18 Seagrass Distribution in South Florida: A Multi-Agency Coordinated Monitoring Program

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INTRODUCTION

Seagrass beds are a vitally important component of the nearshore marine environment. Seagrasses provide habitat for commercially and economically important fish and invertebrates and feeding grounds for wading and diving birds, as well as enhance sediment stability, decrease wave energy, and increase water clarity (see reviews by McRoy and Helfferich, 1977; Phillips and McRoy, 1980). Seagrass beds are very sensitive to changes in their environment and are particularly vulnerable to any decrease in the transmission of light through the water column and dredging of the sandy and muddy bottoms on which they grow. Much human activity in the coastal zone has the potential to deleteriously affect seagrasses. Dredging and filling of coastal areas for navigation and development can directly remove potential seagrass habitat (Zieman and Zieman, 1989), alter hydrological conditions that lead to erosion (Giesen et al., 1990; Larkum and West, 1990), and cause a reduction in light available to seagrasses by increasing turbidity (Onuf, 1994). Increasing human population density in coastal regions has often led to eutrophication, which can reduce light available for seagrasses; eutrophication has been implicated in the loss of seagrasses from many areas of the world (e.g., Orth and Moore, 1983; Cambridge et al., 1986). Recreational and commercial use of seagrass beds also can damage them. For example, contact of the bottom by outboard motors can cause scars that can take years to recover (Zieman, 1976); the cumulative impacts of such frequent events can lead to complete loss of seagrass beds from heavily trafficked areas (Sargent et al., 1995). Commercial harvesting of shellfish can also have severe effects on seagrass beds (Thayer et al., 1984).

Seagrasses are a dominant component of the hydroscape of South Florida, and they occupy the position between the freshwater environments of the mainland and the deep ocean. Seagrass communities are found from the mangrove-lined estuaries of Florida Bay, the Shark River drainage, and the Ten Thousand Islands out to back-reef environments and open continental shelf waters. Six species of rooted aquatic vascular plants, or seagrasses, are commonly found in south Florida: *Thalassia testudinum* Banks ex. König (turtle grass), *Syringodium filiforme* Kützing (manatee grass), *Halodule wrightii* Ascherson (shoal grass), *Halophila decipiens* Ostenfeld, *Halophila engelmanni* Ascherson, and *Ruppia maritima* L. (widgeon grass). One additional species, *Halophila johnsonii* Eiseman, occurs in Florida, but its distribution is limited to the Indian River Lagoon and extreme northern Biscayne Bay (Eiseman and McMillan, 1980), which is outside of the geographic scope of this paper. The general patterns of the distribution and relative abundance of these species are described (see Zieman, 1982; Zieman and Zieman, 1989, for review), but specific information on the areal extent of seagrass species in south Florida is incomplete (Iverson and Bittaker, 1986). In general, *R. maritima* is restricted to areas near freshwater sources. In areas of stable salinity, stable sediments, and high light availability, *T. testudinum* is often dominant. In slightly deeper or more frequently disturbed areas, *H. wrightii* and/or *S. filiforme* are often found. The *Halophila* species generally are restricted to low-light environments such as deep waters where <15% of surface light penetrates to the bottom, or to shallow turbid waters.

Previous surveys have documented the widespread occurrence of seagrasses in the South Florida region. In the area of Florida Bay within Everglades National Park, there are *ca.* 2000 km^2 of seagrasses, mostly dominated by *Thalassia testudinum* (Zieman et al., 1989). Using diver surveys, Iverson and Bittaker (1986) estimated that an additional 2900 km^2 of seagrass beds can be found in outer Florida Bay (defined as water depths >2 m); these beds were a mixture of *T. testudinum*, *Syringodium filiforme*, *Halodule wrightii*, and *Halophila decipiens*. A more intensive *in situ* and aerial survey of the entire southeastern Gulf of Mexico region documented 16,600 km^2 of seagrass beds in the area north of the Florida Keys and south of Cape Romano (Continental Shelf Associates, 1991). By far the most common seagrass encountered in this large area was *H. decipiens*. On the Atlantic Ocean side of the Florida Keys, at least an additional 1029 km^2 of seagrass beds has been reported (Klein and Orlando, 1994); this brings the estimate of total seagrass habitat in the South Florida region to at least 17,629 km^2 of semicontinuous beds.

The nearshore marine and estuarine habitats of South Florida are managed by a diverse group of governmental agencies at local, state, and federal levels (Figure 18.1). At the local level, county agencies are charged with protection of biotic resources; three counties occupy the shoreline of our study area: Monroe, Miami–Dade, and Collier. The State of Florida's Department of Environmental Protection (FDEP) has jurisdiction on biotic resources in state waters (i.e., within 3 nautical miles of the shoreline). Some of the marine area controlled by the state is further managed by subagencies of FDEP. For example, John Pennekamp Coral Reef State Park occupies a sizeable portion of the potential seagrass habitat in South Florida; the state parks are administered by their own agency (FDEP Division of Parks and Recreation). The South Florida Water Management District, a Florida state agency, is charged with environmental protection of state waters in addition to its primary goals of flood control and water supply. Many agencies of the federal government also exercise control over marine waters of the area. Within the Department of the Interior, the National Park Service (NPS) and the Fish and Wildlife Service (FWS) each control large areas in south Florida. Everglades National Park and Dry Tortugas National Park are largely marine parks. The FWS operates a number of wildlife sanctuaries in the region that have large areas of seagrass habitat within their boundaries. The U.S. Department of Commerce is also involved in management of the region; the Key Largo, Looe Key, and Florida Keys National Marine Sanctuaries are operated by the National Oceanographic and Atmospheric Administration, an agency of the Department of Commerce. The U.S. Environmental Protection Agency (EPA) also has regulatory authority over the marine waters in South Florida. Each agency that has some administrative authority over the marine environment has its own mission; these missions sometimes conflict. This myriad of overlapping agencies is also a regulatory gauntlet for people who wish to exploit the resource (e.g., tourism operators, fishermen) as well as for scientists doing research in the area.

