ISSN 1930-1448

FISH AND WILDLIFE RESEARCH INSTITUTE
TECHNICAL REPORTS

A Regional Assessment of Florida Manatees (*Trichechus manatus latirostris*) and the Caloosahatchee River, Florida

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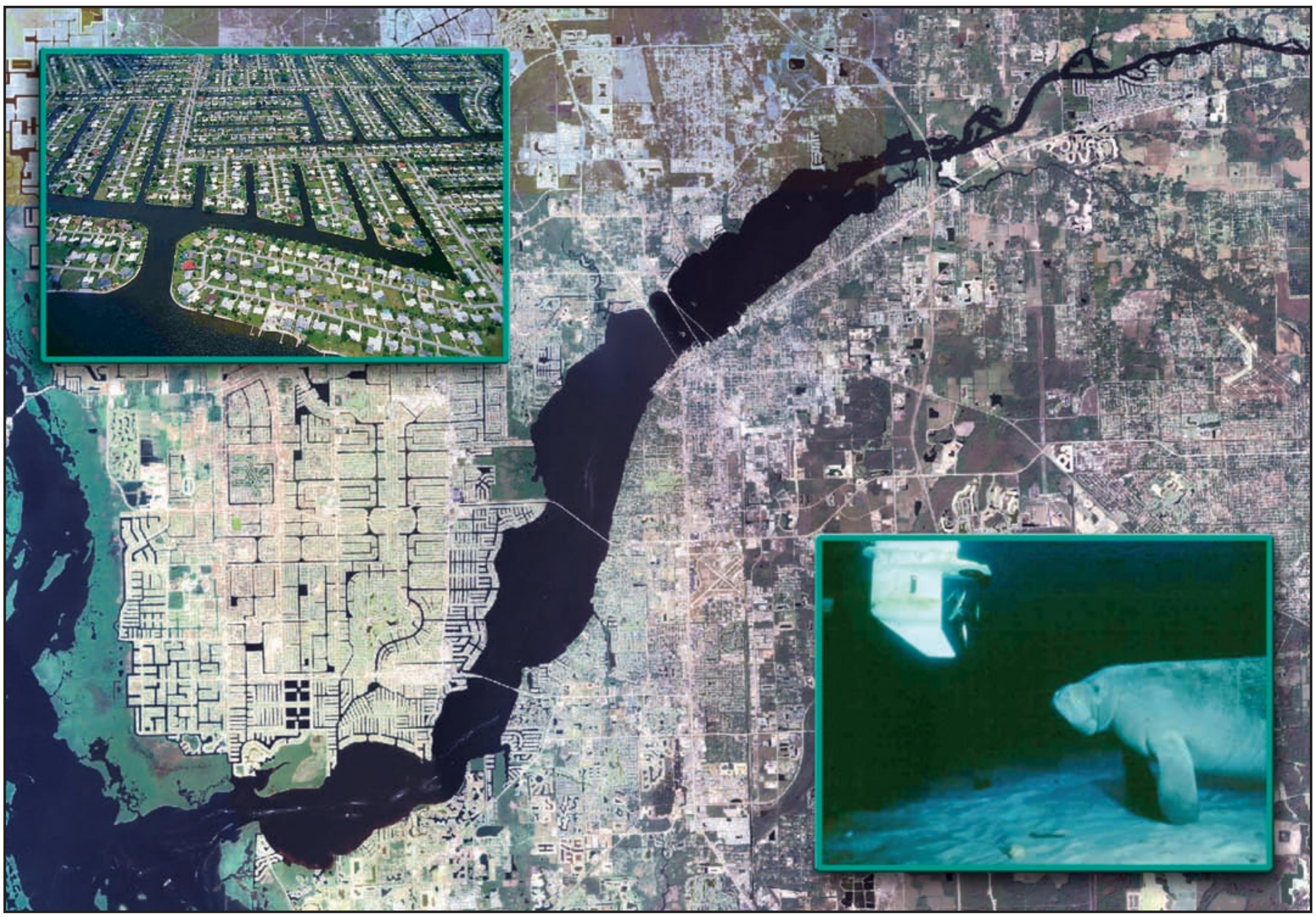

Florida Fish and Wildlife Conservation Commission

FWRI Technical Report TR-10

2006

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Cover Photographs

Aerial photography composite of the Caloosahatchee River
Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute
Upper inset: Oblique aerial photograph of canals in Cape Coral
Photo courtesy of South Florida Water Management District
Lower inset: Underwater view of manatee and boat propeller
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Document Citation

McDonald, S. L., and R. O. Flamm. 2006. A Regional Assessment of Florida Manatees (*Trichechus manatus latirostris*) and the Caloosahatchee River, Florida. Florida Fish and Wildlife Conservation Commission FWRI Technical Report TR-10. iv + 52 pp.

Document Production

This document was composed in Microsoft Word® and produced using QuarkXPress® on Apple Macintosh® computers. The headline font is Adobe® Avant Garde, the text font is Adobe® Palatino, and the cover headline is Adobe® Gill Sans.

The cover and text papers used in this publication meet the minimum requirements of the American National Standard for Permanence of Paper for Printed Library Materials Z39.48—1992.

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A Regional Assessment of Florida Manatees (*Trichechus manatus latirostris*) and the Caloosahatchee River, Florida

Executive Summary

We used a "weight-of-evidence" approach to provide environmental managers with a comprehensive analysis of Florida manatee use of the Caloosahatchee River, Florida, and the surrounding area. A "weight-of-evidence" analysis is a qualitative approach to synthesizing information and data from a variety of sources to increase our understanding of complex relationships. We examined human use of the river, habitat features, large- and fine-scale manatee movements (from telemetry data), manatee distribution and relative abundance (from aerial survey data), and manatee deaths (from FWC carcass-recovery data). The section of the river between Shell Point and the Edison Bridge (Mid Region) is an important travel corridor between the secondary warm-water and feeding areas west of Shell Point (West Region) and the feeding, resting, and primary warm-water areas east of the Edison Bridge (East Region). The importance of each region changes seasonally. Manatee use of the East Region is highest during winter (December–February). While traveling up- or downriver, manatees appear to use shallow areas near seawalls for feeding, drinking, resting, or thermoregulation. Data indicate that manatees usually travel relatively close to the shoreline and cross the river in the narrow areas of Redfish Point and Shell Point. While en route, manatees sometimes stop at secondary aggregation areas. Over the past 13 years, carcass recovery locations have shown that watercraft-related manatee deaths have increased at a faster rate in the study area than in either southwestern Florida or statewide. The evidence suggests that the East Region may be a sink for fatally injured manatees in winter. Because large numbers of both manatees and boats occur at the river mouth, San Carlos Bay, Redfish Point, and Matlacha Pass, manatees are more likely to be harmed by boats in these locations than they are in other portions of the study area.

Introduction

The State of Florida has a history of protecting the Florida manatee (*Trichechus manatus latirostris*) dating back to the late 19th century. Currently, the most common regulatory mechanism implemented to protect manatees is the designation of speed zones in Florida waterways. Regulations are proposed based on the best available information, such as manatee mortality, distribution, habitat, and other relevant data for an area. A regional assessment is one mechanism for providing comprehensive information to managers when they evaluate existing or future regulation of an area.

The regional assessment detailed in this report examines manatee use of the Caloosahatchee River in Lee County, Florida, between the W.P. Franklin Lock and Dam and Matlacha Pass (including San Carlos Bay). We examined human use of the river, habitat features, large and fine-scale manatee movements (from telemetry data), manatee distribution and relative abundance (from aerial survey data), and manatee deaths (from FWC carcass recovery data).

History of the Caloosahatchee River

Prior to the late 19th century, the Caloosahatchee River was a meandering waterway that ran from Lake Flirt to San Carlos Bay (Gunter and Hall, 1962; Kimes and Crocker, 1998). In 1881, dredging began to connect the river's headwaters with Lake Okeechobee (Scholle and Foster, 1999). This procedure caused severe flooding downstream, especially during the hurricane season. To mitigate the flooding effects, various spillways, locks, and dams were constructed, including the locks at Moore Haven and Ortona. In 1947, the Central and Southern Florida (C&SF) Project was authorized to manage the flood-control system and water-supply issues of the Caloosahatchee River basin. The C&SF project involved widening and straightening the river and constructing the Olga Lock and Dam (now known as the W.P. Franklin Lock and Dam). The river today is 65 miles long with a 25-foot-deep channel. Figure 1 depicts the river from the mouth to the Franklin Lock and Dam.

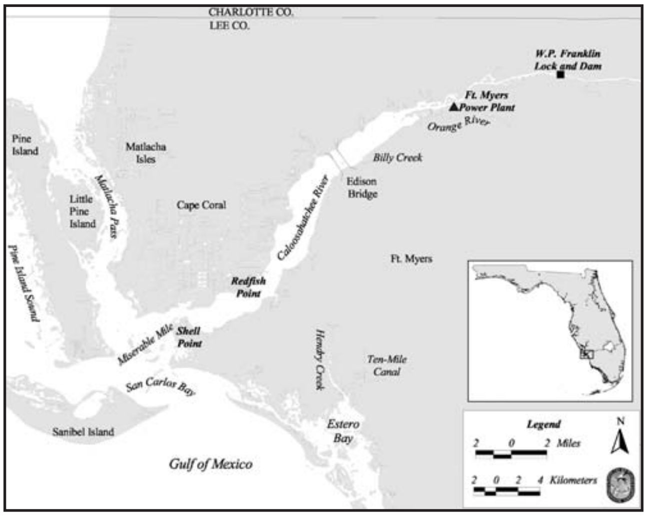

Figure 1 *Caloosahatchee River from the mouth to the W.P. Franklin Lock and Dam, Estero Bay, and Matlacha Pass.*

The Study Area

The study area includes San Carlos Bay, Matlacha Pass, and the Caloosahatchee River eastward to the Franklin Lock and Dam. The area from the Edison Bridge to the Franklin Lock and Dam is referred to here as the East Region, the area of the Caloosahatchee River from Shell Point to the Edison Bridge is the Mid Region, and the area west of Shell Point (San Carlos Bay and Matlacha Pass) is the West Region.

The Florida Manatee

The Florida manatee (*Trichechus manatus latirostris*) is one of two subspecies of the West Indian manatee (*T. manatus*). Florida manatees are native to Florida, with fossil evidence dating back 2–3 million years. Manatees inhabit the southeastern United States, principally occupying the marine, estuarine, and freshwater inland waters of Florida. They are relatively solitary, herbivorous marine mammals, but they will aggregate in areas with critical resources, such as warm water, fresh water, quiet resting areas, and submerged and emergent aquatic vegetation (marine and freshwater).

Life History

Like most large mammals, manatees have a potentially long life span, mature slowly, are slow to reproduce, and have a high parental investment (O'Shea *et al.*, 1995; USFWS, 2001). As a consequence of these characteristics, the manatee population is vulnerable to high mortality rates, especially to high rates of adult mortality (Eberhardt and O'Shea, 1995; Marmontel *et al.*, 1997). Table 1 summarizes manatee life-history traits.

Feeding

Manatees feed on a variety of marine, freshwater, and terrestrial plants. Common forage species include shoalgrass (*Halodule wrightii*), manateegrass (*Syringodium filiforme*), turtlegrass (*Thalassia testudinum*), tapegrass (*Vallisneria americana*), and widgeongrass (*Ruppia maritima*) (Hartman, 1979; Packard, 1981; Bengtson, 1981, 1983; Ledder, 1986; Lefebvre and Powell, 1990; Smith, 1993; Lefebvre *et al.*, 2000). Manatees feed on seagrass plant parts both above and below the sediment, depending upon the type of substrate and the plant species. Feeding strategy may also depend on vegetation density. Rooting behavior was observed in dense seagrass meadows, whereas grazing has been reported along the edges of previously grazed, sparse beds (Packard, 1981; Lefebvre and Powell, 1990; Smith, 1993; Lefebvre *et al.*,, 2000). Manatees have also been documented feeding on the edges of seagrass beds near deep water (Bengtson, 1981; Packard, 1981; Lefebvre and Frohlich, 1986). Such edges may provide forage-species diversity, access to escape routes, or both (Packard, 1981; Lefebvre and Frohlich, 1986; Smith, 1993). Ledder (1986), Lefebvre and Powell (1990), and Lefebvre *et al.* (2000) reported that manatees showed a preference for shoalgrass. Hartman (1979) reported manatees selectively foraged on young tapegrass in freshwater systems.

Bengtson (1983) found that foraging duration depended upon season. Manatees spent less time foraging in spring than fall, presumably because of the higher-quality vegetation associated with spring growth and fewer physiological demands on the manatees (Bengtson, 1983).

Threats—Anthropogenic

According to the U.S. Census Bureau (2001), Florida's human population increased by 23% between 1990 and 2000, and projections suggest the population of Florida will increase by 5.5 million people over the next 25 years. To meet the increased demand for water that a growth in human population will entail, it is likely that spring flows and water quality will decline. If human demands on the aquifer at Blue Spring increase as projected, by 2010 the flow may not be sufficient to provide adequate thermal refuge for the manatee population that uses the run during winter (Reynolds, 2000). Another likely effect of an increasing human population will be additional sewage and non-point-source runoff, both of which reduce water clarity, causing a decline in the health and abundance of submerged aquatic vegetation (SAV) (Stevenson *et al.*, 1993). For most of the year, the availability of SAV does

Table 1 *Estimates of manatee life-history traits and related statistics. Except as noted, information was obtained from O'Shea* et al.*, 1995 (table modified from USFWS, 2001).*

Life-History Trait		**Data**
Maximum determined age		59 years
Gestation		11–14 months
Litter size		1
% twins	Upper St. Johns River	1.79%
	Northwest	1.40%
Sex ratio at birth		1:01
Calf survival[a]	Upper St. Johns River, 1st year	0.810 (0.727–0.873)
	Upper St. Johns River, 2nd Year	0.915 (0.827–0.960)
Annual adult survival[a]	Atlantic coast	0.937 (0.008) SE
	Upper St. Johns River	0.960 (0.011) SE
	Northwest	0.956 (0.007) SE
	Southwest	0.908 (0.019) SE
Age at first pregnancy (female)		3–4 years
Mean age at first reproduction (female)		5 years
Age at spermatogenesis (male)		2–3 years
Proportion pregnant	Salvaged carcasses	33%
	Upper St. Johns River (photo-ID)	41%
Proportion nursing, 1st-year calves during winter	Mean	36%
	Upper St. Johns River	30%
	Northwest	36%
	Atlantic coast	38%
Calf dependency		1.2 years
Interbirth interval		2.5 years
Highest number of births		May–Sept
Highest frequency in mating herds		Feb–July
No. verified carcasses in Florida[b]		5,183 (1974–2003)
No. documented in ID catalog		>2,000 (1975–2003)
Highest minimum count (aerial surveys)[b]		3,300 in Jan 5–6, 2001

[a]From Langtimm *et al.*, 2004
[b]Data provided by the Fish and Wildlife Research Institute, FWC.

not seem to be a limiting factor for manatees. During cold weather, however, manatees require forage associated with warm-water aggregation sites. Without conservation measures to protect these winter habitats, manatees would have to travel greater distances, aggregate into smaller areas, and forage in suboptimal environments.

From 1976 to 2001, watercraft collisions accounted for approximately 25% of all manatee deaths and were the single greatest human-related cause of manatee mortality (FWC, unpublished data). In 2001, there were more than 943,000 registered vessels in Florida (FWC, http://myfwc.com/law/boating), and every winter many thousands of out-of-state boaters visit Florida. The number of registered vessels in Florida has increased by an average of 2.9% per year during the past 25 years (FWC, unpublished data). Given that about 97% of registrations are for recreational watercraft (Wright *et al.*, 1995), it can be expected that there will be a continued increase in the use of recreational vessels on the waterways of Florida as the human population increases. In addition to the expected increase in boat numbers during the coming century, there are other factors that may act synergistically to increase the risk of fatal collisions between manatees and watercraft. Relatively new modifications to the design of vessel hulls and engines allow boats to travel at higher speeds in shallower waters (Wright *et al.*, 1995), thus threatening manatees and scarring seagrass beds. Unfortunately, boater compliance with existing slow-speed zones is inconsistent (Gorzelany, 1998; Shapiro, 2001).

Although manatees seem to have adapted to urban landscapes by exploiting industrial thermal and freshwater effluents, marinas, and man-made canals, new development and more people will add to the number of vessels on Florida's waterways. Currently there is no mandatory, statewide boater-education or licensing program for anyone older than 21, nor does the state require boat-rental businesses to educate customers about manatee speed zones. In one study at the Homosassa River, rental-boat traffic violated the idle speed zone at the mouth of the river significantly more than all other traffic (Shapiro, 2001). Increased vessel traffic coupled with the lack of a statewide, mandatory boater education or licensing program and a lack of funding for additional law enforcement could increase the likelihood of a manatee being struck by a boat.

Sublethal effects of increased vessel traffic and a growing human population include injury and disturbance. Researchers do not know the extent to which these sublethal "takes" of manatees affect basic biological functions such as reproduction and feeding. Most adult manatee carcasses bear scars from previous boat strikes, and the healed, skeletal fractures of some indicate that they had survived previous traumatic impacts (Wright *et al.,* 1995). Of the more than 1,000 living individuals in the manatee photo-identification database (Beck and Reid, 1995), 97% had scar patterns from multiple boat strikes (O'Shea *et al.,* 2001). It should be noted that the photo-identification database contains only animals with scars or other identifiable features. After being struck by a boat, a manatee would have to direct its energetic resources toward healing and maintenance before it could use them in energetically expensive activities like reproduction. Nonlethal injuries may reduce the breeding success of wounded females and may permanently remove some animals from the breeding population (O'Shea, 1995; Reynolds, 1999).

Increased vessel traffic and human recreational activities may disturb manatees by causing them to leave preferred habitats (temporarily or permanently) or to alter biologically important behaviors such as feeding, suckling, or resting (Powell, 1981; Buckingham, 1990; O'Shea, 1995). In Crystal River, Buckingham (1990), Buckingham *et al.* (1999), and King (2001) documented increased manatee use of sanctuaries at times of increased boat traffic. King (2001) also reported behavioral changes of the manatees in response to the presence of human swimmers. These changes included decreased resting and suckling and increased milling, swimming, and cavorting.

Other threats caused by human activities include entanglement in fishing gear or debris; entrapment or crushing in water-control structures, locks, and pipes; exposure to contaminants; and incidental ingestion of debris (Beck and Barros, 1991; Ackerman *et al.,* 1995). Indirect effects from increased vessel traffic include increased water turbidity from wake action and decline of seagrass beds due to scarring by propellers (Sargent *et al.,* 1995).

Threats—Natural

Potentially catastrophic, naturally occurring threats to manatees include exposure to cold temperatures, hurricanes, red tide (*Karenia brevis*) events, and disease. When temperatures drop below 20°C, manatees seek warm water because they are unable to tolerate prolonged exposure to temperatures below about 16°C (Irvine, 1983). Since 1974, major spikes in cold-related manatee deaths occurred during the cold winters of 1976–77, 1980–81, 1983–84, 1989–90, 1995–96, and 2000–01 (O'Shea *et al.,* 1985; Ackerman *et al.,* 1995; FWC, unpublished data). Death from exposure to cold can occur by acute exposure (hypothermia) or by chronic exposure. Manatees chronically exposed to water temperatures below 20°C display a range of clinical and pathological signs such as emaciation, edema, atrophy of fats, and dehydration (Bonde *et al.,* 1983; O'Shea *et al.,* 1985; Bossart *et al.,* 2003). Manatee carcasses with evidence of cold-stress often show reduced gastrointestinal tract activity, a condition that can reduce an animal's buoyancy. Juveniles and subadults are the most vulnerable to cold-related death (Bonde *et al.,* 1983; O'Shea *et al.,* 1985; Ackerman *et al.,* 1995; Bossart *et al.,* 2003). At these life stages, inexperienced manatees may not be able to read temperature cues as well as mature animals can, and their small size can magnify the metabolic effects of cold exposure (O'Shea *et al.,* 1985; Worthy *et al.,* 2000). In captive experiments, Worthy *et al.* (2000) found that smaller manatees were unable to increase their metabolic rates when exposed to cold, thus rendering them more susceptible to temperatures below 20°C.

Although cold-related deaths are a natural occurrence, potential deregulation of the power industry and deterioration of natural artesian springs threaten many of the warm-water refuges that manatees use during the cold season (Reynolds, 2000). Manatees rely on the current network of warm-water sites for refuge during the cold season (Figure 2). Continued high counts at selected power plants in eastern and southwestern Florida highlight the manatee's dependence on this network (Reynolds, 2002). Despite their dependence on warm water, it has been well documented that manatees will leave these refuges for short periods to forage in colder water (Hartman, 1974, 1979; Bengtson, 1981, 1983; Packard *et al.,* 1989; Barton and Reynolds, 2001; Edwards *et al.,* 2003). Therefore,

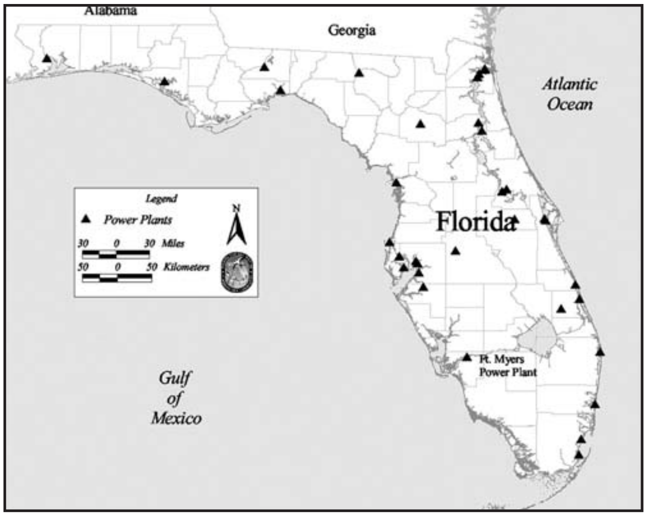

Figure 2 *Statewide industrial warm-water sites where manatees aggregate.*

managers should continue to identify and preserve areas that provide manatees with warm water as well as with associated foraging grounds. Following a 1999 workshop to discuss the status of warm-water refugia, the United States Fish and Wildlife Service (USFWS) created a Warm Water Task Force. This team of biologists, managers, and industry members is exploring approaches to mitigating the possibility of losing these important habitat areas.

Hurricanes are another type of weather-related catastrophe that can potentially affect manatee populations. In northwestern Florida, adult survival rates were lower in years with severe storms or hurricanes than in years without them (Langtimm and Beck, 2003). Severe storms and hurricanes could also result in permanent, large-scale emigration. In eastern Australia, for example, the simultaneous occurrence of flooding and a cyclone, combined with poor watershed-management practices, resulted in the loss of 1,000 km^2 of seagrass beds and in the mass movement and mortality of dugongs (*Dugong dugon*), a sirenian relative of the manatee (Preen and Marsh, 1995).

Manatees on Florida's west coast are frequently exposed to brevetoxin, a potent neurotoxin, during red tide events. Manatees are exposed through inhalation and ingestion of the toxin. According to Landsberg and Steidinger (1998: 97), "a unique combination of environmental, geographical, and biological factors must co-occur to cause these mortalities." These factors include high salinity, high concentrations of red tide organisms, co-occurrence of those high concentrations of red tide organisms and manatees, and long periods of exposure. Manatees appear to be at highest risk in coastal southwestern Florida when salinities are higher than 28 ppt and when many manatees disperse into the algal bloom (Landsberg and Steidinger, 1998). West coast manatees are frequently exposed to brevetoxin as a consequence of red tide events. In 1996, 151 manatees died in southwestern Florida from brevetoxicosis (red tide poisoning). This epizootic was particularly detrimental to manatees because more adults than any other age class were killed (Pitchford, 2002). Researchers believe another red tide epizootic killed at least 37 manatees in 1982 (O'Shea *et al.*, 1991). In 2002 and 2003 combined, 133 manatees were killed by effects of red tide, and in 2005, 81 manatees were suspected to have died from brevetoxicosis.

In addition to red tide, manatees may be exposed to infectious diseases. Spread of such pathogens could be particularly rapid during winter, when manatees are concentrated in warm-water refuges. Large-scale mortality events caused by disease or toxins, including oil spills and biotoxins, have decimated other populations of marine mammals, including seals and dolphins, sometimes eliminating 50% or more of the individuals (Harwood and Hall, 1990).

Distribution and Movements

Telemetry (via satellite and radio tags) is one tool researchers use to study manatee distribution and movements. Deutsch *et al.* (1998) provided a comprehensive review of satellite- and radio-tracked manatees. Telemetry studies can help determine long-range movements, rates of travel, travel distances, timing of migrations, and destination places. Radio and satellite tags, however, have limitations. Radio tags are difficult to locate, and tracking is limited to good weather in areas accessible to humans (Deutsch *et al.*, 1998). Historically, satellite tags have not been able to detect fine-scale movements because of the imprecision associated with the available technology. In addition, the tag often becomes submerged or produces low-quality hits when a manatee travels at a quick pace. Despite the limitations of telemetry studies, Deutsch *et al.* (1998) and others ascertained that manatees are capable of extensive seasonal migrations. They have been able to document patterns of site-fidelity and important life-history events such as mating and suckling.

In an attempt to reduce the biases of satellite telemetry, Weigle *et al.* (2001) and Flamm *et al.* (2005) have created innovative ways of analyzing data from tagged manatees. They calculated manatee travel paths, "places," and corridors based on empirically determined depth-preferences. The manatee travel patterns calculated by Weigle *et al.* (2001) and Flamm *et al.* (2005) support the widely established concepts that manatees prefer warm-water areas in winter and areas associated with fresh water in the remaining three seasons (Hartman, 1979; Shane, 1984; Rathbun *et al.*, 1990; O'Shea, 1995; Reynolds, 1999).

Weigle *et al.* (2001) and Flamm *et al.* (2005) also found no differences in the travel paths of males, and females with calves, or females without calves. However, they reported that travel rates for male manatees were significantly faster than those of females (with or without calves). Moreover, a few males moved almost continuously, whereas small females and females with calves tended to travel shorter distances and remained at certain locations for protracted periods before repeating this pattern elsewhere (Weigle *et al.*, 2001). Large females and females without calves traveled more extensively. On the Atlantic coast, Deutsch *et al.* (2000) also reported that males traveled at faster rates.

Manatees have adapted well to the urban landscapes of coastal Florida by using man-made canals and artificial freshwater sources and by consuming exotic species of vegetation. Spring marks the dispersal of manatees from their winter aggregation areas. In the warm months, manatees are ubiquitous throughout Florida and southern Georgia. Some manatees may spend the warm season in areas that others occupy during winter (Deutsch *et al.*, 2000; Weigle *et al.*, 2001). Consequently, management strategies in selected areas may affect substantial portions of the population.

Population

A workshop on the population biology of the manatee was held in April 2002. Although trends from aerial surveys indicated that the manatee population has increased during the past few decades (Ackerman, 2002), the use of aerial surveys as an indicator of population status was criticized because biases are associated with these methods. The ability of an observer to detect the presence of a manatee varies widely and depends not only on the observer's ability or experience but also on a suite of variables that include survey conditions (water clarity, depth, and temperature; glare; cloud cover; wind; sea state; tides; air temperature), location, time of day, season, number of manatees present (group size), and manatee behavior (Packard and Mulholland, 1983; Lefebvre *et al.*, 1995; O'Shea *et al.*, 2001). Several studies have attempted to quantify these biases (Packard and Mulholland, 1983; Packard *et al.*, 1985, 1986; Lefebvre and Kochman, 1991; Garrott *et al.*, 1994). Packard *et al.* (1985) investigated visibility bias by comparing aerial counts with ground counts and by comparing the number of observed radio-tagged animals to the number actually present. They found that visibility bias changed with habitat type and varied even when standardized survey techniques were employed. Lefebvre *et al.* (1995) suggested several ways to improve aerial survey techniques to increase their utility: 1) develop standard sampling protocols for surveying aggregation sites, 2) develop standard sampling protocols for surveying during the warm season, 3) initiate experiments to quantify bias, and 4) develop a correction factor to account for bias.

