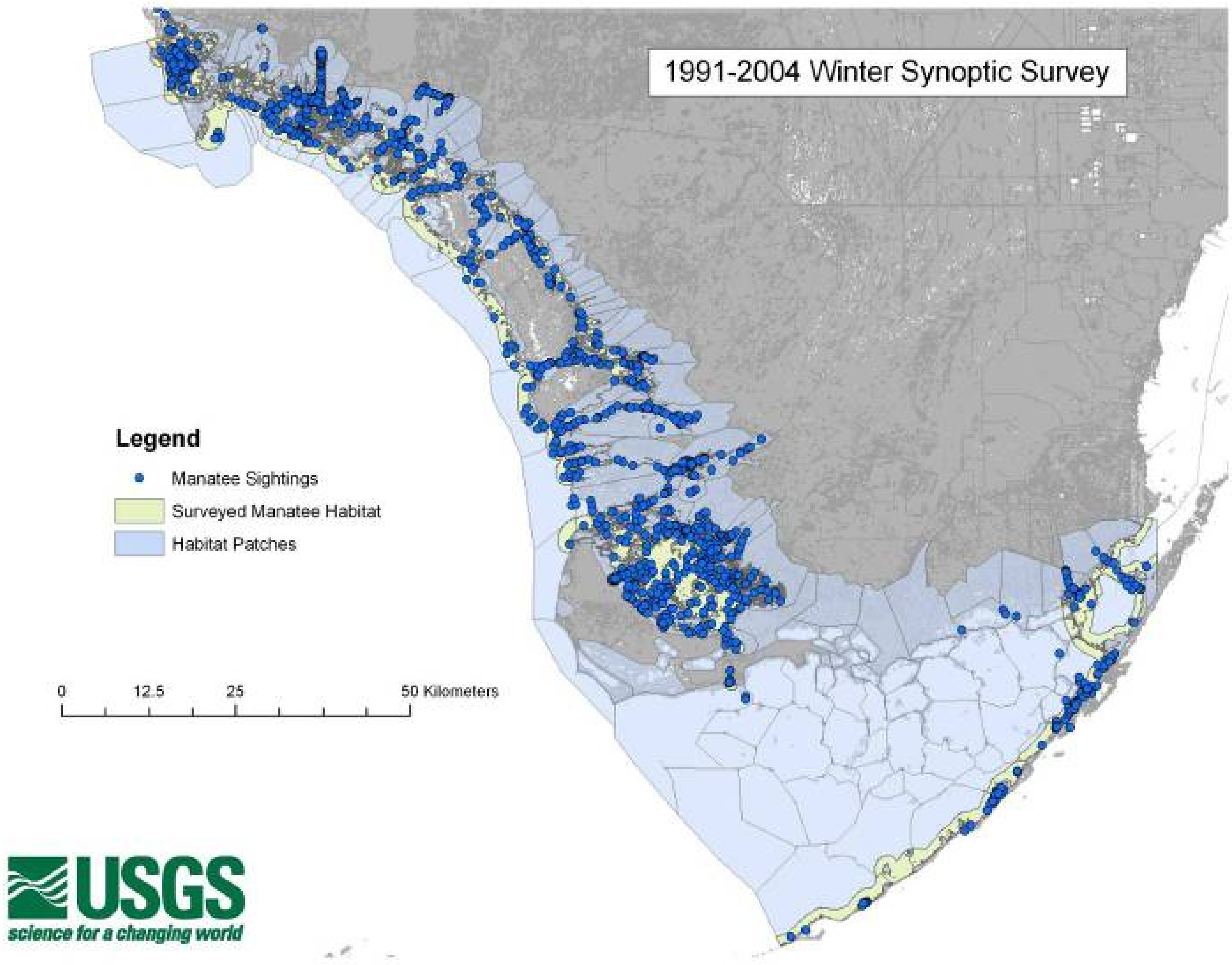

Figure 33. Manatee group sightings for winter synoptic aerial surveys 1991 – 2004 (light-green and blue polygons represent surveyed and unsurveyed habitat patches, respectively).

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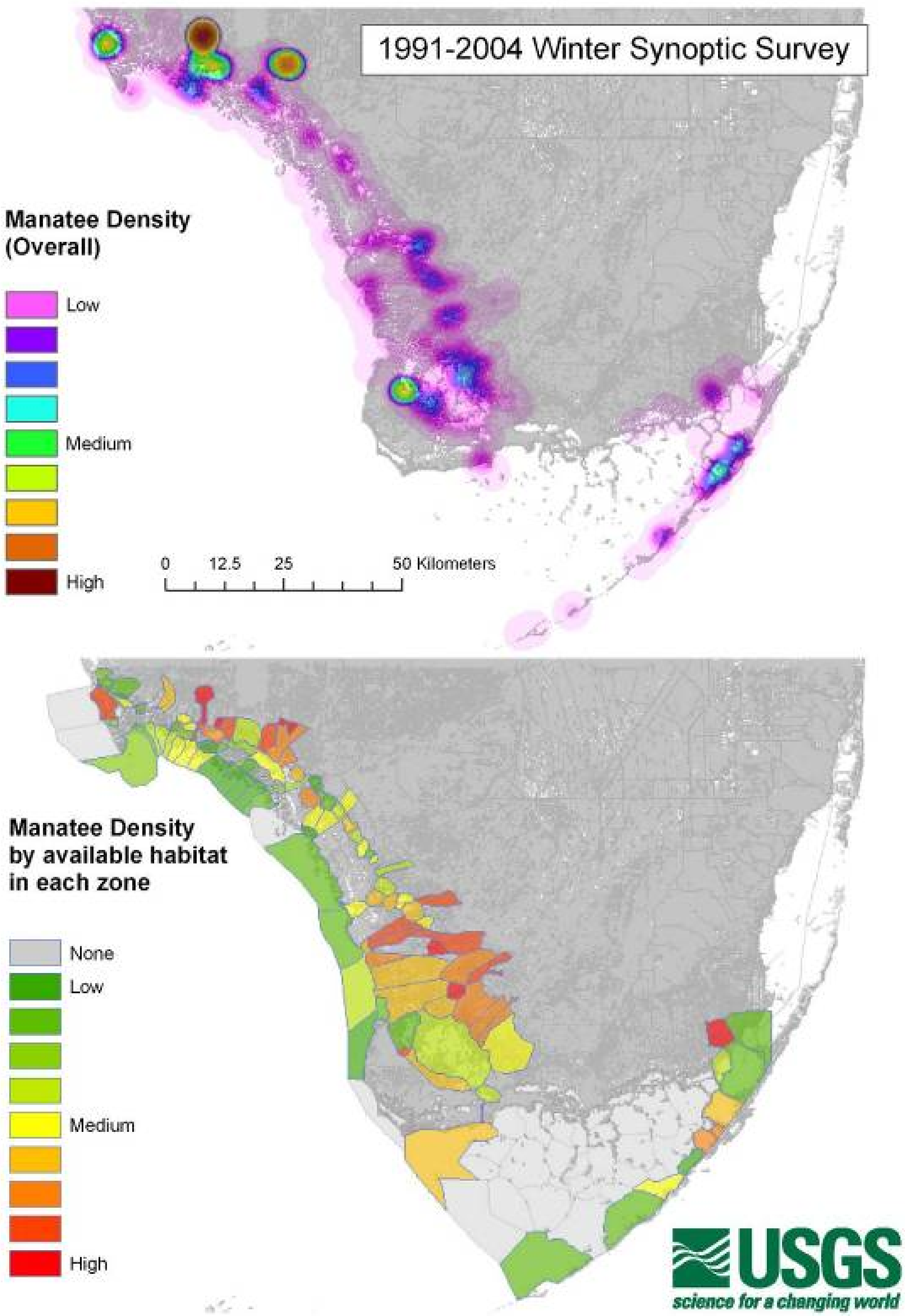

Figure 34. Kernel density map (top) and habitat polygon map (bottom) showing relative densities of manatee group sightings for winter synoptic aerial surveys 1991 – 2004

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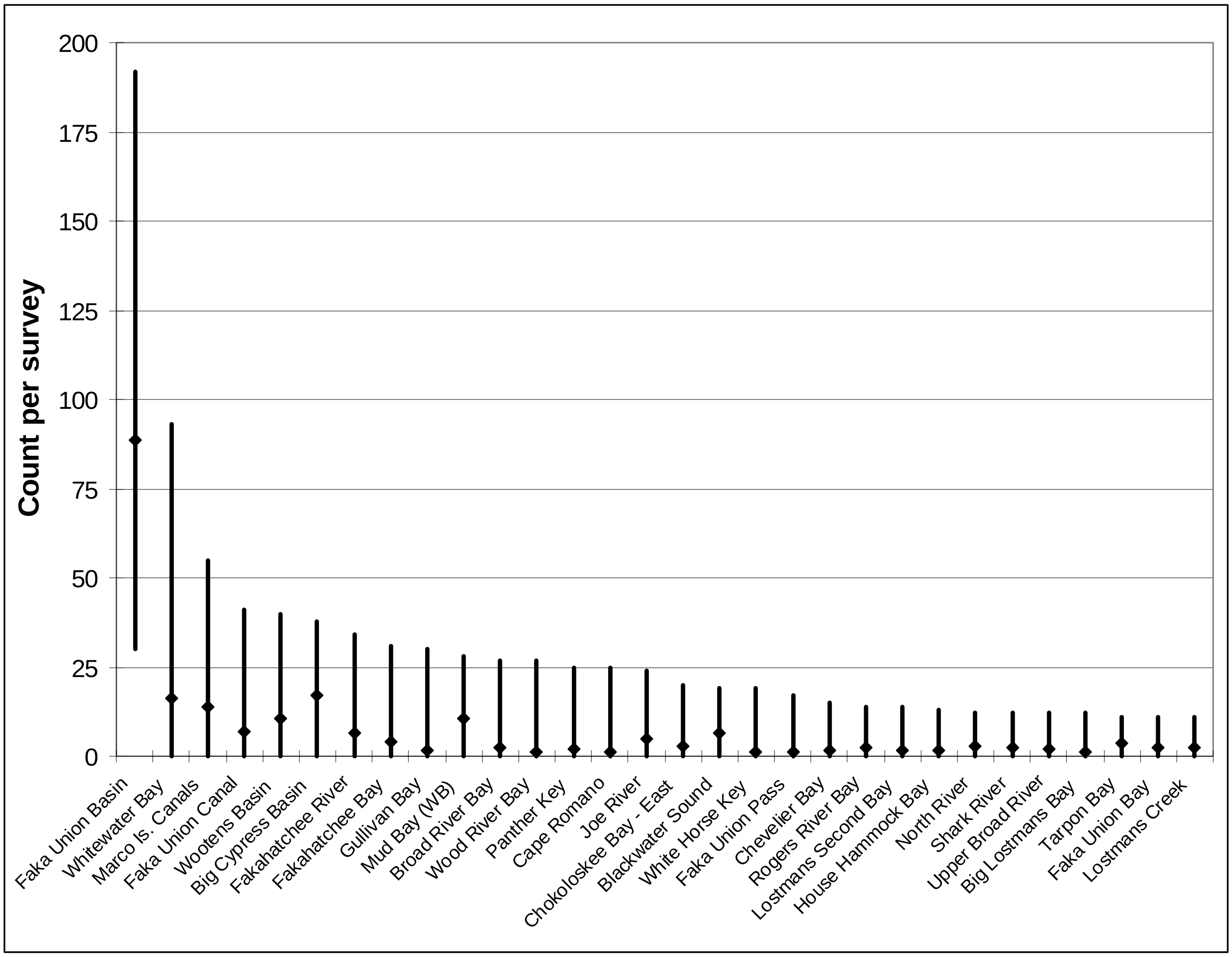

Figure 35. Sites with highest winter use (at least 10 individuals seen) based on synoptic aerial surveys (1991 – 2004). Vertical lines show maximum and minimum counts for all surveys; tick mark shows mean count. Sites are defined by polygonal zones (see map in Fig. 2).

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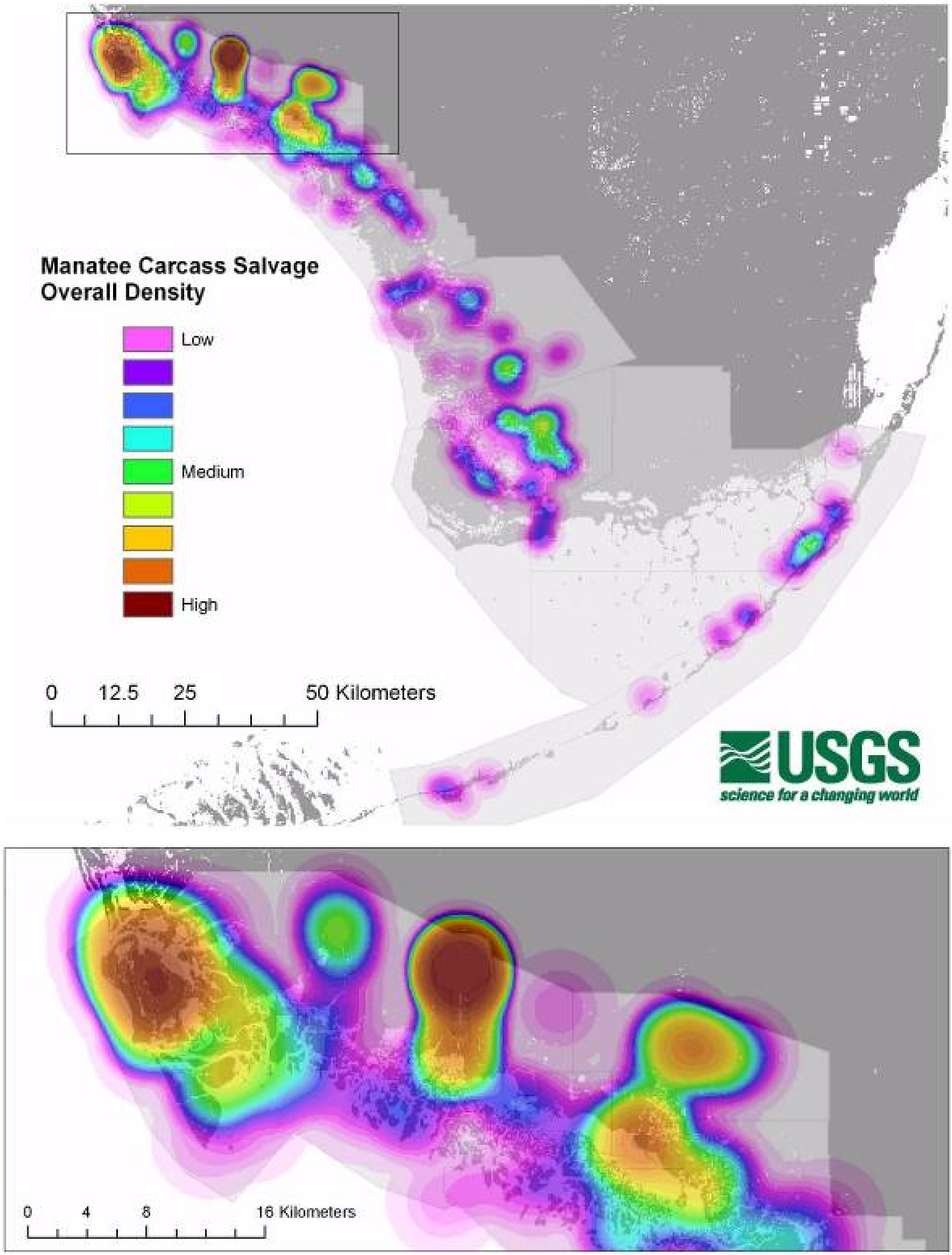

Figure 36. Map of carcass salvage data showing overall spatial density of carcasses from 1977 – 2004. Marco Island (Region 9), POI (Region 8a), Chokoloskee Bay (Region 7), Barron River (Region 7), and the east side of Whitewater Bay (Region 4) show concentrations of recovered carcasses.