While the details of each agency's mission vary, they all have the same goal: a healthy, stable, and sustainable environment. All of the agencies have also recognized the need for proper resource assessment and monitoring of the seagrass communities of South Florida. The critical role of seagrasses in South Florida has recently been demonstrated. A poorly understood dieoff of dense stands of *Thalassia testudinum* in Florida Bay began in 1987 (Fourqurean and Robblee, 1999). In the initial stages of this dieoff, *ca.* 4000 ha of dense *T. testudinum* beds in western and central Florida Bay died suddenly (Robblee et al., 1991). While this area of seagrass was small when compared to the total amount of seagrass habitat in South Florida, the ramifications of the loss were great. Turbidity in the water column and algal blooms followed the loss of seagrasses (Phlips et al., 1995), leading to a dieoff of sponges (Butler et al., 1995) and a general decline in seagrass beds that had survived the initial dieoff over an area of *ca.* 1000 km^2 (Hall et al., 1999). While deterioration of the seagrass beds across the entire region has yet to occur in South Florida, the fact that the western half of Florida Bay continues to respond to changes wrought by the catastrophic loss of a relatively small area of seagrass (Durako et al., 2002) underscores the importance of healthy seagrass beds to a sustainable marine environment in South Florida. Regulatory agencies in South Florida have taken the opportunity to act in a coordinated effort before region-wide degradation, in the hopes that we will be able to detect, and possibly avert, regional-scale seagrass loss.

Monitoring programs have been implemented in response to three major seagrass-related concerns in South Florida: the relationship of seagrass communities to water quality in the Florida Keys National Marine Sanctuary (FKNMS), changing freshwater runoff in northeast Florida Bay, and the poorly understood seagrass dieoff event that began in Florida Bay in 1987. Communication among scientists and resource managers in South Florida has led to the complementary design of these three monitoring programs. The programs not only are providing data to address the original question of concern, but are also providing data that can be combined to give a comprehensive view of the distribution and status of seagrass communities in the region as a whole. The goal of this paper is not to address any of the questions that led to the original creation of the monitoring efforts, but to use the data to develop an integrated description of the distribution, relative abundance, and species composition of the seagrass communities from the entire South Florida region.

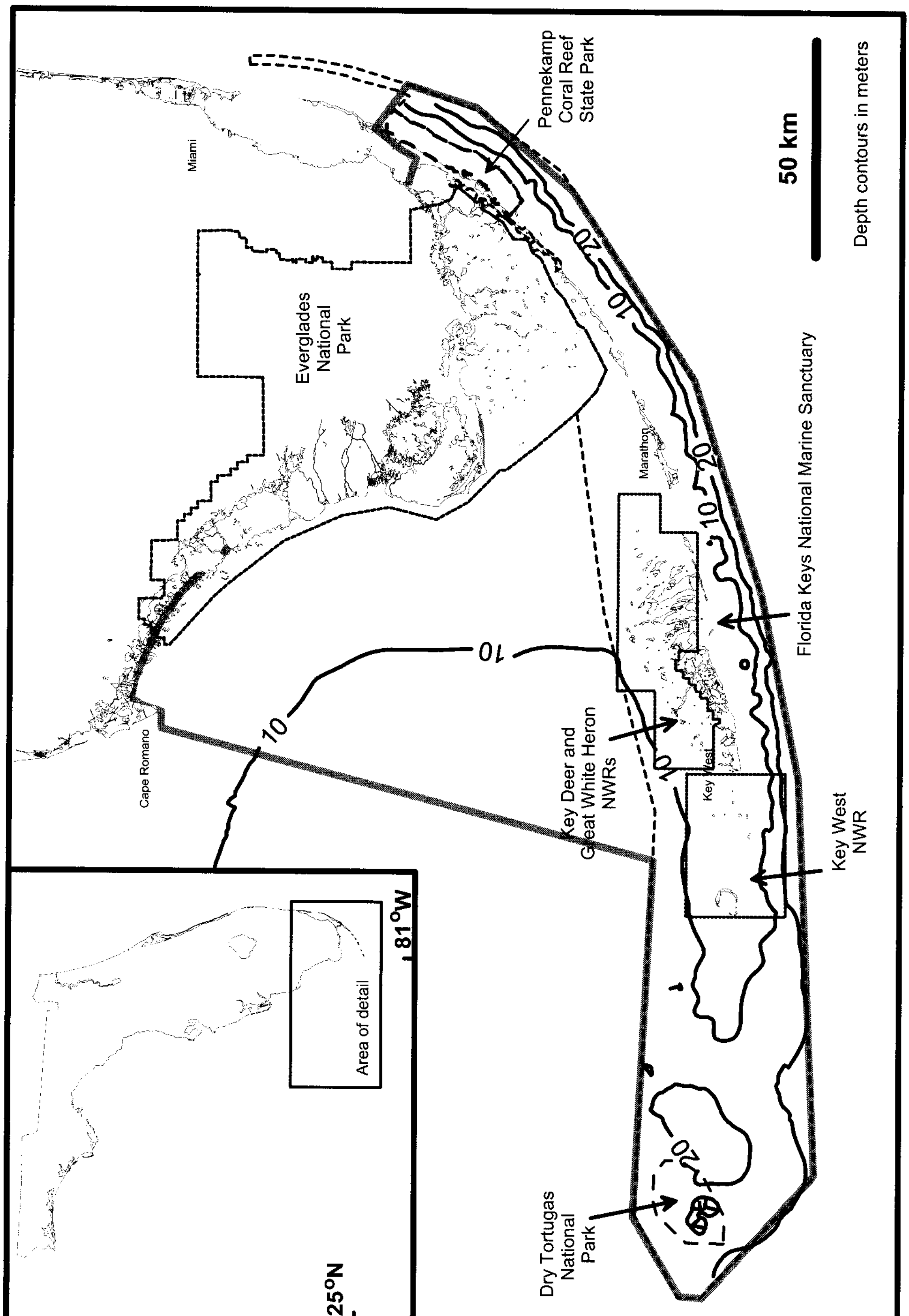

FIGURE 18.1 Area of seagrass surveys in South Florida. The geographic extent of surveys is delineated by the solid gray line. Management jurisdictional boundaries are given for the major management areas in the region.