In cooperation with Mote Marine Laboratory (MML) and North Carolina State University, scientists at the Fish and Wildlife Research Institute (FWRI) have initiated research to quantify biases and develop a correction factor for one warm-water refuge (Edwards *et al.*, unpublished). In winter 2002–2003, FWRI completed its fourth and final field season of a study at Tampa Electric Company's (TECO) Big Bend power plant to develop a calibration factor that will allow researchers to correct for biases of surveys flown at that particular warm-water source. This study used multiple regression analysis, mark-resight sampling, and information about manatee diving behavior to quantify and assess the effects of visibility and sampling biases. FWRI and MML also recently completed a joint study to quantify perception bias by using tandem surveys in Sarasota Bay (Koelsch and Ackerman, 2001).

In 1990, the Florida legislature mandated that the [then] Florida Department of Environmental Protection [now FWC, in part] conduct an annual "impartial scientific benchmark census of the manatee population." To fulfill this requirement, in 1991 the FWC began conducting annual synoptic aerial surveys. Because of the biases described above, these synoptic surveys are an unreliable gauge of population trends (Ackerman, 1995; Lefebvre *et al.*, 1995; O'Shea *et al.*, 2001; USFWS, 2001). Scientists have been unable to quantify the relationships between the number of manatees counted on these surveys and the true population size (Ackerman, 1995; Lefebvre *et al.*, 1995; O'Shea *et al.*, 2001; USFWS, 2001).

To create an objective, measurable assessment of the status of the manatee population, the USFWS convened the Manatee Population Status Working Group (MPSWG). This group of biologists and population experts are a subcommittee of the Florida Manatee Recovery Team. In spring 2001, they prepared a manatee population status statement (MPSWG, 2001). Using the long-term mark-recapture database of photographically identified individuals, the MPSWG created benchmarks to assess manatee population growth and assist in evaluating the species for the federal government's proposed reclassification of it from endangered to threatened. These benchmarks did not involve a population count but rather an estimate of annual survival rates determined through photo-identification and sight-resight analyses. The working group determined that measures of how many individuals survive from year to year is a better estimate of population viability than is a minimum threshold population size (USFWS, 2001).

Legislation

Manatees are listed as endangered under the federal Endangered Species Act of 1973 (ESA, 16 U.S.C. 1531 et seq.). They are also protected under the federal Marine Mammal Protection Act of 1972 (MMPA,16 U.S.C. 1361 et seq.) and the state's Florida Manatee Sanctuary Act (FMSA, FS 370.12). All three statutes protect manatees by prohibiting their "take." "Take" is defined similarly in all three laws. Essentially, it is illegal to harass, hunt, capture, kill, harm, pursue, shoot, wound, trap, collect, annoy, molest, or disturb a manatee or attempt to engage in any such conduct. The MMPA and ESA allow the federal government to prohibit activities that will "take" manatees. The USFWS can restrict development and create manatee speed zones, refuges, and sanctuaries.

Section 4(f) of the federal ESA requires the USFWS to "develop and implement recovery plans for the conservation of endangered and threatened species." The Third Revision of the Florida Manatee Recovery Plan was completed in the fall of 2001. The plan was developed with the assistance of a Recovery Team, a group of scientists, managers, industry members, and nongovernmental organizations (NGOs). The ultimate goal of the plan was to "assure the long-term viability of the Florida manatee in the wild" (USFWS, 2001: iv). This comprehensive plan details specific tasks aimed at achieving the following objectives: minimize causes of manatee disturbance, harassment, injury, and mortality; determine and monitor the status of manatee populations; protect, identify, evaluate, and monitor manatee habitats; and facilitate manatee recovery through public awareness and education. In addition to creating the MPSWG, this Recovery Plan has created the Warm Water Task Force, which is a subset of the Manatee Habitat Status Working Group (HWG). The goal of the HWG is parallel to that of the MPSWG: "to (1)assist managers responsible for protecting habitat; (2) help identify information needs; (3) ensure the implementation of tasks needed to identify, monitor, and evaluate habitat; and (4) refine and improve the recovery criteria that address threats to manatee habitat" (USFWS, 2001: 84).

An outgrowth of the Federal Recovery Plan was the development of Manatee Protection Plans (MPPs) by the FWC. These plans incorporate manatee protection measures into county comprehensive plans by providing recommendations for boat-facility sitings, waterfront development, and manatee speed zones. A 1989 Florida state policy directive required 13 key counties to create MPPs. Although the FWC had been responsible for guiding those creating and for approving these MPPs, it had no legal authority to require counties to create such plans. Starting in 2001, the Florida Legislature stipulated that if a county could not show significant progress toward development of an MPP, all permits in that county would be suspended. In May 2002, the Florida legislature amended the FMSA to require the 13 key counties to develop MPPs by 2004. Moreover, the state now has the authority to identify additional key counties and require those counties to devise MPPs. All MPPs must be approved by the FWC and become incorporated into county comprehensive plans.

In addition to approval of MPPs, the FMSA gives the FWC the authority to create manatee speed zones and safe havens (FAC Chapter 68C-22). The state is also responsible for working with power companies to include manatee protection measures in their National Point Source Elimination Discharge System (NPDES) permits. The FMSA declared the entire state of Florida as a manatee sanctuary and established the Save the Manatee Trust Fund. This fund subsidizes FWC manatee research, education, and management programs through revenues generated from sales of the manatee license tag. Although manatees are also listed as endangered under the Florida Endangered Species Act, this list does not confer added protection to the species.

Manatee Use of the Caloosahatchee River

To provide a comprehensive view of manatee use of the study area, we conducted an extensive literature search and reviewed boater use, habitat, aerial survey, telemetry, and manatee mortality information. We analyzed manatee, vessel-traffic, and habitat data collected over the past few decades and recent aerial survey counts from spring 2002.

Review of Vessel Activity

Introduction

The 2000 census reported that Lee County had 440,888 residents, an increase in the population of 31.6% since 1990. In 2000, there were 40,725 registered watercraft in Lee County, of which 39,217 were classified as recreational vessels (http://myfwc.com/law/boating). Several studies have been conducted on vessel activity in

Table 2 *Barge traffic servicing the FPL Ft. Myers power plant, 1997–2002.*

Year	Heavy-Oil Barges	Light-Oil Barges	Total Barge Trips
1997	163	7	170
1998	241	3	244
1999	247	9	256
2000	235	47	282
2001	150	26	176
2002	0	13	13

Lee County (Gorzelany, 1998; Sidman and Flamm, 2001; Sidman *et al.,* 2000, 2001). Areas of recreational boating activities, high-use vessel-traffic travel corridors, and boating travel origins and destinations were identified. In addition, boater compliance with posted speed zones was examined for 12 sites in the Caloosahatchee River. This section summarizes information from these studies on vessel traffic and boater behavior in Lee County.

Gorzelany (1998) collected boat traffic, boating activity, and vessel compliance data using aerial, boat, and land-based surveys. He gathered more than 500 hours of observational data between September 1997 and August 1998 in Lee and Charlotte counties. Sidman and Flamm (2001) and Sidman *et al.* (2000, 2001) characterized boaters' behaviors and boating travel-corridors in Lee and Charlotte counties using aerial surveys made in 1998, opinions of FWC Division of Law Enforcement staff and local boating experts expressed in a series of meetings in 2000, and responses to telephone and mail surveys of boaters conducted in 2000.

Vessel Traffic

FUEL BARGE TRAFFIC

There is no deepwater port associated with the Caloosahatchee River, and thus, no ship traffic. However, some barge traffic crosses Florida passing through Lake Okeechobee and several locks. The maximum length of a vessel that can lock though this system is 250 feet (K. Estock, U.S. Army Corps of Engineers, personal communication). Because of silting in the river over the last few years, barges currently can draw only about eight feet (B. Tibble, Florida Power and Light, personal communication). The most frequent ship traffic in the study area has been barges going to and from the Florida Power and Light (FPL) power plant near the Orange River. These barges travel from a terminal in Boca Grande, delivering heavy and light oil to the power plant (Table 2).

OTHER VESSEL TRAFFIC

In Lee County, vessel traffic increased as the day progressed, and there were roughly twice the number of boats on the weekends than on weekdays. Gorzelany (1998) reported that the highest traffic volumes were in spring and the lowest were in winter. Sidman and Flamm (2001) reported that Lee County boaters preferred to use their boats in spring and summer.

Seventy percent of the vessels observed on the Caloosahatchee River were between 16 and 25 feet long (Gorzelany, 1998). The three most common vessel types were open fishermen, ski boats, and yachts. Near Centennial Park (Edison Bridge area), the majority of the traffic consisted of ski boats. Farther downstream, San Carlos Bay was dominated by yachts, which accounted for the greatest number of observations (2,654) at any site. Yachts were characterized by their enclosed space, which may range from a small cuddy cabin to larger areas for sleeping and eating.

During aerial surveys over the Caloosahatchee River, Gorzelany (1998) counted the highest total number of vessels in eastern San Carlos Bay, including Miserable Mile, and the lowest numbers in the mid-upper and upper Caloosahatchee River. In a one-hour interval, the Miserable Mile location had the highest number of vessels observed at any site, with 5.25 different vessels passing by per minute. When accounting for area, eastern San Carlos Bay had the second highest density of boats, with 2.15 vessels/km^2. Boat traffic was most concentrated in the vicinity of tidal inlets and within the Intracoastal Waterway (ICW), Miserable Mile, and the lower Caloosahatchee River.

In a study that examined boaters' behavior principally in Charlotte Harbor, Sidman and Flamm (2001) noted that the lower Caloosahatchee River had the greatest boat density and congestion. Specifically, Shell Point (the confluence of the Caloosahatchee River and San Carlos Bay) and the area immediately southwest of the Edison Bridge west to San Carlos Bay were identified as high-use boating-travel corridors (Figure 3).

Sources and Destinations

When leaving the Caloosahatchee River, the majority of vessels (62%) traveled south toward the Gulf of Mexico (Gorzelany, 1998). Gorzelany also recorded the majority of traffic exiting the river before 1259h (22.5 vessels/hour) and entering the river in the afternoon (after 1359h; 27.2 vessels/hour). From 1300 to 1359h, roughly equal amounts of traffic traveled in both directions. Traffic did not have a temporal pattern near the Edison Bridge, however, with just over half of the traffic traveling downriver (53%), approximately one-third traveling upriver (28%), and the remainder stay-

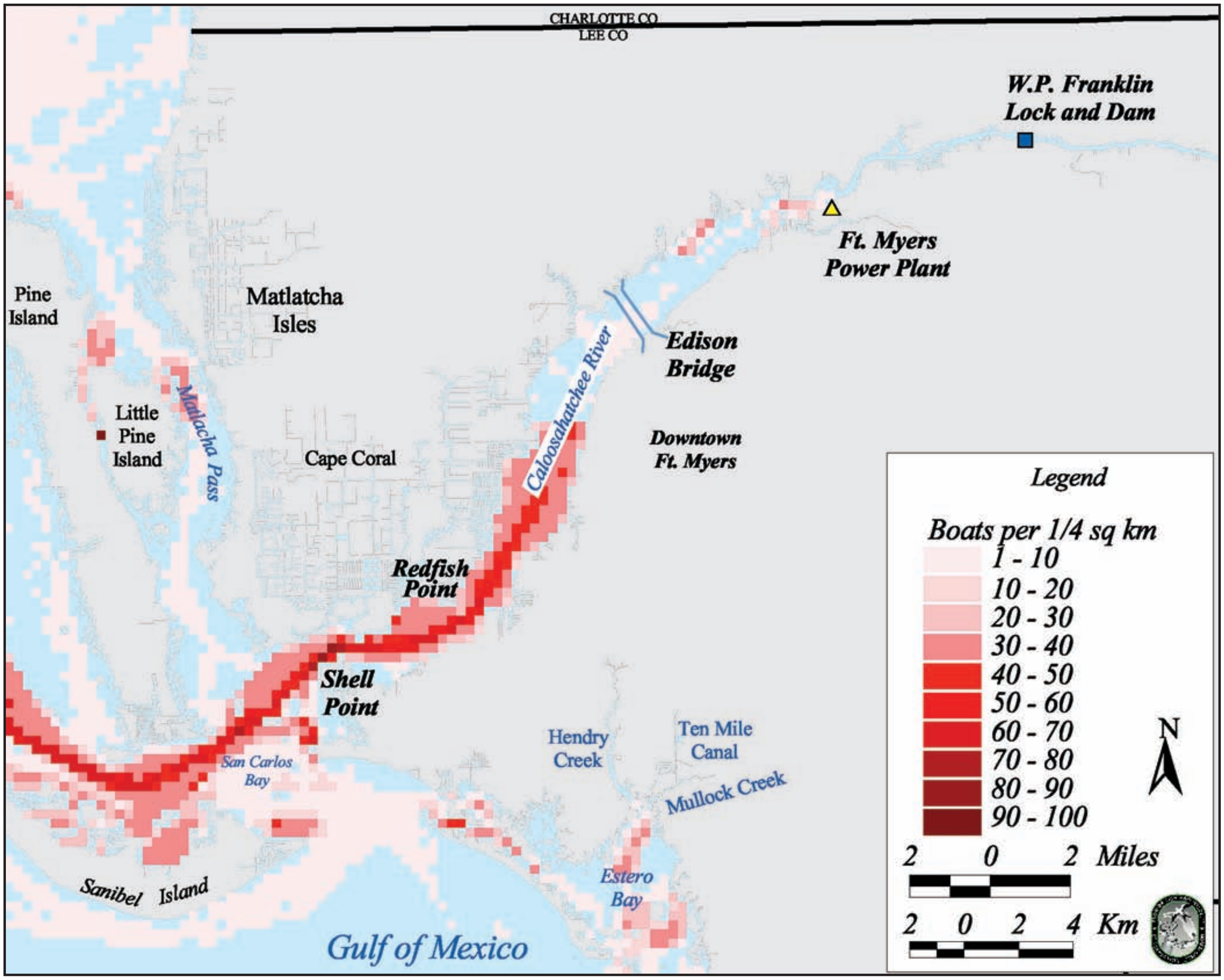

Figure 3 *Travel corridors used heavily by watercraft (from Sidman* et al., *2001). Darker areas indicate higher use.*

ing within the immediate area (Gorzelany, 1998).

Telephone and mail surveys revealed that more than 40% of respondents docked their boats in a canal behind their home (Sidman *et al.,* 2001). The digitized launch sites and travel routes of 192 boaters responding to a mail survey showed that for the Caloosahatchee River, launches for approximately 70% of the respondents originated in the Cape Coral canal system; the remainder were located along the south shore of the Caloosahatchee River (Figure 4). These boaters then traveled from the canals or the southern shore to the channel and then westward out the mouth of the river. These travel routes supported Gorzelany's findings that highest vessel traffic occurred near tidal inlets and in the ICW. Boaters who started in the Cape Coral and Ft. Myers areas identified Useppa Island and Boca Grande (North Pine Island Sound) as their favorite destinations (Sidman *et al.,* 2001). Consequently, boaters most often turned north at the mouth of the river, which contradicts Gorzelany's finding that 62% of the observed traffic traveled south upon exiting the river. However, the boaters surveyed by Sidman *et al.* (2001) represented a specialized subset of the vessel traffic observed by Gorzelany. Moreover, Sidman *et al.*'s survey requested the destinations of the last two trips rather than common or favorite destinations. The timing of the survey (spring–summer) may have also influenced the boaters' destinations and travel routes.

Boating Activities

In the Caloosahatchee River, Gorzelany (1998) reported the majority (76%) of the vessel traffic as "traveling" and approximately 20% as "anchored/drifting." In the Mis-

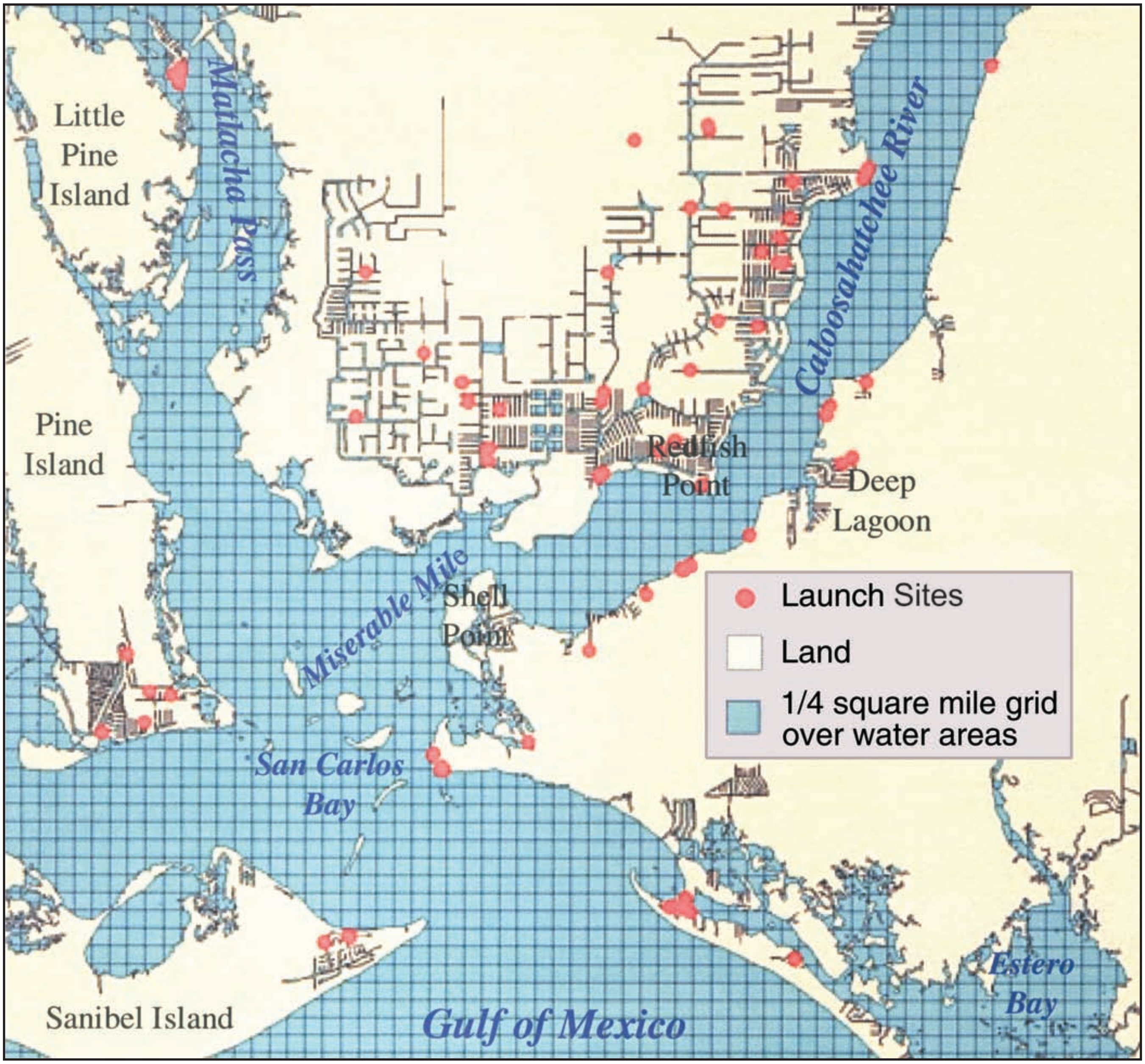

Figure 4 *Boat-launch sites along the lower Caloosahatchee River (from Sidman* et al., *2001).*

erable Mile area of San Carlos Bay, the proportion of traveling vessels increased to 98%. According to Sidman and Flamm (2001), though, the confluence of the Caloosahatchee River and San Carlos Bay also supported a high diversity of boating activities, such as fishing, cruising, and sailing. This diversity likely contributed to the high traffic density in this area.

Sidman *et al.* (2001) found that personal watercraft use was highest in areas of beach access. These beach-access areas often coincided with popular leisure and picnic areas and included Shell Point, Redfish Point, and San Carlos Bay.

Vessel Compliance with Regulatory Zones

Gorzelany (1998) found that compliance with manatee speed zones was highly inconsistent among 12 sites along the Caloosahatchee River (12%–77%). Several variables were associated with compliance levels, including location, type of speed zone, vessel type, and vessel size. The interaction between these variables was site-specific. Therefore, when contemplating management options or future research, each site should be examined independently. When law enforcement was present, compliance with posted speed zones increased significantly (Gorzelany, 1998; Shapiro, 2001). However, the probability of encountering a law enforcement officer (local, state, or federal) at any specific time between 0800h and 1600h in a discrete segment of a manatee speed zone in the Caloosahatchee River was 5.1% (Gorzelany, 1998).

The absolute number of speeding vessels probably has a greater effect on manatees than does the percent compliance. Despite the fact that the Shell Island site had almost 60% compliance, Gorzelany (1998) recorded nearly two and a half times the number of violations there than at the next busiest site, which had a 39% compliance rate.

The following trends also emerged. Compliance was highly associated with vessel type and vessel size. Personal watercraft and jonboats were the least compliant, whereas sailboats and pontoon boats were consistently the most compliant (Gorzelany, 1998). The Personal Watercraft Industry Association (http://www.pwia.org/) publicizes that riding PWCs is a "sport." These vessels are designed and marketed for recreational use with the intent of traveling at high speeds in relatively shallow water. Pontoon boats and sailboats, on the other hand, can be awkward and difficult to maneuver at high speeds. Many sailboats have a fixed keel and are thus relegated to the deep water provided by channels. Blatant noncompliance decreased with increasing vessel size, and larger vessels composed the smallest proportion of the observations. Smaller boats are very maneuverable at high speeds and are able to navigate a variety of areas, whereas larger boats are restricted to major channels and deeper water. To avoid potential accidents in congested areas, larger vessels must travel at reduced speeds.

Summary

Vessel traffic in the Caloosahatchee River is highest on weekend afternoons in spring. Yachts, ski boats, and open fishermen boats are the three most common vessel types found between the Edison Bridge and Miserable Mile. In this area, the most common vessel sizes range from 16 to 39 feet. Highest traffic densities occur at Shell Point, where the Caloosahatchee River and San Carlos Bay converge.

Many of the boats observed in the lower Caloosahatchee River originated in the Cape Coral canal system and traveled west to the Gulf of Mexico. The highly variable, site-specific nature of boaters' behavior and vessel compliance requires scientists and managers to deal with each site independently. When assessing threats to manatees, however, compliance rates are not as relevant as the total number of blatant violations. An area with heavy boat traffic and relatively high compliance may still have a greater total number of blatant violations that could pose a threat to manatees than an area with less traffic and low compliance, such as Shell Point, which has a maximum rate of one unique vessel every 11.4 seconds (Gorzelany, 1998).

Habitat Information

Introduction

The estuarine portion of the Caloosahatchee River is delimited upstream by the W.P. Franklin Lock and Dam (Franklin locks). The Franklin locks lie roughly 25 miles upstream from Shell Point and act as a salinity barrier. Extreme quantities of fresh water released from Lake Okeechobee and upstream runoff followed by periods of drought have altered the estuarine ecosystem downstream of the locks. Since the construction of the locks in 1968, downstream turbidity has increased, resulting in decreases in light penetration and in SAV in the estuary (Science Subgroup, 1996; SFWMD, 2000).

This section examines habitat characteristics of the study area including water temperature, salinity, forage, and bathymetry. Specifically, we identify important manatee habitats called "places," based on the features that may act as attractants for manatees or provide necessary resources.

Warm-Water Aggregations

Warm-water refuges at the Florida Power and Light (FPL) power plant, Franklin locks, and Matlacha Isles play an important role in defining manatee movements between Shell Point and the Edison Bridge during winter.

FPL POWER PLANT—PRIMARY WARM–WATER SITE

Intake pipes for the FPL Ft. Myers power plant are located on the Caloosahatchee River approximately 1.5 miles east of Interstate Route I-75. The warmed effluent, roughly 7°C above ambient temperature (FPL intake temperature), is discharged into the Orange River (FPL, 2002). The thermal plume flows down the Orange River into the Caloosahatchee River. As many as 434 manatees have been counted at the power plant discharge area in a single day (Reynolds, 1996).

In 2001, the power plant began construction to "repower" by converting to natural gas. During winter 2001–2002, the amount of warm-water effluent produced by the plant was only a fraction of the normal level. To address the decrease in warm water and pro-

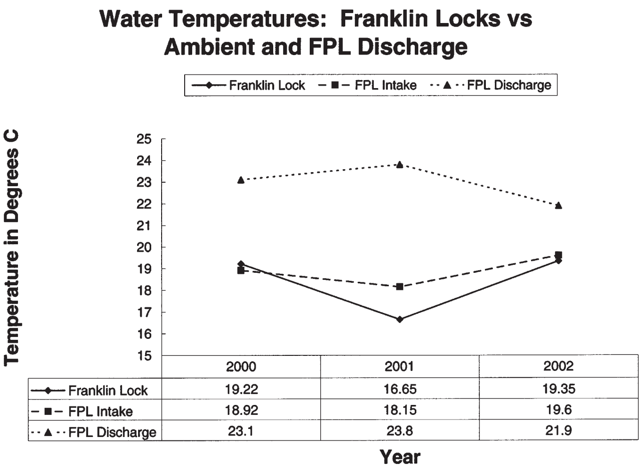

Figure 5 *Average January water temperatures (degrees C) at the W.P. Franklin Locks and Dam, FPL intake pipe, and FPL discharge canal, 2000–2002 (FPL, 2002).*

vide adequate habitat for manatees, "donkey boilers" were installed on 4 January 2002 (Reynolds, 2002). The reduction in warm-water flow at the traditional outfall prompted manatees to gather at two secondary winter refuge sites, the Franklin locks and Matlacha Isles.

FRANKLIN LOCK AND DAM— SECONDARY WARM–WATER SITE

Immediately downstream of the Franklin Lock and Dam there is a 56-foot-deep dredged channel. Although not warmed by a thermal effluent, this deep channel cools more slowly than the main river does (Packard *et al.*, 1989). Packard *et al.* (1989) reported increased manatee use of the upstream areas of the Caloosahatchee River estuary in 1985 in response to an interruption of the FPL plant's thermal effluent. These upstream areas included deep channels, places with abundant aquatic vegetation, and the Franklin locks. When temperatures at the locks and in the Orange River were the same, roughly equal numbers of manatees were counted at each location, but the number of individuals at the power plant exceeded the number at the locks when lock temperatures dropped below 17°C (Packard *et al.*, 1989), so temperatures of 17°–18°C seemed to trigger manatee movements between the FPL plant and the locks. It is during these times of frequent manatee trips between the power plant and the lock that manatees are at the greatest risk of harmful collisions with motorboats in this area.

Figure 5 compares average water temperatures for January 2000, 2001, and 2002 at three locations: Franklin locks, FPL intake (ambient Caloosahatchee River), and FPL discharge. In 2000 and 2002, a temperature probe at the locks recorded temperatures close to ambient. Winter 2000–2001 was cooler than normal (National Oceanic and Atmospheric Administration [NOAA], 2001). Lock temperatures in January 2001 were substantially cooler than they were in 2000 and 2002, a likely consequence of the colder-than-average air temperatures. The temperature probe at the locks was located three feet below the surface. Presumably, bottom temperatures at the locks do not cool as quickly nor vary as widely as the temperatures three feet below the surface do. Reynolds (2002) posited that manatees wallow in sediments to aid in thermoregulation. Consequently, manatees use the locks as an alternative warm-water refuge because of the heat retained in the deeper waters and sediments.