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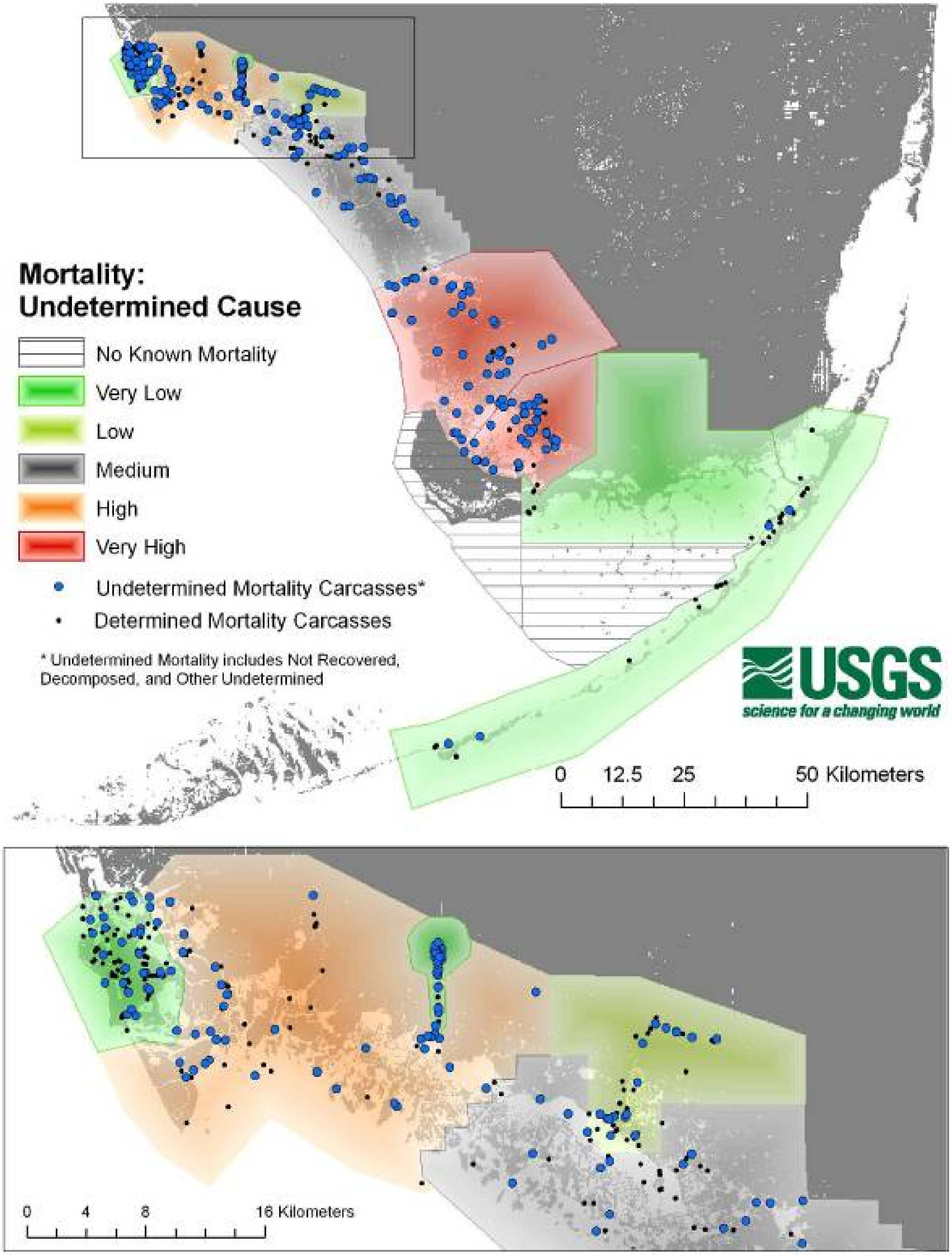

Figure 37. Map of carcass salvage data with undetermined cause of mortality (1974 – 2004). Regions 4 and 5 have disproportionately high numbers of carcasses of undetermined cause, while POI (Region 8a) and Marco Island (Region 9) have disproportionately low numbers.

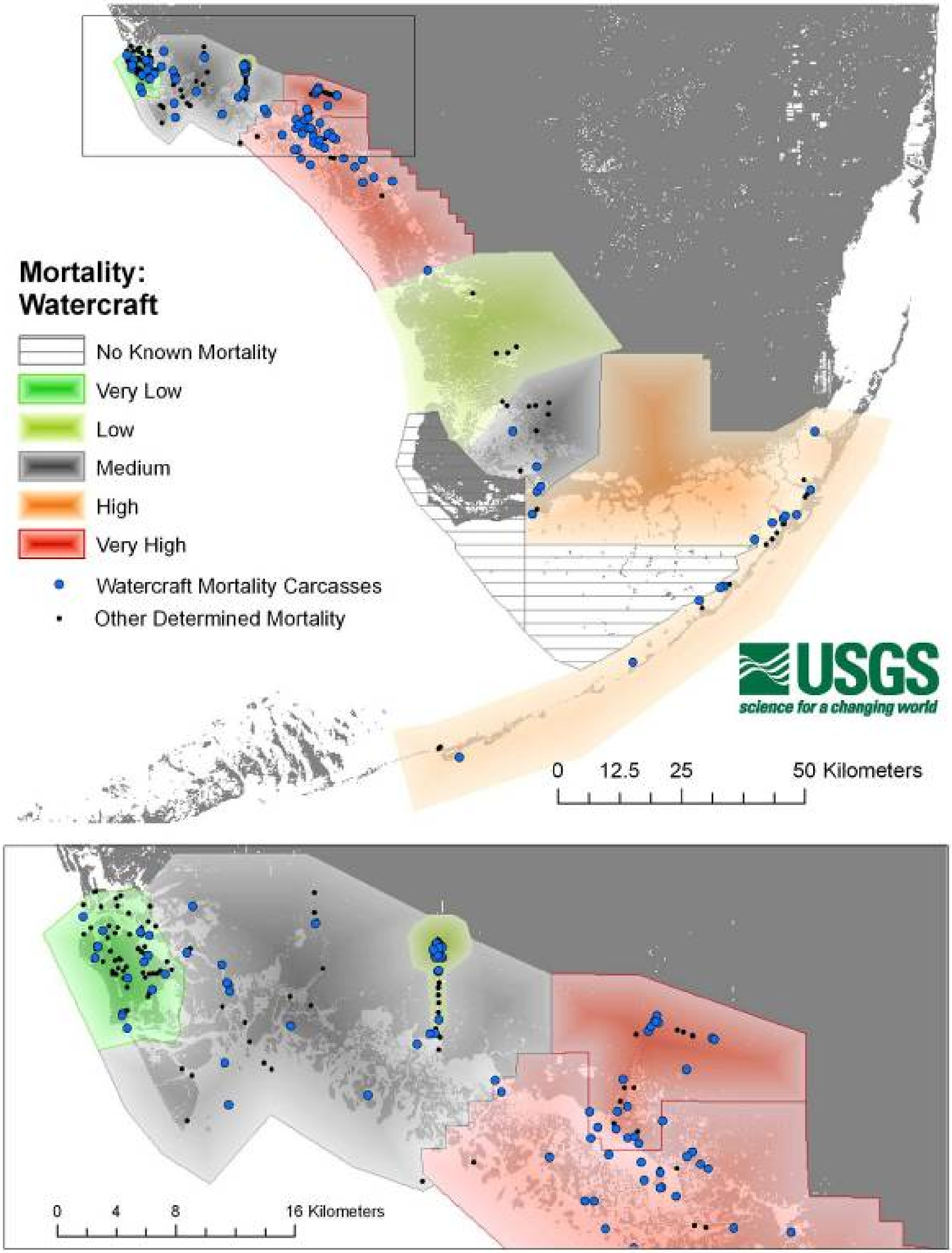

Figure 38. Map of carcass salvage data due to watercraft (1974 – 2004). Regions 6 and 7, the Everglades City – Chokoloskee area, had disproportionately high numbers of recovered carcasses, while POI (Region 8a) and Marco Island (Region 9) had disproportionately low numbers.

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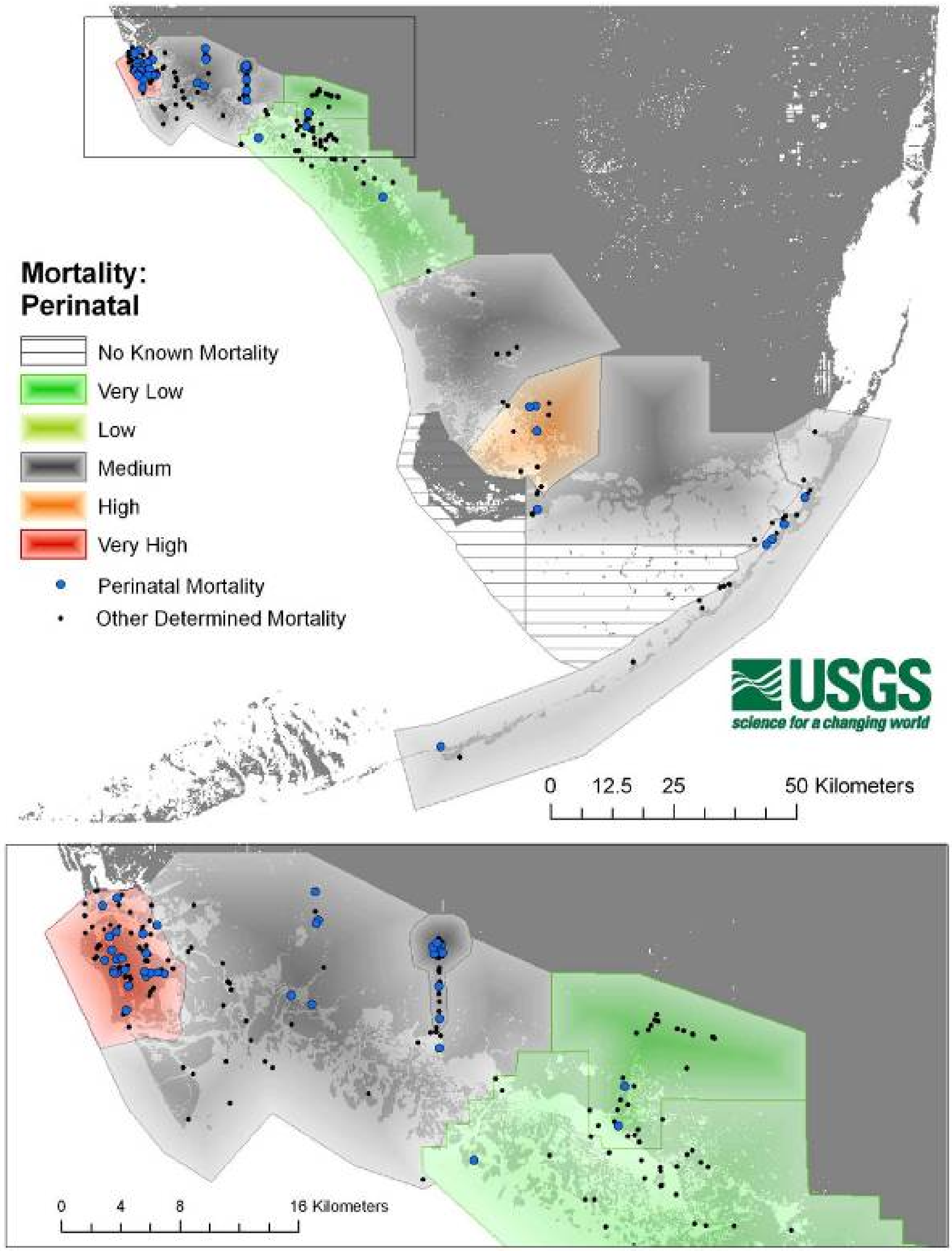

Figure 39. Map of carcass salvage data with mortality due to perinatal death (1974 – 2004). Marco Island (Region 9) had disproportionately high numbers of perinatal carcasses (Whitewater Bay (Region 4) also was high, but the sample size there was too small to provide much reliability).

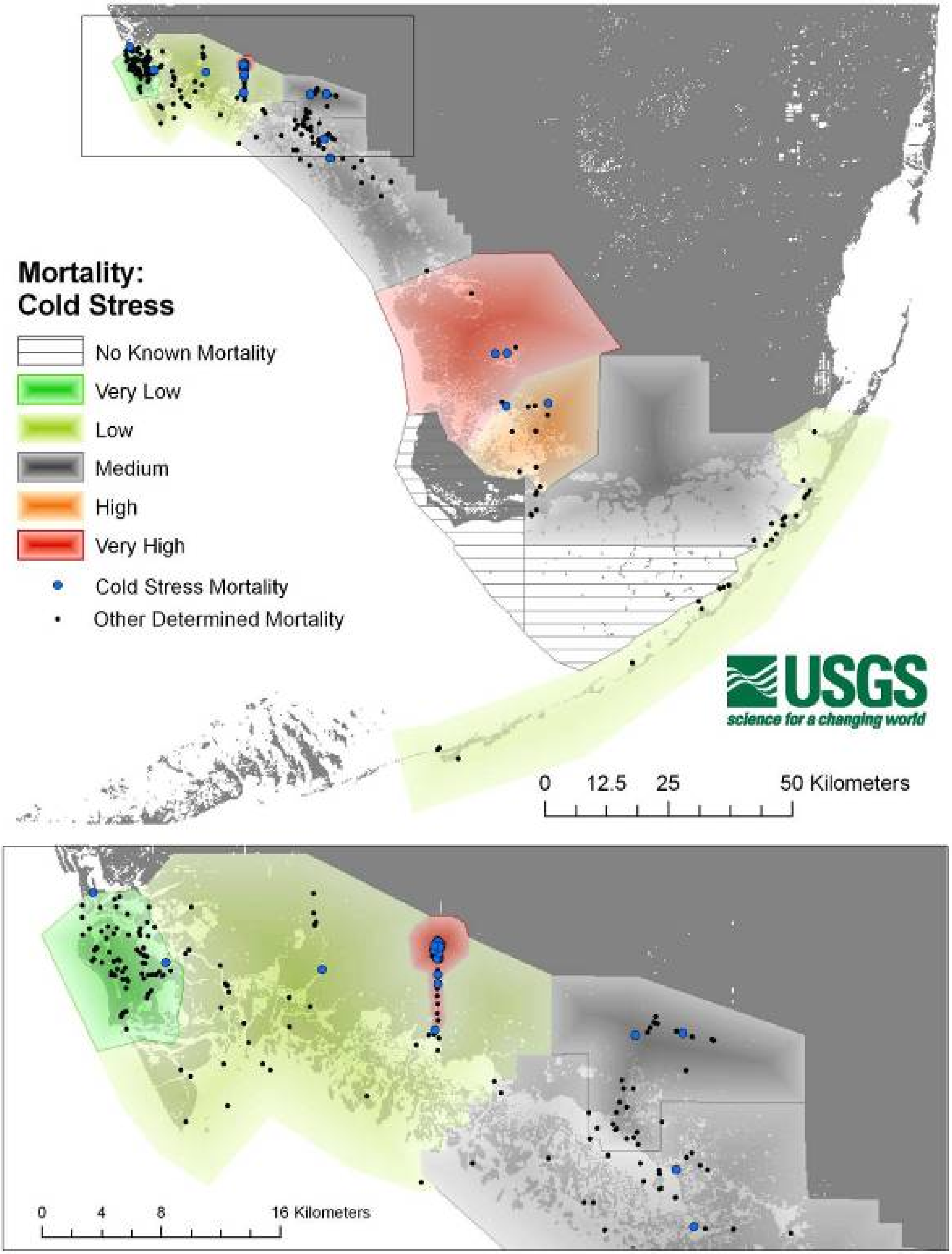

Figure 40. Map of carcass salvage data with mortality due to cold stress (1974 – 2004). POI (Region 8a) had disproportionately high numbers of cold stress carcasses.

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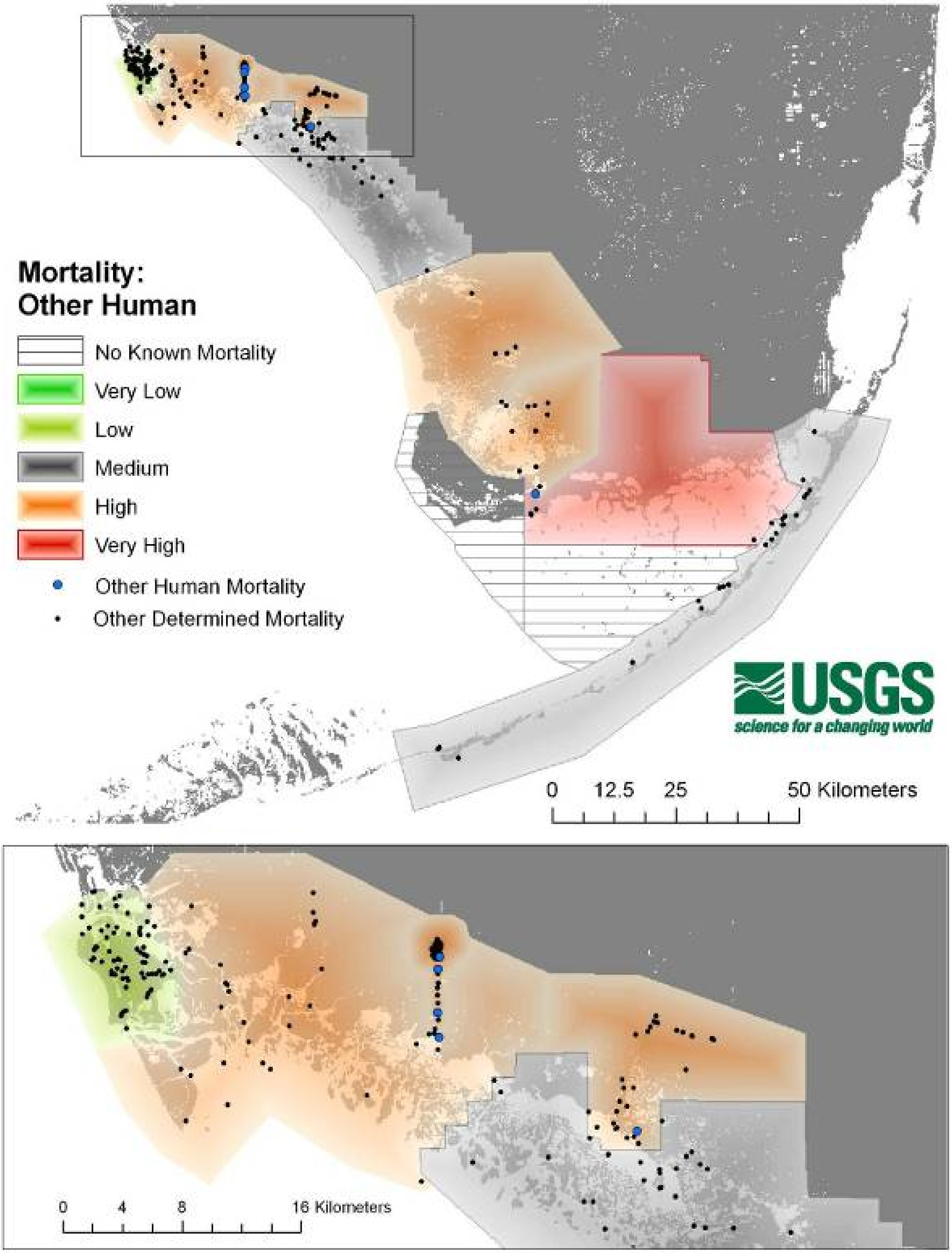

Figure 41. Map of carcass salvage data with mortality due to human causes other than watercraft (1974 – 2004).