THREE SEAGRASS MONITORING PROGRAMS IN SOUTH FLORIDA

SEAGRASS COMMUNITIES AS INDICATORS OF WATER QUALITY IN THE FLORIDA KEYS NATIONAL MARINE SANCTUARY

The FKNMS was established by the Florida Keys National Marine Sanctuary and Protection Act of 1990 to "preserve and protect the physical and biological components of the South Florida estuarine and marine ecosystem to ensure its viability for the use and enjoyment of present and future generations" (NOAA, 1996). Seagrasses are an important biological component of the FKNMS. Water quality and the health of seagrass communities have been linked in many locations around the world; as water quality has deteriorated, seagrass communities have been lost (e.g., Orth and Moore, 1983; Cambridge et al., 1986). Concern has been raised over the role of eutrophication and its relation to the status of seagrass communities in the waters of the FKNMS (Lapointe et al., 1990; Tomasko and Lapointe, 1991; Lapointe and Clark, 1992; Lapointe et al., 1994). Because of these concerns, the U.S. EPA established a monitoring program in 1995 designed to define the status and trends of seagrass communities as a part of its comprehensive Water Quality Protection Plan for the FKNMS (Figure 18.2). This program was designed to determine regional-scale gradients in the status of the seagrass communities of the sanctuary.

GAUGING THE EFFECTS OF CHANGING FRESHWATER FLOW ON BENTHIC COMMUNITIES OF FLORIDA BAY

Much of the historic freshwater inflow to Florida Bay has been severely altered by canal dredging and dike building in the Everglades ecosystem directly to the north, altering the pattern of salinity in Florida Bay (Smith et al., 1989; Light and Dineen, 1994; McIvor et al., 1994). The present system is one in which hypersalinity is common (Tabb et al., 1962; Fourqurean et al., 1993). It has been hypothesized that changes in the freshwater flow into Florida Bay have led to changes in benthic communities, such that *Thalassia testudinum* is more prevalent in northeast Florida Bay today than historically, when *Halodule wrightii* was more common (Zieman, 1982). Salinity plays a very important role in controlling benthic plant communities in the upper estuaries of Florida Bay; areas of high variability in salinity have low biomass of submerged plants (Montague and Ley, 1993). Currently, water managers are attempting to restore much of the historic flow of freshwater to the northeastern part of Florida Bay by engineering manipulations of the C-111 canal system. If these changes have an effect on salinity in Florida Bay, it is probable that benthic communities in Florida Bay will respond to the hydrologic changes. The South Florida Water Management District (SFWMD) and Miami–Dade County Department of Environmental Resources Management (DERM) began a monitoring program in 1993 to assess the effects of changing freshwater flows on the macrophyte communities of northeast Florida Bay (Figure 18.3). It should be obvious that both the quality and the quantity of the water flowing into Florida Bay are critical to the success of this management program.

DETERMINING THE CAUSES AND EXTENT OF SEAGRASS DIEOFF IN FLORIDA BAY

Florida Bay is currently undergoing an unprecedented modification of its ecosystems (Fourqurean and Robblee, 1999). The mass mortality of seagrasses within Florida Bay (Robblee et al., 1991) and the more recent widespread algal blooms (Butler et al., 1995; Phlips et al., 1995; Phlips and Badylak, 1996) may have far-reaching consequences on the habitat quality and restoration potential of this important ecosystem. Causes of the mortality of seagrasses have yet to be fully described, but it is clear that a pathogen (Durako and Kuss, 1994), sulfide toxicity (Carlson et al., 1994), and salinity (Zieman et al., 1999) all play some role in the mortality of the dominant seagrass in Florida Bay, *Thalassia testudinum*. In 1995, the FDEP initiated a monitoring and research program designed