MATLACHA ISLES— SECONDARY WARM–WATER SITE

The canals of Matlacha Isles lie at the northern end of Matlacha Pass. These canals are important manatee habitats during the cold season (Lefebvre and Frohlich, 1986; Barton and Reynolds, 2001). In March 2002, Reynolds (2002) counted 125 manatees using the area. As at the locks, manatee movements to and from Matlacha Isles appeared to be related to water temperature and, more specifically, to bottom temperatures (Barton and Reynolds, 2001).

Observational and time-depth recorder data from tagged manatees showed that manatees were more active from evening to morning when aggregated at warm-water refuges during cold weather (Barton and Reynolds, 2001; Deutsch *et al.*, 2003). Barton and Reynolds (2001) observed feeding in the late-evening to early-morning hours (1900h – 0600h) at Matlacha. Bengtson (1981) and Deutsch *et al.* (2003) reported that wintertime manatee foraging trips began in the late afternoon to early evening. Barton and Reynolds (2001) also observed that peaks in traveling occurred at certain times of the day: the greatest movement into the canal system occurred at 0600h–0800h, and the greatest movement out of the system occurred at 1700h–1900h.

Fresh Water

Although manatees aggregate at freshwater discharges, it is not known to what extent, if at all, manatees physiologically require fresh water. Hartman (1979) theorized that the manatee's attraction to virtually any type of fresh water is related to osmoregulation. However, Ortiz (1994) found that manatees obtain necessary fresh water from their diet and can maintain water balance in saltwater environments without drinking. Regardless of the reason, manatees are attracted to freshwater sources, especially in areas of high or fluc-

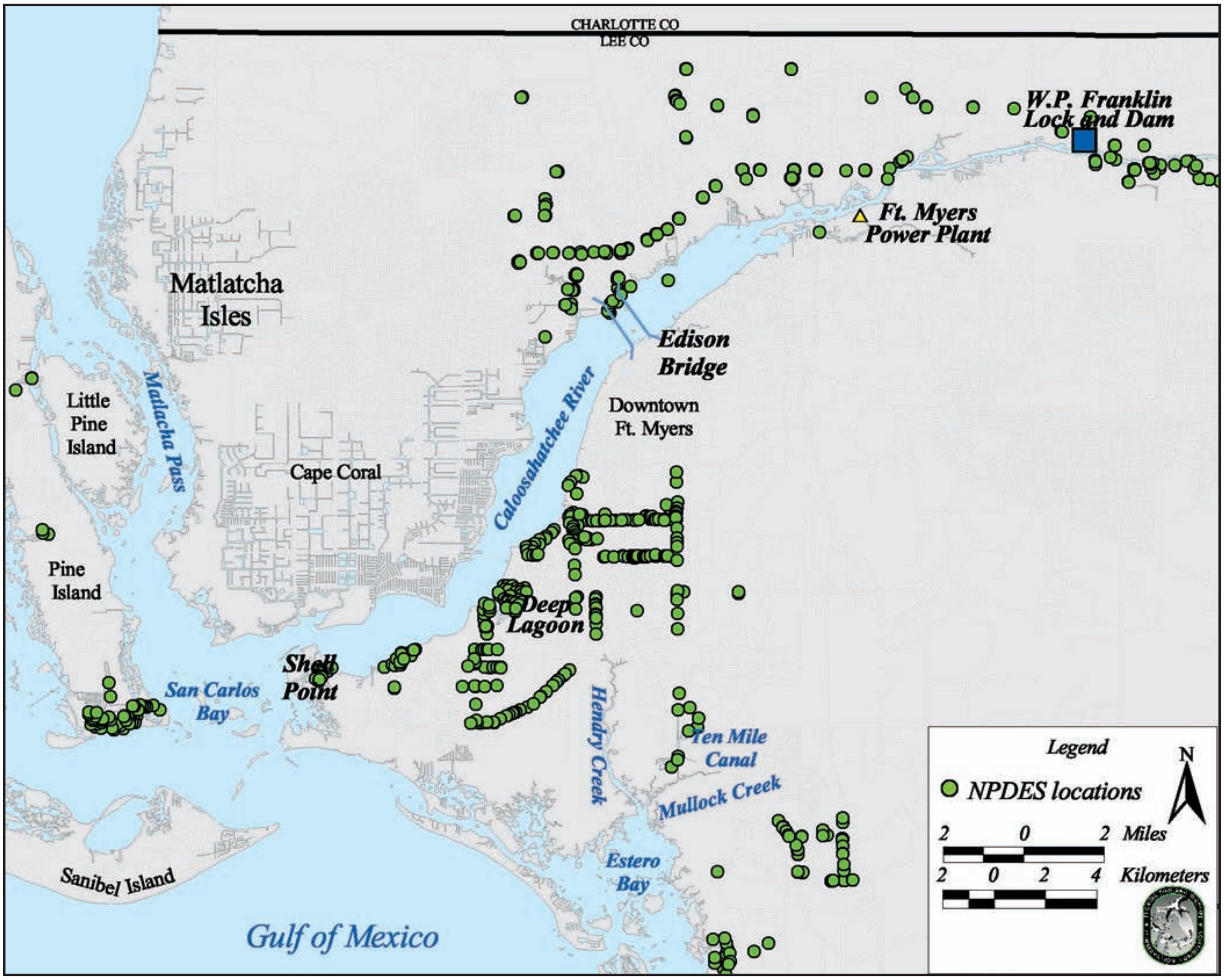

Figure 6 *Authorized National Pollutant Discharge Elimination System locations for the Caloosahatchee River, updated through April 2002. Coverage provided by Lee County Department of Public Works.*

tuating salinity. Such sources occur between the Edison Bridge and Shell Point, where a substantial portion of the shoreline on both sides of the river has been stabilized by seawalls. Figure 6 identifies National Pollutant Discharge Elimination System (NPDES) locations near the Caloosahatchee River. These areas, concentrated along the southern shore of the river, may be focal attractants to manatees when there are no upstream freshwater discharges in the river.

Smaller Important Places

Staff at FWC's Charlotte Harbor field laboratory have identified other places important to manatees (see also Telemetry and Aerial Survey Sections; Figure 7). These secondary sites may be important because they contain fresh water, have deep water to aid in thermoregulation, have seagrass beds, or are areas of minimal disturbance. Some canals and deep basins may be used principally during the passage of early- or late-winter cold fronts. Manatees are frequently observed in these secondary sites during rapid cooling spells that do not drop the ambient water temperatures greatly. These smaller places include the following areas:

Eight Lakes—Located in the southwestern portion of the Cape Coral canals, this area is approximately 24 feet deep and is probably a secondary warm-water aggregation area as described above. Temperatures recorded in Eight Lakes between December and February averaged almost 1°C above the ambient temperatures that were collected from a NOAA temperature probe at the Edison Bridge (FWC unpublished data, NOAA 2002). The Eight Lakes temperature probe measured temperatures three to four feet below

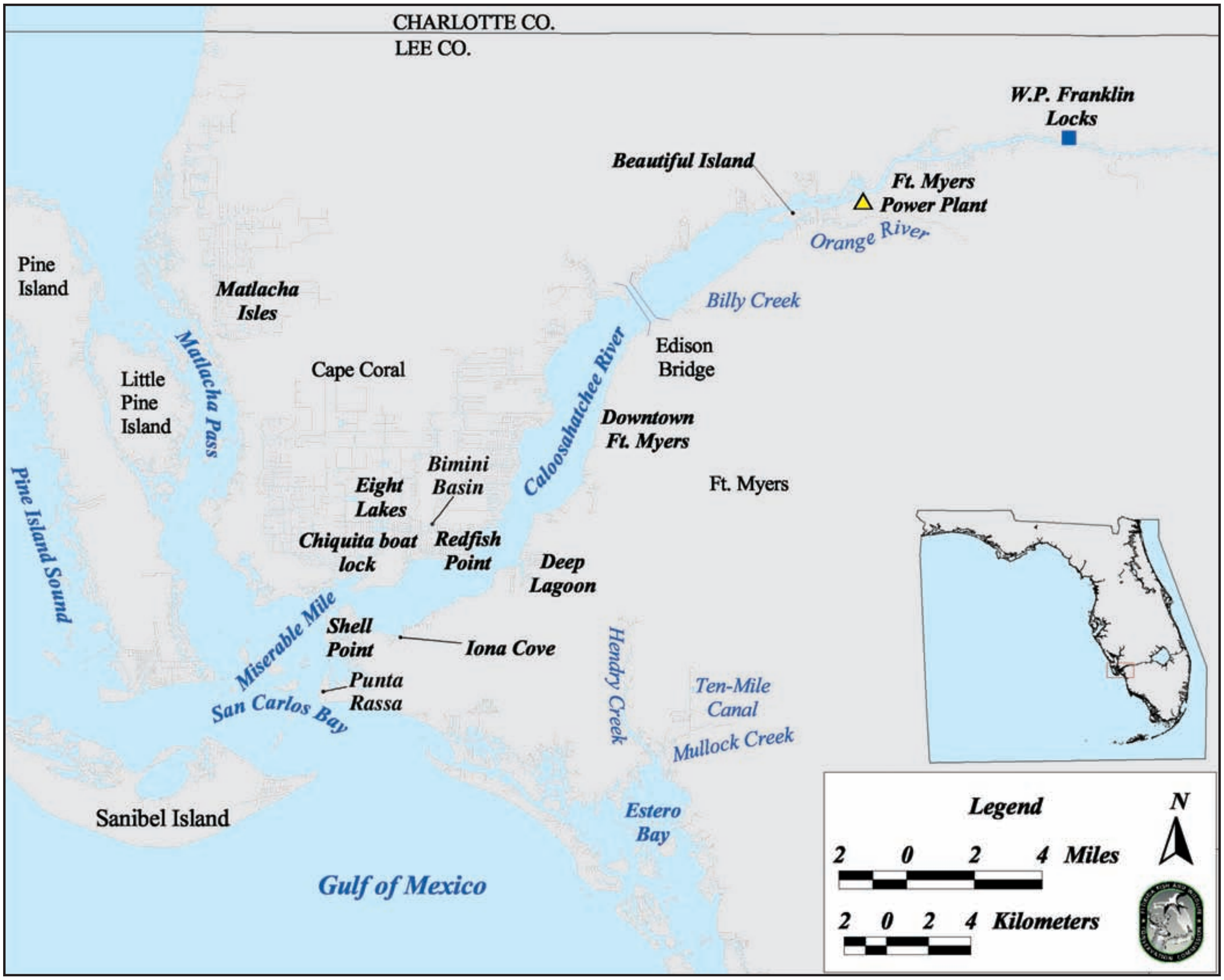

Figure 7 *Secondary manatee-aggregation areas (bold face) along the Caloosahatchee River.*

the surface, and it is likely that bottom and sediment temperatures were warmer.

Chiquita Boat Lock—This boat lock and canal lies southwest of Eight Lakes. It contains a freshwater source and allows boat access to Eight Lakes.

Bimini Basin—This is a shallow basin (6 ft) northeast of the Eight Lakes. It may be used for resting.

Shell Point Village lagoon—This area contains a pipe believed to discharge fresh water. Local residents frequently report manatee sightings, and manatees have been observed during aerial surveys here.

Punta Rassa—This area contains seagrass beds and is a possible feeding aggregation site.

Beautiful Island—Beautiful Island is located east of the Edison Bridge and downstream from the mouth of the Orange River. This is a probable feeding site and often contains beds of tapegrass (*Vallisneria americana*).

Downtown Ft. Myers marinas—Manatees frequently aggregate in marinas, presumably for the fresh water discharged from hoses.

Deep Lagoon—Located on the southern shore of the Caloosahatchee River, Deep Lagoon lies across the river from Redfish Point. This area contains a marina where manatees may seek fresh water, a place for resting, or warm water.

Iona Cove—This cove is located on the eastern portion of Shell Point. Manatees have been observed feeding here in years past (K. Frohlich, FWC, personal communication). However, seagrass abundance is known to wax and wane in this region of the estuary in response to prolonged fluctuations in salinity.

Billy Creek—FWC staff have received reports of occasional winter manatee sightings here. Sediments in this creek may retain some heat, providing a temporary warm-water refuge.

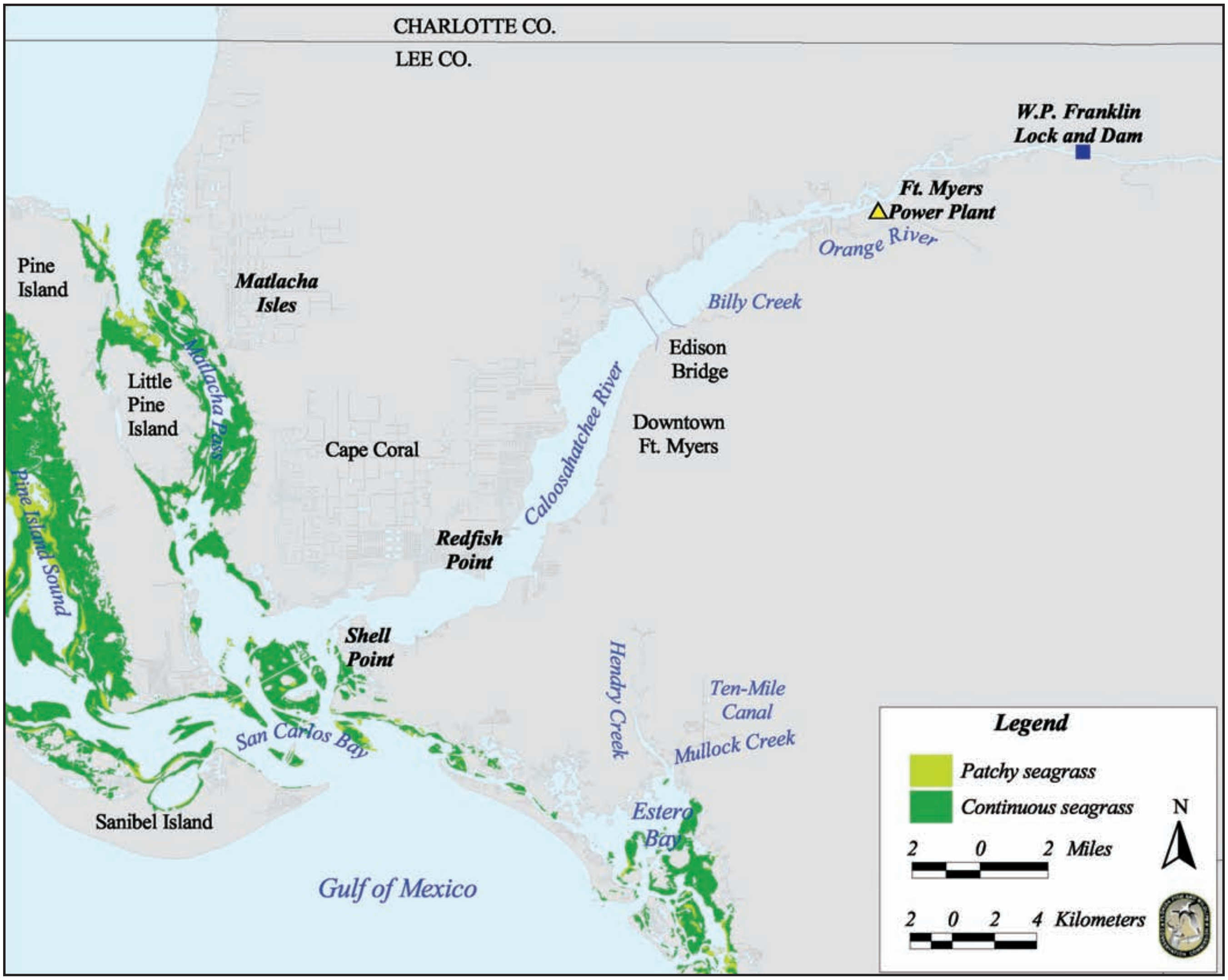

Figure 8 *Seagrass distribution in San Carlos Bay, Matlacha Pass, and a portion of Pine Island Sound, 1999.*

Seagrasses, Aquatic Freshwater Vegetation, and Salinity Changes

Figure 8 shows 1999 seagrass coverage at the mouth of the Caloosahatchee River, Matlacha Isles, and San Carlos Bay. Sections of the river between the Edison Bridge and Shell Point do not contain any seagrass patches. The seagrass beds closest to the river are between Punta Rassa and Shell Point and immediately west of Shell Point in the Miserable Mile area. The following discussion explains some of the variability and patchiness of SAV between the Edison Bridge and Shell Point.

Figure 9 is an idealized map of seagrass and SAV coverage under "average" conditions (Chamberlain and Doering, 1998). Controlled releases or pulses of fresh water from Lake Okeechobee, upstream runoff, and prolonged periods of drought can severely, although temporarily, alter the salinity gradient (Figures 10, 11). Estevez (2000) reported that variations in salinity adversely affect seagrass biomass more than actual salinity levels. Salinity fluctuations increase turbidity, reduce light penetration, and alter the pattern of SAV distribution. Chamberlain and Doering (1998) have estimated that the optimum freshwater inflow requirements should be 300–800 cubic feet per second (cfs) to maintain an ecologically balanced system in the Caloosahatchee estuary. They based their estimation on freshwater and saltwater tolerances of a few indicator species, including Cuban shoalgrass (*Halodule wrightii*), turtlegrass (*Thalassia testudinum*), and tapegrass (*Vallisneria americana*).

The SFWMD (2000) will attempt to maintain 300 cfs as the mean monthly flow during the dry season and no more than 2,800 cfs mean monthly flow during the

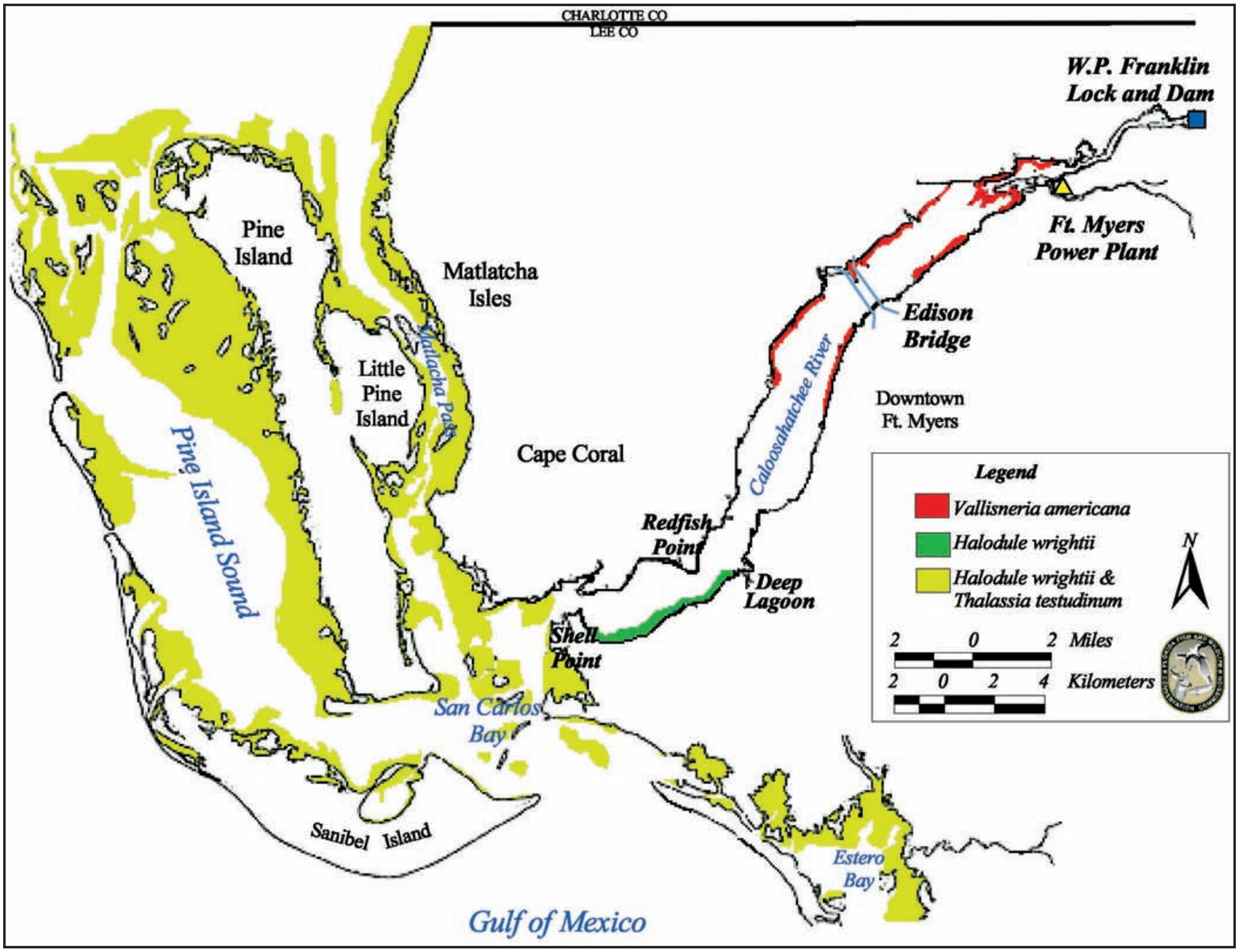

Figure 9 *Seagrass and SAV distribution in the Caloosahatchee River and Estero Bay under optimum conditions (from Chamberlain and Doering, 1998).*

wet season. If the South Florida Water Management District (SFWMD) maintains inflows within recommended guidelines, there should be a minimal effect on the distribution of submerged vegetation. However, according to the SFWMD (2000), 31-year simulation models did not predict significant reductions in the number of high-discharge events until 2010. Even then, simulated minimum criteria (300 cfs) were not met 76 times, whereas maximum criteria (2,800 cfs) were exceeded 45 times. Therefore, the system will continue to be dynamic over the next several years. Large changes in salinity will alter the distribution and abundance of SAV. In periods of drought, marine seagrass beds may extend along the shoreline upstream to the Cape Coral Bridge (P. Doering, SFWMD, personal communication). During the wet season, freshwater inflows may kill marine SAV but increase freshwater SAV growth between the Edison and the Mid Point Memorial Bridges (P. Doering, SFWMD, personal communication). One researcher (S. Bortone, the Conservancy of SW Florida, personal communication) suspects there may be beds of mixed species (freshwater and marine), in areas where variable salinity would not alter the distribution of SAV but would affect the species composition. Despite salinity fluctuations, as long as other environmental conditions are not limiting, some type of SAV will probably occupy the shelf as the salinity wedge moves up or downriver (Estevez, 2000).

Because scientists do not know the principal regrowth mechanism (seeds, existing rhizomes, etc.) for SAV affected by salinity variations, the time frame for recolonization by either freshwater or marine species is unknown and may range from weeks to months (P. Doering, SFWMD, personal communication; S. Bortone, the Conservancy of Southwest Florida, personal communication). Estevez (2000) reported that widgeon-

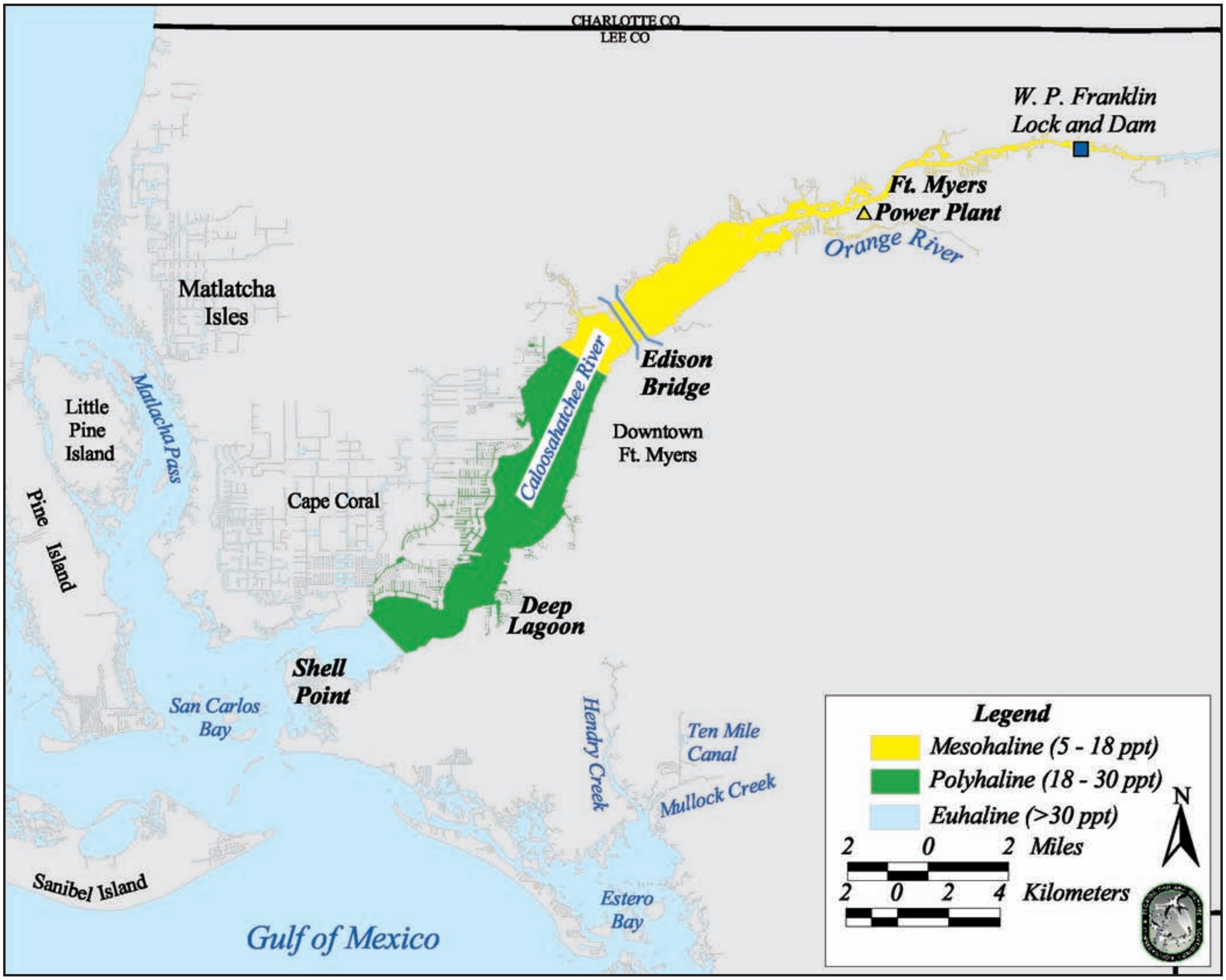

Figure 10 *Salinity gradient of the Caloosahatchee River estuary during periods of low freshwater inflow (from USGS, 2001).*

grass (*Ruppia maritima*) is probably the first to grow after denuding from extreme salinity changes, replacing Cuban shoalgrass when salinity decreases and tapegrass when salinity increases. Sustained periods of salinity extremes could substantially reduce SAV. Temporary elimination of SAV would force manatees to find food elsewhere, either upstream for freshwater species or downstream to San Carlos Bay, Matlacha Isles, Pine Island Sound, or Estero Bay for seagrass. Overall, manatees probably feed opportunistically along the shallow shelf areas between Shell Point and the Edison Bridge while en route to important habitats outside of these boundaries.

Although lower salinity will increase the likelihood of tapegrass growth, oligohaline conditions can also decrease water clarity and darken water color. Bortone and Turpin (2000) found that tapegrass in the Caloosahatchee River actually grew faster under conditions of higher salinity but better water clarity. Therefore, in addition to salinity fluctuations, water color and turbidity contribute to the unpredictable and patchy distribution of SAV in the Caloosahatchee River.