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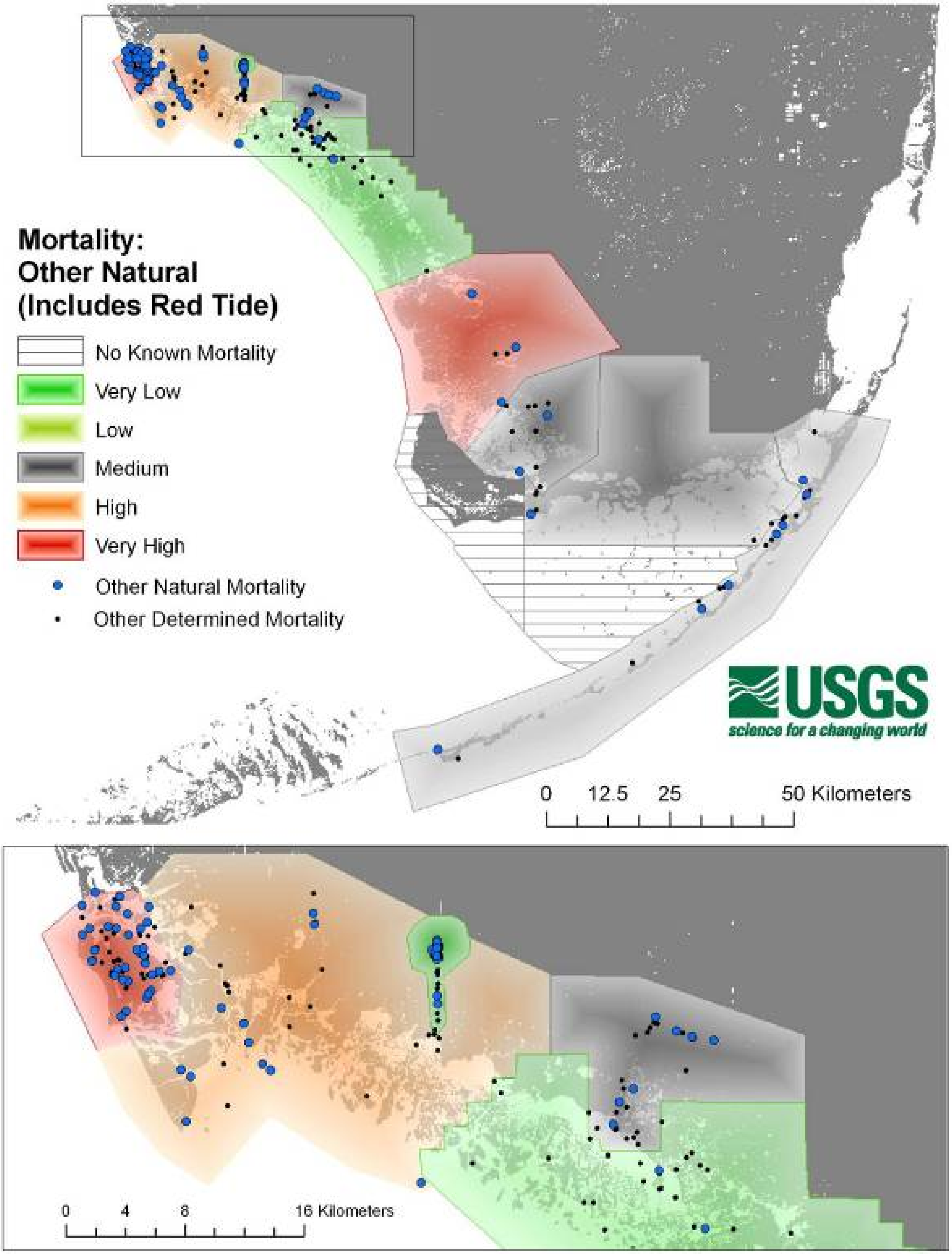

Figure 42. Map of carcass salvage data with mortality due to natural causes (including red tide) (1974 – 2004). The northwest region of the study area showed high numbers of carcasses.

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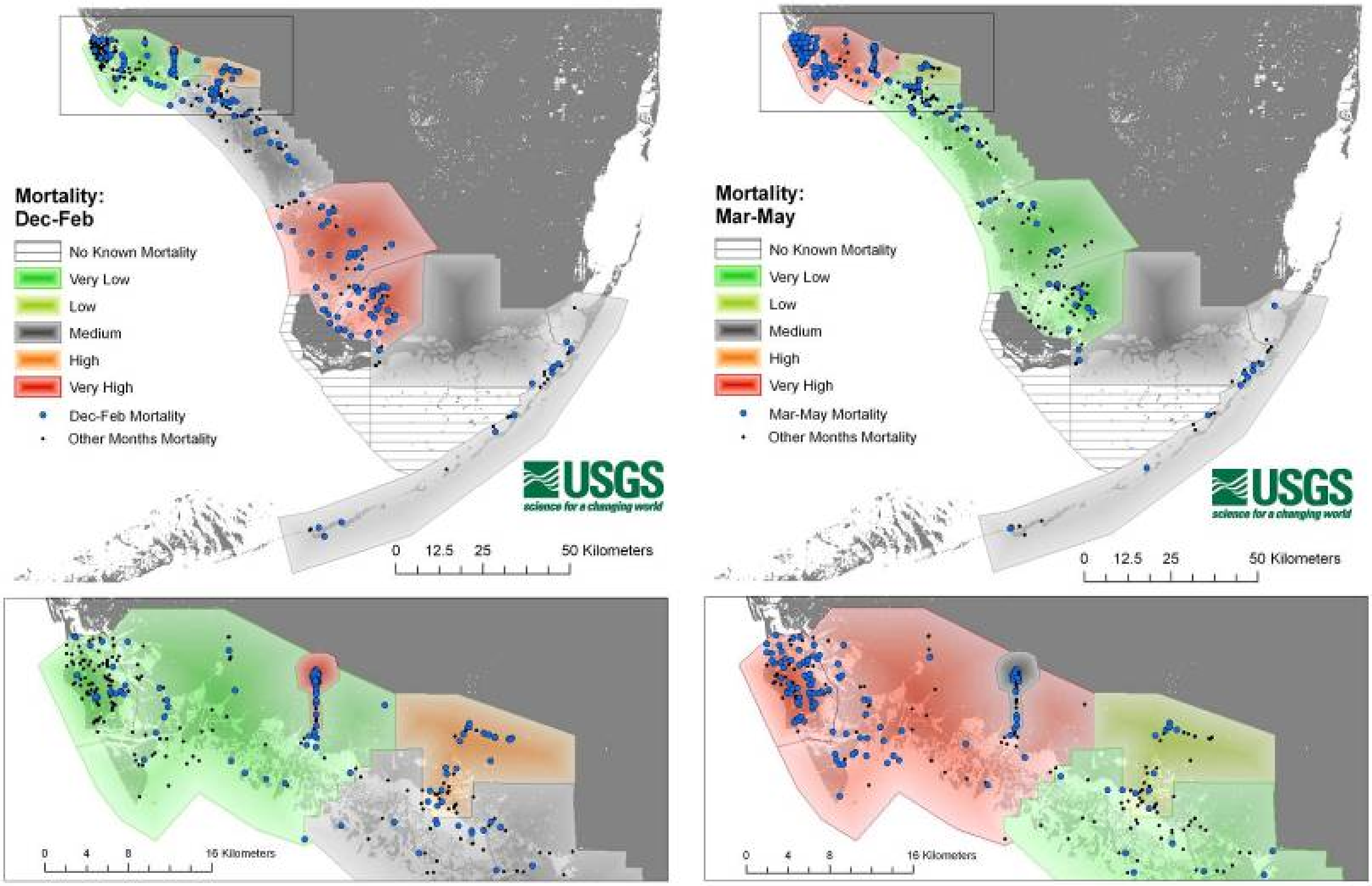

Figure 43. Map of carcass salvage data with carcasses recovered in winter and spring quarters (1974 – 2004). Whitewater Bay region and POI showed disproportionately high numbers of carcasses during winter, while Marco Island to Everglades City showed high numbers in spring.

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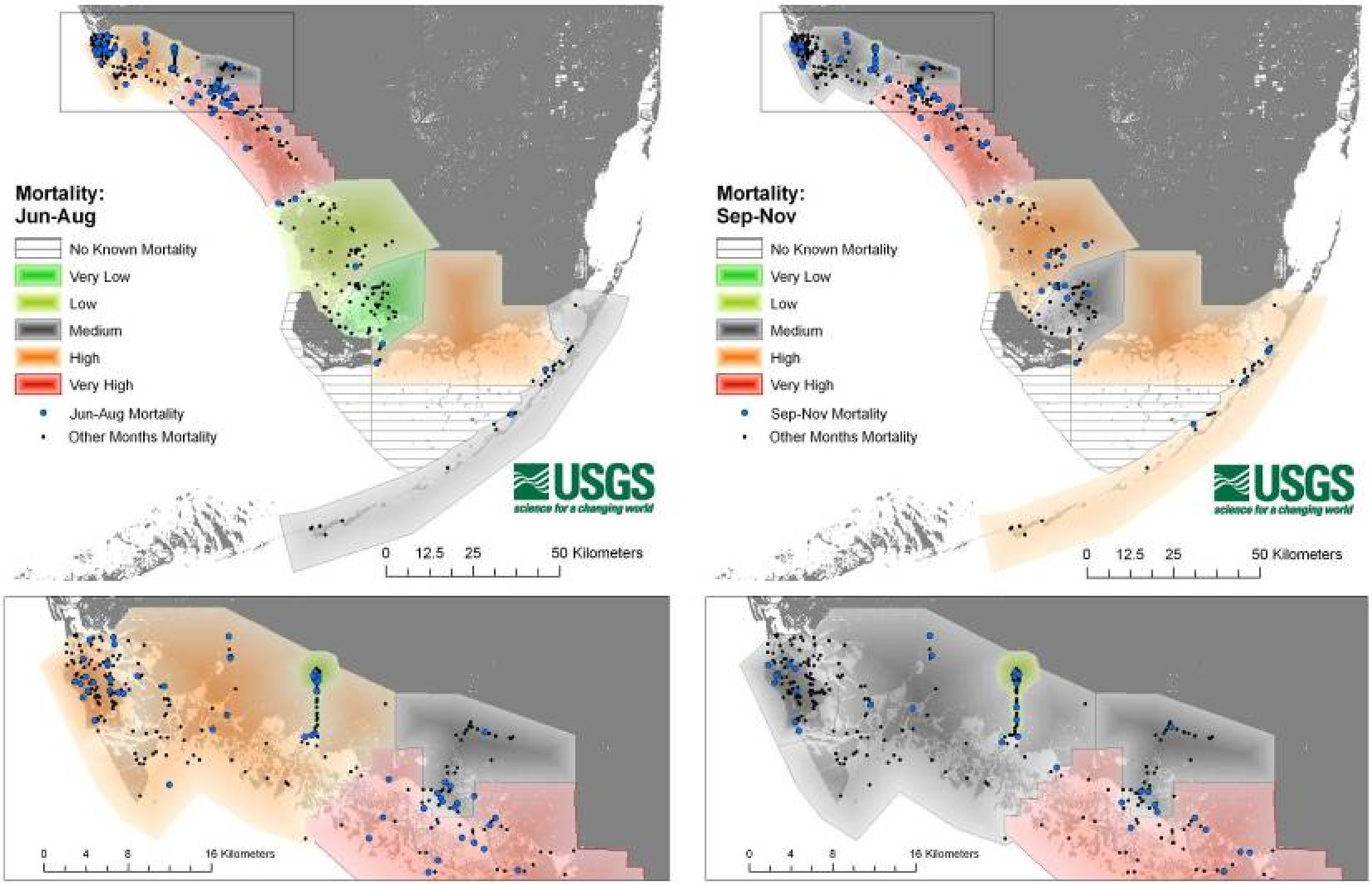

Figure 44. Map of carcass salvage data with carcasses recovered in summer and fall quarters (1974 – 2004). The Chokoloskee region showed high numbers recovered in both summer and fall.

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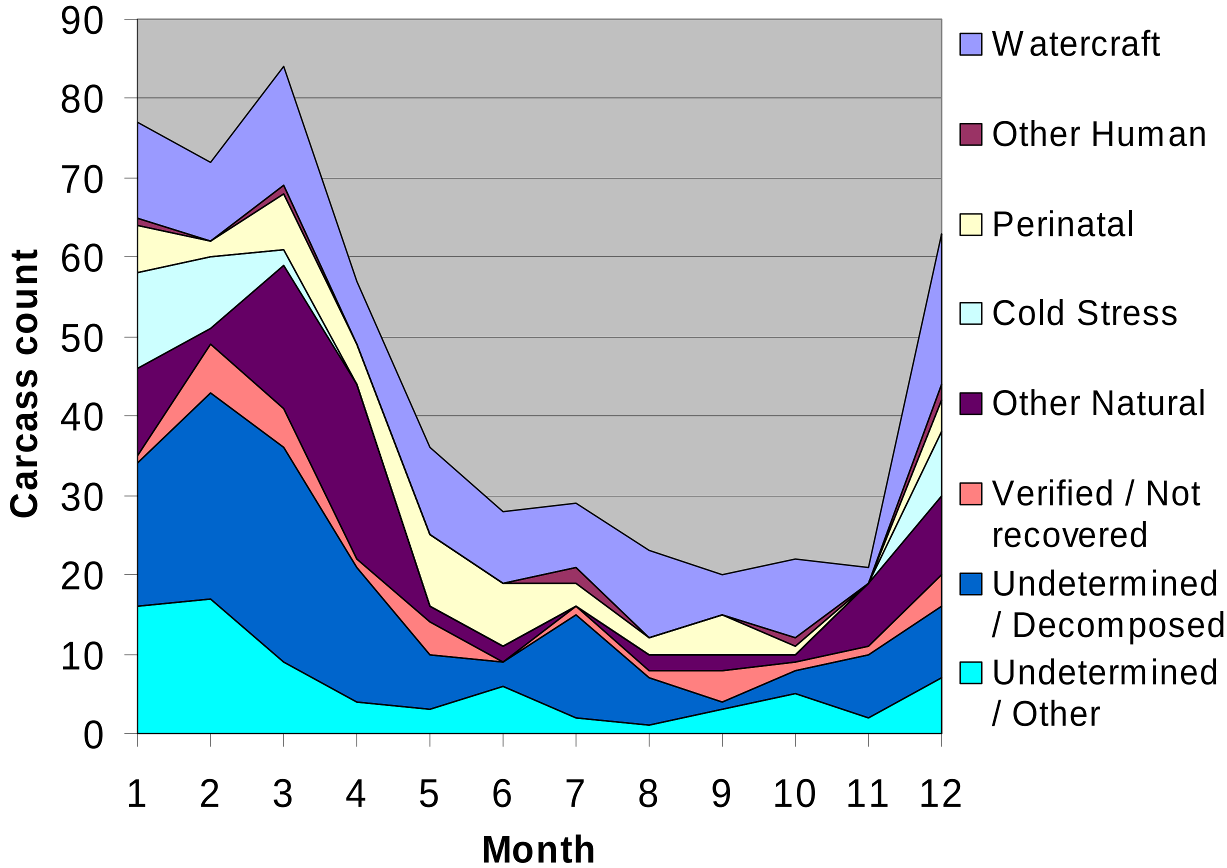

Figure 45. Monthly patterns in carcass salvage data by mortality categories (1975 – 2004). A disproportionately high number of undetermined carcasses were recovered during and just after winter months.