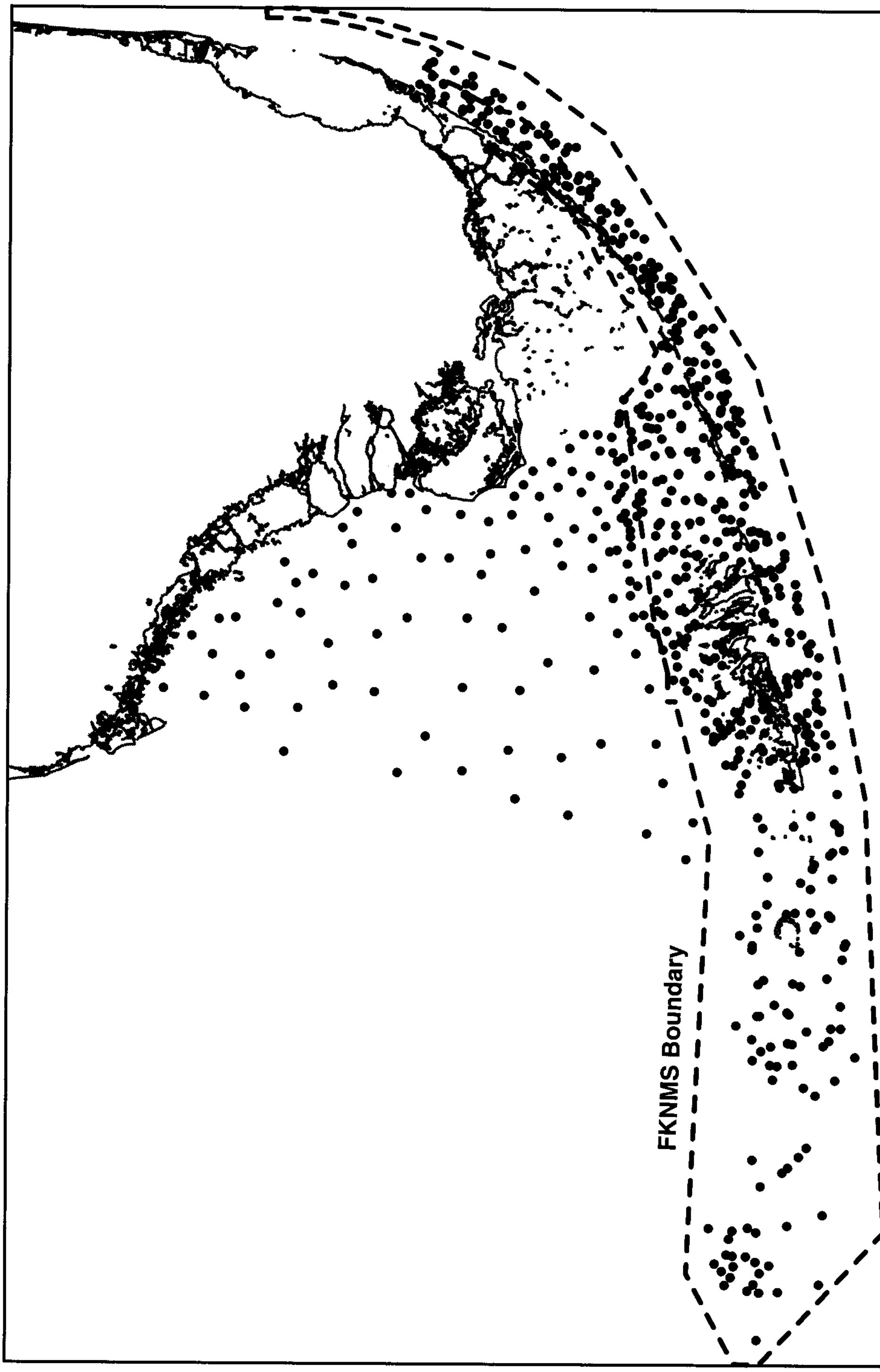

FIGURE 18.2 Station locations for the U.S. Environmental Protection Agency-funded monitoring program for determining water quality within the Florida Keys National Marine Sanctuary (FKNMS).

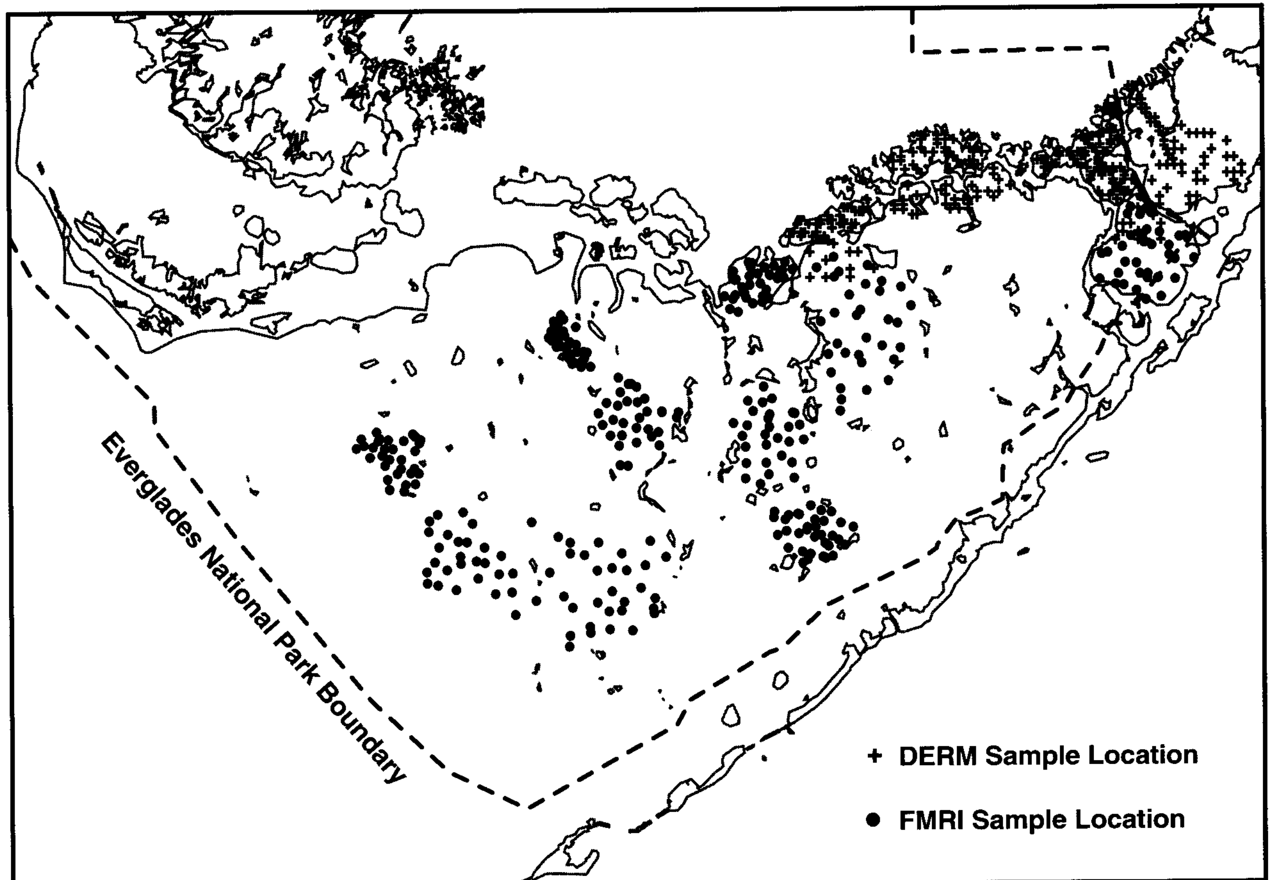

FIGURE 18.3 Station locations in Florida Bay within Everglades National Park. Filled circles are sites sampled in the Florida Department of Environmental Protection's Fish-Habitat Assessment Program (FHAP), funded by Florida DEP, the U.S. Geological Survey–Biological Resources Division, and Everglades National Park, designed to investigate the causes and consequences of seagrass dieoff in Florida Bay. Crosses indicate Miami–Dade County Department of Environmental Resources Management (DERM) sampling locations in the South Florida Water Management District/DERM-funded project investigating the consequences of changing freshwater discharge into Florida Bay on benthic communities.

to provide spatially comprehensive status and trends information on the benthic communities of Florida Bay (Figure 18.3). Trend data from this monitoring program are reported elsewhere in this volume (Durako et al., 2002).