Seasonal changes in SAV abundance and quality will affect the duration of manatee foraging periods (Bengtson, 1983). In the Caloosahatchee River, tapegrass has the highest quality in the form of new growth from May to August and the greatest quantity or biomass from July to October (Bortone and Turpin, 2000). Bengtson (1983) reported increased manatee foraging rates in the St. Johns River in fall, prior to the physiological stresses of winter and when vegetation was of lower quality. Manatees in the Caloosahatchee River may behave similarly, especially in the less variable feeding areas upstream of the Edison Bridge or downstream of Shell Point.

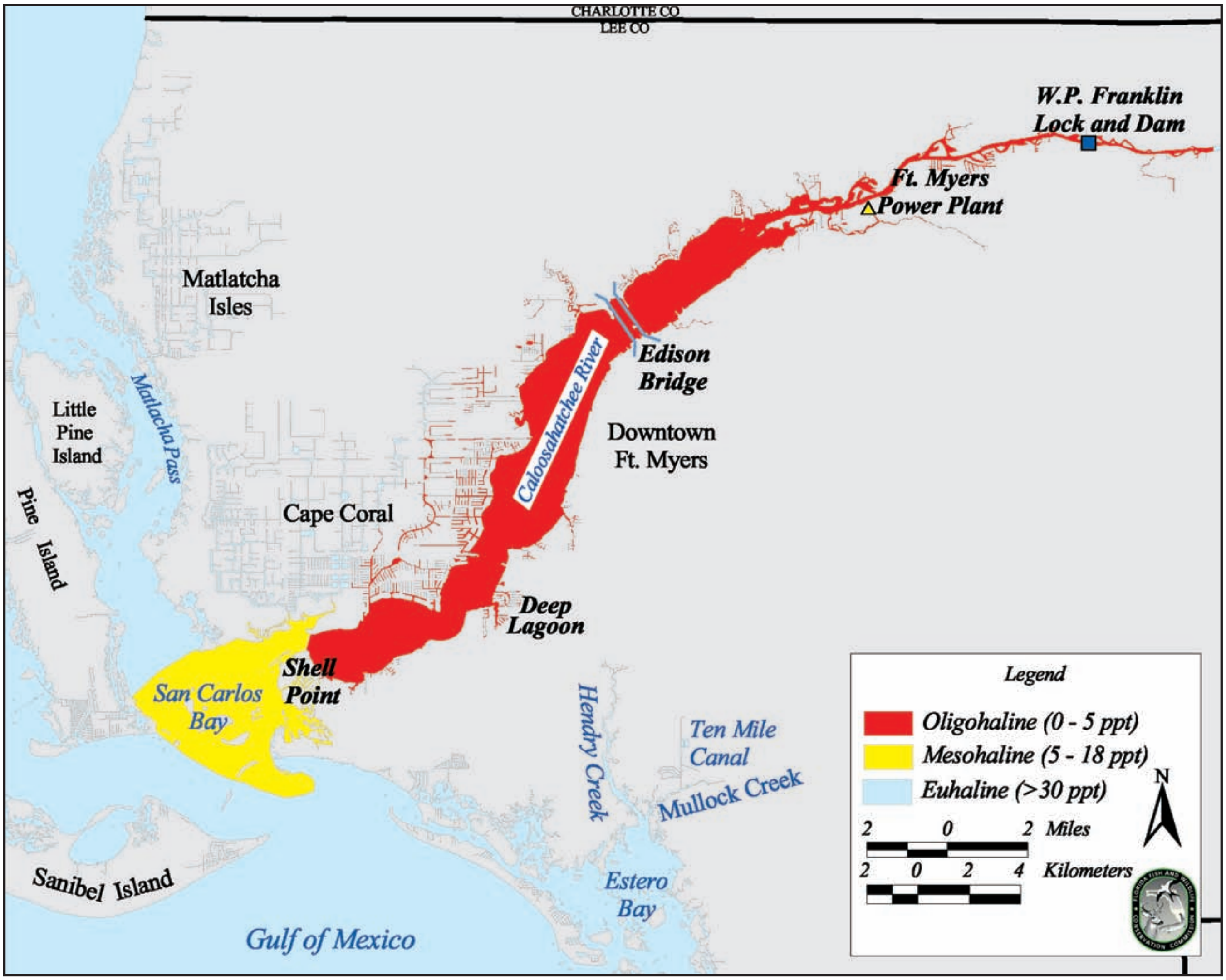

Figure 11 *Salinity gradient of the Caloosahatchee River estuary during periods of high freshwater inflow (from USGS, 2001).*

Bathymetry

Figure 12 shows the bathymetry of the Caloosahatchee River (FWC 2000). Manatees can travel the length and breadth of the study area even though it is shallow. The average depth of the river's edge is 3 feet (0.9 m), and the center, including the channel, ranges from 6 to 25 feet in depth (1.8–7.6 m). Manatees are capable of traversing shallow areas to obtain access to warm-water refuges, feed on shoreline vegetation, or rest (Hartman, 1979; FWC, 2002).

Summary

The Caloosahatchee River between the Edison Bridge and Shell Point links habitats used by manatees, including warm-water refugia, feeding areas, and resting areas. The distribution of submerged aquatic vegetation (marine and freshwater) between Shell Point and the Edison Bridge is variable and patchy because of drastic fluctuations in salinity and high turbidity. Salinity changes are caused by periodic freshwater discharges from Lake Okeechobee, upstream runoff, and periods of drought, whereas turbidity results from development and vessel traffic. Manatees travel between more stable feeding areas found upstream (freshwater) and downstream (estuarine), although they presumably feed opportunistically while passing through the area. Selected areas in the Cape Coral and Ft. Myers canals likely afford manatees with fresh water through stormwater runoff and drainage, resting habitats, and possible nursery areas. In winter, manatees may also use a few of these canals as temporary warm-water sites.

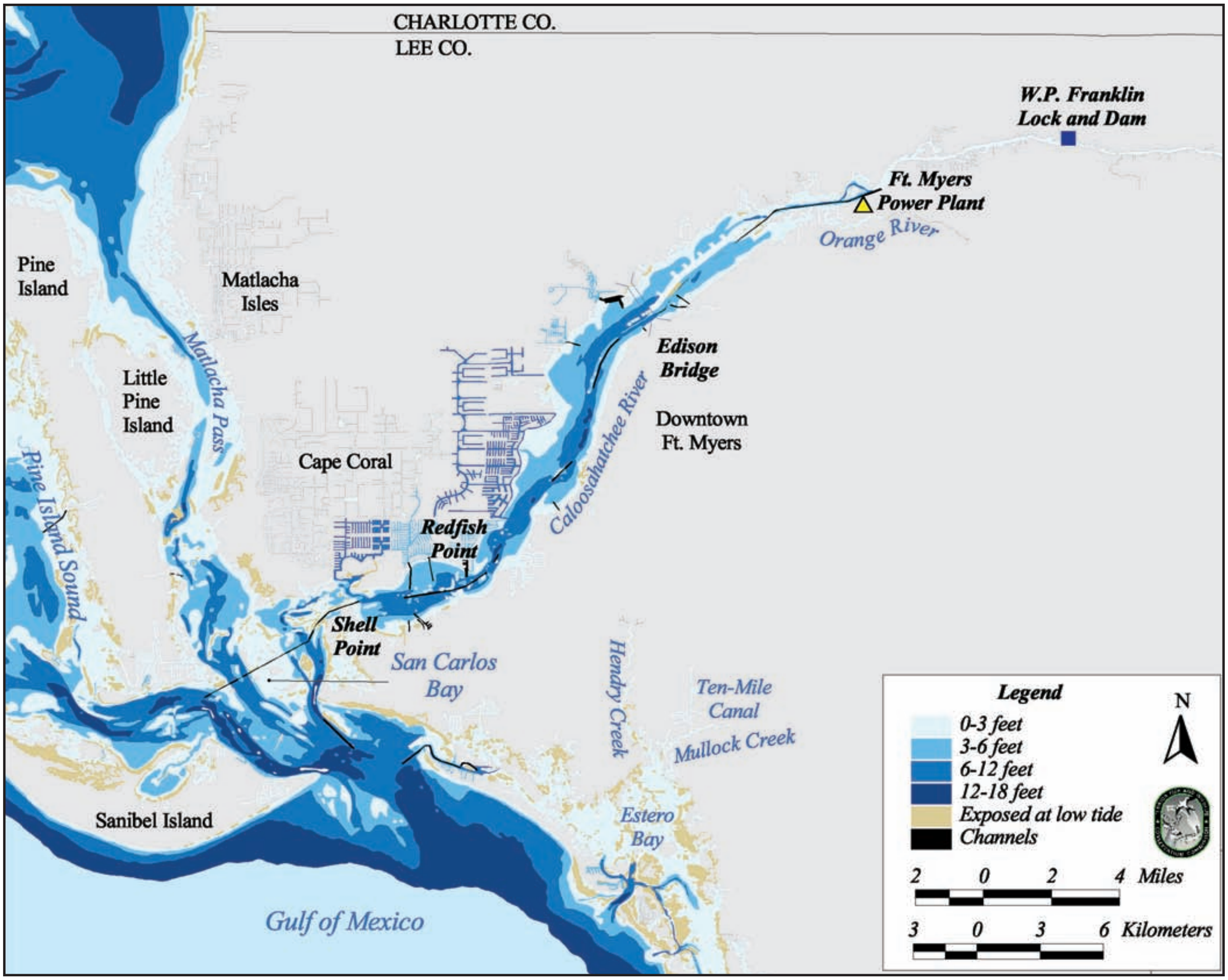

Figure 12 *Bathymetry of the Caloosahatchee River estuary, San Carlos Bay, and Matlacha Pass (data from FWC, 2000).*

Places and Corridors: A Summary of Telemetry Information

Introduction

Telemetry data provide a unique view of manatee ecology. Rather than collecting data on many animals at one time, as in aerial surveys, biologists use telemetry to gather data more intensively on a few individuals over long periods of time. By examining the sequence of telemetry locations, we can explore many aspects of manatee travel behavior, including migration, differences in movement patterns between individuals, and the locations of manatee travel corridors and places (Flamm *et al.,* 2005). A "place" is defined as an area frequented by manatees for extended periods. Places include key habitats for manatee feeding, resting, and thermoregulation. "Corridors" are areas visited regularly by manatees for brief periods as they travel from place to place. This section summarizes seasonal manatee travel paths and delineates places and corridors in and around the Caloosahatchee River.

Materials and Methods

FIELD METHODS

Methods for radio-tagging and tracking manatees are well established (Lefebvre and Frohlich, 1986; Rathbun *et al.,* 1987, 1990; Deutsch *et al.,* 1998, 2003; Weigle *et al.,* 2001). We analyzed data from 26 manatees (17 females and 9 males) that were tracked by using satellite tags from 1991–2001. Nine of the 26 (4 females, 5 males) were captive-born or long-term captives that were released into the wild. The wild-caught manatees were tagged and tracked for studies conducted by FWC and Mote

Marine Laboratory. Three wild manatees were tagged at Warm Mineral Springs, three were tagged at Matlacha Isles, and one was tagged in Collier County. The remaining 10 individuals were tagged throughout southwestern Florida, as described in Weigle *et al.* (2001). Tagged manatees were tracked by truck and boat. Tagging duration ranged from 2 to 128 weeks; the average was 37.6 weeks.

ANALYTICAL METHODS

Satellite telemetry data were processed to shift or delete points that were positioned on land. Telemetry points were located on land because of positional errors introduced during Service ARGOS's estimation of the manatees' locations and the reductions in map resolution resulting from the conversion of the Florida shoreline vector coverage to a raster map (Weigle *et al.*, 2001). Points located on land and within 1 km of water were moved to the nearest cell of water based on straight-line distance. If several water pixels were equidistant from the satellite-estimated position, one was selected randomly. Points farther than 1 km from water were not used in this study. All points moved to water were verified by field biologists familiar with the travel histories of the manatees and the area.

The manatee travel-path analysis transformed point data into raster maps displaying manatee places and corridors (Weigle *et al.,* 2001; Flamm *et al.*, 2005). A raster map is similar in structure to a piece of graph paper; it consists of evenly sized cells arranged into rows and columns. Each cell in the map has a number assigned to it that represents a theme in the map. For example, in a map of the Florida shoreline, cells with the value '1' correspond with land, and cells with a '2' correspond with water. To generate places and corridors, we first delimited travel paths, calculated manatee residence times per cell (minutes/cell), and then combined and interpreted the results in terms of manatee places and travel corridors. Places and corridors were first estimated for individual animals and then combined into a single map of places and corridors for the study area. The analytical methods are discussed in more detail below.

TRAVEL PATH MODEL

A travel path is defined as the line drawn between two telemetry locations. Travel paths were delineated using an approach called a cost-surface analysis (Flamm *et al.,* 2005). A cost-surface is a raster map in which cell values represent the "cost" associated with the passing of an object, in this case a manatee, through a cell. The higher the cost, the less likely that the cell will be crossed. In this analysis, costs were based on the association between water depth and the most accurate ARGOS accuracy location, class 3. In a cost-path analysis, the least costly path between two points is mapped. The Geographic Information System (GIS) Arc/Info (ESRI, Redlands, CA) includes programs that draw the path between points that has the least "cost." Manatee travel paths were filtered to include only those lines with the following attributes: first, the manatees' travel time between two telemetry points must not have exceeded three days' duration; second, the end point of the path must not be a location of a retagging or tag-removal episode; third, the start point must not be a location where the tag malfunctioned; fourth, neither the start point nor the end point should have an ARGOS accuracy location class of 0; and fifth, the movement rate associated with the travel path must not exceed 3,000 meters per hour.

Paths for individual manatees were analyzed to map "residence times," "visit frequencies," and "mean-residence-times-per-visit." Residence times were the estimated number of minutes, interpolated linearly, that a manatee spent in each cell that it crossed during movement between two telemetry locations. For example, if a manatee crossed 15 cells over a three-hour period, each cell would be assigned 12 minutes of manatee time (180 min/15 cells). Visit frequencies were the number of times an individual's path was delineated across each cell during the entire time it was tagged. The mean-residence-time-per-visit for each manatee was calculated as the sum of the manatee's residence times spent in a cell divided by the number of times the manatee visited that cell.

PLACES AND CORRIDORS MODEL

Travel-behavior patches were based on mean residence times and on the number of visits. Places were defined as cells with three or more visits of more than five minutes per visit. Similarly, cells with three or more visits of five minutes or less per visit were called corridors. Small places and corridors, those less than one-tenth the size of the largest place and corridor, were deleted from the map. Maps of places for all manatees that traveled through the study area were combined, as were the maps of corridors. Places and corridors were then expanded by five cells in all directions to coalesce small adjacent patches.

Results and Discussion

SEASONAL DISTRIBUTION

Figures 13 and 14 depict cold- and warm-season travel paths, respectively, for manatees in and near the Caloosahatchee River. Their travels in the Caloosahatchee River composed only a small portion of their

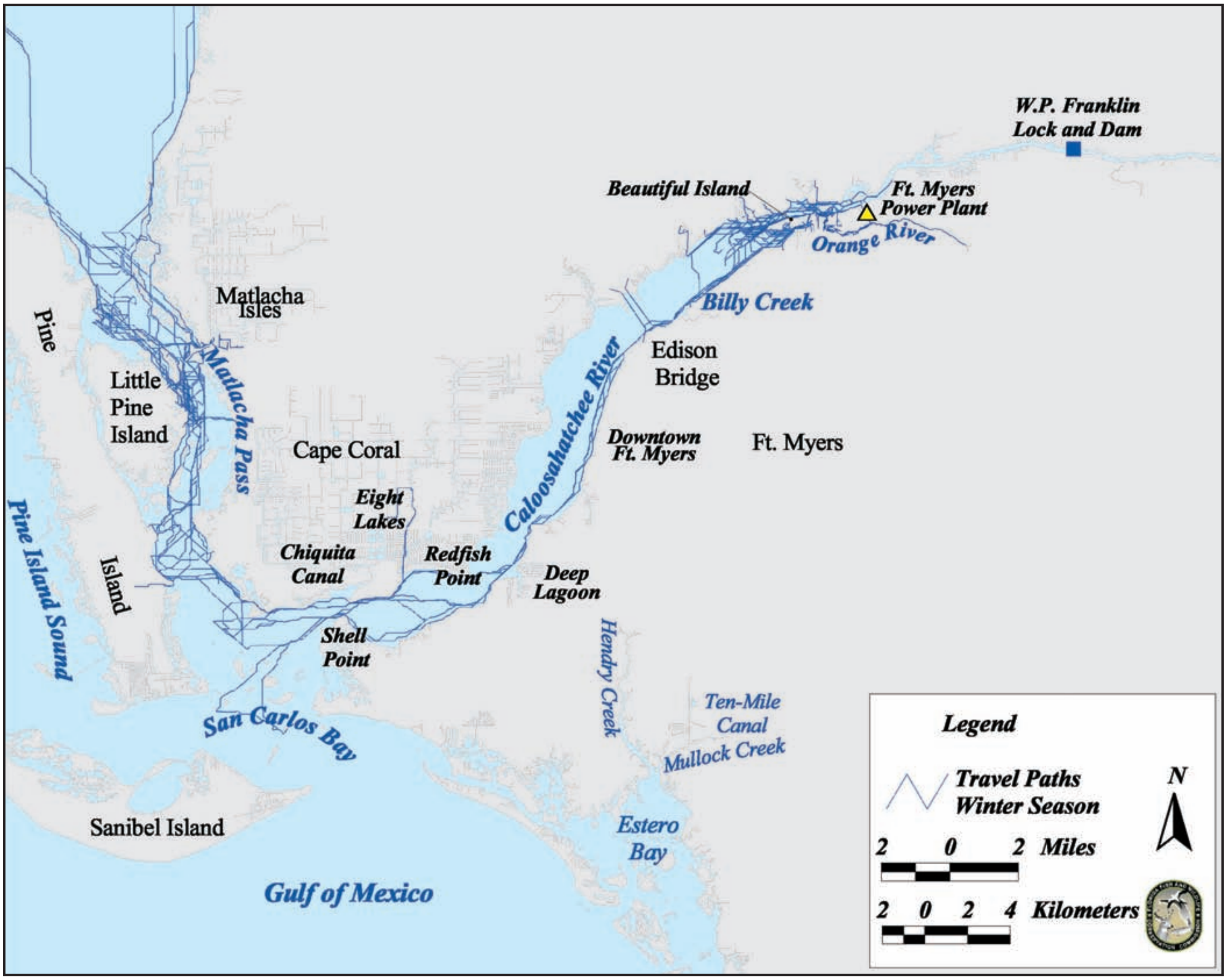

Figure 13 *Winter (December–February) travel paths of eight satellite-tagged manatees, 1991–1996.*

total range (Weigle *et al.,* 2001). Although the extent of the total range traveled by each individual varied, none of these manatees remained entirely within the Caloosahatchee River system. Lefebvre and Frohlich (1986) found that manatees who were radio-tagged within the Caloosahatchee River moved away from the river in early March. This has important implications for management. Activities that affect manatee ecology in the Caloosahatchee River will ultimately affect manatees throughout much of southwestern Florida. All manatees tagged during both warm (March–November) and cold (December–February) seasons spent portions of each season in the river. The warm season included the transitional months of March and November, when weather can be either cold or warm.

Movements during the cold season were generally more restricted than during the warm season and were concentrated near the warm-water effluent of the Ft. Myers power plant and in Matlacha Isles. Some individuals traveled between these two warm-water areas. One manatee also spent time in the Cape Coral Canal system (Weigle *et al.,* 2001). During winter 1985, manatees were concentrated in and around the warm-water areas of the Orange and upper Caloosahatchee rivers (Lefebvre and Frohlich, 1986). In winter 1986, however, tagged manatees spent more time in the lower Caloosahatchee River, including the Cape Coral canals and Deep Lagoon. West of Shell Point, manatees appear to have moved between Matlacha Isles, Matlacha Pass, and the seagrass beds in San Carlos Bay (FWC, unpublished data). Lefebvre and Frohlich (1986) also reported that manatees used these areas, specifically from February to May.

In mild winter seasons such as early 2002, data in-

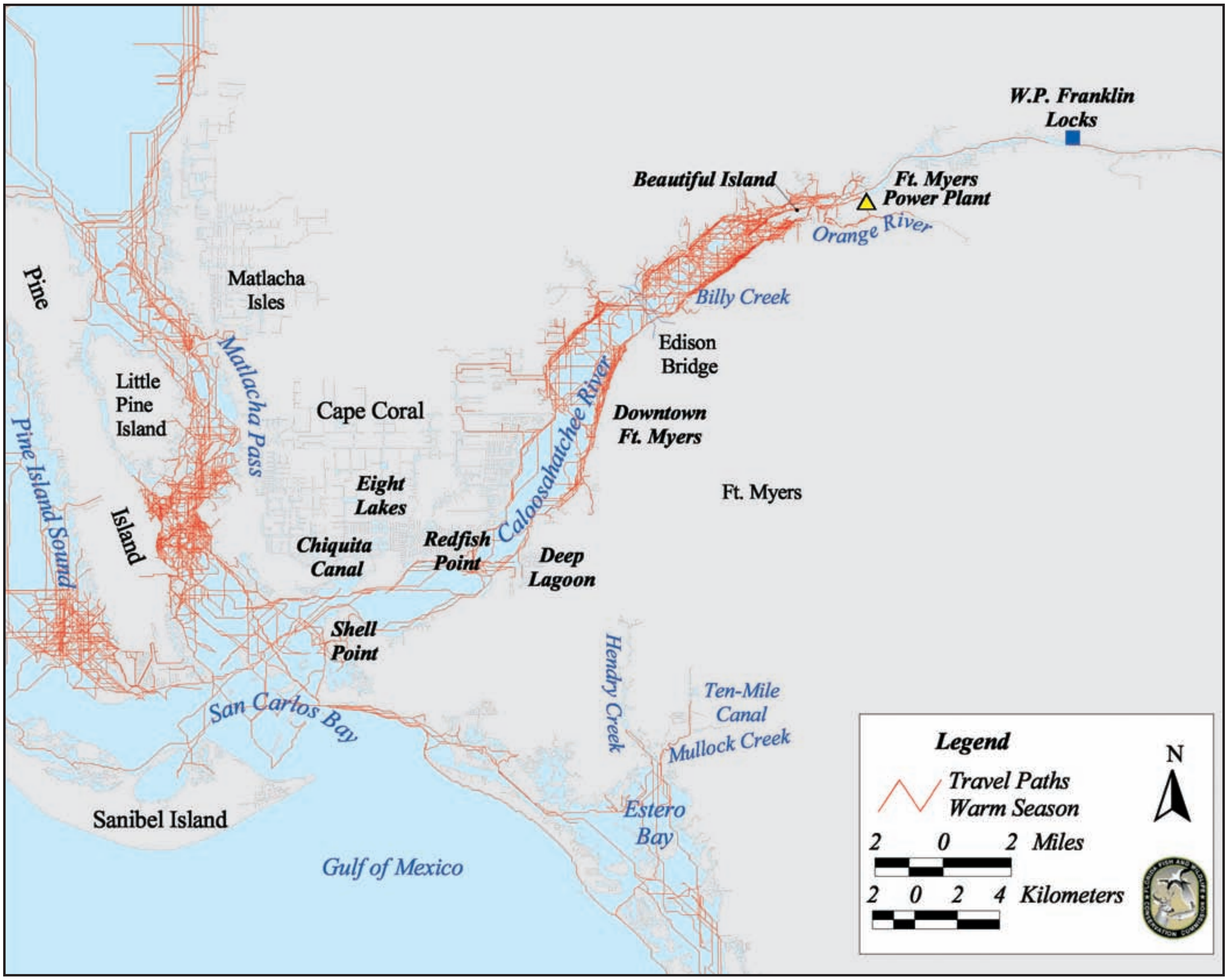

Figure 14 *Warm season (March–November) travel paths of nine satellite-tagged manatees, 1991–1996.*

dicate that manatees venture out to feed more frequently and move farther from the refugia. Because high numbers of animals use the warm-water refuges in winter, increases in manatee movements during this season will increase the likelihood of interactions with boats.

Warm-season use of the Caloosahatchee River appears to be extensive. Results suggest that manatees use the portion of the river between Shell Point and the Edison Bridge primarily as a travel corridor connecting important habitat areas (Figure 15). The upriver areas include feeding habitats near the Orange River and Beautiful Island. Food resources occur downriver near San Carlos Bay, Matlacha Pass, and Matlacha Isles. Manatees also used the extensive canal systems of Cape Coral and Ft. Myers, most likely for obtaining fresh water and for resting.

PLACES

Figures 15 and 16 display the manatee places in the Caloosahatchee River identified by the model. Some places could reflect data from only one manatee but other places reflect data from several manatees. The majority of places mapped by the model lie east of the Edison Bridge and west of Shell Point. Lefebvre and Frohlich (1986) found that tagged manatees were associated with seagrass beds in San Carlos Bay and Matlacha Pass in the warm season. As described in the habitat section, more reliable manatee feeding grounds lie west of Shell Point and east of the Edison Bridge. Both of these areas also contain important warm-water refuges: the Ft. Myers power plant and Matlacha Isles. The model again substantiates our hypothesis that manatees spend less time in the mid-river area.

Although primarily a travel corridor, the area between the Edison Bridge and Shell Point includes some

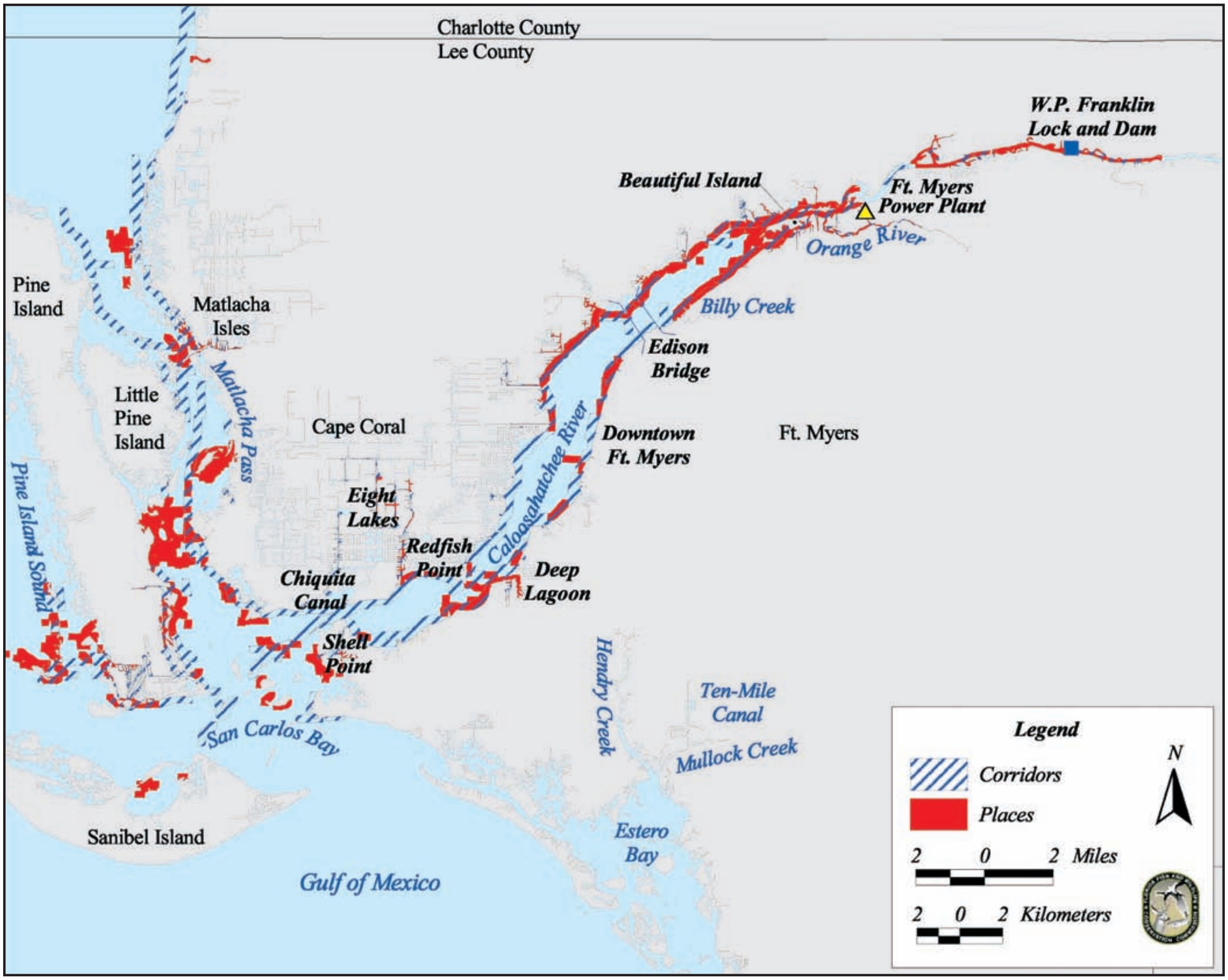

Figure 15 *Manatee places and corridors in and around the Caloosahatchee River, derived from satellite- and radio-telemetry data of 26 manatees between 1991 and 2001.*

places within the residential canals in Cape Coral and Ft. Myers (Figure 16). Canals can provide quiet areas for resting, calving, and suckling (Shane, 1983). In addition, low-energy areas, such as canals, tend to contain fine-grained sediments that retain heat during winter and are cooler in summer (Reynolds, 2002). During the cold season, deep canals may provide temporary shelter from sudden cold fronts or serve as stop-over areas where manatees can find warmth while traveling to major warm-water aggregation sites. The banks of this portion of the Caloosahatchee River are highly urbanized and heavily seawalled. Seawalls can act to concentrate freshwater run-off via discharge pipes and can serve as attractants when the freshwater discharge from Lake Okeechobee is low.