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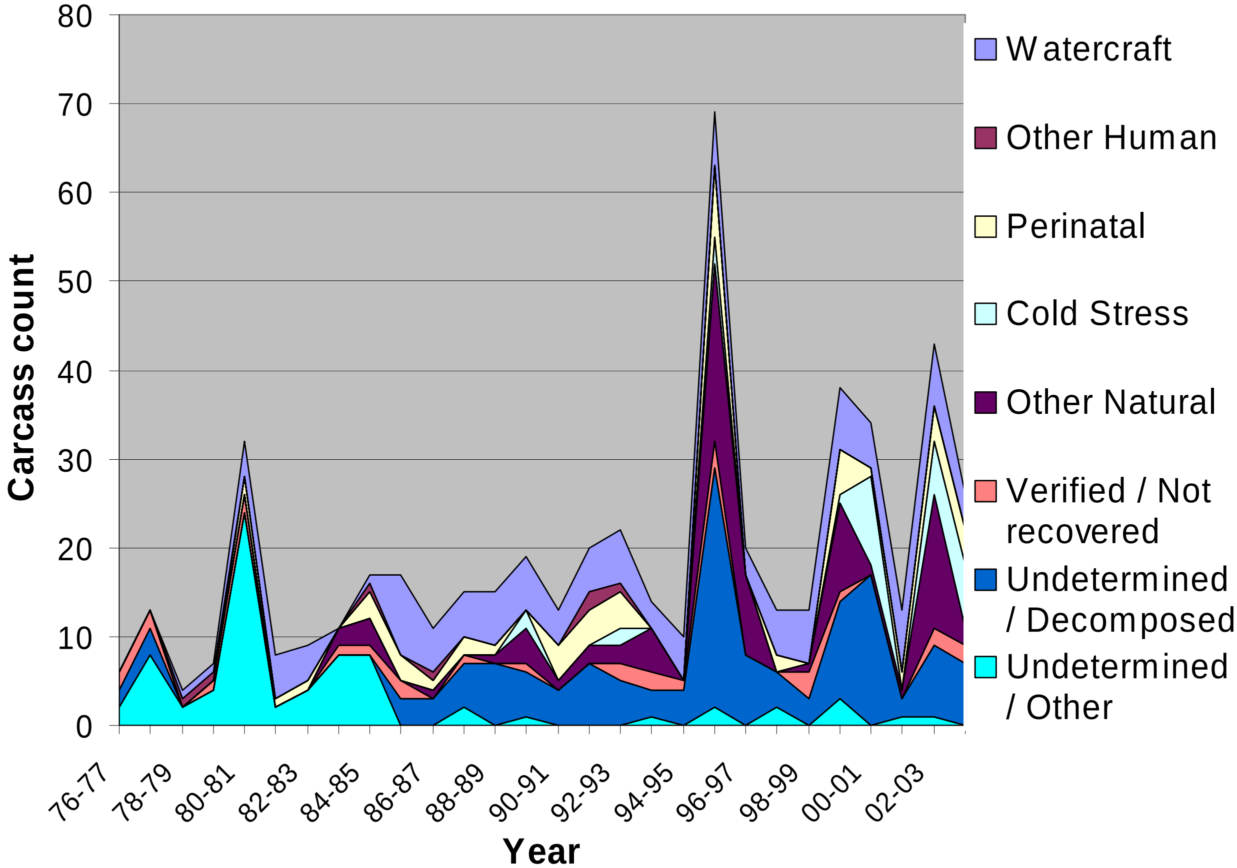

Figure 46. Annual carcass counts by mortality categories (year is from December – November). Peaks in natural mortality may be largely attributable to red tide events. Undetermined categories may be largely attributable to cold stress (see Fig. 13).

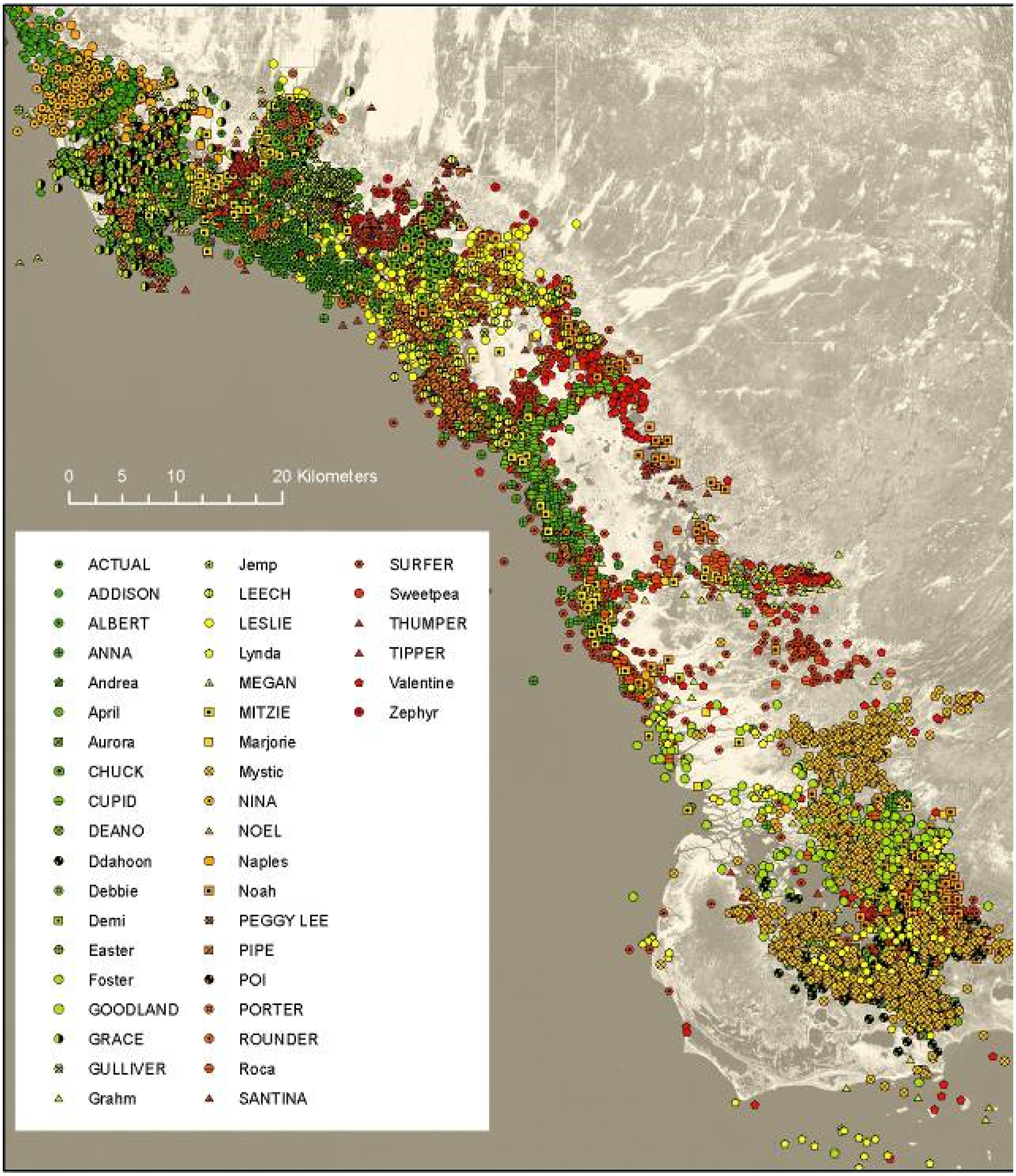

Figure 47. Map of Argos PTT radiotelemetry data showing habitat coverage of 44 tagged manatees from 1992 – 2003. These data include wild-caught and captive-raised individuals and demonstrate their cosmopolitan habitat use in the study area.

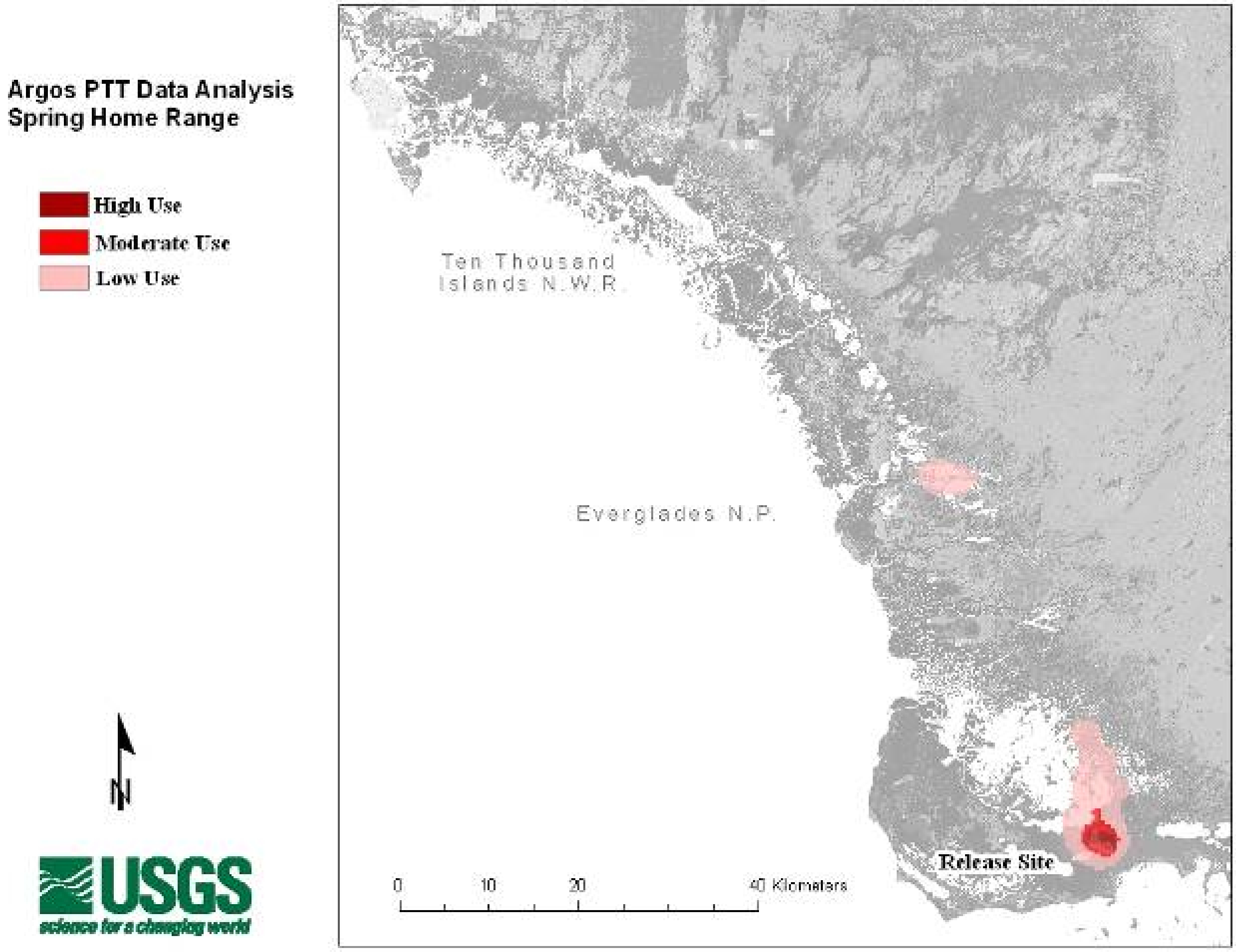

Figure 48. Composite home range map for nine naïve, captive-raised animals based on Argos PTT radiotelemetry data, spring season. Areas of high use include Coot Bay, at the release site, with lower use areas in Whitewater Bay and vicinity of Big Lostmans Bay.

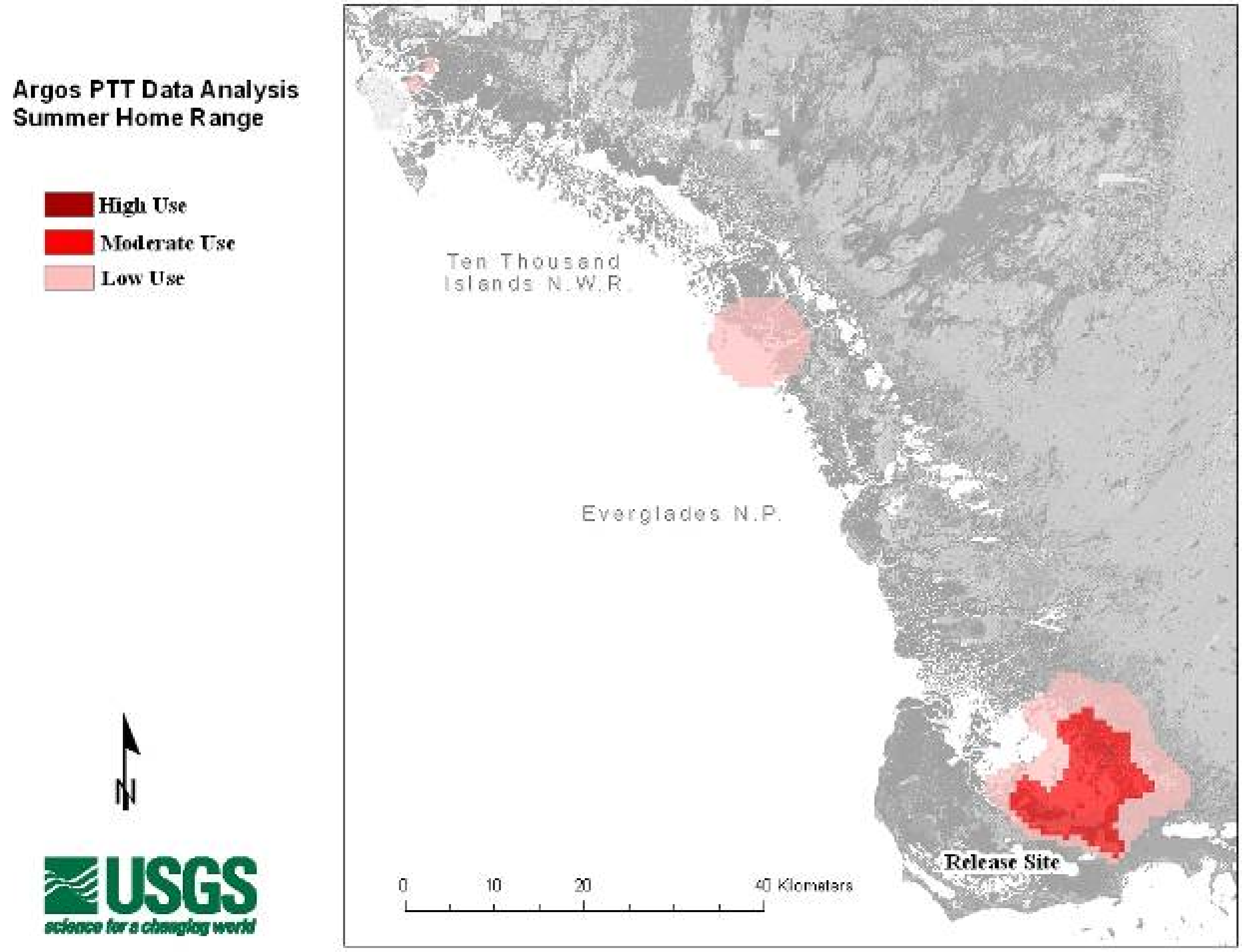

Figure 49. Composite home range map for nine naïve, captive-raised animals based on Argos PTT radiotelemetry data, summer season. Areas of high and moderate use are concentrated in the eastern half of Whitewater Bay extending into North River, Roberts River, Lane Bay, Coot Bay (release site), and Joe River. An area of low use occurs off the Chatham and Huston Rivers near Pavilion Key.