METHODS

Plant ecologists have worked for many years to devise the best metric for describing the structural characteristics of plant communities. Each question that may be asked about community structure has its own optimal method for assessment. Moreover, the scale at which a study is being conducted also influences the sampling methods. The prime questions motivating the seagrass monitoring programs in south Florida are: (1) What species make up the seagrass beds? (2) What are the relative abundances of the species? (3) Are there spatial trends in the structure of seagrass communities? (4) Are there temporal trends in the structure of the seagrass communities? Given that the area to be assessed is *ca.* 19,000 km^2, the methods adopted for these projects required rapidity and precision, sometimes at the expense of detail. Hence, we chose to utilize a rapid, visual assessment technique developed early in the 20th century by the plant sociologist Braun–Blanquet (Braun–Blanquet, 1972). This method is very quick, requiring only minutes at each sampling site; yet, it is robust and highly repeatable, thereby minimizing among-observer differences. In this method, a series of quadrats are randomly placed on the bottom at a given location. Each quadrat is examined by a scientist using SCUBA apparatus. All species occurring in the quadrat are listed, and a ranking based on abundance of the species in that quadrat is assigned for each species. We have adopted a modified Braun–Blanquet scale for our work in south Florida (Table 18.1). Cover, as defined for this purpose, is the fraction of the total quadrat area that is obscured by a particular taxon when viewed from directly above. The only allowable scores for each taxon in each quadrat are listed in Table 18.1. The choice of quadrat size is also very important for this technique; it is important that the quadrats be of sufficient size to accurately represent the make-up of the community, yet small enough so that they may be rapidly assessed, sometime under very turbid conditions. We have found that quadrats 0.5 m on a side (0.25 m^2) work well in South Florida seagrass communities.

Slightly different methods are used to ensure an unbiased placement of sampling quadrats in the three monitoring programs. In the FKNMS program, 10 quadrats are placed at each site by locating the quadrats at predetermined random distances along a 50-m transect placed in a north–south direction at each site. In the water management and seagrass dieoff monitoring

TABLE 18.1
Braun–Blanquet Abundance Scale Used to Assess Seagrass Density[a]

Cover Class	Description
0	Absent
0.1	Solitary individual ramet, less than 5% cover
0.5	Few individual ramets, less than 5% cover
1	Many individual ramets, less than 5% cover
2	5–25% cover
3	25–50% cover
4	50–75% cover
5	75–100% cover

[a] Cover is defined as the fraction of the bottom that is obscured by the species when viewed by a diver from directly above.

programs, four sample quadrats are haphazardly placed at each site. In the SFWMD/DERM, the quadrats are placed off of the port, starboard, bow, and stern of the small boat used as a research vessel, resulting in a spacing of about 5 m between quadrats. In the seagrass dieoff program, the quadrats are placed a few meters north, south, east, and west of the site location, resulting in a similar layout of quadrats as the water management program.

From the raw observations of species cover in each quadrat at a site, a single density estimate is calculated for each plant taxon encountered in the quadrats at a site. Density is calculated as $D_i = \sum S_{ij}/N$, where D_i = density of taxon i; j = quadrat number from 1 to N, the total number of quadrats sampled at a site; and S_{ij} = the Braun–Blanquet score for taxon i in quadrat j. For any taxon, D can range between 0 and 5, the maximum Braun–Blanquet score. At a site, however, the sum of all taxa D values can actually be greater than 5. This results from the relatively broad cover ranges for each Braun–Blanquet value and the fact that seagrass canopies are three dimensional. It should also be noted that a taxon may be observed at a site by the sample collector, but unless the taxa falls within one of the randomly placed observation quadrats, the taxon receives a $D = 0$. For this reason, our methods underestimate the true areal distribution of rare taxa by defining a lower density limit for inclusion in the survey. In addition, species richness S is calculated for each site by summing the number of taxa for which $D > 0$.

When attempting to describe the distribution of habitat types in a landscape, it is important to sample in a way that allows for unbiased interpolation of the actual sample points to produce the distribution maps. This means that all points within the landscape must have an equal probability of being sampled, and that sampling effort be quasi-evenly distributed across the landscape. Yet, pure random distribution of sampling points often leads to clumped and nonuniformly distributed data points. To meet both of these requirements, we have used the stratified random method of hexagonal tesselation, developed by the U.S. EPA's EMAP program, to locate our sampling locations. The entire region to be sampled was defined and, based on the number of samples to be collected, the region was divided into hexagonal subunits. One random location was then chosen as a sample site from within each hexagonal subunit. These randomly-chosen sites are located in the field using differential global positioning systems (DGPS) which is accurate to ±5 m in South Florida.

Sites within the boundaries of the FKNMS (Figure 18.2) were sampled during the summer months of 1996 and 1997. Additionally, 100 sites were sampled in a roughly triangular area north of the FKNMS defined by Cape Romano, Key West, and Florida Bay during August 1998 as part of the FKNMS program. Data within Florida Bay were all collected in the summer of 1998 (Figure 18.3): the seagrass dieoff program sampled 378 sites, and the SFWMD/DERM program sampled 228 sites within Florida Bay.

Point data on species density were used to produce continuous maps of the density of seagrass species, as well as maps of species richness. A krigging algorithm (Watson, 1992) was used to interpolate between the random point data. A spatial analysis program (SURFER, Golden Software; Golden, CO) was used to compute areas of seagrass coverage from these interpolated surfaces.

Since no species density data were normally distributed, correlations between densities of species, and between species densities and depth were tested using the nonparametric Spearman's ρ; significances of correlations were assessed using two-tailed tests.