The following areas between the Edison Bridge and Shell Point that were mapped as places were verified by FWRI field biologists as being important secondary aggregation areas (Figure 7, habitat section):

North shore west of the Edison Bridge—This area is heavily seawalled and leads to several canals in Cape Coral. This area could provide fresh water, quiet resting spots, and fine-grained sediments for thermoregulation.

Downtown Ft. Myers—This place contains several boat slips and marinas that discharge fresh water in amounts that can attract manatees. It is also heavily seawalled. This portion of the river is shallow enough to support seagrass beds, but temporal variation in salinity, urban run-off, and wake action limit SAV growth. Manatees are probably attracted to fresh water and patchy forage.

Redfish Point—The Cape Coral Yacht Club is located at Redfish Point. The yacht club attracts mana-

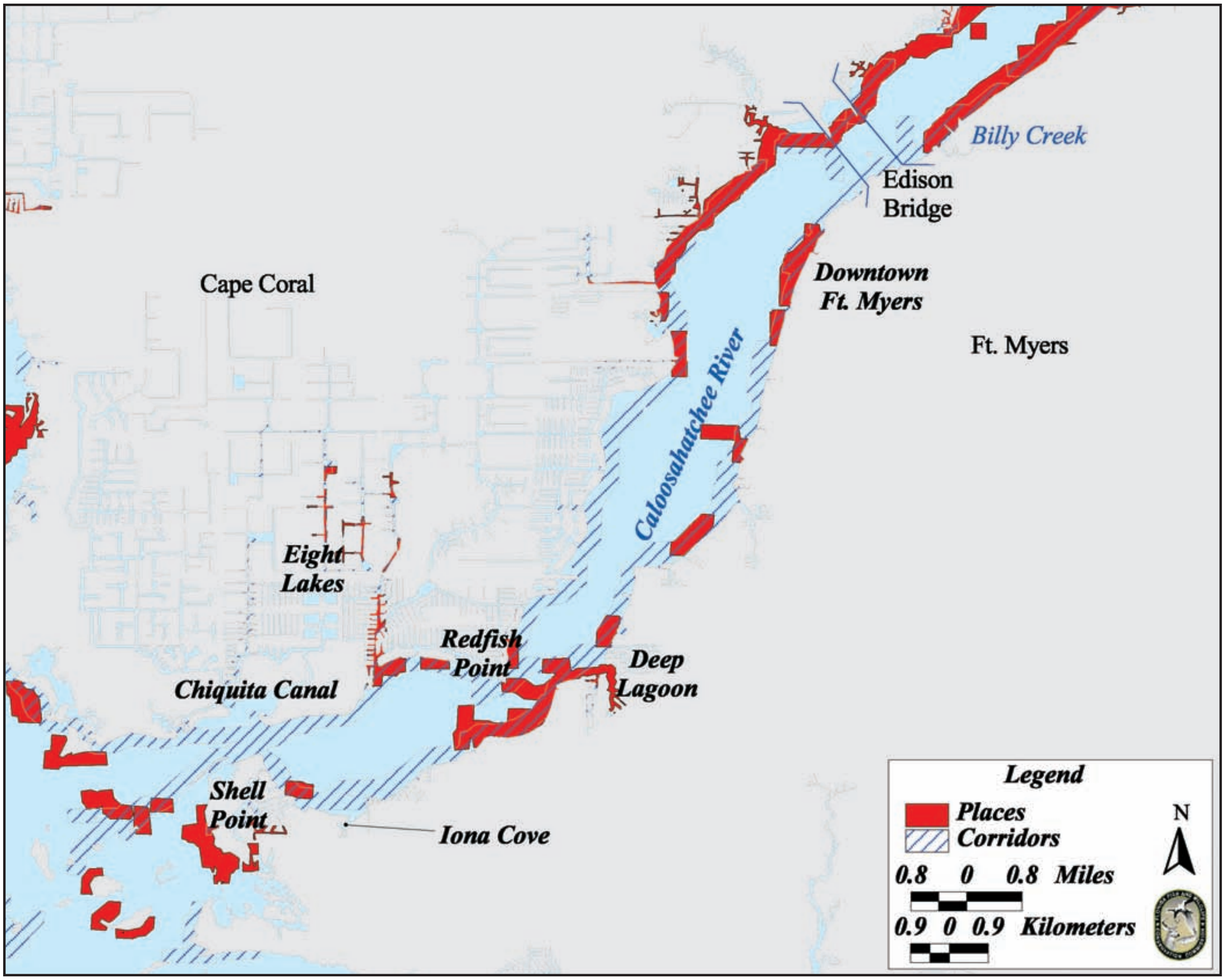

Figure 16 *Manatee places and corridors between the Edison Bridge and Shell Point, derived from satellite- and radio-telemetry data of 26 manatees between 1991 and 2001.*

tees because of the freshwater run-off from boat maintenance. Redfish Cove, also used by manatees, contains seagrass beds (L. Keith, FWC, personal communication). Various entrance points into the Cape Coral canal system line this section of the river. One interesting feature here is that the river is relatively narrow (1,000 m), and the entire width was identified as an important place as well as a corridor for manatees (see below). Across the river from Redfish Point lies the Deep Lagoon Marina and the entrance to Deep Lagoon. Evidence suggests that manatees travel between Redfish Point and Deep Lagoon.

Cape Coral Canals—The Cape Coral canals provide resting areas and some fresh water for manatees. Certain canals contain deep basins that serve as temporary warm-water sites.

Deep Lagoon and the south shore across from Redfish Point—This area contains two marinas and numerous NPDES locations (Figure 6, Habitat Section). There are many dead-end canals branching off from the lagoon. It is likely that manatees use this area for resting, fresh water, and thermoregulation.

Iona Cove—This area was identified as a feeding area with variable SAV availability (K. Frohlich, FWC, personal communication; see Habitat section).

CORRIDORS

Evidence suggests that the area between the Edison Bridge and Shell Point is a manatee travel corridor (Figures 15 and 16). The travel corridors estimated by the model follow the shoreline of the Caloosahatchee River. Flamm *et al.* (2005) found that travel corridors also followed the shoreline in Tampa Bay. By staying close to the shoreline, manatees could opportunistically feed, drink, or rest. In addition, much of the vessel traffic along the Caloosahatchee River is concentrated in the channel. Manatees would minimize the likelihood of disturbance or contact with watercraft by traveling closer to shore. We do not yet know how manatees navigate nor how they create cognitive maps of their environment. Swimming close to the shoreline may assist them with navigation and allow them to detect canal entrances or other important "landmarks" as well as sense salinity and temperature gradients.

It is difficult to assess whether travel corridors near the shoreline are, in part, a relic of the telemetry data. The model is limited by the frequency and accuracy of the telemetry gear and assumes that the depth distribution based on places can be used to represent depth preferences during travel. We do not know, retrospectively, if a manatee took a direct route from one place to another, if it meandered between satellite hits, or if it used the channels while traveling between points picked up by the satellite near shore. Hartman (1979) reported that manatees used the deepest channels as travel corridors in Citrus County. When conducting aerial surveys of manatees in northeastern Florida and southeastern Georgia, however, Kinnaird (1985) reported that 82% of the manatees that were observed traveling were swimming within five meters of shore. Future studies that apply satellite-linked GPS tags will increase the accuracy of the locations, register more frequently, and consequently help refine our assessment of manatee use of the Caloosahatchee River.

Two important corridors for manatees are near Redfish Point and Shell Point. Data suggest that manatees cross the river in these areas (Figure 16). The river narrows in both places (1,000 m at Redfish Point and 710 m at Shell Point). In addition to the width, manatees may cross at Redfish Point because both sides of the river contain important places such as the entrance to the Cape Coral Canals and Deep Lagoon. Redfish Point may also have certain features that manatees use for navigation.

To travel up the Caloosahatchee River from the gulf or from the river to points west, vessels must pass by Shell Point, thereby creating a substantial area of overlap between boats and manatees in a comparatively narrow portion of the river. Gorzelany (1998) recorded an average of more than five boats per minute passing Shell Point. Outside the channel, the river is a bit wider and shallower than in the channel itself. Less boat traffic in this area would appear to provide a less dangerous travel corridor for manatees. When approached by boats, however, manatees have been observed to head for deeper water (Nowacek *et al.,* 2000, 2004). Consequently, there would be fewer options for escape from watercraft when the manatee is outside the channel.

Summary

Results from recent tagging studies on manatee distribution and movements in and around the Caloosahatchee River support findings of similar studies conducted during the 1980s. During the cold season, manatees mostly use areas near the Ft. Myers FPL power plant and Matlacha Isles, and their movements are more restricted than during the warm season. Manatees principally use the Caloosahatchee River between Shell Point and the Edison Bridge as a travel corridor between important habitats near the river's mouth (San Carlos Bay and Matlacha Pass) and those upriver (Beautiful Island and the Orange River). Manatees appear to stay near the shoreline while traveling, perhaps for navigation and boat-avoidance or to maximize their feeding, drinking, and resting opportunities. While en route, manatees may stop at selected minor aggregation areas, such as the canals in Ft. Myers and Cape Coral. They also appear to exploit highly urbanized, shallow areas near seawalls.

Manatee Mortality

Introduction

A program dedicated to Florida manatee rescue, carcass recovery, and necropsy was instituted in 1974 (Odell and Reynolds, 1979; Beck *et al.,* 1982; Irvine *et al.,* 1981; O'Shea *et al.,* 1985; Ackerman *et al.,* 1995). The long-term manatee mortality database generated from this program holds information about cause of death; local, county, and statewide mortality trends over time; life-history, anatomical, pathological, histological, and physiological information; manatee demographics; and environmental health. Between 1976 and 2001, manatee deaths increased statewide by approximately 6.0% annually ($r^2 = 0.83$, $P < 0.001$; Figure 17). Table 3 shows the breakdown of most of these death categories statewide.

The following discussion will focus on information gathered from manatee carcasses recovered principally from the Caloosahatchee River between 1976 and 2001 (FWC, unpublished data). Relevant information from areas surrounding the Caloosahatchee River are also discussed to place the findings in a broader geographic context so that they are on a scale appropriate to that of manatee movements (see Telemetry section).

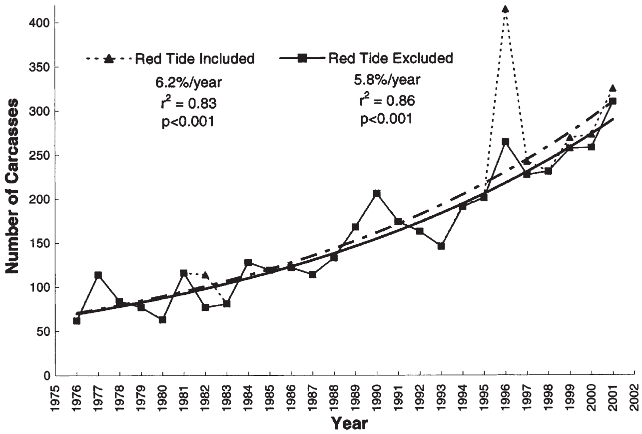

Figure 17 *Trends in statewide manatee deaths (all causes, including and excluding red tide) from 1976 to 2001.*

Materials and Methods

For the purposes of this analysis, the river was divided into three regions: (1) West = San Carlos Bay and Matlacha Pass; (2) Mid = Shell Point to the Edison Bridge; and (3) East = the Edison Bridge to the Franklin locks (Figure 18). Procedures for recovering carcasses, collecting information about cause of death, and analyzing trends are described in O'Shea *et al.* (1985) and Ackerman *et al.* (1995). Causes of death were divided into anthropogenic (human-related) and natural. Human-related deaths included collisions with watercraft, interactions with locks and flood-control structures, and "other human." Natural deaths included cold-related, red tide, perinatal, and "other natural." Red tide does not appear separately in the tables in this report because deaths attributed to this category were not distinguished from the category of "other natural" until after the 1996 epizootic.

Temporal trends in the number of manatee deaths were analyzed by calculating weighted-means (Flamm, 2001). Years were transformed so that the midpoint year between 1976 and 2001 (1988.5) equaled zero. The number of carcasses recovered in each year was multiplied by the value of the transformed year. We added the results and divided them by the total number of carcasses:

$$y = (\sum_{i=-12.5}^{n} iP)/C;$$

where n = number of years (26); i = year (transformed); P = number of carcasses during year i; and C = the total number of carcasses. A positive deviation from zero indicated increasing trends in mortality. The larger the deviation, the faster the increase in recent years.

Trends in the number of manatee deaths per year were calculated by using exponential regression (Ackerman *et al.*, 1995). The annual percentage change in carcasses, as percent per year, was calculated from the linear coefficient of the regression (b1). If there were zero carcasses in any year, a standard transformation of 1 was added to the count of carcasses in each year [ln(Carcasses + 1)] (Ackerman *et al.*, 1995). Regression analyses were conducted in MS Excel as follows:

ln(Carcasses) = b0 + b1(Year);

Annual percentage rate of change (%/year) = $(e^{b1} - 1) \cdot 100\%$.

Based on the median year, we also divided the exponential regression trend analyses into two equal time-frames: 1976–1988 and 1989–2001. In some analyses, we adjusted for red tide by subtracting the number of carcasses that were suspected to have died from red tide in each year from the total number of carcasses for that year (FWC, unpublished data). Sporadic red tide blooms can kill manatees unpredictably and catastrophically, leaving some years with unusually high numbers of manatee deaths that can substantially alter regression trend analyses. By adjusting for red tide, the outliers were removed from the dataset.

Seasons were defined as follows: winter (December–February), spring (March–May), summer (June–August), and fall (September–November). We examined five variables and analyzed their associations with manatee deaths using two-way contingency tables. Pearson chi-square tests were employed to detect significant differences from an expected distribution (Sokal and Rohlf, 1997). A significant difference indicated that the two variables were not independent. The pairs of variables tested were cause of death and season, cause of death and month, cause of death and carcass size, carcass size and season, cause of death and region, and season and region. Carcass size-classes were defined by O'Shea *et al.* (1985): calves were smaller than 176 cm and included aborted fetuses and small dependent calves, subadults ranged from 176 cm to 275 cm and included large dependent calves and independent subadults, and adults were manatees longer than 275 cm.

Manatee carcass locations may not reflect the places where the animal died. In some cases, manatees may be able to survive from days to months with an injury or infection and so may travel some distance before expiring. Currents, tides, and wind also play important roles in determining where carcasses are ultimately found.

Results and Discussion

Between 1976 and 2001, the 927 manatee carcasses recovered from Lee County accounted for 21.4% of the statewide total. Twenty-two percent (204) of these were recovered between Shell Point and the Edison Bridge,

Table 3 *Breakdown of annual manatee deaths statewide, 1976–2001.*

Year	Watercraft	Flood Gate /Lock	Other Human	Perinatal	Cold Stress	Other Natural	Verified, Not Recovered	Undetermined, Too Decomposed	Undetermined	Totals
1976	10	4	0	14	0	2	9	7	16	**62**
1977	13	6	5	9	0	1	16	10	54	**114**
1978	21	9	1	10	0	3	6	7	27	**84**
1979	24	8	9	9	0	4	5	0	18	**77**
1980	16	8	2	13	0	5	4	0	15	**63**
1981	24	2	4	13	0	9	2	0	62	**116**
1982	20	3	1	14	0	41	6	0	29	**114**
1983	15	7	5	18	0	6	2	0	28	**81**
1984	34	3	1	25	0	24	1	0	40	**128**
1985	33	3	3	23	0	19	6	4	28	**119**
1986	33	3	1	27	12	1	6	31	8	**122**
1987	39	5	2	30	6	10	0	15	7	**114**
1988	43	7	4	30	9	15	2	16	7	**133**
1989	50	3	5	38	14	18	1	24	15	**168**
1990	47	3	4	44	46	21	1	25	15	**206**
1991	53	9	6	53	1	13	0	34	5	**174**
1992	38	5	6	48	1	19	1	38	7	**163**
1993	35	6	6	39	2	22	2	29	5	**146**
1994	49	15	5	46	4	33	3	33	4	**192**
1995	42	8	5	56	0	35	2	49	4	**201**
1996	61	10	0	61	17	101	12	143	10	**415**
1997	54	8	8	61	3	43	4	56	5	**242**
1998	66	9	6	53	9	12	4	62	10	**231**
1999	82	15	8	53	5	37	7	59	3	**269**
2000	78	8	8	58	14	37	9	57	4	**273**
2001	81	1	8	62	31	33	2	103	4	**325**
Totals	**1,061**	**168**	**113**	**907**	**174**	**564**	**113**	**802**	**430**	**4,332**
Percent	**24.5%**	**3.9%**	**2.6%**	**20.9%**	**4.0%**	**13.0%**	**2.6%**	**18.5%**	**9.9%**	

including the surrounding canals of Cape Coral and Ft. Myers. Figure 18 depicts where carcasses were recovered in the study area.

REGIONAL DISTRIBUTION AND DENSITY

Tables 4–6 illustrate the numbers of carcasses recovered annually from each region. The annual rate of increase in the number of carcasses recovered was greatest in the West Region, that in the East Region was similar to the statewide trend, and that in the Mid Region was lowest (Table 7; Figure 19). The annual rate of increase in the number of manatee carcasses recovered in each of these three regions was lower than was the rate for southwestern Florida (Pinellas County south to Monroe County). However, substantial fluctuations across years are indicated by the low r^2 values.

The weighted-means trends analysis showed that deaths increased in all regions (Table 8; see Flamm, 2001). The West Region had the greatest deviation from zero for all death categories combined, with 4.1 years as the weighted mean. The number of carcasses recovered in the West Region more than tripled from the first time period (1976–1988) to the second (1989–2001; Table 9). The weighted-means trend analysis combined with the number of carcasses recovered in each period distinguished the West Region as an area with a faster recent increase in the number of manatee deaths than the East or Mid regions.

The West Region had the largest area (130.8 km^2 of water) but the fewest carcasses at 124. Thus, the West Region had the lowest density of manatee carcasses at 0.95 carcasses per km^2. The Mid Region, with an area of 64.1 km^2, had the greatest number of carcasses with 204 but a density of only 3.2 carcasses per km^2. The East Region was the smallest area (20.5 km^2 of water), but it had 156 carcasses for a density of 7.6 per km^2.

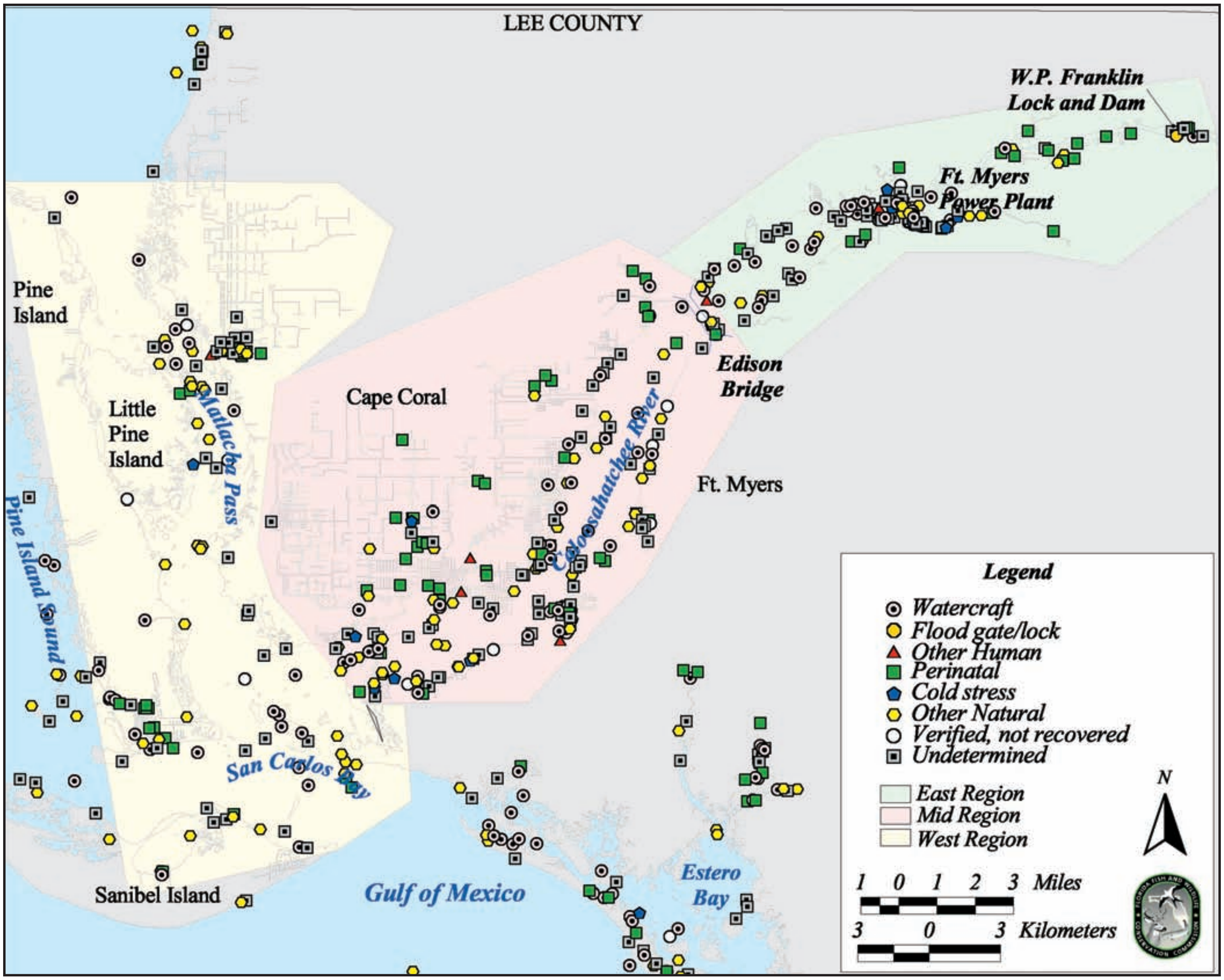

Figure 18 *Manatee carcass recovery locations from 1976 to 2001 in the study area, which is divided regionally: East Region (green), Mid Region (pink), and West Region (yellow).*

TIME PERIOD

When combining data for the three regions, 329 deaths, or 68%, occurred in 1989–2001 compared to 155 in 1976–1988 (from Table 9). Annual rates of increase for all causes of death, however, slowed from 7.4% (r^2 = 0.36, P = 0.02) during 1976–1988 to 5.8% (r^2 = 0.24, P = 0.05) during 1989–2001 when adjusted for red tide (Table 7).

SEASON

Of the 484 deaths in the study area, 34% occurred in spring, followed closely by 32% in winter (Table 10). The summer months had the fewest carcasses at 15%; 44% of these were perinatals. Winter and spring had more "other natural" deaths, and summer and fall had more perinatals (Table 10).

We found significant seasonal and monthly variation in the number of deaths between the three regions (χ^2_{season} = 37.9, p_{season} < 0.001; χ^2_{month} = 58.1, p_{month} < 0.001). There were more carcasses than expected in the East Region during winter (especially in January), in the Mid Region in spring, and in the West Region in October. This supports findings from telemetry studies (Lefebvre and Frohlich, 1986; FWC, unpublished data) and aerial survey observations (FWC, 2000) of a shift in manatee distribution from winter warm-water sites and associated feeding areas upriver to spring feeding habitats downriver and in San Carlos Bay. The October increase of carcasses in the West Region may reflect a fall seasonal shift and overlap in manatee distribution (see distribution section). That is, manatees using the Caloosahatchee River in the warm season

***Table 4** Breakdown of annual manatee deaths in the East Region, 1976–2001.*

Year	Watercraft	Flood Gate /Lock	Other Human	Perinatal	Cold Stress	Other Natural	Verified, Not Recovered	Undetermined, Too Decomposed	Undetermined	Totals
1976	0	0	0	0	0	0	0	0	0	**0**
1977	0	0	0	1	0	0	1	0	1	**3**
1978	0	0	0	0	0	1	1	0	0	**2**
1979	0	0	0	0	0	1	0	0	0	**1**
1980	0	0	0	1	0	1	0	0	1	**3**
1981	0	0	1	1	0	1	0	0	3	**6**
1982	0	0	0	0	0	7	0	0	1	**8**
1983	1	0	1	1	0	2	0	0	4	**9**
1984	1	0	0	2	0	0	0	0	3	**6**
1985	1	0	0	1	0	1	2	1	1	**7**
1986	0	0	0	0	1	0	0	1	0	**2**
1987	1	0	0	1	0	0	0	0	0	**2**
1988	2	0	0	0	0	0	0	0	0	**2**
1989	0	0	0	1	0	0	0	1	1	**3**
1990	2	0	0	1	0	1	0	2	1	**7**
1991	1	0	0	0	0	0	0	1	0	**2**
1992	0	0	0	2	0	2	0	0	0	**4**
1993	0	0	0	1	0	0	0	3	0	**4**
1994	3	0	0	2	0	2	0	2	0	**9**
1995	3	0	1	1	0	3	0	2	0	**10**
1996	1	0	0	1	2	2	0	18	0	**24**
1997	0	0	0	0	0	2	0	2	3	**7**
1998	2	0	1	0	1	2	0	1	0	**7**
1999	1	1	0	1	0	0	0	4	0	**7**
2000	2	0	0	1	0	2	0	1	0	**6**
2001	7	0	0	1	2	3	0	2	0	**15**
Totals	**28**	**1**	**4**	**20**	**6**	**33**	**4**	**41**	**19**	**156**
Percent	**17.9%**	**0.6%**	**2.6%**	**12.8%**	**3.8%**	**21.2%**	**2.6%**	**26.3%**	**12.2%**	

may be leaving the river for their over-wintering areas, while animals who spend the warm season elsewhere may be returning. Manatees must also pass through the West Region when migrating north or south. We previously established that the West Region is an important feeding area (see Habitat and Telemetry sections). Manatees may be increasing foraging times in the West Region during the fall prior to completing their migration. In the St. Johns River, Bengtson (1983) documented increased time spent foraging in the fall. He attributed this to the seasonal decline in vegetation quality and the manatees' preparation for winter.