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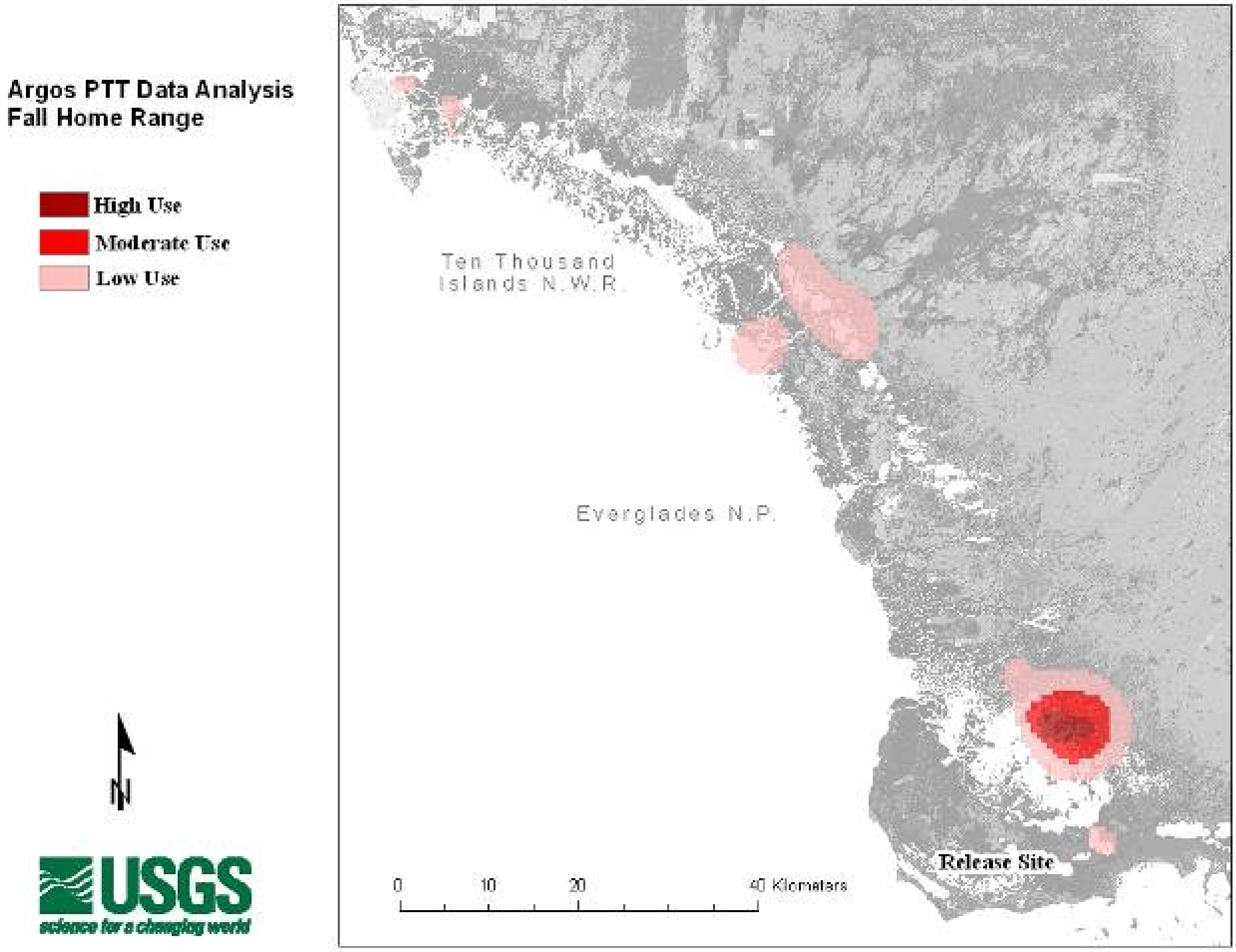

Figure 50. Composite home range map for six naïve, captive-raised animals based on Argos PTT radiotelemetry data, fall season. Areas of high use include northeast Whitewater Bay and into the North and Roberts Rivers. Areas of low use occur at Coot Bay (release site), the mouth of the Chatham and Huston Rivers, the Huston Bay complex, and Sanctuary Sound and Goodland Bay near Marco Island.

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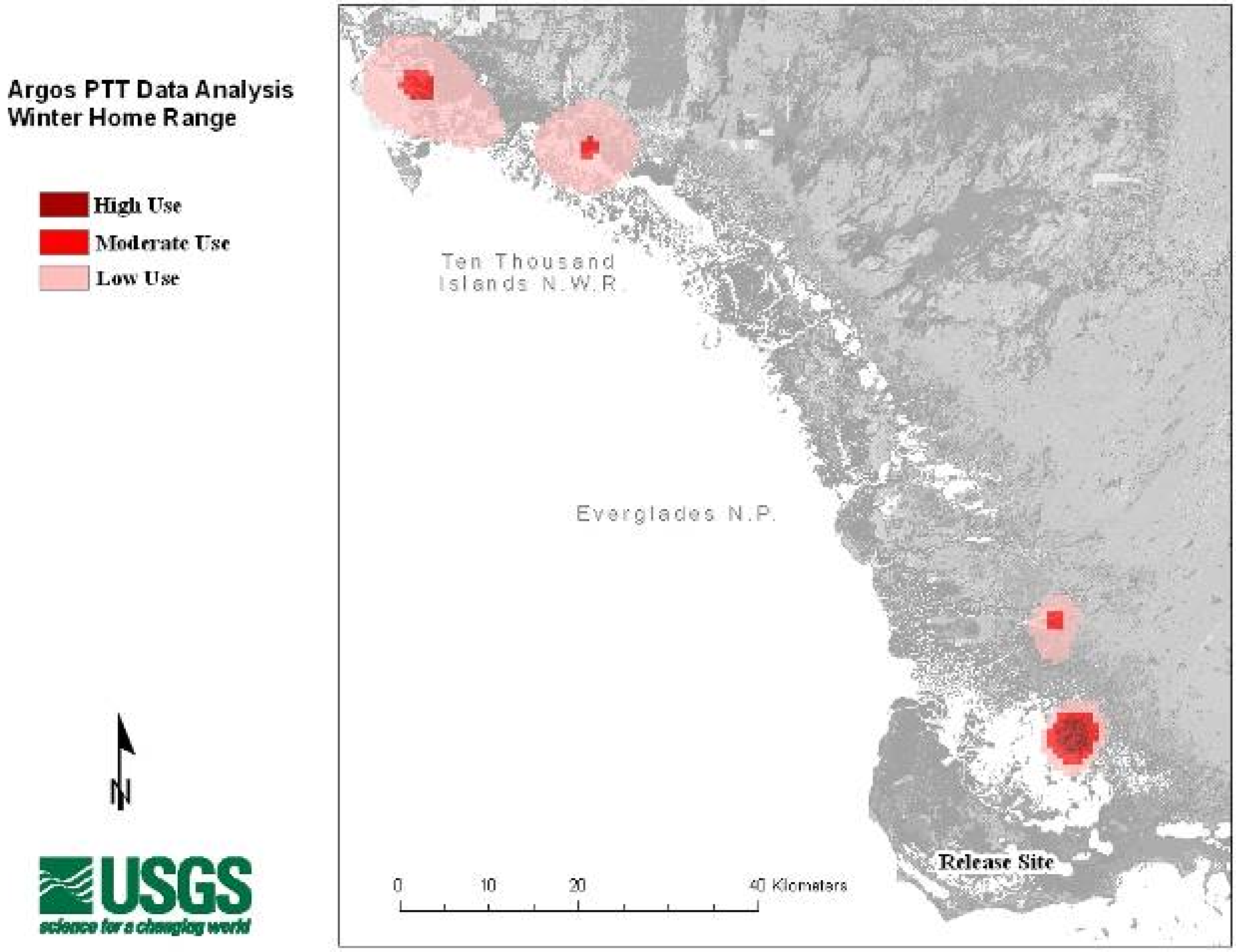

Figure 51. Composite home range map for four naïve, captive-raised animals based on Argos PTT radiotelemetry data, winter season. Areas of high use include northeast Whitewater Bay extending into the North River. Areas of moderate use include Tarpon Bay, mouth of the Fakahatchee River, the Marco Island canals and Addison Bay area.

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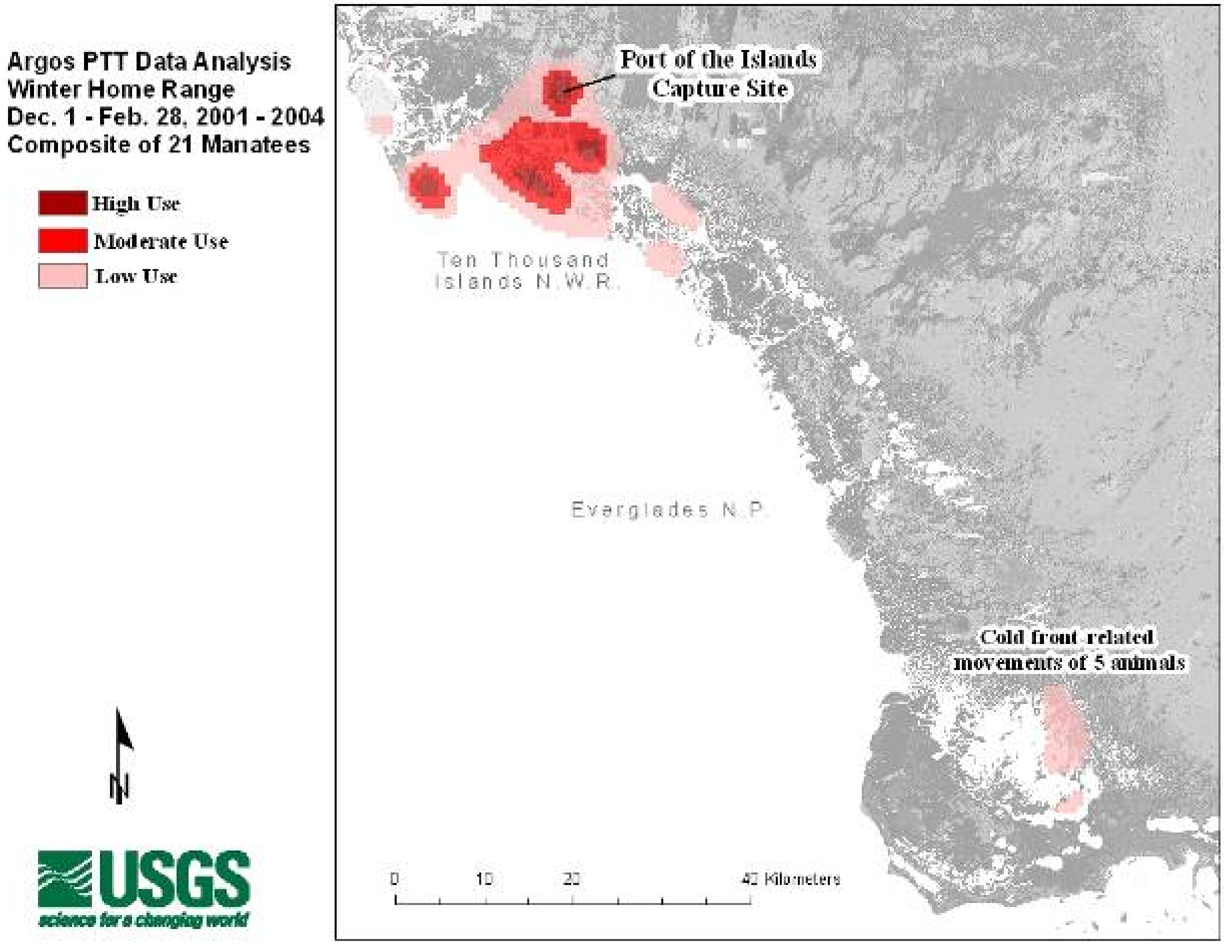

Figure 52. Composite winter home range map based on Argos PTT radiotelemetry data from 21 tagged manatees, 2001 – 2005. Areas of high use include POI capture site (a major winter refuge), mouth of the Fakahatchee River, and shoals off Cape Romano and vicinity of Round Key. Five animals moved briefly to Whitewater Bay during the winter quarter.

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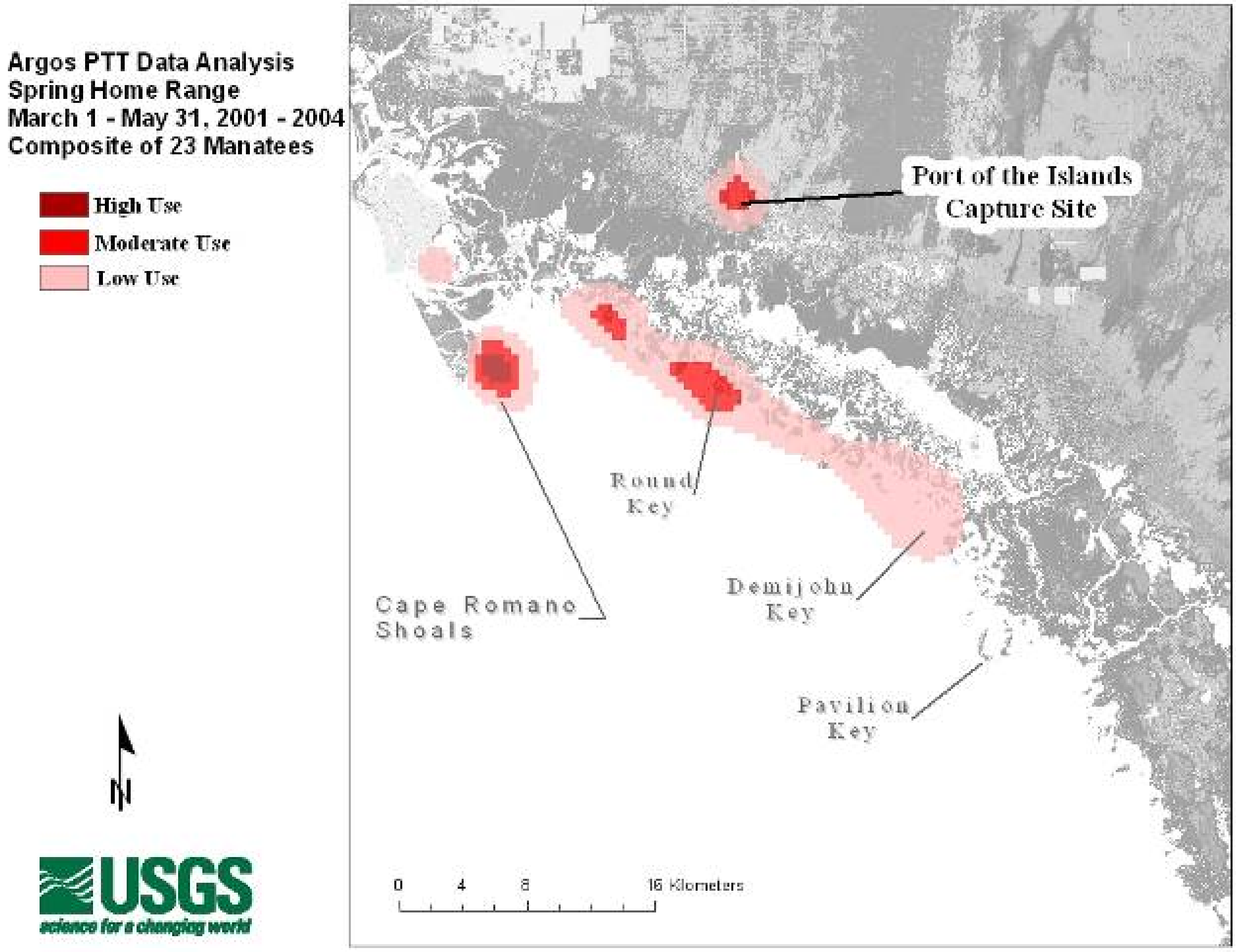

Figure 53. Composite spring home range map based on Argos PTT radiotelemetry data from 23 tagged manatees, 2001 – 2005. Areas of high use include POI capture site, and shoals off Cape Romano, vicinity of Turtle Key and Round Key.

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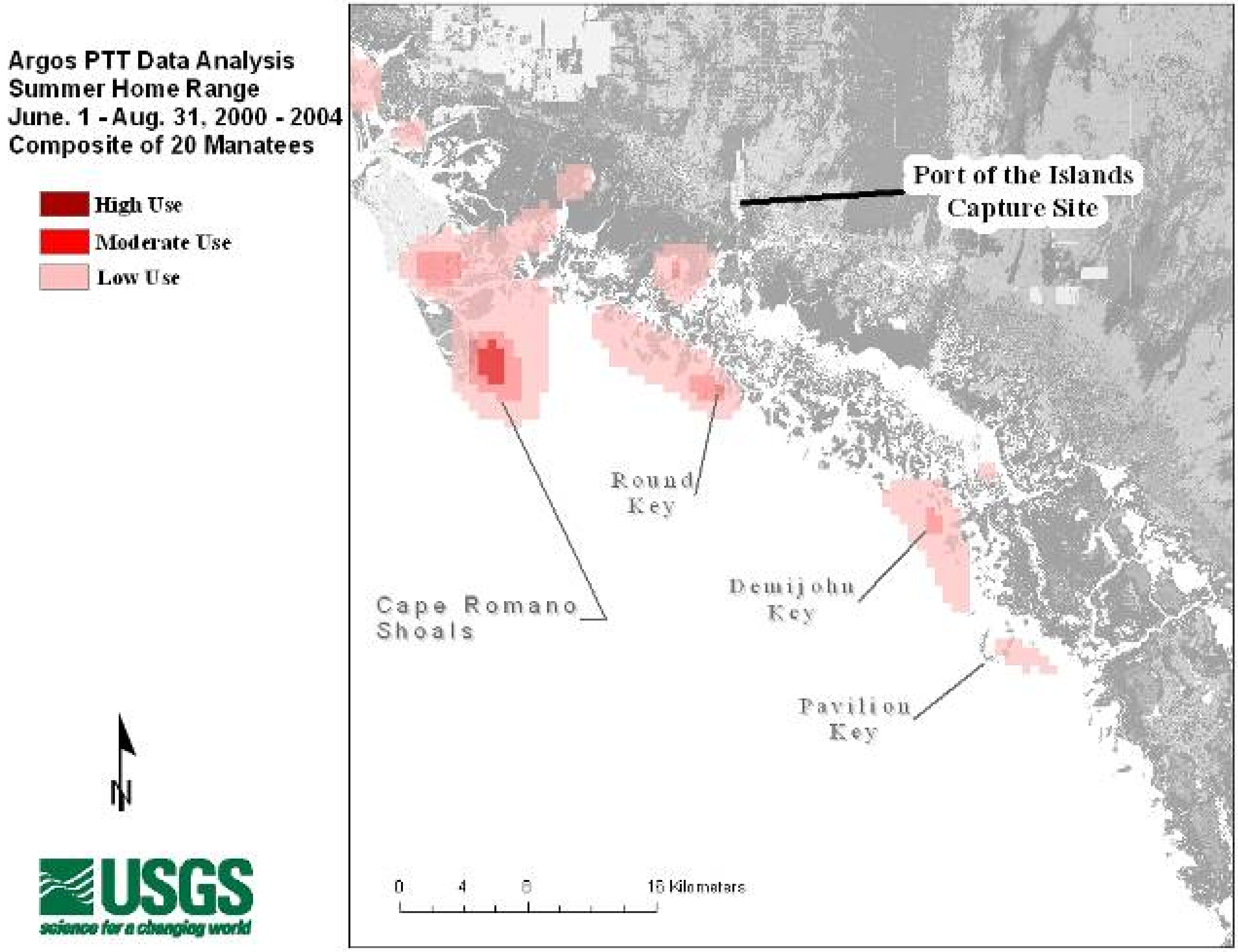

Figure 54. Composite summer home range map based on Argos PTT radiotelemetry data from 23 tagged manatees, 2000 – 2004. Area of highest use was the shoals off Cape Romano.