RESULTS

We assessed the seagrass species composition and density of 1207 sites distributed across 19,402 km^2 of nearshore marine and estuarine environments in South Florida (Figure 18.1). At these sites, a total of 8434 quadrats (0.25 m^2) were sampled, covering an area of 2108.5 m^2. At least one species of seagrass was common enough to be counted in our quadrats at 1056 of the 1207 sites, or 87.5% of all sampling sites (Table 18.2). *Thalassia testudinum*, found at 898 sites, was the most commonly encountered species. *Halodule wrightii* was the second most commonly encountered species, occurring at 459 sites, followed by *Syringodium filiforme* (239 sites), *Halophila decipiens* (96 sites), *Ruppia maritima* (41 sites) and *Halophila engelmanni* (28 sites).

Differing morphology and life-history characteristics are apparent in the comparison of the relative densities of the species (Table 18.2). With two exceptions, only *Thalassia testudinum* and *Syringodium filiforme* were found to occur at very high density ($D > 4$; 4≡ 50–75% cover; Table 18.1); 6.0% of all 1207 sites sampled had very dense cover of *T. testudinum*, and 1.8% of all sites had very dense beds of *S. filiforme*. Because seagrass beds in the region often contain more than one seagrass species, very dense beds of total seagrass cover were found at 18.1% of the sites sampled. Density greater than 4 was very rare for the seagrass species of smaller stature than *T. testudinum* and *S. filiforme*. Even the two larger species were most often found to have moderate density at most sites.

Species-specific differences in density tendency were found (Table 18.2). Restricting the analysis to only those sites where a species was found, *Thalassia testudinum* and *Syringodium filiforme* were most frequently encountered at *D* between 1 and 2, although *D* was higher and lower than this mode at a significant number of sites. The other species were almost always found at lower D: *Halodule wrightii*, *Halophila decipiens*, *Halophila engelmanni*, and *Ruppia maritima* were most commonly found to have D between 0.1 and 0.5. This lower mean D may have multiple causes. Some species, such as *H. wrightii* and *H. engelmanni*, are often found as understory plants beneath a canopy of *T. testudinum* or *S. filiforme*. Other species, like *H. decipiens* and *R. maritima*, tend to occur at the extremes of the available habitat for seagrasses, and their *D* may be limited by the environment. Because more than one species may contribute to the overall seagrass *D*, sites with seagrass were most frequently observed in the 2 to 3 density class.

The density of one species was frequently correlated with densities of other seagrasses (Table 18.3). No relationship between the density of *Thalassia testudinum* and *Syringodium filiforme* was observed, but *T. testudinum* density was positively correlated to *Halodule wrightii* density and negatively correlated to the densities of *Halophila engelmanni*, *Halophila decipiens*, and *Ruppia maritima*. *Syringodium filiforme* density was not correlated to the densities of *H. wrightii* or *H. decipiens* but was positively correlated to *H. engelmanni* density and negatively correlated to *R. maritima* density. *Halodule wrightii* density was negatively correlated with *H. decipiens* density and positively correlated with the density of *H. engelmanni* and *R. maritima*. *Halophila decipiens* and *R. maritima* densities were negatively correlated, while no significant relationship between the densities of the two congeners of *Halophila* was found. No significant relationship was present between *H. engelmanni* and *R. maritima*, most likely due to the small number of stations where either species occurred.

Water depth was significantly related to the densities of all seagrass species except for *Halophila engelmanni* (Table 18.3). Densities of *Thalassia testudinum*, *Halodule wrightii*, and *Ruppia maritima* were higher in shallow water, while *Syringodium filiforme* and *Halophila decipiens* densities were higher in deeper water. Owing to the coastal nature of the region surveyed, shallow sites were much more common than deep sites. 43% of all of the sites fell within the depth range of 0 to 2 m; fewer than 10% of the sites were deeper than 10 m (Table 18.4). The likelihood of finding *T. testudinum* at a site decreased as site depth increased. More than 80% of sites shallower than 4 m supported *T. testudinum*. While *H. wrightii* was most likely to be encountered at the shallowest sites, a significant number of relatively deep stations also supported this species. *Ruppia maritima* was restricted to only those sites shallower than 2 m. *Syringodium filiforme* was much less common at the shallowest sites than at mid-depth sites; it was particularly common in the depth range 6 to 8 m; 45.6% of all sites in this depth class supported *S. filiforme*. *Halophila decipiens*, in contrast, was absent from the shallowest sites, but was found at over 50% of all sites sampled that were deeper than 18 m. *Halophila engelmanni* presence showed no clear relationship with water depth.

With the exception of *Ruppia maritima*, the seagrass species had similar ranges of depth of occurrence, but clear differences existed in the median depth at which each species was recorded (Table 18.5). *Ruppia maritima* was never found deeper than 1.4 m, with a median depth of 0.9 m.

TABLE 18.2
Distribution of Seagrass Density (D) at the 1207 Sampling Sites

	Density Class (D)								
Species	**0**	**$0 < D \le 0.1$**	**$0.1 < D \le 0.5$**	**$0.5 < D \le 1$**	**$1 < D \le 2$**	**$2 < D \le 3$**	**$3 < D \le 4$**	**$4 < D \le 5$**	**$D > 5$**
Number of Sites									
Thalassia testudinum	309	33	116	111	240	201	124	73	0
Syringodium filiforme	968	24	32	44	70	25	22	22	0
Halodule wrightii	748	56	162	76	109	43	12	1	0
Halophila decipiens	1111	27	26	11	13	11	7	1	0
Halophila engelmanni	1179	11	12	3	2	0	0	0	0
Ruppia maritima	1166	2	18	10	9	2	0	0	0
Σ D for all seagrasses	151	32	80	79	223	233	190	155	64
Fraction of All Sites Sampled (%)									
Thalassia testudinum	25.6	2.7	9.6	9.2	19.9	16.7	10.3	6.0	0.0
Syringodium filiforme	80.2	2.0	2.7	3.6	5.8	2.1	1.8	1.8	0.0
Halodule wrightii	62.0	4.6	13.4	6.3	9.0	3.6	1.0	0.1	0.0
Halophila decipiens	92.0	2.2	2.2	0.9	1.1	0.9	0.6	0.1	0.0
Halophila engelmanni	97.7	0.9	1.0	0.2	0.2	0.0	0.0	0.0	0.0
Ruppia maritima	96.6	0.2	1.5	0.8	0.7	0.2	0.0	0.0	0.0
Σ D for all seagrasses	12.5	2.7	6.6	6.5	18.5	19.3	15.7	12.8	5.3
Fraction of Sites Where Species Occurs (%)									
Thalassia testudinum		3.7	12.9	12.4	26.7	22.4	13.8	8.1	0.0
Syringodium filiforme		10.0	13.4	18.4	29.3	10.5	9.2	9.2	0.0
Halodule wrightii		12.2	35.3	16.6	23.7	9.4	2.6	0.2	0.0
Halophila decipiens		28.1	27.1	11.5	13.5	11.5	7.3	1.0	0.0
Halophila engelmanni		39.3	42.9	10.7	7.1	0.0	0.0	0.0	0.0
Ruppia maritima		4.9	43.9	24.4	22.0	4.9	0.0	0.0	0.0
Σ D for all seagrasses		3.0	7.6	7.5	21.1	22.1	18.0	14.7	6.1