Figure 20 shows monthly trends in manatee deaths between 1976 and 2001 for the three regions combined, for all death categories combined, and for the separate categories of watercraft, perinatal, "other natural," and undetermined. There was a peak in March that reflected increases in watercraft, "other natural," and undetermined deaths. When red tide-related deaths were removed, the spring peak disappeared, as evidenced by fewer "other natural" and undetermined carcasses (Figure 20). O'Shea *et al.* (1991) reported that an early downstream migration contributed to red tide deaths in 1982. These were classified under the "other natural" category and occurred between February and April. Moreover, vessel traffic peaks in Lee County during spring (Gorzelany, 1998). Increased manatee movements in spring can increase their risk of exposure to both red tide and boat strikes.

There was a significant increase in perinatal deaths in summer in the Mid Region ($\chi^2 = 120$, $P < 0.001$). The peak occurred in August ($\chi^2 = 194$, $P < 0.001$). Although there is no defined breeding season for manatees, spring and summer peaks in calf carcasses have been reported by Hartman (1979), Irvine *et al.* (1981), and Ackerman *et al.* (1995).

Table 5 *Breakdown of annual manatee deaths in the Mid Region, 1976–2001.*

Year	Watercraft	Flood Gate /Lock	Other Human	Perinatal	Cold Stress	Other Natural	Verified, Not Recovered	Undetermined, Too Decomposed	Undetermined	Totals
1976	1	0	0	0	0	0	0	0	0	**1**
1977	2	0	0	0	0	0	1	0	2	**5**
1978	1	0	0	0	0	0	0	0	1	**2**
1979	0	0	1	0	0	0	0	0	1	**2**
1980	2	0	0	1	0	0	0	0	1	**4**
1981	2	0	0	0	0	0	0	0	1	**3**
1982	2	0	0	1	0	17	1	0	2	**23**
1983	0	0	0	3	0	0	0	0	1	**4**
1984	0	0	0	2	0	0	0	0	4	**6**
1985	1	0	0	1	0	0	0	0	0	**2**
1986	1	0	0	0	0	0	1	3	1	**6**
1987	0	0	0	0	0	1	0	3	1	**5**
1988	2	0	0	5	1	0	0	2	0	**10**
1989	0	0	0	0	0	1	0	1	2	**4**
1990	2	0	0	4	1	2	0	2	2	**13**
1991	0	0	0	2	0	0	0	1	0	**3**
1992	1	0	1	1	0	1	0	3	1	**8**
1993	3	0	1	1	0	0	0	0	0	**5**
1994	2	0	0	1	0	1	0	5	0	**9**
1995	1	0	0	1	0	1	0	1	0	**4**
1996	4	0	0	5	2	11	2	14	1	**39**
1997	5	0	0	3	1	6	0	3	0	**18**
1998	1	0	0	2	0	2	0	1	0	**6**
1999	2	0	0	0	0	1	0	1	0	**4**
2000	3	0	1	2	0	3	1	2	0	**12**
2001	3	0	0	0	1	0	0	2	0	**6**
Totals	**41**	**0**	**4**	**35**	**6**	**47**	**6**	**44**	**21**	**204**
Percent	**20.1%**	**0.0%**	**2.0%**	**17.2%**	**2.9%**	**23.0%**	**2.9%**	**21.6%**	**10.3%**	

SIZE CLASS

Subadult carcasses make up approximately 48% of all manatee deaths in the three regions combined. Statewide, subadults make up 40% of all manatee carcasses, whereas in southwestern Florida they compose roughly 44%.

Collier, Lee, and Charlotte counties have the same disproportionately high percentages of subadult carcasses (47%, 47%, and 48%, respectively). Historically, red tide epizootics have occurred in these three counties. The proportion of subadult carcasses in the three regions of the Caloosahatchee River may reflect the composition of subadults in the live population. Pitchford (2002) documented that the 1996 red tide epizootic killed more adults (ages 5–10) than any other age class. Moreover, adult survival rates are substantially lower in the southwest than in any other region in the state (Langtimm *et al.,* 2004). Analyses of survival rates suggested a drop in adult survival immediately following the 1996 red tide epizootic. Because of higher adult mortality in the southwest region (specifically in Lee, Collier, and Charlotte counties), the population could be younger there than elsewhere. Pitchford (2002) found that, on average, adult manatees from southwestern Florida died at a much younger age than did manatees in other regions statewide. Accordingly, causes of death (*e.g.,* cold) that differentially affect subadults may be more important in the Caloosahatchee River area and southwestern Florida than in other parts of the state.

NATURAL CAUSES OF DEATH

RED TIDE

The most obvious difference in cause of death when comparing the Caloosahatchee River area with the rest of the state is in the "other natural" category, where "other natural" deaths compose between 21% and 25% of all deaths in the study area but only 13% of all deaths statewide (Table 9). Manatees using the lower Caloosa-

Table 6 *Breakdown of annual manatee deaths in the West Region, 1976–2001.*

Year	Watercraft	Flood Gate /Lock	Other Human	Perinatal	Cold Stress	Other Natural	Verified, Not Recovered	Undetermined, Too Decomposed	Undetermined	Totals
1976	0	0	0	2	0	0	1	0	0	**3**
1977	0	0	0	1	0	0	0	1	0	**2**
1978	0	0	0	0	0	1	0	0	0	**1**
1979	0	0	0	0	0	0	0	0	0	**0**
1980	0	0	0	0	0	0	0	0	0	**0**
1981	0	0	0	2	0	0	0	0	1	**3**
1982	1	0	0	0	0	9	1	0	0	**11**
1983	0	0	0	0	0	1	0	0	0	**1**
1984	0	0	0	0	0	1	0	0	2	**3**
1985	0	0	0	0	0	1	0	0	0	**1**
1986	0	0	0	0	0	0	1	1	0	**2**
1987	2	0	0	0	0	0	0	0	0	**2**
1988	0	0	0	0	0	1	0	1	0	**2**
1989	0	0	0	2	0	0	0	1	0	**3**
1990	0	0	0	1	1	0	0	2	0	**4**
1991	1	0	0	4	0	0	0	0	0	**5**
1992	1	0	0	1	0	0	0	2	0	**4**
1993	1	0	0	2	0	1	0	0	0	**4**
1994	1	0	0	2	0	1	0	1	0	**5**
1995	0	0	0	6	0	0	0	0	1	**7**
1996	4	0	0	0	0	9	1	10	2	**26**
1997	1	0	0	2	0	1	0	1	0	**5**
1998	1	0	0	1	0	1	0	1	0	**4**
1999	3	0	1	0	0	2	0	2	0	**8**
2000	3	0	0	1	0	2	0	2	0	**8**
2001	5	0	0	1	0	0	0	3	1	**10**
Totals	**24**	**0**	**1**	**28**	**1**	**31**	**4**	**28**	**7**	**124**
Percent	**19.4%**	**0.0%**	**0.8%**	**22.6%**	**0.8%**	**25.0%**	**3.2%**	**22.6%**	**5.6%**	

hatchee River and outer waters in late winter and spring are periodically exposed to brevetoxin, a neurotoxin released by the red tide organism *Karenia brevis* (O'Shea *et al.,* 1991; Bossart *et al.,* 1998). Red tide caused high numbers of manatee deaths in 1982, 1996, 2002, 2003, and 2005 (O'Shea *et al.,* 1985; Bossart *et al.,* 1998; FWC unpublished data). The 1982 red tide event was concentrated at the mouth of the Caloosahatchee River and San Carlos Bay. Above-normal temperatures led to early manatee migration downstream from the power plant and resulted in a large influx of manatees into the affected area (Beeler and O'Shea, 1988; O'Shea *et al.,* 1991). A suite of factors including salinity, red tide concentration, and manatee distribution makes it difficult to predict where or when an epizootic will occur (Landsberg and Steidinger, 1998). Because capturing and relocating exposed manatees is not feasible, even if we were able to predict such events, there is very little we can do to prevent manatee deaths related to red tide.

COLD–RELATED

Cold-related deaths were not distinguished from "undetermined" or "other natural" prior to 1986 (Ackerman *et al.,* 1995). Cold-related deaths accounted for a portion of the significant association between season and cause of death (Table 10). The FPL power plant in Ft. Myers supports one of the largest warm-water manatee aggregations in the state (O'Shea *et al.,* 1985; Packard *et al.,* 1989; Reynolds, 1996). In the winter of 1995–1996, Reynolds (1996) counted 434 manatees near the power plant during one survey. The relatively low number of cold-related deaths in the Caloosahatchee River (Table 5) indicates that the power plant affords manatees a high level of protection from severe cold. Campbell and Irvine (1981) likened the configuration of the Orange River discharge area to a natural spring run. Cold weather does not currently threaten manatees in this area to the extent that it does manatees overwintering farther south (*e.g.,* in the Everglades). For example, in

Table 7 *Annual rates of increase of manatee deaths in all regions combined, in each region, statewide, and in southwestern Florida. Causes of death consist of all excluding red tide, watercraft, and all excluding both watercraft and red tide. Time periods are 1976–2001, 1976–1988, and 1989–2001.*

Time Period	Location	Cause of Death	Rate of Increase/Year	Adjusted r^2	*P* value	Confidence (±95%)
1976–2001	All Regions	All–Red Tide Excluded	6.1%	0.64	<0.001	±1.8%
1976–2001	East	All–Red Tide Excluded	5.6%	0.40	<0.001	±2.7%
1976–2001	Mid	All–Red Tide Excluded	4.4%	0.34	0.001	±2.4%
1976–2001	West	All–Red Tide Excluded	6.7%	0.61	<0.001	±2.1%
1976–2001	Statewide	All–Red Tide Excluded	5.8%	0.86	<0.001	±0.9%
1976–2001	Southwest FL	All–Red Tide Excluded	7.7%	0.80	<0.001	±1.5%
1976–2001	All Regions	Watercraft	6.8%	0.55	<0.001	±2.5%
1976–2001	East	Watercraft	4.9%	0.37	<0.001	±2.6%
1976–2001	Mid	Watercraft	2.9%	0.13	0.042	±2.8%
1976–2001	West	Watercraft	5.8%	0.52	<0.001	±2.2%
1976–2001	Statewide	Watercraft	6.9%	0.84	<0.001	±1.2%
1976–2001	Southwest FL	Watercraft	10.2%	0.88	<0.001	±1.4%
1976–1988	All Regions	All–Red Tide Excluded	7.4%	0.36	0.017	±5.8%
1976–1988	Statewide	All–Red Tide Excluded	4.7%	0.38	0.014	±3.5%
1976–1988	Southwest FL	All–Red Tide Excluded	9.8%	0.47	0.006	±6.2%
1989–2001	All Regions	All–Red Tide Excluded	5.8%	0.24	0.052	±5.9%
1989–2001	Statewide	All–Red Tide Excluded	4.8%	0.66	<0.001	±2.1%
1989–2001	Southwest FL	All–Red Tide Excluded	6.2%	0.66	<0.001	±2.7%
1976–1988	All Regions	Watercraft	5.1%	0.14	0.116	±6.6%
1976–1988	Statewide	Watercraft	9.9%	0.71	<0.001	±3.9%
1976–1988	Southwest FL	Watercraft	15.9%	0.83	<0.001	±4.3%
1989–2001	All Regions	Watercraft	15.1%	0.61	<0.001	±7.2%
1989–2001	Statewide	Watercraft	5.5%	0.54	0.003	±3.1%
1989–2001	Southwest FL	Watercraft	9.2%	0.75	<0.001	±3.2%
1976–1988	All Regions	Non-watercraft, Red Tide excluded	6.9%	0.30	0.032	±6.1%
1976–1988	Statewide	Non-watercraft, Red Tide excluded	3.1%	0.14	0.113	±4.0%
1976–1988	Southwest FL	Non-watercraft, Red Tide excluded	7.5%	0.28	0.036	±6.9%
1989–2001	All Regions	Non-watercraft, Red Tide excluded	2.4%	–0.02	0.399	±6.2%
1989–2001	Statewide	Non-watercraft, Red Tide excluded	4.6%	0.60	0.001	±2.3%
1989–2001	Southwest FL	Non-watercraft, Red Tide excluded	4.9%	0.44	0.008	±3.3%

the colder-than-average winter of 2000–2001, manatees that overwintered in the Ten Thousand Islands area showed signs of cold-stress, while those that overwintered at the Tampa Electric Company's Big Bend power plant in Tampa did not (R. Bonde, USGS, and H. Edwards, FWC, personal communication). In severely cold weather, however, a sizeable portion of the southwestern Florida manatee population could be at risk of hypothermia or cold stress if the warm-water discharge at the Ft. Myers FPL power plant decreased substantially or shut off completely. The alternative warm-water sources discussed in the habitat section probably would not be able to protect all the manatees that use the power plant.

PERINATAL (CALVES LESS THAN 150 CM)

Within the Mid Region, perinatal deaths were highly variable, ranging from zero to five per year (Table 5). They constituted 17% of all deaths but 21% of deaths when the red tide epizootics were removed from the data set, a percentage that mirrors the statewide average of 20.9% (Tables 9 and 11). The weighted-means trend analysis revealed that perinatal deaths were increasing more recently statewide and in southwestern

Table 8 *Trends in manatee deaths (including red tide and cold-related) calculated as weighted means, where carcass recoveries were weighted by year. Years were transformed so that the midpoint year (1988.5) = 0. A positive deviation from zero indicates increasing trends in mortality. The larger the deviation, the faster the increase in recent years.*

Death Category	East	Mid	West	All (3 Regions)	Southwest	Statewide
All Causes	3.2	2.5	4.1	3.1	4	3.2
Watercraft	6.2	2.8	7.6	5.1	4.9	3.5
Other Natural	1.7	2.2	1.8	1.9	4.6	4.3
Perinatal	1.3	2.6	2.6	2.3	3.8	3.8

Table 9 *Manatee deaths (including red tide) in each region and statewide during two equal time periods, 1976–1988 and 1989–2001.*

	Watercraft	Flood Gate /Lock	Other Human	Perinatal	Cold Stress	Other Natural	Verified, Not Recovered	Undetermined, Too Decomposed	Undetermined	Totals
East										
1976–1988	6	0	2	8	1	14	4	2	14	51
	11.8%	0.0%	3.9%	15.7%	2.0%	27.5%	7.8%	3.9%	27.5%	
1989–2001	22	1	2	12	5	19	0	39	5	105
	21.0%	1.0%	1.9%	11.4%	4.8%	18.1%	0.0%	37.1%	4.8%	
Total	28	1	4	20	6	33	4	41	19	156
	18.0%	0.6%	2.6%	12.8%	3.9%	21.2%	2.6%	26.3%	12.2%	
Mid										
1976–1988	14	0	1	13	1	18	3	8	15	73
	19.2%	0.0%	1.4%	17.8%	1.4%	24.7%	4.1%	11.0%	20.6%	
1989–2001	27	0	3	22	5	29	3	36	6	131
	20.6%	0.0%	2.3%	16.8%	3.8%	22.1%	2.3%	27.5%	4.6%	
Total	41	0	4	35	6	47	6	44	21	204
	20.1%	0.0%	2.0%	17.2%	2.9%	23.0%	2.9%	21.6%	10.3%	
West										
1976–1988	3	0	0	5	0	14	3	3	3	31
	9.7%	0.0%	0.0%	16.1%	0.0%	45.2%	9.7%	9.7%	9.7%	
1989–2001	21	0	1	23	1	17	1	25	4	93
	22.6%	0.0%	1.1%	24.7%	1.1%	18.3%	1.1%	26.9%	4.3%	
Total	24	0	1	28	1	31	4	28	7	124
	19.4%	0.0%	0.8%	22.6%	0.8%	25.0%	3.2%	22.6%	5.7%	
Statewide										
1976–1988	325	68	38	235	27	140	65	90	339	1,327
	24.5%	5.1%	2.9%	17.7%	2.0%	10.6%	4.9%	6.8%	25.6%	
1989–2001	736	100	75	672	147	424	48	712	91	3,005
	24.5%	3.3%	2.5%	22.4%	4.9%	14.1%	1.6%	23.7%	3.0%	
Total	1,061	168	113	907	174	564	113	802	430	4,332
	24.5%	3.9%	2.6%	20.9%	4.0%	13.0%	2.6%	18.5%	9.9%	

Table 10 *Causes of death (includes red tide) by season in all three regions combined.*

	Winter	Spring	Summer	Fall	Totals
Watercraft	22	32	19	20	93
Column %	14.3%	19.3%	26.4%	21.7%	
Row %	23.7%	34.4%	20.4%	21.5%	
Flood gate/lock	0	0	1	0	1
Column %	0.0%	0.0%	1.4%	0.0%	
Row %	0.0%	0.0%	100.0%	0.0%	
Other Human	3	0	2	4	9
Column %	2.0%	0.0%	2.8%	4.4%	
Row %	33.3%	0.0%	22.2%	44.4%	
Perinatal	7	20	32	24	83
Column %	4.6%	12.1%	44.4%	26.1%	
Row %	8.4%	24.1%	38.6%	28.9%	
Cold Stress	11	1	0	1	13
Column %	7.1%	0.6%	0.0%	1.1%	
Row %	84.6%	7.7%	0.0%	7.7%	
Other Natural	47	48	2	14	111
Column %	30.5%	28.9%	2.8%	15.2%	
Row %	42.3%	43.2%	1.8%	12.6%	
Verified, not recovered	4	6	3	1	14
Column %	2.6%	3.6%	4.2%	1.1%	
Row %	28.6%	42.9%	21.4%	7.1%	
Undetermined, too decomposed	38	46	8	21	113
Column %	24.7%	27.7%	11.1%	22.8%	
Row %	33.6%	40.7%	7.1%	18.6%	
Undetermined	22	13	5	7	47
Column %	14.3%	7.8%	6.9%	7.6%	
Row %	46.8%	27.7%	10.6%	14.9%	
Total	**154**	**166**	**72**	**92**	**484**
Row %	**31.8%**	**34.3%**	**14.9%**	**19.0%**	

Florida than they were in the three Caloosahatchee regions (Table 8). Perinatal deaths in summer accounted for a portion of the significant association between cause of death and season (Table 10). Perinatal carcasses were recovered most frequently from the Cape Coral and Ft. Myers canals, Matlacha Isles, and the canals in southern Pine Island and the upper Caloosahatchee River, especially near the Franklin locks (Figure 18). In sheltered, winding canals, it is doubtful that the carcasses drift long distances. In densely populated areas like the Cape Coral Canals, carcasses have a higher likelihood of being observed soon after death. Locations of perinatal carcasses suggest that females use these canals as places for birthing and nursing their calves.

ANTHROPOGENIC CAUSES OF DEATH

FLOOD GATE/LOCK

The Franklin Lock and Dam does not appear to be a substantial threat to manatees in the Caloosahatchee River. Despite high manatee use of the locks (Packard *et al.*, 1989), only one manatee has been reported killed by a structure in this region between 1976 and 2001. That carcass was recovered at the Franklin locks in 1999.

OTHER HUMAN

Nine carcasses were classified as having died from "other human" causes, four each in the Mid and East regions, and one in the West Region (Tables 4–6). One was trapped in a culvert, and the others were entangled in or had ingested debris or fishing gear. These

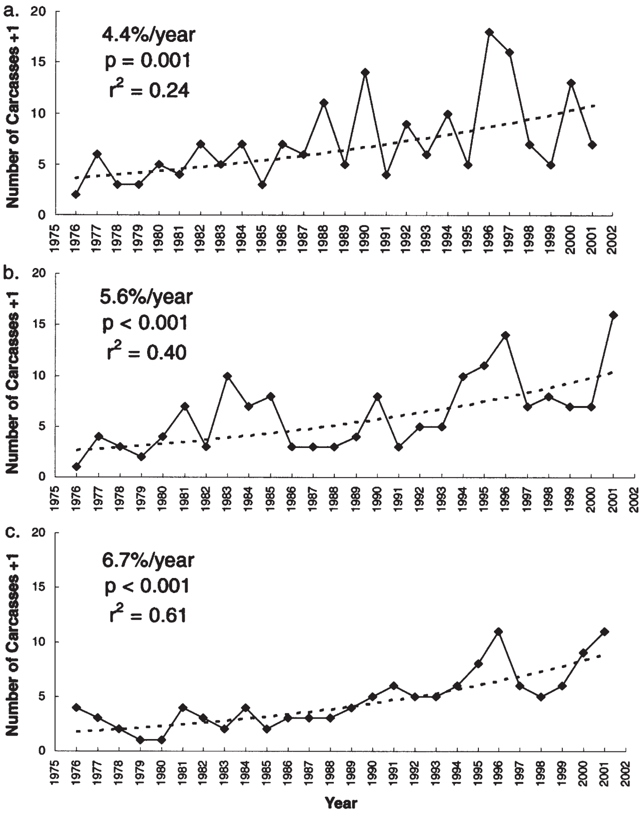

Figure 19 *Tends in manatee deaths in the study area from 1976 to 2001 (all causes excluding red tide) in a) Mid, b) East, and c) West regions.*

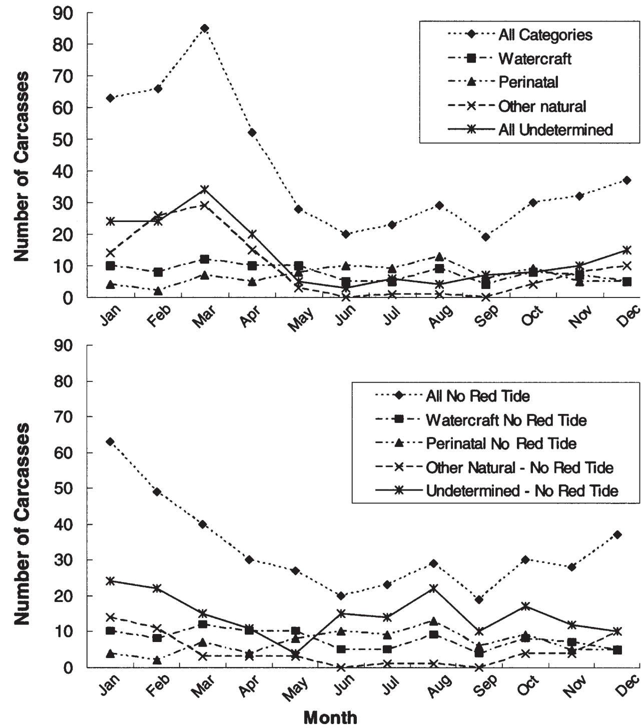

Figure 20 *Total number of manatee carcasses by month in the study area between 1976 and 2001 in watercraft, perinatal, "other natural," undetermined, and all death categories combined including red tide (top) and excluding red tide (bottom).*

deaths occurred sporadically, and no more than one per year died in the study area as a whole.

COLLISIONS WITH WATERCRAFT

Deaths attributed to collisions with watercraft accounted for 19% of all deaths in the study area and 23.5% of deaths with red tide removed (Table 11). All regions showed increases in the number and proportion of watercraft-related deaths between 1976–1988 and 1989–2001 (Table 9). The West Region had the largest increase in the number of watercraft-related deaths between the two time periods, from 3 (9.7%) to 21 (22.6%). Weighted-means trend analysis identified the West Region as the area with the most recent increase in manatees killed by collisions with motorboats (Table 8). Gorzelany (1998) documented the highest vessel counts and densities of boats in eastern San Carlos Bay, which is part of the West Region. He recorded more than five vessels per minute traveling in this area. Sidman and Flamm (2001) and Sidman *et al.* (2000, 2001) determined that the confluence of the Caloosahatchee River and San Carlos Bay had the greatest boat density and congestion in Lee County. They identified this area as a boating "hot spot" and a high-use travel corridor (Figure 3). Sidman and Flamm (2001) also found Matlacha Pass to be an area with high relative boat densities (Figure 3).

The East Region had the second greatest deviation from the median year (6.2 years), with more than triple the number of watercraft carcasses in the second time period of 1989–2001 (Tables 8, 9). The Mid Region is closest to the median (2.8 years) and had the smallest percent increase in watercraft-related deaths (Tables 7, 8). Between the two time periods, vessel-strike deaths in the other two regions increased more than the Mid Region (Table 9). These data suggest a shift in carcass locations to the East and West regions in the most recent 13 years.

A combination of the following factors may contribute to the distribution of boat-strike manatee carcasses among the three regions. First, carcass distribution may reflect the distribution of live manatees. The Mid Region is most likely a travel corridor connecting important habitats to the east and west. Both the East and West regions have manatee attractants such as SAV and warm-water refugia. Analysis of telemetry data revealed that the East and West regions contain important places and corridors, and aerial survey results showed the changing seasonal importance of each region (see Telemetry and Aerial Survey Sections). Second, environmental variables may cause manatee carcasses to drift upstream or

Table 11 *Number and percentage of manatee deaths in each cause-of-death category (unadjusted and adjusted for red tide) in East, West, and Mid regions and in all regions combined.*

	Watercraft	Flood Gate /Lock	Other Human	Perinatal	Cold Stress	Other Natural	Verified, Not Recovered	Undetermined, Too Decomposed	Undetermined	Totals
East										
Unadjusted	28 18.0%	1 0.6%	4 2.6%	20 12.8%	6 3.9%	33 21.2%	4 2.6%	41 26.3%	19 12.2%	156
Adjusted for Red Tide	28 20.4%	1 0.7%	4 2.9%	20 14.6%	6 4.4%	25 18.3%	4 2.9%	30 21.9%	19 13.9%	137
Mid										
Unadjusted	41 20.1%	0 0.0%	4 2.0%	35 17.2%	6 2.9%	47 23.0%	6 2.9%	44 21.6%	21 10.3%	204
Adjusted for Red Tide	41 25.3%	0 0.0%	4 2.5%	34 21.0%	6 3.7%	17 10.5%	6 3.7%	34 21.0%	20 12.4%	162
West										
Unadjusted	24 19.4%	0 0.0%	1 0.8%	28 22.6%	1 0.8%	31 25.0%	4 3.2%	28 22.6%	7 5.7%	124
Adjusted for Red Tide	24 25.0%	0 0.0%	1 1.0%	28 29.2%	1 1.0%	12 12.5%	4 4.2%	21 21.9%	5 5.2%	96
All 3 Regions										
Unadjusted	93 19.2%	1 0.2%	9 1.9%	83 17.2%	13 2.7%	111 22.9%	14 2.9%	113 23.4%	47	484
Adjusted for Red Tide	93 23.5%	1 0.3%	9 2.3%	82 20.8%	13 3.3%	54 13.7%	14 3.5%	85 21.5%	44 11.1%	395

downstream. Third, manatees suffering from a chronic, and ultimately fatal, injury may travel from one region to another before dying. For example, manatees that are fatally struck during winter feeding bouts may die at the power plant. Finally, it is possible that the configuration of manatee speed zones influences watercraft-related mortality rates by changing both the volume of vessel traffic and the configuration of boat traffic patterns. Buffer zones along the sides of the Caloosahatchee River may have decreased the risk of manatees being harmed by collisions with motorboats in the Mid Region. In addition, changes were made to the speed zone in the area near Shell Island (between markers 93 and 99). The previous slow-speed zone in the ICW between 8:00 am and 6:00 pm became shore-to-shore slow speed, with a 25-mph speed zone in the ICW. Gorzelany (1998) documented a change in boat traffic patterns that may have altered the risk to manatees by concentrating all high-speed traffic into a narrow channel.