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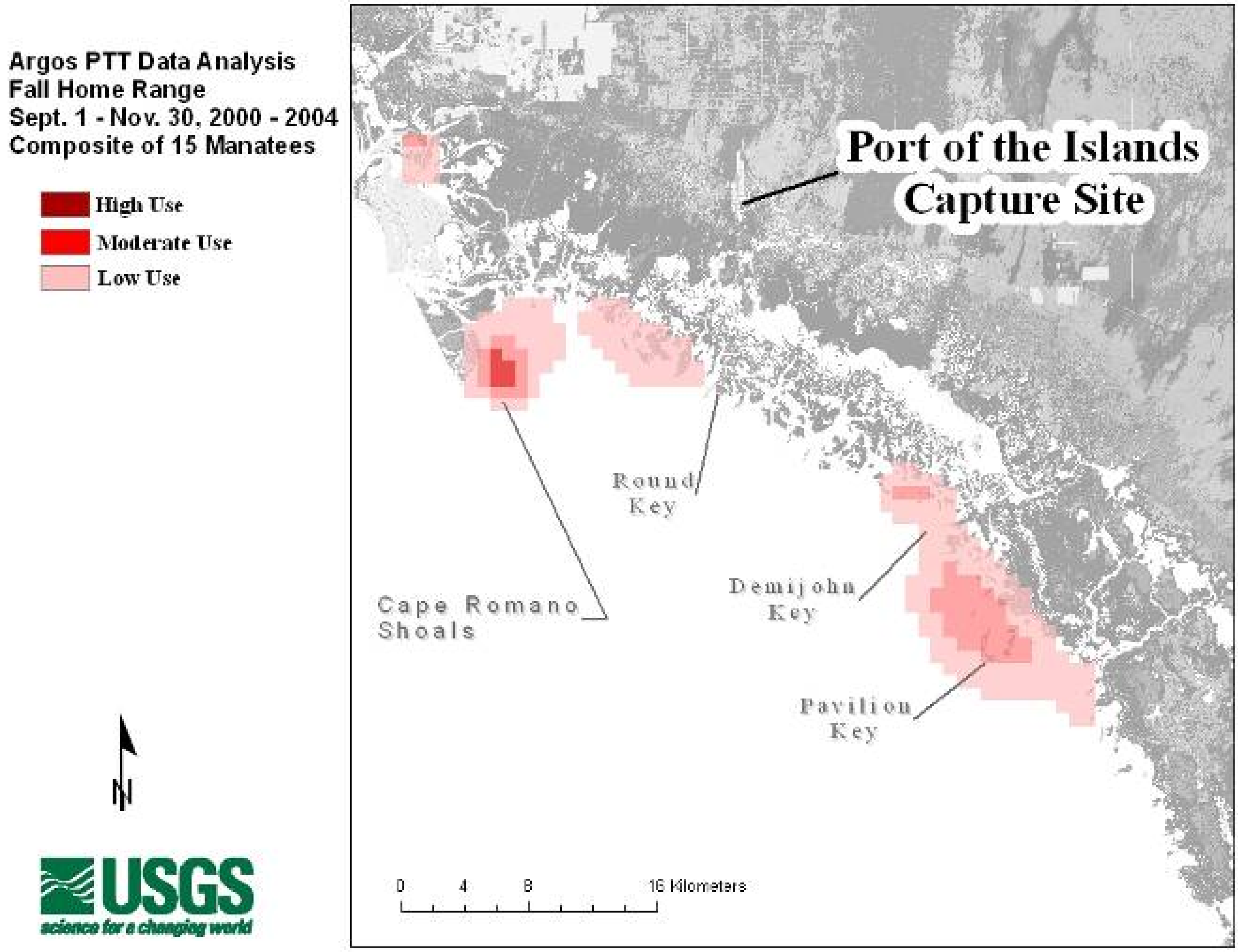

Figure 55. Composite fall home range map based on Argos PTT radiotelemetry data from 15 tagged manatees, 2000 – 2004. Area of highest use was the shoals off Cape Romano.

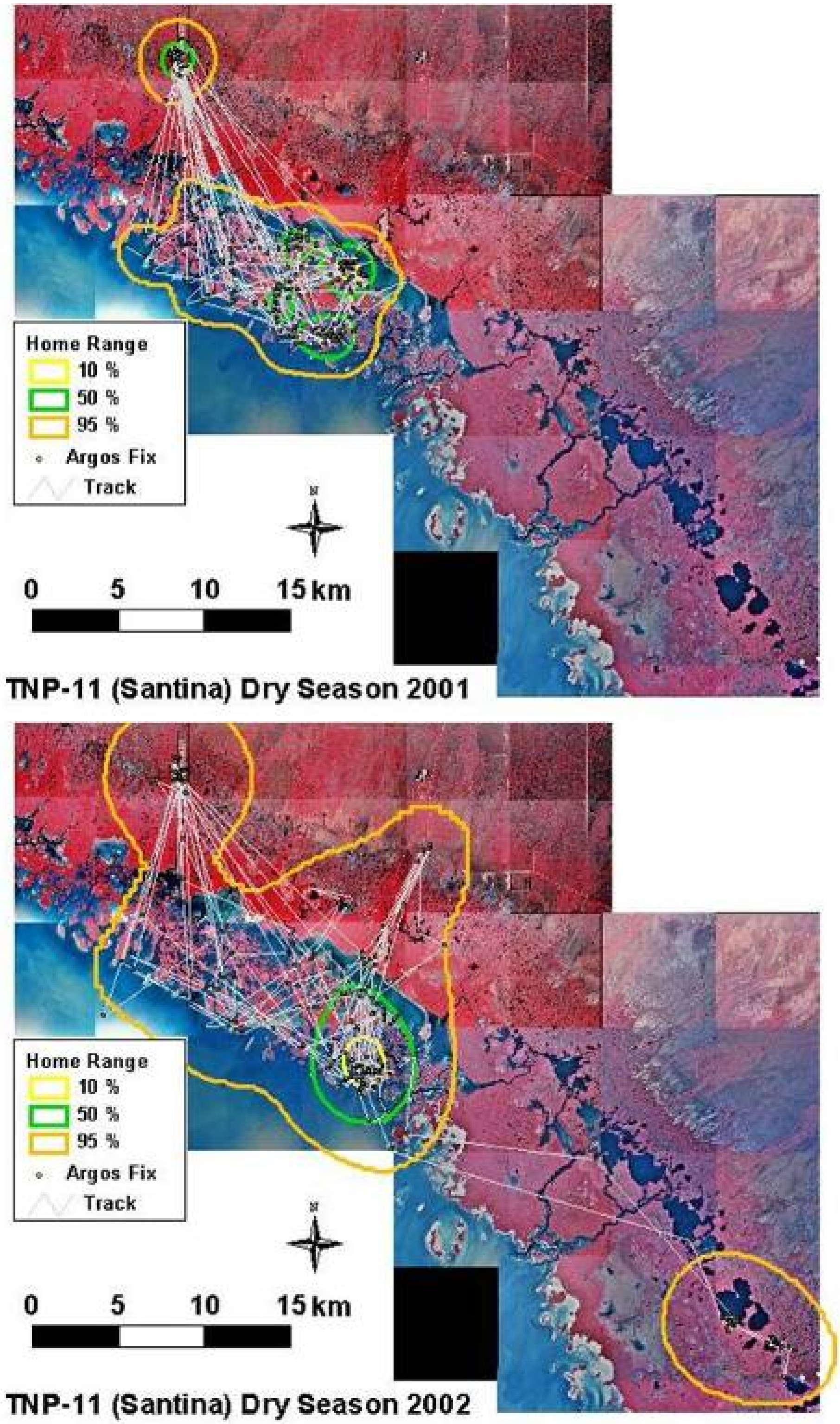

Figure 56. Home range maps for Santina during 2001 and 2002 dry seasons. White lines connect point locations in time sequence. POI is within the 95% use polygon for both years.

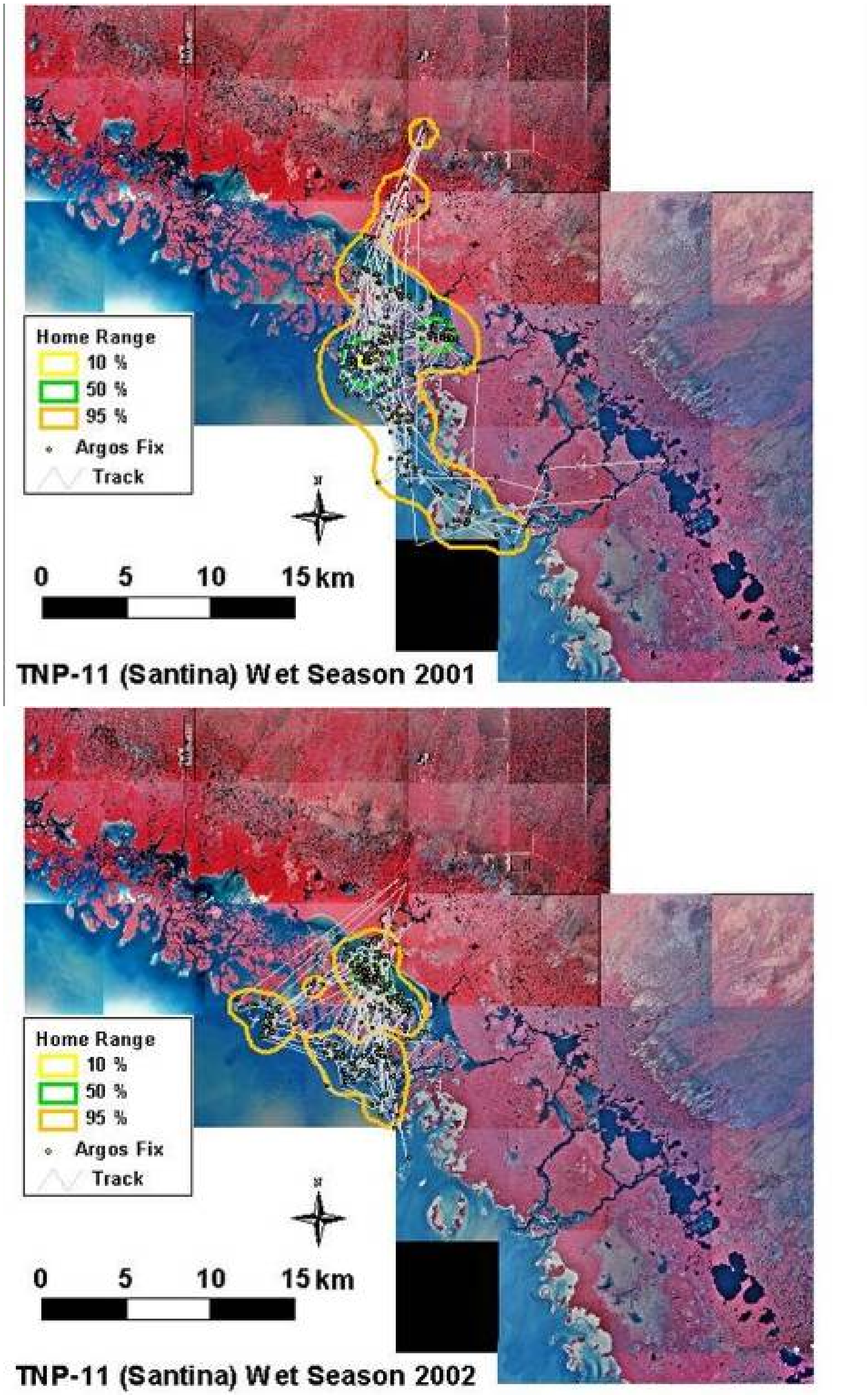

Figure 57. Home range maps for Santina during 2001 and 2002 wet seasons. White lines connect point locations in time sequence. POI is not used at all for both periods, and home range is shifted to the east into ENP compared to the dry season pattern.

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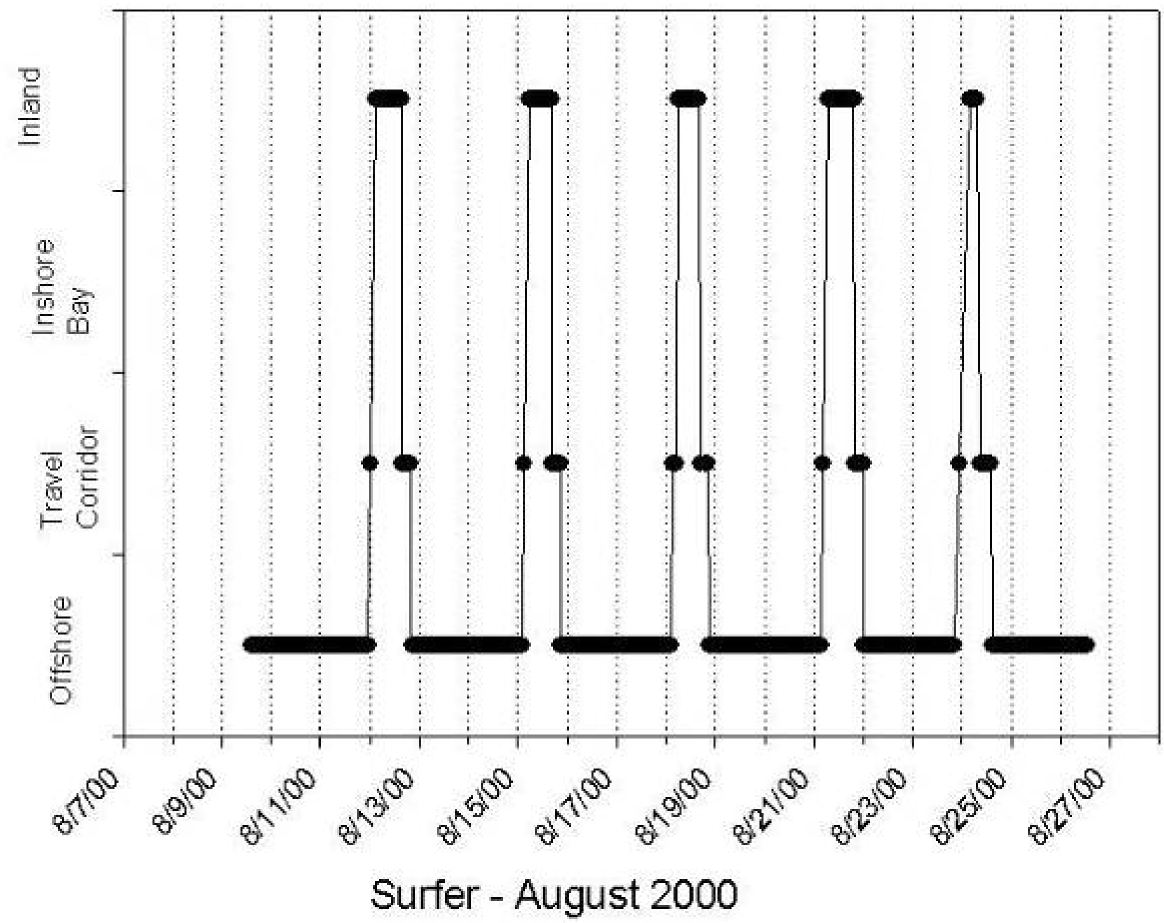

Figure 58. GIS analysis of GPS data for one individual (Surfer) during August 2000, showing regular movement between offshore feeding areas (seagrass) and inland freshwater sites.