TABLE 18.3
Correlations (Nonparametric Spearman's ρ) Between Densities of Seagrass Species and Both Seagrass Species Density and Water Depth from the 1207 Seagrass Sampling Sites[a]

	Depth	*T. testudinum*	*S. filiforme*	*H. wrightii*	*H. decipiens*	*H. engelmanni*	*R. maritima*
Water depth	—	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	0.734	**< 0.001**
Thalassia testudinum	**−0.350**	—	0.580	**0.005**	**< 0.001**	**0.014**	**< 0.001**
Syringodium filiforme	**0.291**	0.016	—	0.092	0.953	**0.034**	**0.001**
Halodule wrightii	**−0.451**	**0.080**	−0.049	—	**0.006**	**< 0.001**	**< 0.001**
Halophila decipiens	**0.317**	**−0.314**	−0.002	**−0.079**	—	.0251	**0.050**
Halophila engelmanni	0.010	**−0.071**	**0.061**	**0.176**	**0.033**	—	0.316
Ruppia maritima	**−0.262**	**−0.129**	**−0.092**	**0.226**	**−0.058**	−0.029	—

[a] Correlation coefficients are below the diagonal; (—) 2-tailed significances are above the diagonal. Significant correlations ($p \leq 0.05$) are in boldface type.

TABLE 18.4
Frequency of Encountering Seagrass Species as a Function of the Depth of the Sample Site

Depth Interval (m)	Number of Sites	Percent of Sites Occupied by						
		Thalassia testudinum	*Syringodium filiforme*	*Halodule wrightii*	*Halophila decipiens*	*Halophila engelmanni*	*Ruppia maritima*	Any Species
0–2	518	83.0	6.4	60.2	0.0	2.9	7.1	95.0
2–4	301	89.0	24.3	29.6	6.0	2.7	0.0	96.0
4–6	121	61.2	37.2	17.4	21.5	0.8	0.0	81.8
6–8	114	68.4	45.6	21.1	11.4	0.0	0.0	78.9
8–10	64	50.0	31.3	6.3	14.1	0.0	0.0	64.1
10–12	36	27.8	27.8	16.7	25.0	5.6	0.0	55.6
12–14	18	11.1	11.1	0.0	16.7	0.0	0.0	27.8
14–16	12	25.0	16.7	8.3	41.7	8.3	0.0	58.3
16–18	10	10.0	20.0	10.0	40.0	0.0	0.0	40.0
18–20	7	0.0	0.0	14.3	57.1	14.3	0.0	57.1
20–22	1	0.0	0.0	0.0	100.0	0.0	0.0	100.0
22–24	0	nd	nd	nd	nd	nd	nd	nd
24–26	4	0.0	0.0	0.0	75.0	0.0	0.0	75.0
26–28	1	0.0	0.0	0.0	100.0	0.0	0.0	100.0

Note: nd = no data.

TABLE 18.5
Depth Range of Sample Sites Where the Six Seagrass Species Were Collected

Species	*n*	Min. Depth	Max. Depth	Mean Depth	Median Depth
Thalassia testudinum	898	0.2	18.0	3.0	2.1
Syringodium filiforme	239	0.9	18.0	5.1	4.6
Halodule wrightii	460	0.2	18.6	2.3	1.4
Halophila decipiens	96	2.4	26.5	8.7	6.2
Halophila engelmannii	28	1.4	18.3	3.9	1.9
Ruppia maritima	41	0.4	1.4	0.9	0.9

Thalassia testudinum and *Syringodium filiforme* were found to have the same maximum depth of 18.0 m, but the median depth for *T. testudinum*, 2.1 m, was shallower than the median depth for *S. filiforme*, 4.6 m. *Halodule wrightii* penetrated slightly deeper in the water column, with a maximum depth of 18.6 m, but the median depth of 1.4 m illustrates the fact that it was most commonly found in shallow water. *Halophila engelmanni* was similar to *H. wrightii* in maximum and median depth. *Halophila decipiens* showed a much different pattern with respect to depth; it was found as deep as 26.5 m, with a median depth of 6.2 m.

Many (47.6%) of the 1207 sampled sites supported more than one species of seagrass (Figure 18.4). Even though it was relatively common for seagrass species to co-occur, a slim plurality (40.0%) of the 1207 sites supported only 1 seagrass species. Two seagrasses were found at 37.8% of all sites. Higher species richness was uncommon; three species were found at 8.6% of sites, and only 1.2% of sites had four or more species. No clear spatial pattern in species richness was apparent; relatively diverse (>3 species) seagrass beds were found on both the Atlantic Ocean and Gulf of Mexico sides of the Florida Keys (Figure 18.5). The only 2 sites with five species (*Thalassia testudinum*, *Syringodium filiforme*, *Halodule wrightii*, *Halophila decipiens*, and *Halophila engelmanni*) were found within the Dry Tortugas National Park.