Between 1976 and 2001, the trend of the annual rate of increase of watercraft-related deaths for the three regions combined was similar to the statewide trend but substantially lower than the trend in southwestern Florida (Table 7). During the most recent time period (1989 to 2001), however, the annual trend in watercraft-related deaths for the three regions combined increased by 15.1% per year ($r^2 = 0.64$, $P < 0.001$; Figure 21). This rate of increase is higher than the rate in southwestern Florida and almost triple the statewide rate during the same time frame (Table 7).

Increases in the number of human-caused manatee deaths and in annual mortality resulting from increased urban development in southwestern Florida were predicted by O'Shea *et al.* (1985). As a result, O'Shea *et al.* (1985: 8) recommended the "establishment of large manatee sanctuaries in western Florida before rapid development leads to an increase in the frequency of human-related deaths."

The 2000 census reported that the human population in Lee County had increased by 31.6% since 1990 (http://quickfacts.census.gov/qfd/states/12000.html). This exceeded the average statewide population growth of 23.5%. Nearby Collier County increased by more than 65%. This may help explain the high (9.2%) annual rate of increase of watercraft-related deaths

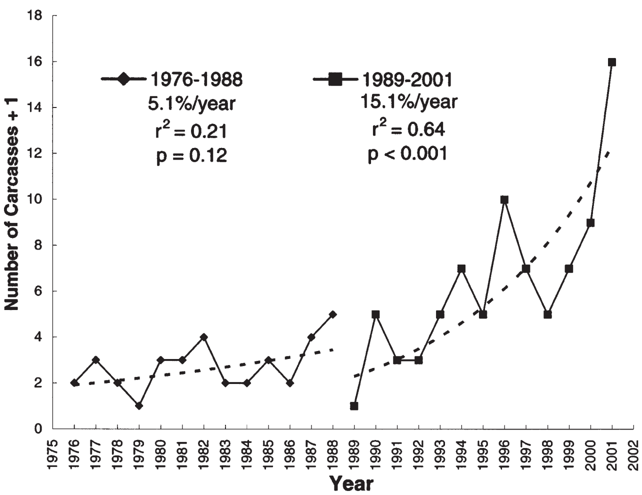

Figure 21 *Trends in watercraft-related manatee deaths in the study area, 1976–1988 and 1989–2001.*

in southwestern Florida between 1989 and 2001.

Although increases in deaths caused by collisions with boats may suggest the presence of more manatees, the 15.1% annual rate of increase in watercraft mortality far exceeds the rate of increase of total deaths and the increase in natural deaths during the same time period (Table 7). These comparisons suggest that vessel abundance increased or that the behaviors of boaters or manatees, or both, changed.

Summary

Manatee deaths from all causes increased in all regions of the Caloosahatchee River. The rates of increase, however, are comparable to statewide rate increases but are slower than those in southwestern Florida as a whole. Red tide may have caused a decrease in the age of the population, as reflected by the higher proportion of subadult carcasses. Adult survival rates decreased immediately after the 1996 red-tide event. The Ft. Myers power plant, and to some extent Matlacha Isles, have protected many manatees from exposure to cold; loss of the power plant could severely threaten manatees in this area. The rate of increase in watercraft-related manatee deaths between 1989 and 2001 in all three regions combined is higher than the rates of increase of all death categories in all three regions combined, of all non-human-related deaths in all three regions combined, of watercraft-related deaths in southwestern Florida, and of watercraft-related deaths statewide. The East and West regions are areas with recent increases in watercraft-related manatee deaths. The West Region had the highest boat density of the three regions (Gorzelany, 1998; Sidman *et al.,* 2000, 2001; Sidman and Flamm, 2001; Figure 3). Habitat, boating, telemetry, and carcass data indicate that manatees in the West Region may be at a higher risk of harmful collisions with watercraft than those in either the Mid or East regions.

Manatee Distribution and Relative Abundance Data Collected Using Aerial Surveys

Introduction

Biologists use aerial surveys as a standard technique to assess manatee distribution and estimate manatee abundance. A distribution aerial survey is a series of flights over the same flight path once or twice per month for one year or more (Ackerman, 1995). Synoptic surveys are winter aerial and ground surveys that cover the manatees' wintering habitats in Florida and southeastern Georgia (Ackerman, 1995). Aerial surveys have also been conducted over power plants, including the FPL Ft. Myers plant, to obtain information about long-term trends in the population at the plants. In contrast to telemetry data, which document the travel history of individual animals over a long period of time, aerial surveys record the instantaneous locations of many manatees during one flight.

The U.S. Fish and Wildlife Service (FWS) conducted the first aerial surveys of manatees in the Caloosahatchee River in 1976 (Irvine and Campbell, 1978). Since 1977, the Florida Power and Light Company (FPL) has sponsored winter surveys of the area around the Ft. Myers power plant (Reynolds and Wilcox, 1994). The first distribution surveys in Lee County were conducted from January 1984 through December 1985 (Frohlich *et al.,* 1991). Additional surveys of Deep Lagoon were made from 1986 to 1988. In Lee County, synoptic surveys included the FPL Ft. Myers power plant, Eight Lakes, Shell Point, Matlacha Isles, and Ten-Mile Canal. Annual highest counts from synoptic surveys in Lee County from 1991 and 1995 to 2001 are presented in Table 12. Counts varied substantially between flights of synoptic surveys, depending on the observer, weather conditions, and time of day. The two coldest winters (1996 and 2001) yielded the highest counts. Researchers, therefore, have found the synoptic numbers to be unsuitable for population trend analyses (Lefebvre *et al.,* 1995).

Manatee distribution surveys can convey a broad picture of seasonal manatee locations and identify important habitat features that attract manatees. This section discusses manatee distribution and relative abundance data collected during aerial surveys conducted in the 1990s over the Caloosahatchee River (FWC, 2000).

Table 12 *Highest manatee counts recorded during synoptic aerial surveys in Lee County.*

Survey Year_Number	Adults	Calves	Total
1991_2	105	13	118
1992_1	177	17	194
1995_2	304	30	334
1996_1	429	45	474
1997_1	380	37	417
1998_1	191	31	222
1999_3	315	59	374
2000_1	284	32	316
2001_1	446	39	485
2002_1	330	17	347
2003_3	438	5	443
2004_1	299	56	355

Materials and Methods

Distribution aerial surveys that included the study area were made twice monthly from December 1994 to November 1995 and from January to December 1997 for a total of 48 flights (Ackerman, 1995; FWC, 2000). The survey route is shown in Figure 22. In 2002, researchers from Mote Marine Laboratory made four additional aerial surveys of the Caloosahatchee River from Shell Point to the Edison Bridge (9 February, 10 and 24 April, and 29 May). Methods for conducting distribution aerial surveys are explained in Ackerman (1995) and Lefebvre *et al.* (1995). Data recorded for each sighting included the number of manatees associated with the point location, number of calves if present, and manatee behavior (Ackerman, 1995). Manatee distribution data from surveys conducted in the 1990s were mapped in a Geographic Information System (GIS) database (FWC, 2000) and analyzed by applying a variable-shape spatial filter to make a contour map of manatee abundance (Flamm *et al.*, 2001).

Spatial filtering is a method for transforming point data mapped in a two-dimensional space into a surface that has characteristics similar to a contour map. In a GIS, spatial filters are applied to raster maps. A raster map is similar in structure to a piece of graph paper in that it consists of evenly sized cells arranged into rows and columns. Each cell in the map has a value that corresponds to one of several attributes of the theme being mapped. For example, in a map of the theme "Florida shoreline," the attributes are land or water. In the raster map, cells that correspond spatially to land are assigned a value, "1," for instance, and those cells corresponding to water might be assigned a value of "2."

Applying a traditional spatial filter involves positioning the center of a polygon over each cell in a raster map, performing a mathematical operation at each position with the values of cells located inside the polygon, and storing the result of the operation in one or more cells in the polygon. An example would be to calculate the average value of all cells within the spatial filter polygon and store the result in the center cell. Usually the result of the mathematical operation is stored either in the cell positioned in the center of the polygon or all cells falling inside the polygon, depending on the goals of the filtering.

A key element of spatial filtering is the shape and size of the polygon. Polygons tend to be isometric shapes, such as squares. Polygon size depends on the question being addressed, because the larger the polygon, the lower the heterogeneity of the landscape—the upper and lower extreme values are smoothed out. In conventional filtering, the shape and size of the polygon are fixed. Although a fixed-shape approach is satisfactory in many instances, it is less appropriate when we want to exclude parts of the landscape from filtering (land in the case of manatees) and guarantee that the polygons are contiguous and not split apart by land.

The type of spatial filter and the method that we used in applying the spatial filter differs from the type of spatial filter and method traditionally used in two ways. First, in contrast to positioning the filter polygon over every cell in the map and performing the mathematical operation, we centered the polygon over the aerial survey point. This approach proved more efficient than the traditional one because we did not filter areas where manatees were not present. Second, to address the constraint that manatees are restricted to the water, we applied a filter that varied in shape to avoid land and always contained the same area of water; this is in contrast to the fixed-shape polygon filter traditionally used. When near land, the shape of the polygon deviated from a circle by expanding along and out from the shoreline until the specified water surface area had accumulated. Only the nearest, contiguous cells to the aerial survey point that satisfied the area criteria were included in the polygon. In this study, the spatial filter polygon had an area of 0.332 km^2 (532 25-m by 25-m cells in the raster map) (Flamm *et al.*, 1991).

The spatial filter worked as follows. Aerial survey points were processed incrementally. First, a polygon having an area of 0.332 km^2 was delineated around the aerial survey point. Only cells that were categorized as water and were contiguous were included in the polygon. Second, the number of animals that the point represented was divided evenly among all 532 cells in the polygon. For example, if the point represented three animals, then each cell in the filter polygon was

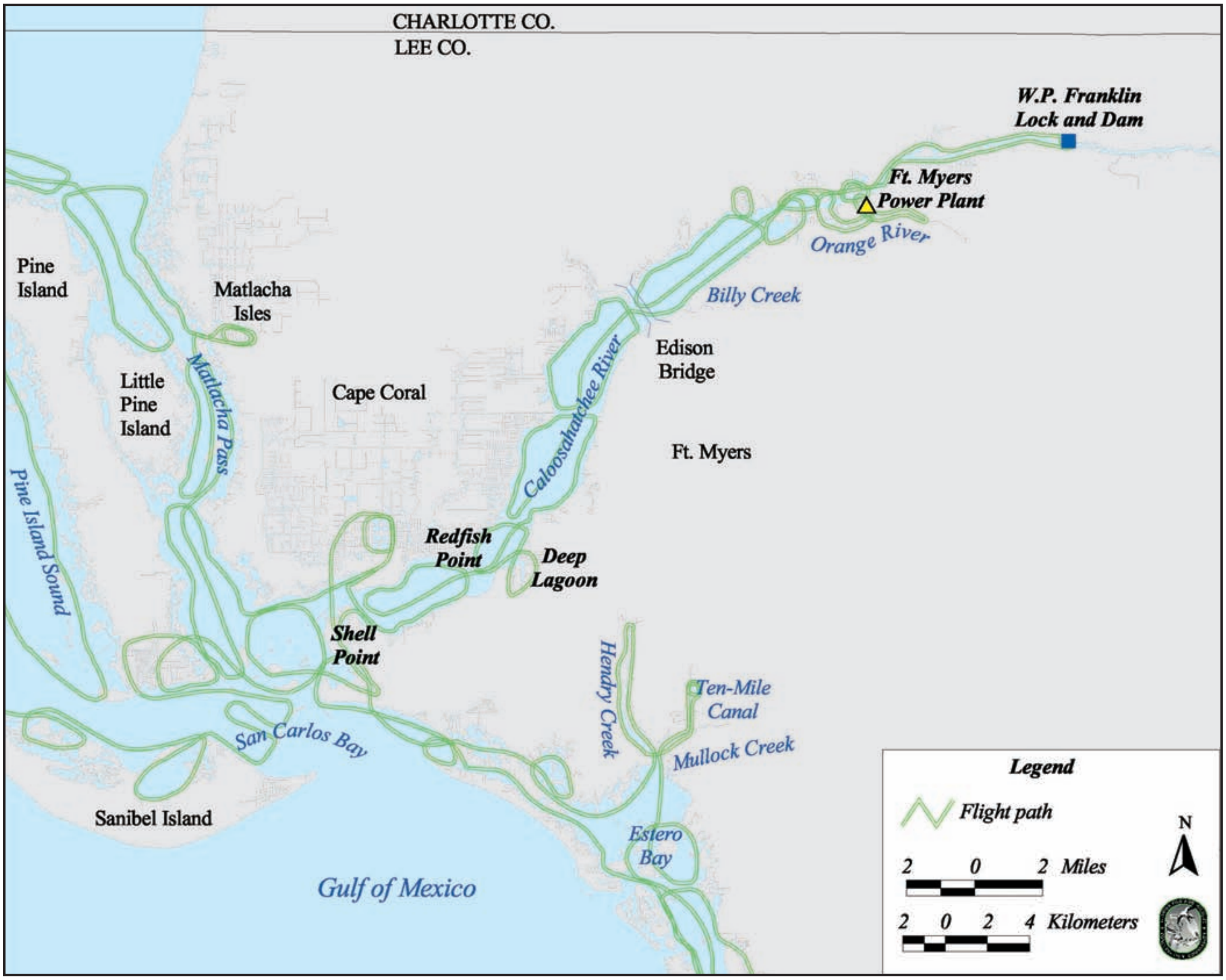

Figure 22 *Flight route for distribution aerial surveys of manatees, October 1994–November 1995 and January–December 1997.*

assigned a value of 0.0056. After each aerial survey point was transformed into a polygon and the cells were assigned their respective values, they were 'added' to a raster map that accumulated all the filter polygons. Addition was conducted using map algebra. Map algebra is an operation conducted with raster maps that involves positioning two or more maps on top of one another, aligning their geographic coordinates. Arithmetic is then performed on spatially corresponding cells. For example, to add two maps together, the values of the cells of the upper left corner of each map (row 1 and column 1) are added together, followed by values in cells in row 1 and column 2. The operation is completed when all corresponding cells in both maps have been added together. The result is a third map representing the sum of the operation. The third map is then divided by the number of aerial survey flights to calculate a per-flight abundance value that is then normalized between the values of 0 and 1. Abundance values were mapped as mean value and less, 0 to 1.0 standard deviation greater than the mean, 1.1 to 2.0 standard deviations, 2.1 to 3.0 standard deviations, and more than 3 standard deviations greater than the mean. The final maps represent relative abundance of manatees in the Caloosahatchee River for cold and warm seasons.

We examined two full years of survey data (December 1994 to November 1995 and January to December 1997) seasonally and monthly. We defined seasons as they were defined in the mortality section: winter (December–February), spring (March–May), summer (June–August), and fall (September–November). The warm season included the spring, summer, and fall months; the cold season contained only the winter months. The same three regions of the Caloosahatchee River ecosystem (East, Mid, and West) de-

Table 13 *Manatee counts and relative seasonal density determined from distribution aerial surveys (December 1994–November 1995 and January–December 1997). This table does not reflect absolute densities because we are unable to quantify the number of manatees counted multiple times between surveys, immigration, or emigration.*

Region	Count	Area (km²)	Count/km²
All Seasons			
East	1,665	20.5	81.2
Mid	818	64.1	12.8
West	2,140	130.8	16.4
Warm (Mar–Nov)			
East	436	20.5	21.3
Mid	441	64.1	6.9
West	1,532	130.8	11.7
Winter (Dec–Feb)			
East	1,229	20.5	60.0
Mid	377	64.1	5.9
West	608	130.8	4.6
Spring (Mar–May)			
East	260	20.5	12.68
Mid	202	64.1	3.15
West	561	130.8	4.29
Summer (Jun–Aug)			
East	124	20.5	6.0
Mid	134	64.1	2.1
West	392	130.8	3.0
Fall (Sep–Nov)			
East	52	20.5	2.5
Mid	105	64.1	1.6
West	579	130.8	4.4

scribed in the mortality section were used in these analyses (see Figure 18 for region boundaries). We divided the total number of individuals counted on all flights in each region by the area of water in the region (Table 13). This was calculated to convey relative density (counts per km²) as a means for comparing regions. We could not calculate absolute densities because we cannot quantify the number of manatees counted multiple times between surveys or because of immigration or emigration. Using two-way contingency tables, we analyzed the associations between manatee sightings and season and month. Pearson chi-square tests were employed to detect significant differences from an expected distribution (Statistica™, 1996). A significant difference indicated that the two variables were not completely independent and that a pattern existed.

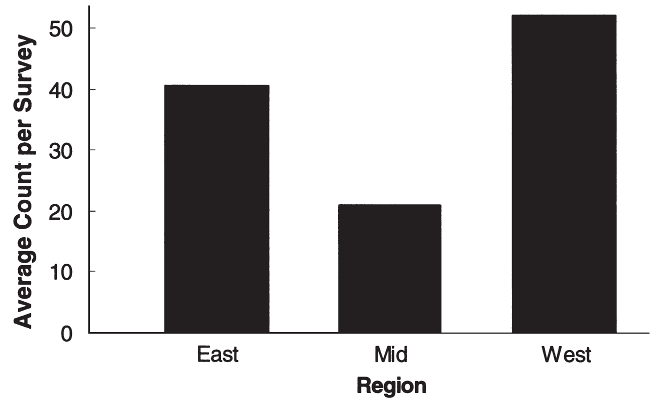

Figure 23 *Average manatee count per survey in each region of the Caloosahatchee River, recorded during 48 distribution aerial surveys conducted December 1994–November 1995 and January–December 1997.*

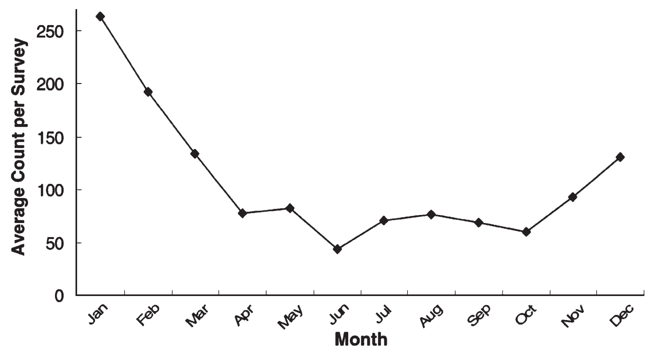

Figure 24 *Average monthly manatee count per survey of all three regions combined, recorded during 48 distribution aerial surveys conducted December 1994–November 1995 and January–December 1997.*

Results and Discussion

Aerial survey results supported telemetry findings that manatees spend more time in the East and West regions of the Caloosahatchee River and used the Mid Region principally as a travel corridor (Figure 23). Because of heavy use during winter and spring and its small area, the East Region had highest cold and warm season counts per km², but in summer and fall, the East had the lowest counts observed in all regions of the Caloosahatchee River (Table 13).

The monthly distribution of manatee sightings from aerial surveys of all three regions revealed the greatest number of manatees from January to March, with smaller peaks in May and August (Figure 24). Significantly more sightings than expected occurred in the East Region in January and February and in the West Region in September and October ($\chi^2 = 1{,}021$, $P < 0.001$; Table 14). The mortality data reported in the previous section showed these same patterns, suggesting an association between areas of high manatee abundance and manatee deaths.

WINTER DISTRIBUTION

Figures 25 and 26 depict the relative abundance of manatees in the Caloosahatchee River in winter. Areas with warm water discussed in the habitat section, including the Orange River and Matlacha Isles, have the highest relative abundances (Figure 25). Other places of interest include Eight Lakes, Chiquita Canal, Iona Cove, and Deep Lagoon in the Mid Region and Beautiful Island and the Franklin locks in the East Region.

Matlacha Isles provides an important warm-water refuge for manatees, as discussed in previous sections. In addition to thermoregulation, manatees use the West Region in winter to travel between Matlacha Isles and the seagrass beds in Matlacha Pass and San Carlos Bay and between Matlacha Isles and the power plant.

Eight Lakes appears to be not only a stop-over site between warm-water refuges and feeding grounds but also a place to seek temporary shelter during sudden cold fronts. Chiquita Canal, Iona Cove, and Deep Lagoon are also used in winter but not extensively. Manatees presumably use Chiquita Canal to travel between the Caloosahatchee River and Eight Lakes. Iona Cove is a possible feeding ground, whereas Deep Lagoon probably stays warmer than the river and provides fresh water.

As discussed in previous sections, the focus of manatee activity in the East Region during the winter is the Fort Myers power plant, and to a lesser extent, the Franklin locks. Winter temperatures in the Orange River commonly exceed those of the Franklin locks. Consequently, more manatees are found near the power plant than the locks (Packard *et al.*, 1989; Reynolds, 2002). When water temperatures are 17°–18°C, manatees frequently move between the locks and the power plant (Packard *et al.*, 1989). On the rare occasions when water temperatures were equal in the Orange River and the Franklin locks, roughly equal numbers of manatees can occur in each area (Packard *et al.*, 1989). It is during these times that manatees are at increased risk of harmful collisions with motorboats between the Orange River and the Franklin locks.

In the East Region, manatees also travel between the warm-water refuges and feeding grounds around Beautiful Island and areas upstream. Although researchers have reported evening and nighttime feeding in winter, manatees presumably forage during the day in milder weather (Bengtson, 1981; Barton and Reynolds, 2001; Edwards *et al.*, 2002). The East Region is critical to manatees overwintering in the Caloosahatchee River ecosystem. In the mortality section, it was reported that there were significantly more winter deaths in this region and suggested that during winter, the power plant may act as a sink for dead manatees.

Table 14 *Monthly counts of manatees observed in each region during distribution aerial surveys, December 1994–November 1995 and January–December 1997.*

Month	Region			Row Totals
	East	Mid	West	
January	635	145	272	1,052
Row %	60.4%	13.8%	25.9%	
February	401	133	234	768
Row %	52.2%	17.3%	30.5%	
March	106	108	324	538
Row %	19.7%	20.1%	60.2%	
April	41	41	73	155
Row %	26.5%	26.5%	47.1%	
May	113	53	164	330
Row %	34.2%	16.1%	49.7%	
June	27	20	84	131
Row %	20.6%	15.3%	64.1%	
July	54	54	106	214
Row %	25.2%	25.2%	49.5%	
August	43	60	202	305
Row %	14.1%	19.7%	66.2%	
September	24	10	242	276
Row %	8.7%	3.6%	87.7%	
October	7	20	154	181
Row %	3.9%	11.1%	85.1%	
November	21	75	183	279
Row %	7.5%	26.9%	65.6%	
December	193	99	102	394
Row %	49.0%	25.1%	25.9%	
Total	**1,665**	**818**	**2,140**	**4,623**
Row %	**36.0%**	**17.7%**	**46.3%**	

WARM–SEASON DISTRIBUTION

Aerial-survey data showed a springtime shift in manatee distribution away from the East Region (Figures 27 and 28). The relative abundance of manatees was moderate throughout the Caloosahatchee River, and manatees were observed principally along the shore of the river (Figure 27). Areas of interest included Matlacha Pass and San Carlos Bay in the West Region; Eight Lakes and Chiquita Canal, Deep Lagoon, and Iona Cove in the Mid Region; and Beautiful Island, Orange River, a few oxbows on the north shore, and the locks of the East Region.

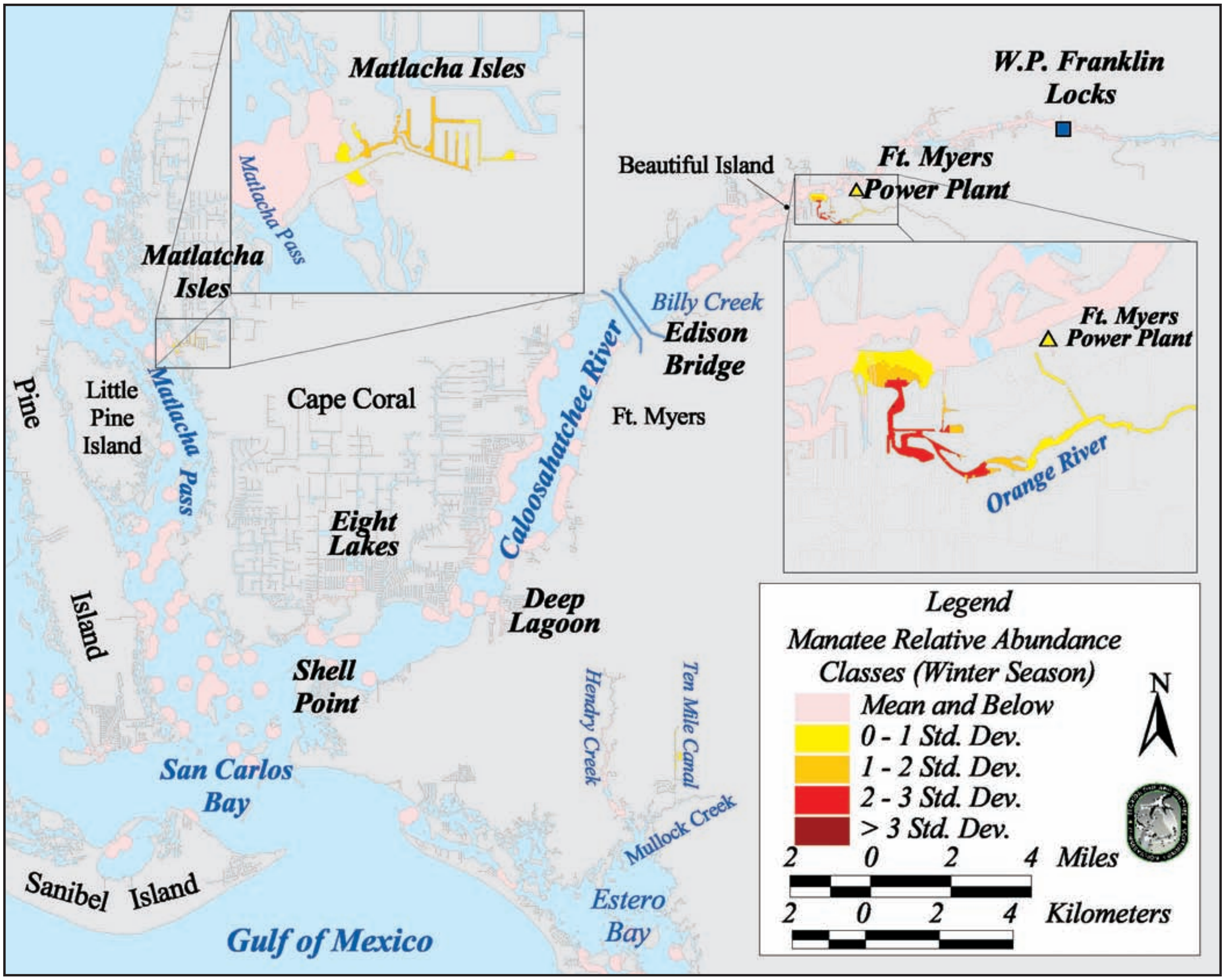

Figure 25 *Results of applying a variable-shape spatial filter to a point coverage of winter aerial surveys (all regions), December 1994–February 1995 and January, February, and December 1997. The filter depicts relative abundance.*

During the warm season, the number of manatees increased substantially in the West Region, which had several moderate- and high-abundance areas. Areas of highest use were San Carlos Bay, particularly near Miserable Mile, and the northeast side of Matlacha Pass. As mentioned previously, these sites contain numerous seagrass beds. Lefebvre and Frohlich (1986) reported manatees feeding in these regions. It is likely that manatees use most of the West Region for feeding during the warm season. In addition to being a feeding area, Matlacha Pass acts as a manatee travel corridor, connecting the Caloosahatchee River with Charlotte Harbor. Manatee use of Matlacha Isles in the warm season is probably reflected by data collected during the transitional months of March and November.