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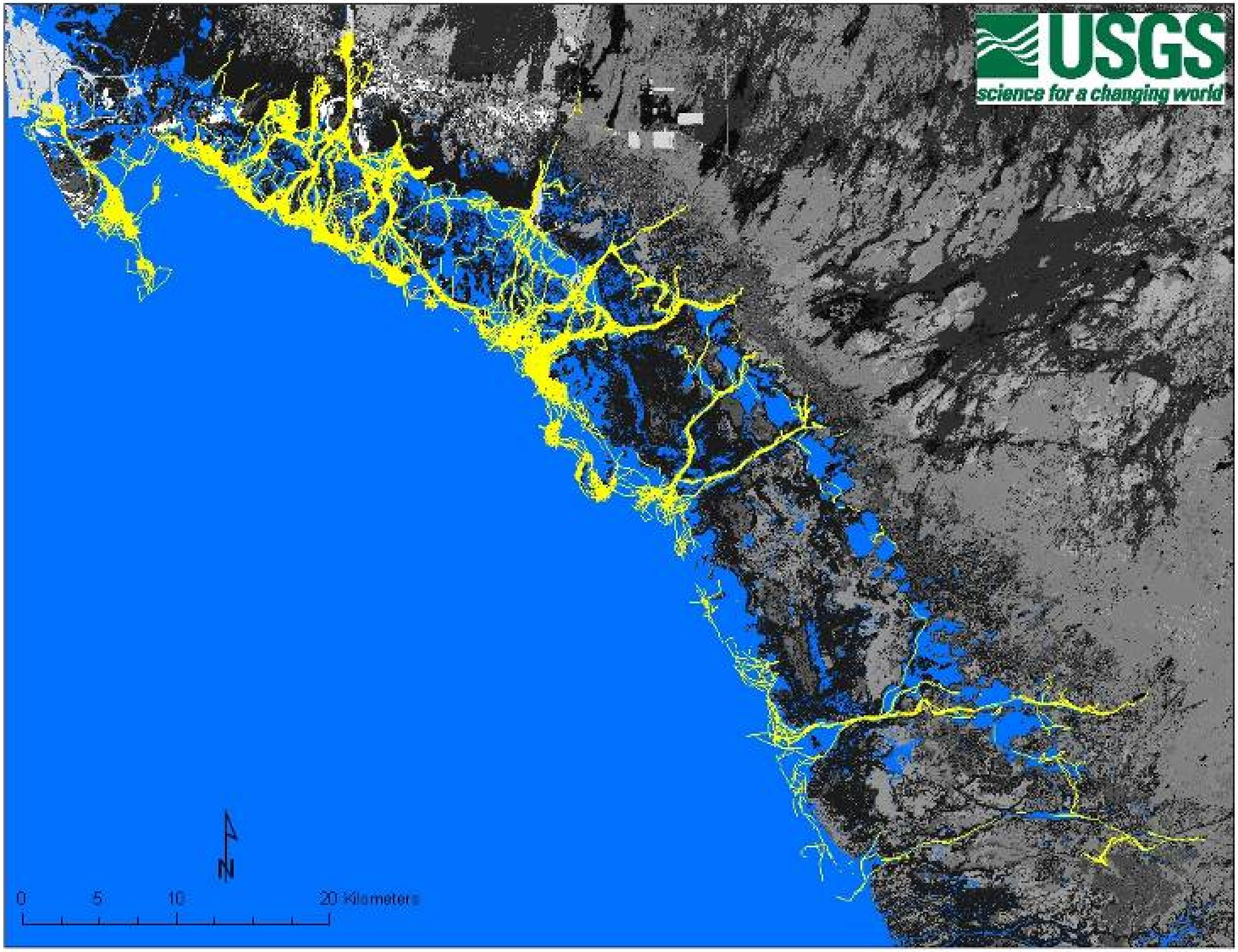

Figure 59. Map of GPS tracks for 15 manatees tagged through August 2004. Pathway segments longer than 1200 meters were deleted (see methods section for explanation).

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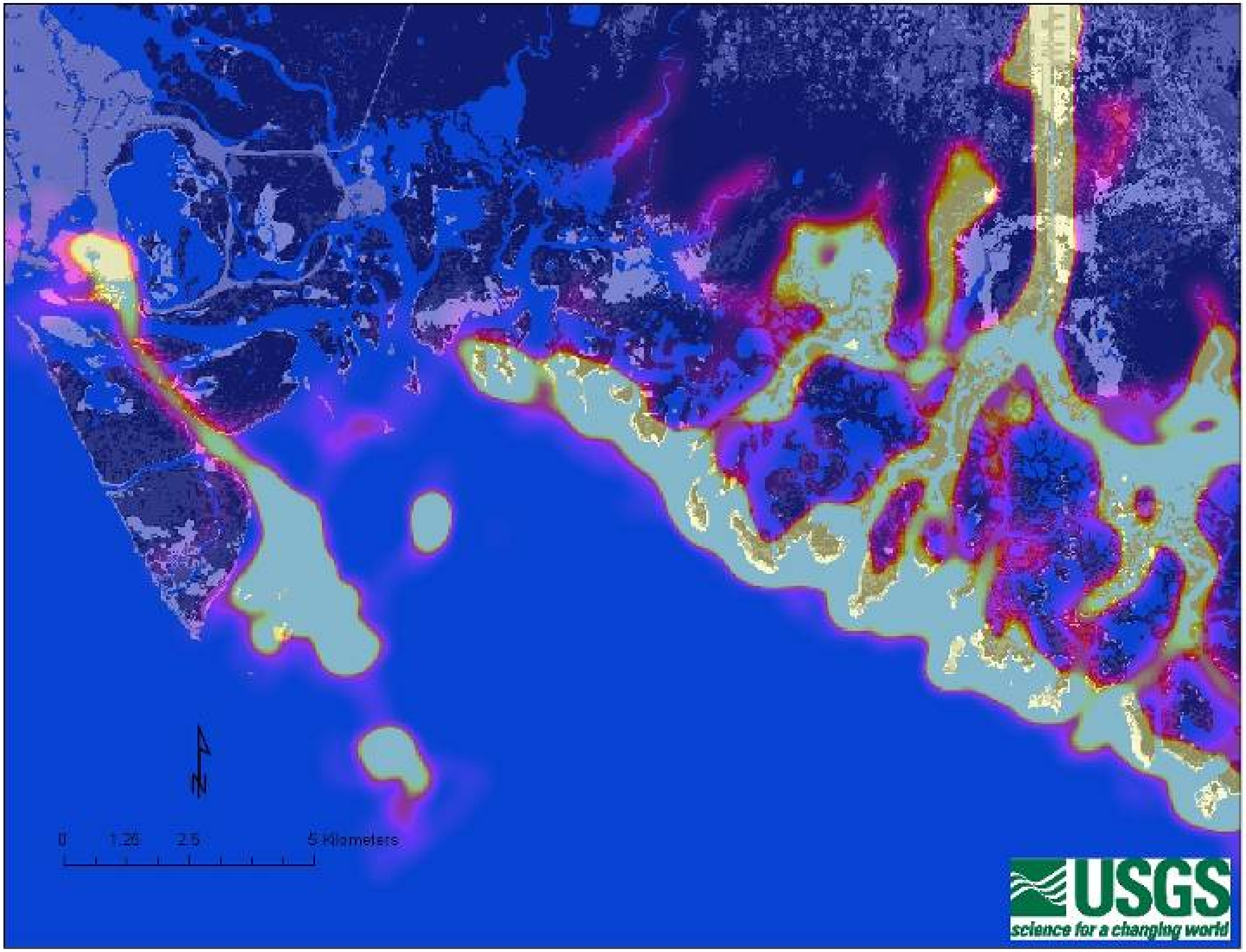

Figure 60. Corridor map showing high use areas based on GPS data from 15 tagged manatees in regions 8 – 9.

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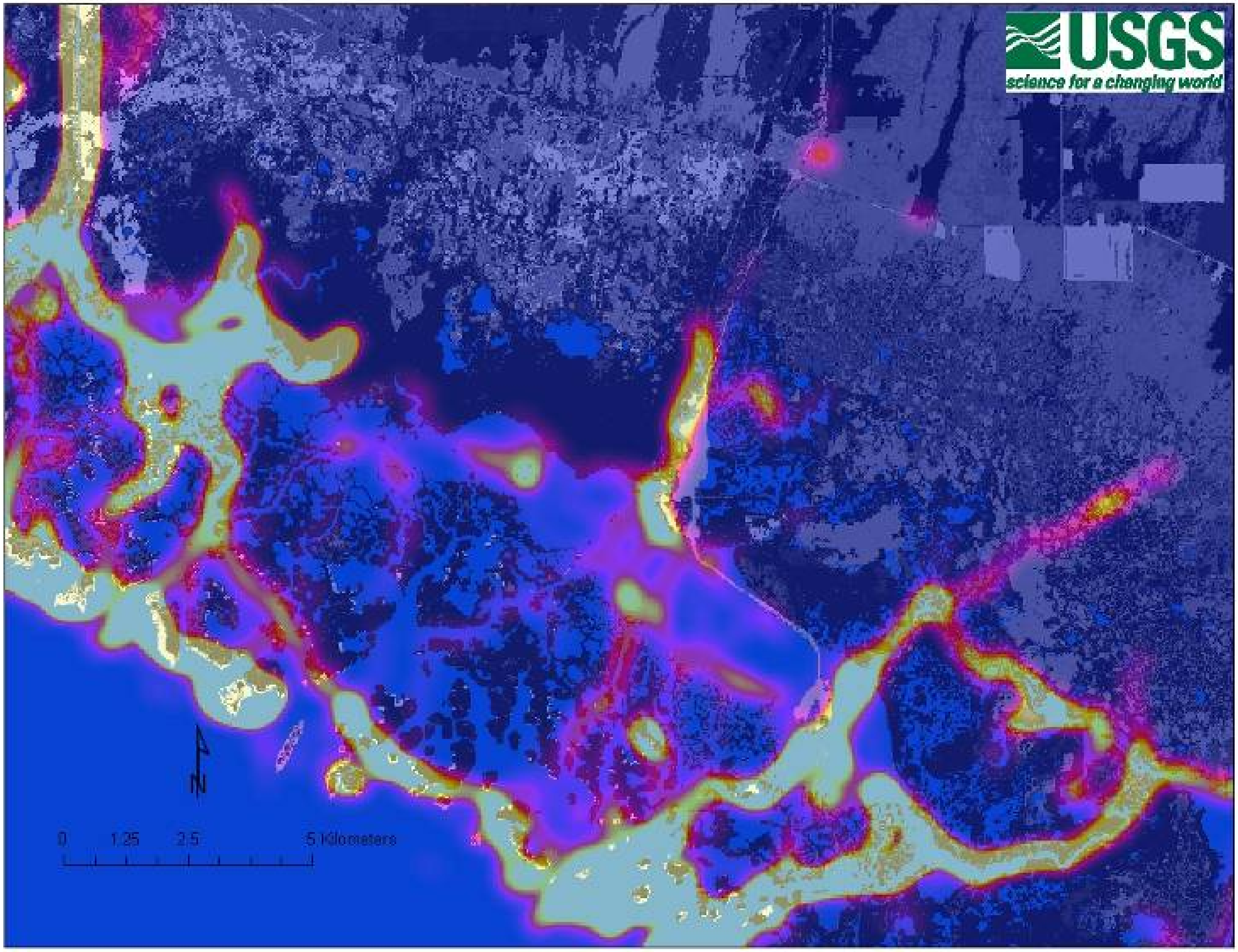

Figure 61. Corridor map showing high use areas based on GPS data from 15 tagged manatees in regions 6 – 8.

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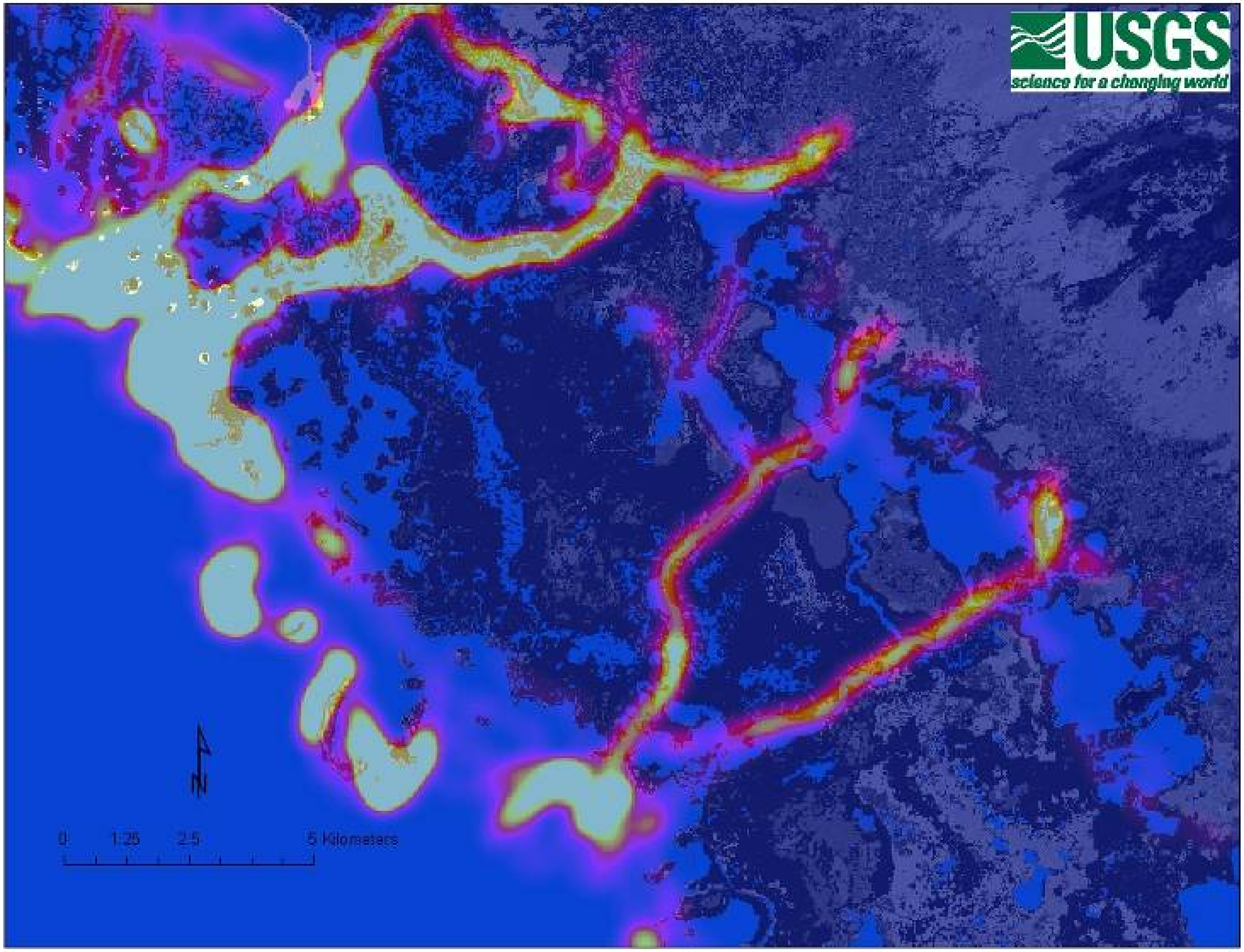

Figure 62. Corridor map showing high use areas based on GPS data from 15 tagged manatees in regions 6 – 7.

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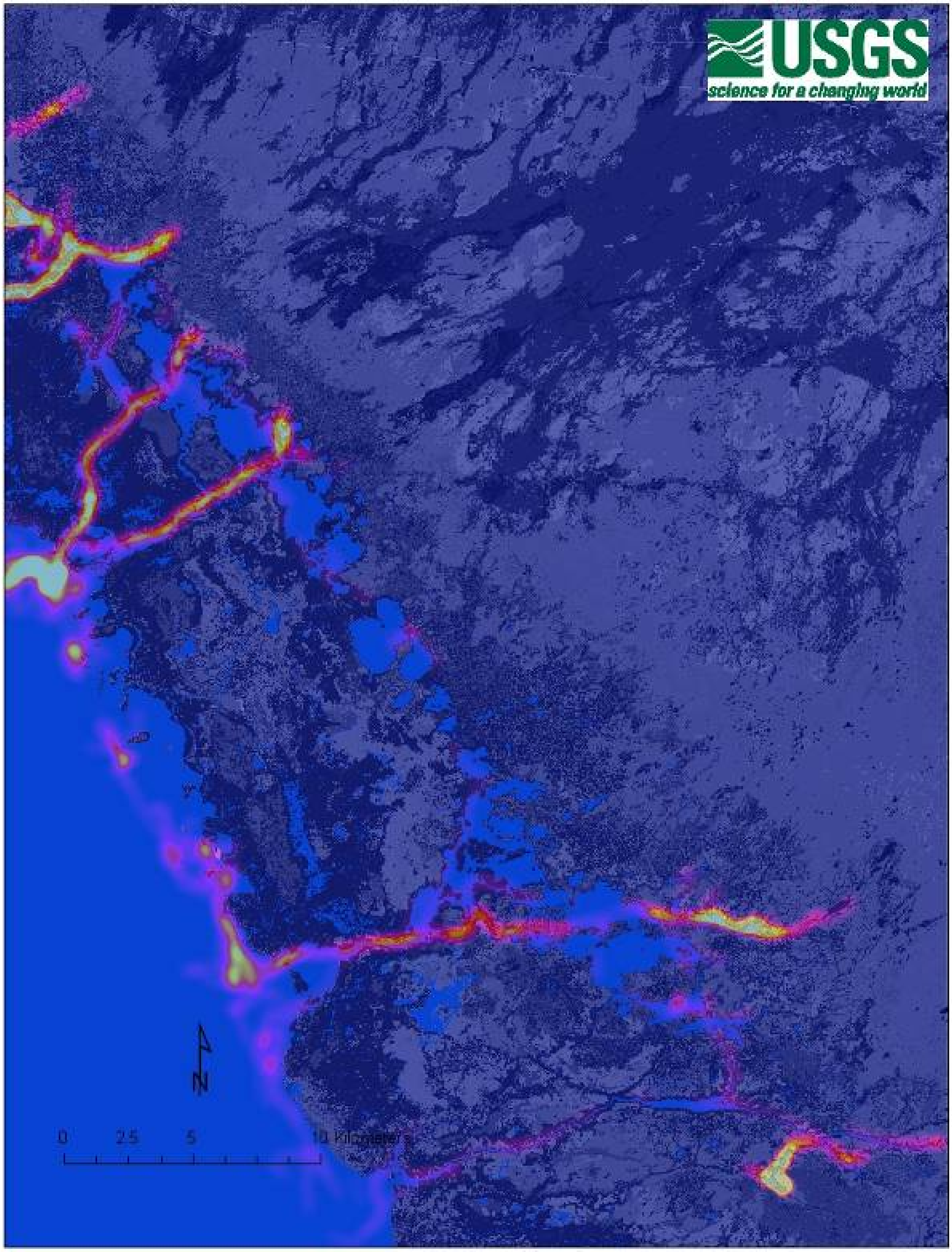

Figure 63. Corridor map showing high use areas based on GPS data from 15 tagged manatees in region 6.