The high-density areas identified by the aerial spatial filter (Figures 27 and 28) correspond well with the places and corridors discussed in the telemetry section (Figure 15). In the Mid Region, highest densities were recorded along the north shore west of the Edison Bridge, near downtown Ft. Myers, and at Eight Lakes, Chiquita Canal, Deep Lagoon, and Iona Cove. The importance of these locations as freshwater sources, resting areas, and nurseries was discussed in both the Telemetry and Habitat sections. Moderate relative abundance occurred on both shores where the river narrows at Shell Point and Redfish Point. This finding agrees with other data indicating that manatees may cross the Caloosahatchee River at these narrow points.

During aerial surveys, manatees were most frequently seen along the shoreline. The survey route (Figure 22) shows that the center of the river was also surveyed, but depth, sea-state, turbidity, and water

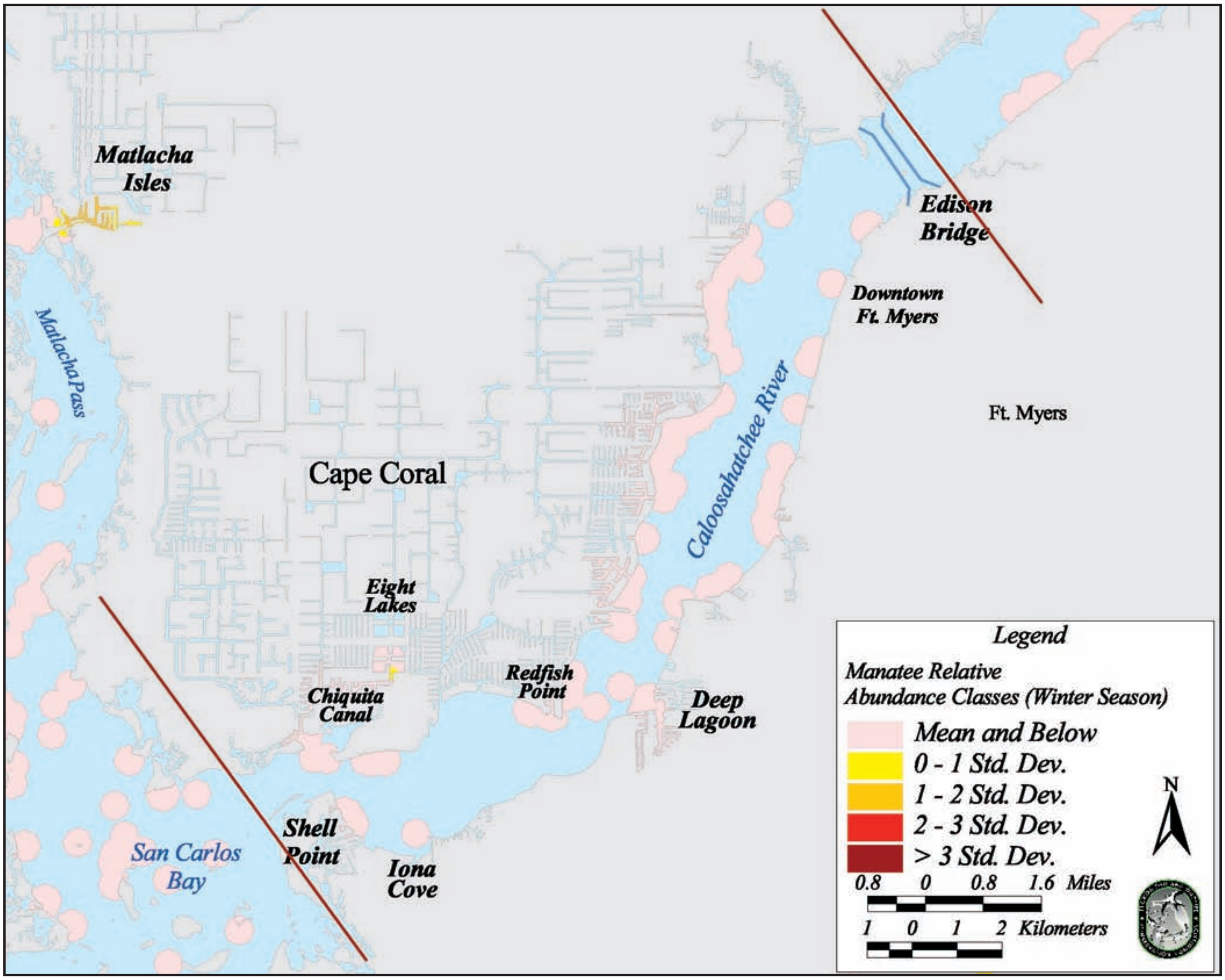

Figure 26 *Results of applying a variable-shape spatial filter to a point coverage of winter aerial surveys (Mid Region), December 1994–February 1995 and January, February, and December 1997. The filter depicts manatee relative abundance. Red lines indicate Mid Region boundaries.*

color in the center of the river make it difficult to see manatees there (B. Ackerman, FWC personal communication). We believe that manatees travel along the shoreline, as indicated by the telemetry travel corridor maps (Figures 15 and 16). However, lack of aerial survey sightings in the center does not necessarily mean that manatees are not using it. The travel paths, places, and corridors discussed in the telemetry section show manatees crossing the river, especially near Redfish Point and Shell Point. Few aerial sightings of manatees in the center may simply indicate that we were unable to see them there.

Manatees use the East Region less intensively in summer and fall than in winter and spring. Only 26% of the aerial survey sightings in the East Region occurred during the nine-month warm season. Manatees were more widespread over their range during the warm season (Figures 27 and 28). At this time manatees are likely feeding on tapegrass and widgeongrass or wallowing in the cooler sediments of the locks or other deeper areas (J. E. Reynolds, Mote Marine Laboratory, personal communication).

2002 SURVEYS OF THE CALOOSAHATCHEE RIVER FROM SHELL POINT TO THE FRANKLIN LOCKS

Figure 29 plots sightings from February to May 2002. February sightings were concentrated upriver, whereas the April and May sightings were more dispersed. Lefebvre and Frohlich (1986) reported the same shift in manatee distribution when they followed tagged animals. Water clarity in the Caloosahatchee River is poor, and

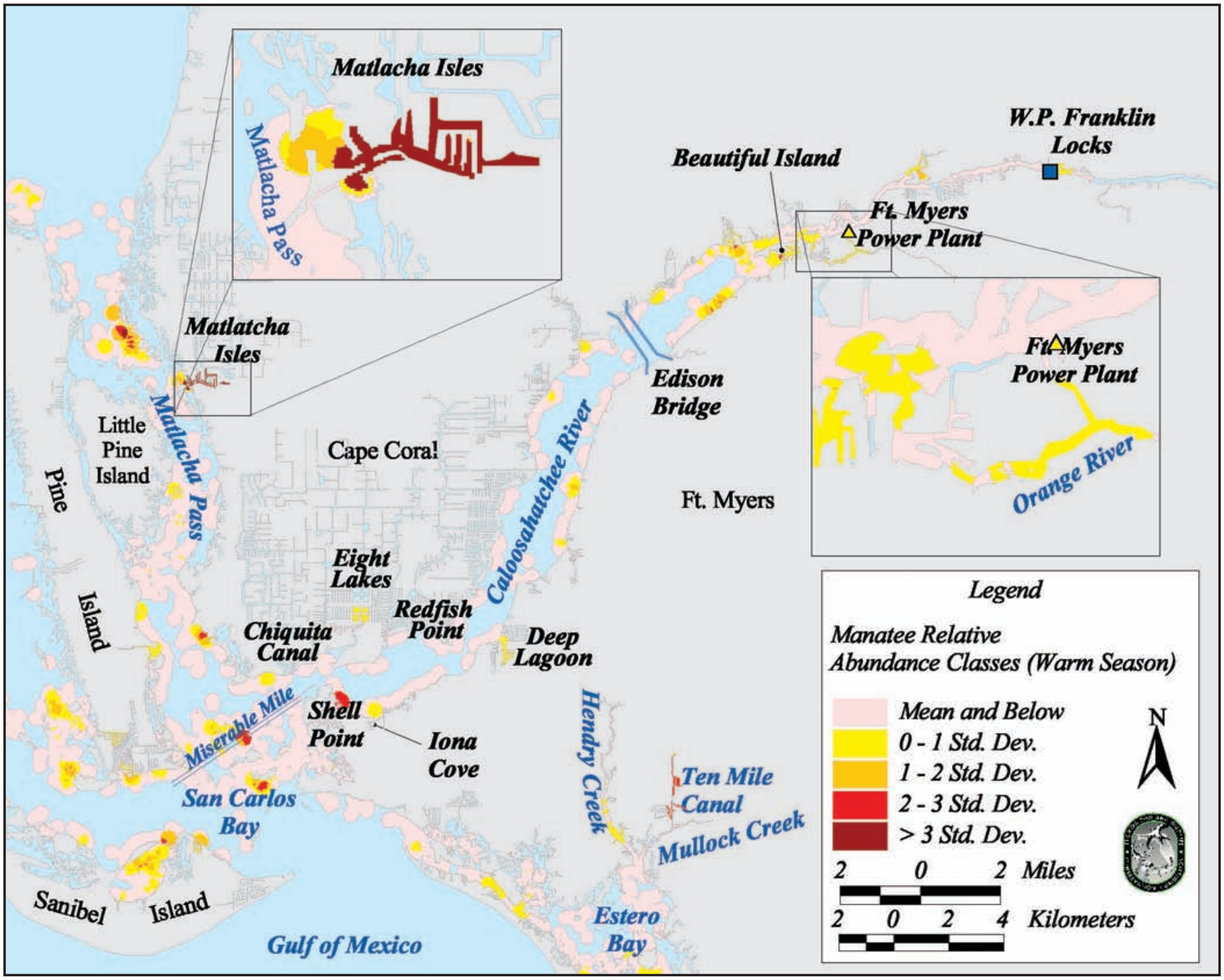

Figure 27 *Results of applying a variable-shape spatial filter to a point coverage of warm-season aerial surveys (all regions), March–November 1995 and March–November 1997. The filter depicts manatee relative abundance.*

counts obtained in this area probably greatly underestimate the number of individuals present (J. Reynolds, Mote Marine Laboratory, personal communication).

Summary

Aerial-survey sightings confirm the patterns of manatee use documented in previous sections. The high-relative-abundance areas identified by the aerial spatial filter are similar to the places and corridors discussed in the Telemetry section. There were more manatee sightings in the East and West regions than in the Mid Region, and the sightings varied with season. The East Region is particularly important to manatees in winter and, because it is a small area, also has a higher relative density of manatees year-round. When water temperatures in the Orange River are similar to those at the Franklin locks, manatees will travel between the two places, putting the animals at increased risk of harmful collisions with boats. Manatees presumably use the Mid Region as a travel corridor, where they swim near the shoreline. Evidence suggests that manatees feed opportunistically in the Mid Region, stopping in the canals of Cape Coral and Ft. Myers for fresh water, birthing, suckling, and thermoregulating. Aerial-survey data support our hypothesis that manatees cross the river in the narrow areas around Shell Point and Redfish Point. Almost 80% of the sightings in the West Region were recorded in the warm season, particularly in Matlacha Pass and San Carlos Bay. Increased sightings in October in the West Region may reveal an overlap between winter and warm-season residents.

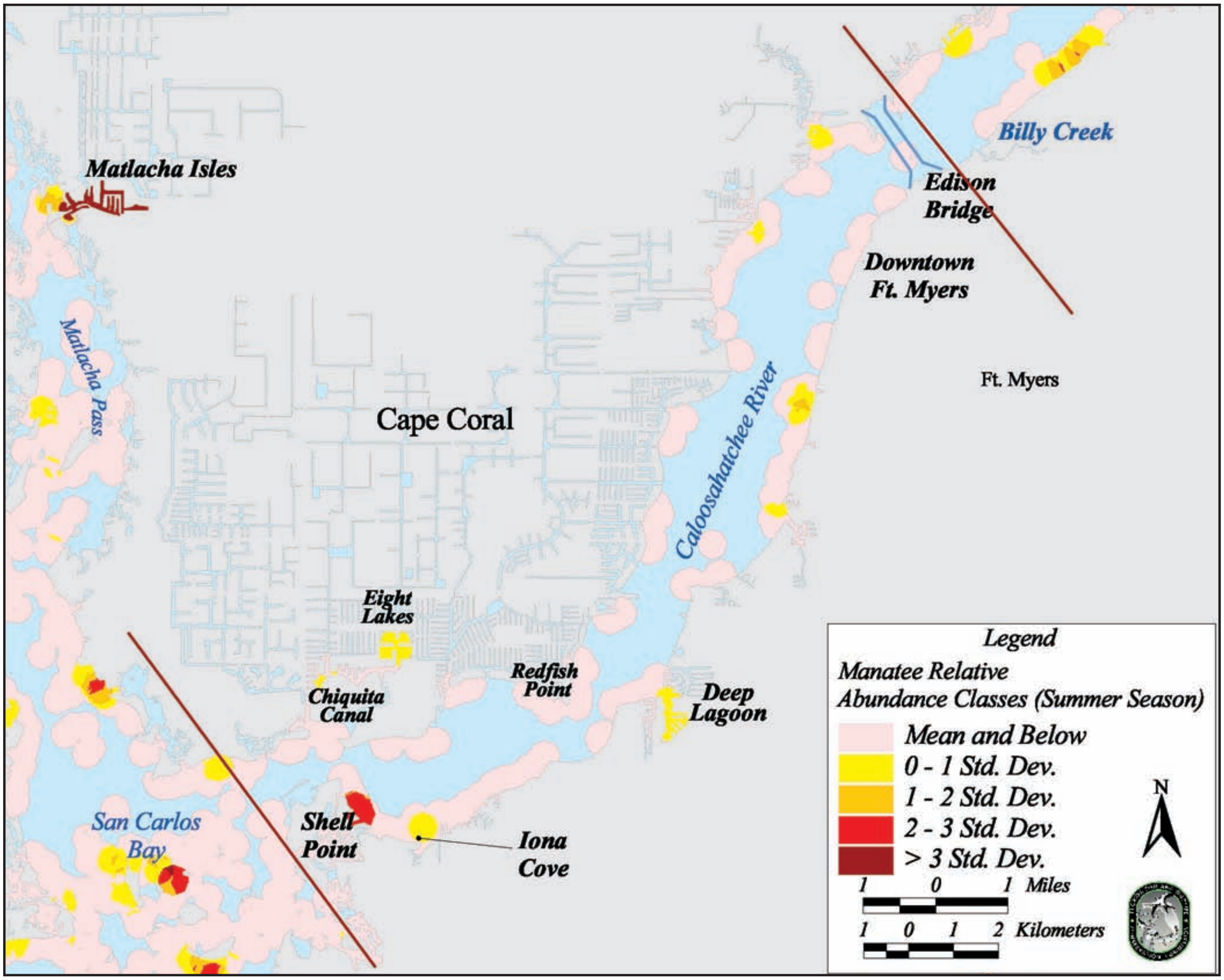

Figure 28 *Results of applying a variable-shape spatial filter to a point coverage of warm-season aerial surveys (Mid Region), March–November 1995 and March–November 1997. The filter depicts manatee relative abundance. Red lines indicate Mid Region boundaries.*

Conclusions

All data indicate that the Caloosahatchee River is an important place for large numbers of manatees in southwestern Florida. Manatees are supported by the river year-round because of ample fresh water, numerous quiet canals, warm-water refugia, and areas of abundant submerged aquatic vegetation. Travel paths derived from telemetry data show that for some manatees, the river composes only a small portion of their total range (Weigle *et al.*, 2001). Consequently, any impacts to manatees in the Caloosahatchee River could ultimately affect manatees throughout southwestern Florida and those who cross the state via Lake Okeechobee.

Distribution of Manatees

Manatees use the Mid Region, between Shell Point and the Edison Bridge, principally as a travel corridor. Requisites such as warm water are found more abundantly west of Shell Point (West Region) and east of the Edison Bridge (East Region). Food is patchy in the Mid Region because fluctuations in salinity and increased turbidity have caused a reduction in SAV. However, manatees opportunistically exploit some resources during their travels. Minor aggregation areas include Eight Lakes, Chiquita Canal, Cape Coral Canals (in general), Iona Cove, Deep Lagoon, and downtown Ft. Myers. Two places of particular importance in the Mid

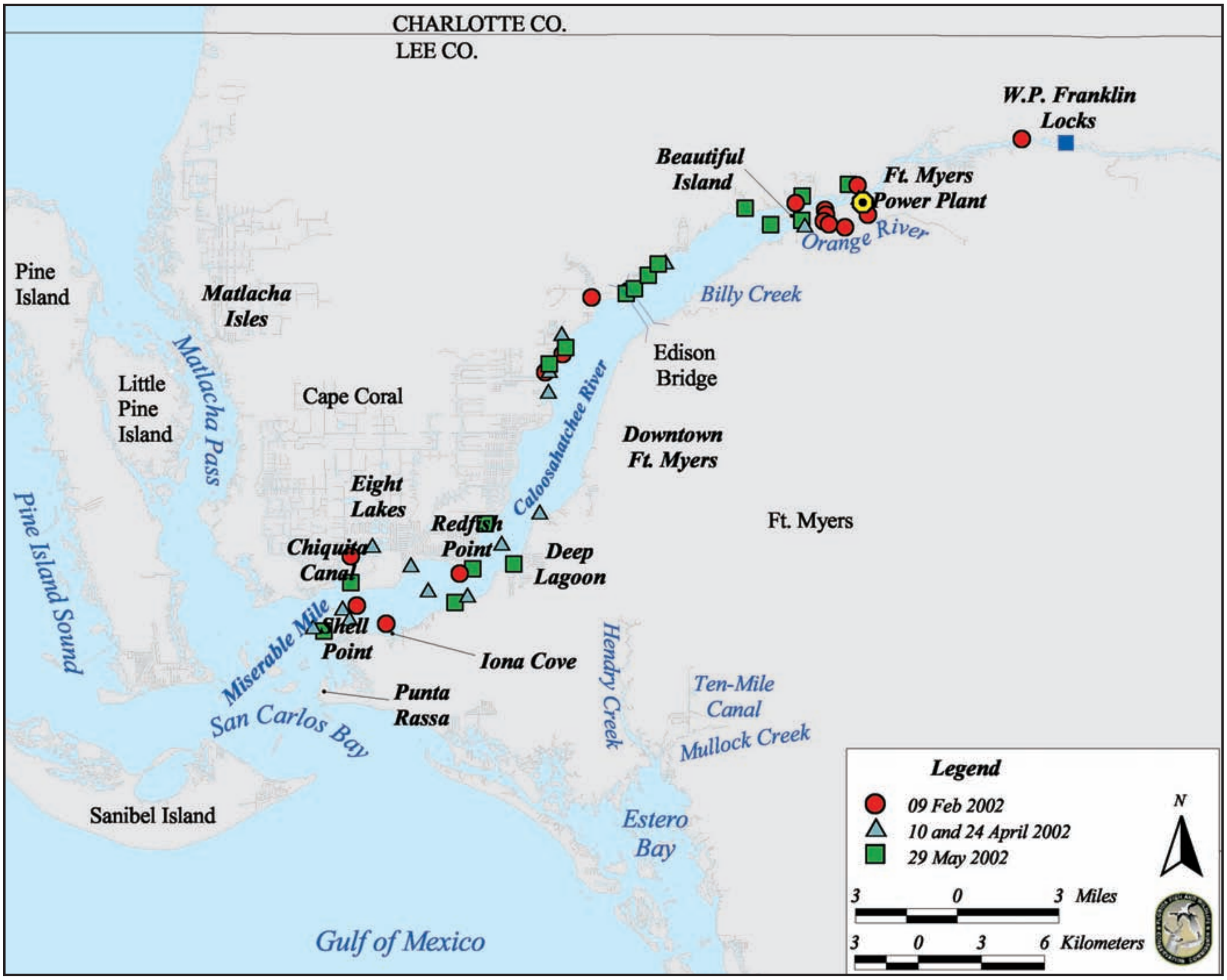

Figure 29 *Locations of manatees sighted during survey flights between the mouth of the Caloosahatchee River and the W.P. Franklin Lock and Dam, February–May 2002. Each point represents 1 to 12 manatees (Mote Marine Laboratory, unpublished data).*

Region are Redfish Point and Shell Point. Manatees must pass Shell Point to enter or leave the river. Redfish Point contains fresh water and many entrances into the canals of Cape Coral. Based on this information and that derived from telemetry, manatees presumably cross the river in these narrow areas and spend time in the center of the river between Redfish Point and Deep Lagoon.

Telemetry studies by Lefebvre and Frohlich (1986) and Weigle *et al.* (2001) reported seasonal changes in manatee distribution in the Caloosahatchee River. During spring (March–June), winter residents (December–February) migrate downriver from east of the Edison Bridge. Aerial survey sightings and carcass recovery locations reflect this pattern of changing seasonal distribution. Manatee travel paths show restricted, wintertime movements that are concentrated upriver, near Matlacha Isles, and occasionally between the two refugia. During the warm season, manatees use the river extensively, taking advantage of available resources such as SAV, fresh water, and resting areas.

Distribution of Humans

Data indicate that large areas of overlap between boats and manatees exist in and around the Caloosahatchee River. One area of particular importance is the mouth of the Caloosahatchee River. This section was identified as a boating "hot spot," with the highest vessel counts, most congestion, and greatest density of boats in Lee County (Gorzelany, 1998; Sidman and Flamm, 2001). Much of the traffic originates in the Cape Coral and Ft. Myers canals and travels out the mouth of the river. Gorzelany (1998) recorded highest traffic volumes in the spring (March–May), which coincides with the shift and dispersal of manatees from winter refugia to warm-weather habitats and feeding areas. Simultaneous increases in vessel traffic and manatee movements can result in a high risk of manatee-motorboat collisions. Mortality data show a peak in manatee boat-strike deaths from March to May (Table 10).

Mortality and Injury

There is a trend of an increasing number of manatee deaths in and around the Caloosahatchee River. When comparing the first 13 study years (1976–1988) with the most recent 13 years (1989–2001), the annual rate of increase of manatee deaths (all categories) in the Caloosahatchee River (East, Mid, and West regions combined) has actually slowed from 7.4% per year to 5.8% per year. Between 1989 and 2001, however, the annual rate of increase for watercraft-related manatee deaths was 15.1%. Although increases in boat-strike deaths may suggest the presence of more manatees, the 15.1% annual rate of increase of watercraft-related deaths far exceeds the rate of increase of total deaths in the same time period (5.8%), suggesting a change in boater abundance and/or behavior.

In winter, data indicate that the East Region is a sink for fatally injured manatees. In some winters, increased manatee movements between the power plant and the Franklin locks also increase the likelihood of harmful collisions with boats in this area. Evidence suggests that the mouth of the river, San Carlos Bay, Redfish Point, and Matlacha Pass are other areas where manatees are at risk of being struck by a boat.

Between time periods one (1976–1988) and two (1989–2001) there were fewer watercraft-related manatee deaths in the Mid Region than in either the East or West regions. We discussed several possibilities for explaining this pattern: carcass distribution may reflect distribution of live manatees; manatees may be struck elsewhere, then swim to these areas and die there; carcasses may drift into these areas; or the configuration of the speed zones may have changed boat traffic, putting manatees at greater risk of being struck by a boat near the mouth and decreasing that risk in the Mid Region. Because of limitations in determining where manatees are actually struck and killed, it is extremely difficult to attribute increasing trends in watercraft-related deaths to one particular source. Moreover, none of the possibilities mentioned explain why watercraft-related deaths since 1989 are increasing in the Caloosahatchee River area faster than in southwestern Florida or in the state as a whole. Consequently, biologists and managers are often asked the question, Do manatee speed zones work?

Research Needs

At this time, answering that question with any certainty is not possible. We know that assessment of mortality rates is not a direct measure of speed zone effectiveness. Even if a manatee speed zone achieved a very high level of compliance (*e.g.,* 90%), extremely high traffic volumes would still create a substantial threat to manatees (*e.g.,* at the mouth of the Caloosahatchee River). Conversely, a low rate of boater compliance would also put manatees at risk of harmful collisions with watercraft. As the human population continues to increase in southwestern Florida, we are probably recovering a higher proportion of carcasses than before, but we are still unable to determine the number of carcasses that go unreported. Furthermore, we do not know what would have happened if the speed zone rules were never enacted. In other words, there is no way to control for the many variables that contribute to watercraft-related manatee deaths, so it is difficult to assess the effect of one variable—the presence or absence of speed zones. Most carcasses bear scars from multiple boat strikes, and we do not know the extent to which nonlethal injuries affect manatee health and reproduction (O'Shea *et al.,* 2001; Wright *et al.,* 1995).

Some of the variables that are involved in trying to address the question, Do speed zones work? are the following: exact location of death, habitat characteristics, vessel traffic, compliance levels, manatee behavior, manatee travel paths, and boat speed, size, and type. The best way to address this question is by applying a simulation model to a risk analysis. Simulation models can incorporate a multitude of variables and an infinite number of scenarios and replications that would take years to assess without the use of models. Through multiple simulations, the model would create risk maps of particular areas under the different chosen scenarios. FWRI staff are beginning to investigate the use of risk analysis. Currently, however, our best method may be through a "weight-of-evidence" approach. By examining the variables described in this report (habitat, manatee distribution, movements, and hot spots; and human use) we can get a better understanding of how the living manatee and human populations behave and the risks that manatees encounter.

To improve our understanding of human behavior and attitudes, we should continue investigating boat traffic patterns and the effects of manatee speed zones on these patterns. Are some speed zones shifting traffic in such a way as to increase risk to manatees? Past studies have focused on boater behavior but lacked examination of the reasons behind the observed behavior. Sociologists have the ability to question the resource user to determine why he or she chooses to behave in a certain manner (*i.e.*, comply with a speed zone). Attitudes, motivations, and behaviors of the public are not only important components of a risk assessment model, but they can provide managers and law enforcement with information to better seek alternative means of influencing human behavior (Sorice *et al.*, 2004).

Improvements in manatee research methods will also provide better parameters for the risk assessment model. The scientific community involved in manatee research continues to explore different ways of mining, collecting, and analyzing data about manatees. Newly available, satellite-linked GPS tags allow us to map fine-scale movements. By using GPS-tags in conjunction with time-depth data loggers and behavioral observations, we can create a more complete, detailed picture about when manatees travel, where they go, and what they are doing. Improved spatial filters will more accurately depict relative abundance, and simulation models will give us a better method of assessing risks to manatees under an unlimited number of scenarios. These risk assessments are currently the most appropriate and effective way to answer the prevalent question, Do manatee speed zones work?

Acknowledgments

The authors thank the following people for their assistance, insights, and prompt responses to data requests: Dr. John E. Reynolds, III and Rachel Nostrom (Mote Marine Laboratory), Tracy McCord and Winifred Perkins (Florida Power and Light Corporation), Amy Hoyt (Lee County Department of Public Works), Catherine Corbett (Charlotte Harbor National Estuary Program), Dr. Peter Doering (South Florida Water Management District), and Dr. Steve Bortone (the Conservancy of Southwest Florida). We thank the following former and current employees of the Florida Fish and Wildlife Conservation Commission (FWC): Bruce Ackerman, Margie Barlas, Holly Edwards, Patti Haase, Elsa Haubold, Lucy Keith, Gil McRae, Meghan Pitchford, Thomas Pitchford, Tanya Pulfer, Sentiel "Butch" Rommel, William Sargent, Alexander Smith, and Earnest Truby for their assistance and insights. We also wish to thank the following former and current FWC staff for editorial review and expertise: Bruce Ackerman, Kristin Child, Mary Duncan, Charles "Chip" Deutsch, Holly Edwards, Llyn French, Kipp Frohlich, Elsa Haubold, Judy Leiby, Ron Mezich, Thomas Pitchford, Tanya Pulfer, James Quinn, Kelly Schratwieser, Kent Smith, Michael Sorice, Linda Torres, and Leslie Ward-Geiger.

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