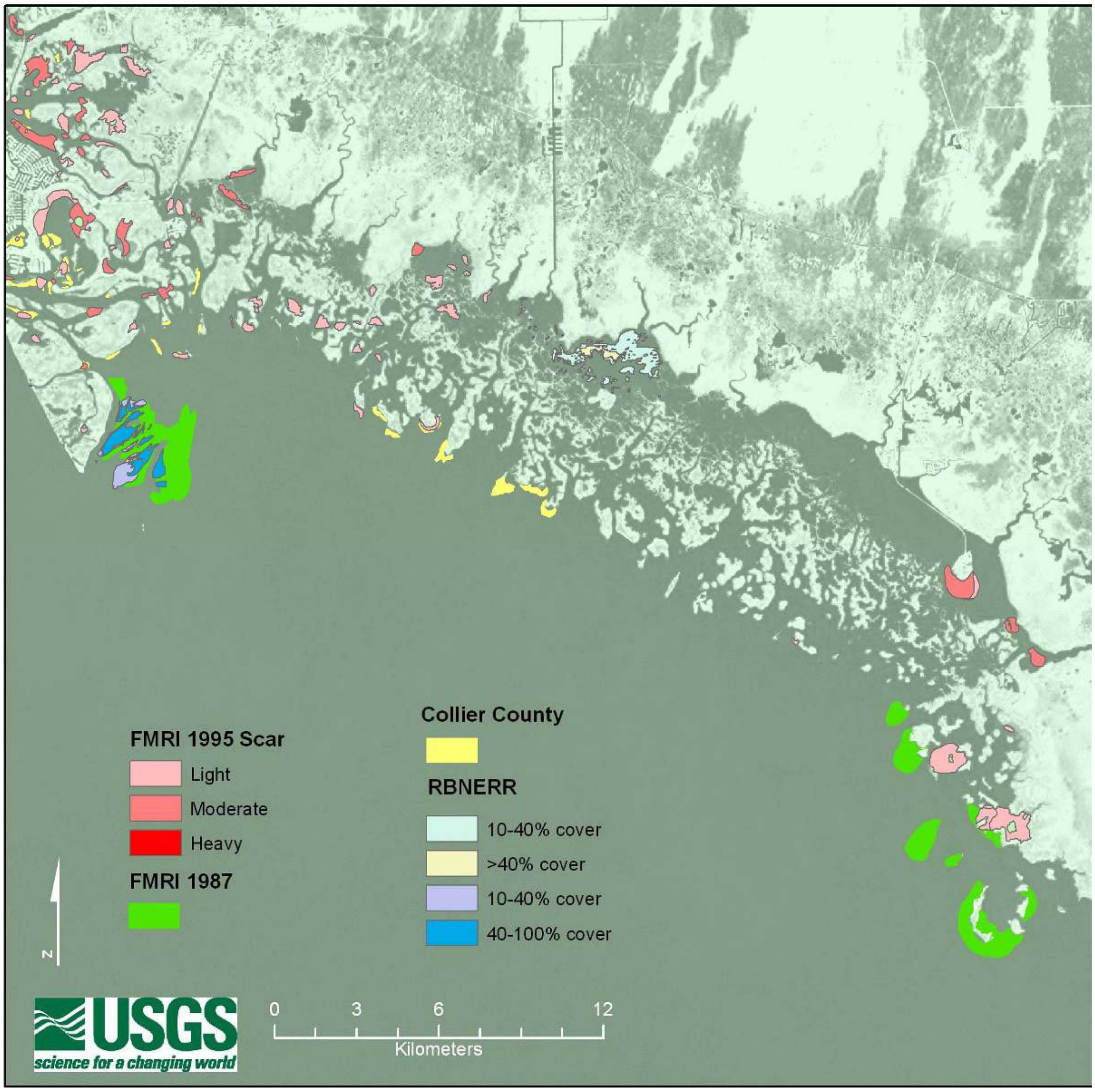

Figure 64. Map of seagrass beds and SAV based on data from FMRI (FWC), RBNERR, and Collier County.

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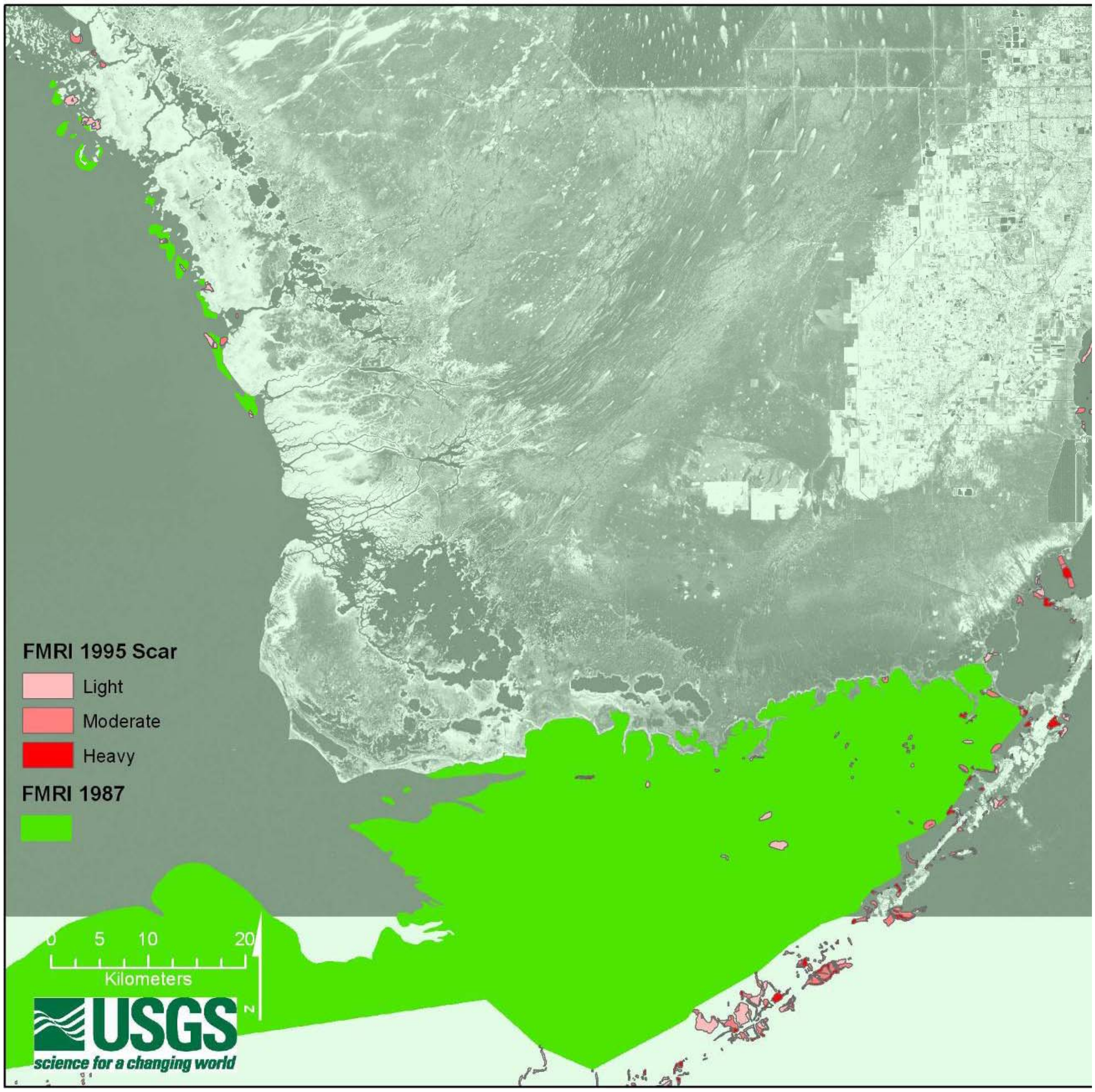

Figure 65. Map of seagrass beds and SAV based on data from FMRI (FWC), RBNERR, and Collier County.

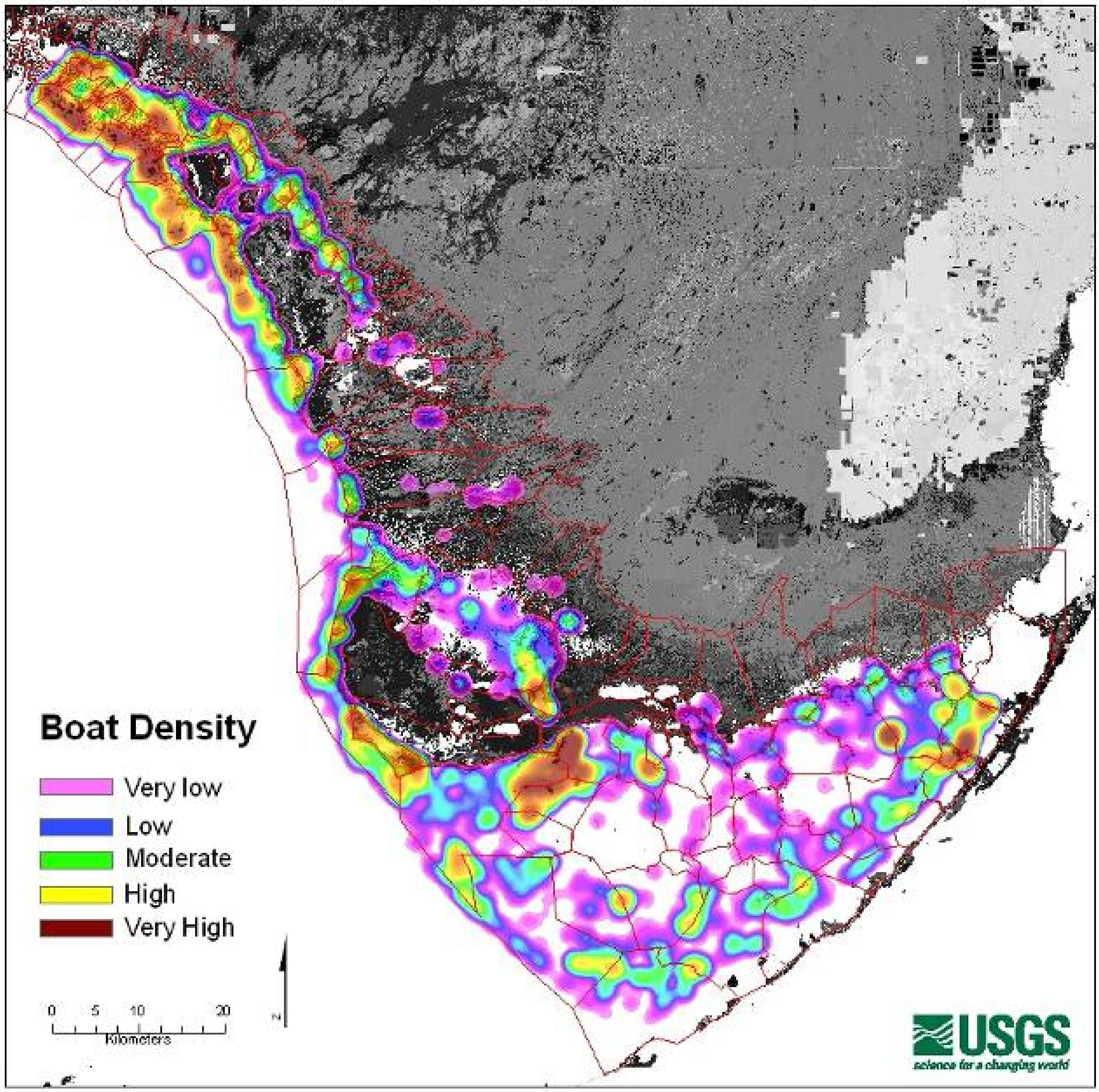

Figure 66. Relative density of power boats based on aerial surveys conducted October 1983 – September 1984 (four flights per month; alternating weekday and weekend), generated using a kernel density function.

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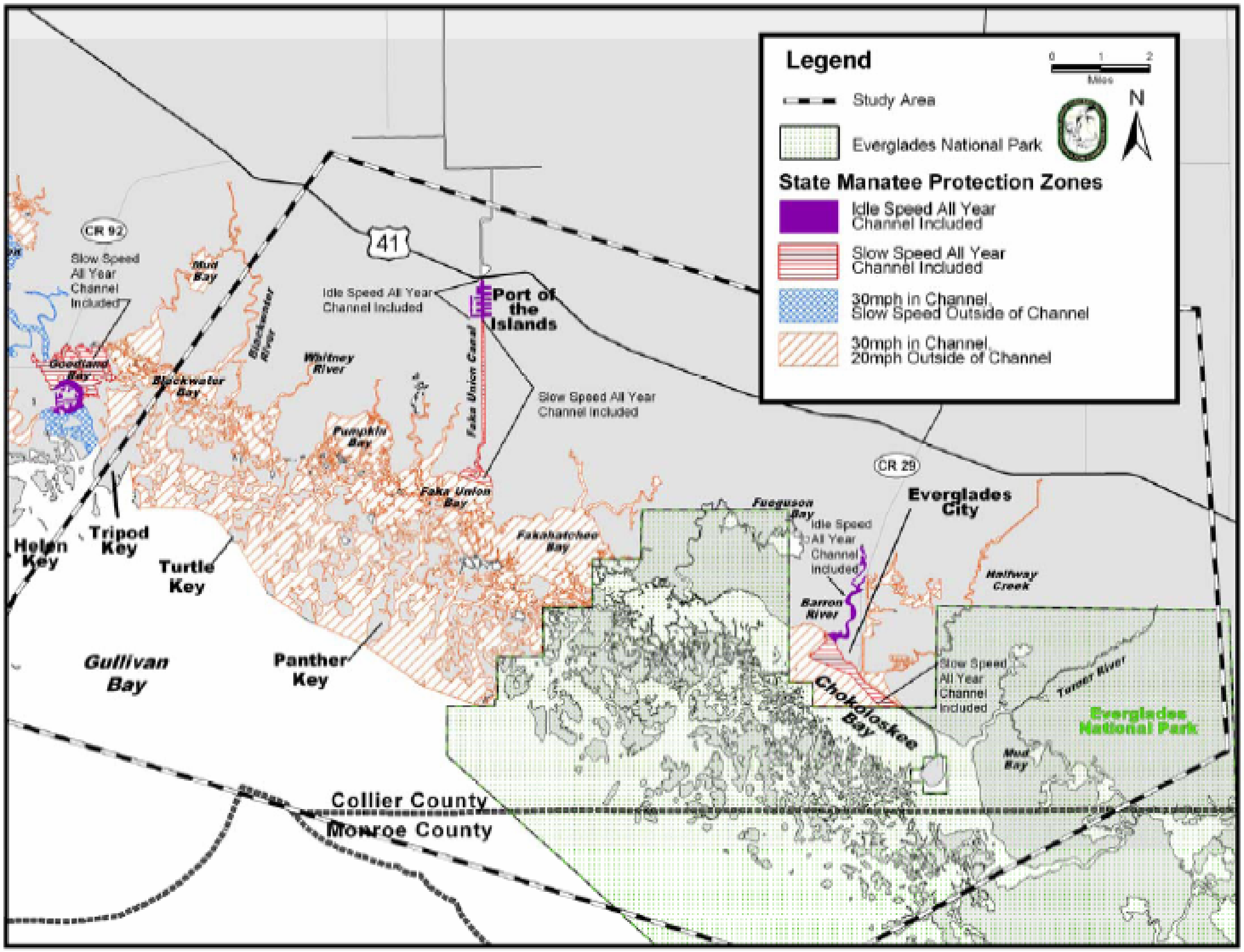

Figure 67. Map of speed zones for boats in Collier County adjacent to Everglades National Park (courtesy of FWC).