Because sampling intensity varied spatially due to different goals of the three monitoring programs, frequency of occurrence data (Table 18.2) cannot be used directly to calculate the relative importance, in terms of area, of the six seagrass species in south Florida. Instead, maps of the occurrence of each species were analyzed for their areal extent. *Thalassia testudinum* was the most common seagrass in the sampling region. Density of *T. testudinum* was highest in Florida Bay, in the area between the upper Florida Keys and the reef tract, and in the shallow, protected waters north and west of Key West (Figure 18.6). In all, 8482 km^2 of *T. testudinum* beds were mapped, which was 43.7% of the 19,402 km^2 survey area. Roughly half of this total area was made up of very sparse *T. testudinum* cover: 3927 km^2 of the *T. testudinum* area had $D < 1$ (Table 18.6).

Second to *Thalassia testudinum* in terms of areal extent was *Halophila decipiens*, which was found to cover 7410 km^2, or 38.2% of the survey area (Table 18.6). In contrast to *T. testudinum*, however, *H. decipiens* was found predominantly in the waters of the southwest Florida Shelf, to the west of the Florida Mainland and to the north of the FKNMS (Figure 18.7). Most of this coverage consists of low-density seagrass beds: Of the 7410 km^2 of total area, 4652 km^2 consisted of areas where $D < 1$. Only rarely did *H. decipiens* form very dense beds; the area for which $D > 3$ was less than 1% of the total area surveyed.

Syringodium filiforme was also commonly encountered and was found to cover 4879 km^2. While *Thalassia testudinum* had the highest density immediately adjacent to the Florida Keys and in Florida Bay (Figure 18.6), *S. filiforme* density generally increased in an offshore direction until reaching the reef tract (Figure 18.8). A very dense bed of *S. filiforme* dominated the area to the north of the middle Florida Keys, north of Marathon and west of Florida Bay, encompassing about 350 km^2. Most of the area that supported *S. filiforme* had sparse cover; 3537 km^2 of the total area of *S. filiforme* had $D < 1$ (Table 18.6).

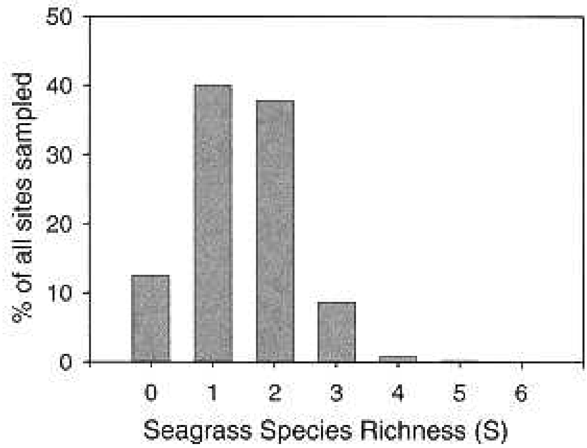

FIGURE 18.4 Frequency histogram of the Species Richness, *S*, at sampling locations. *S* is defined as the number of seagrass species occurring at a station (see text).

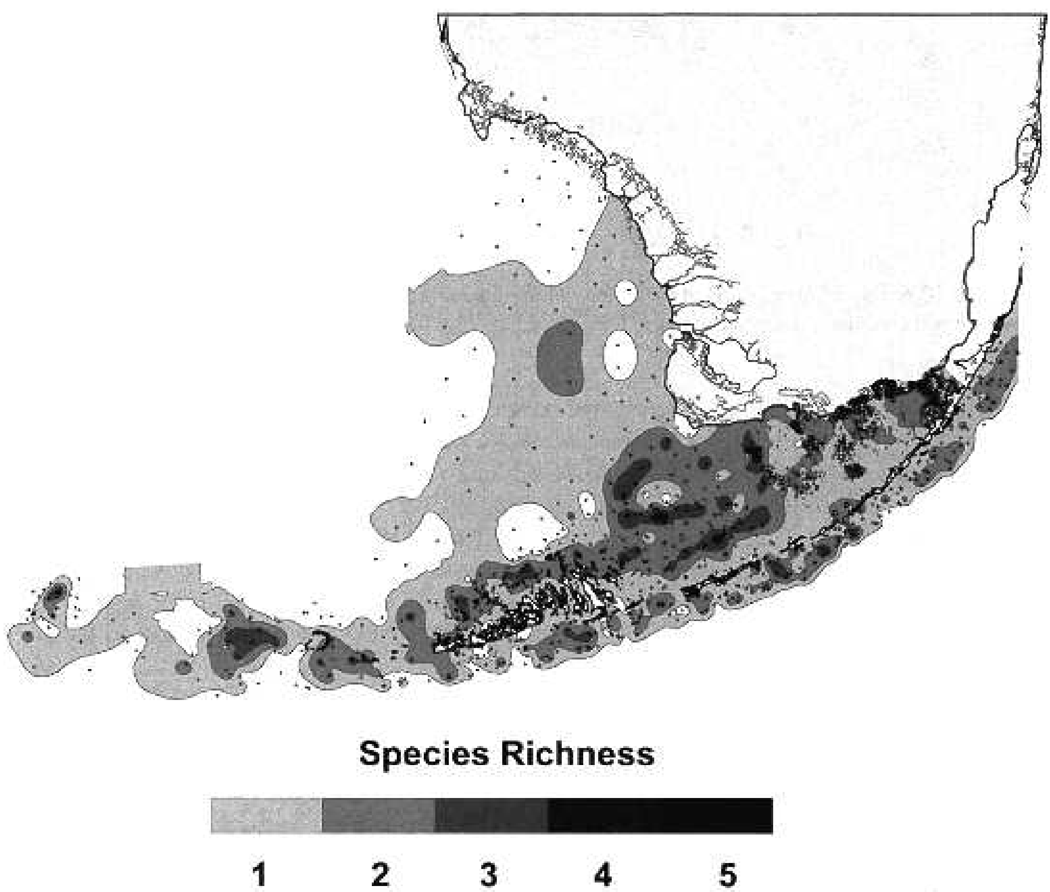

FIGURE 18.5 Spatial distribution of species richness of seagrass beds across the South Florida hydroscape. Small crosses indicate sampling points.

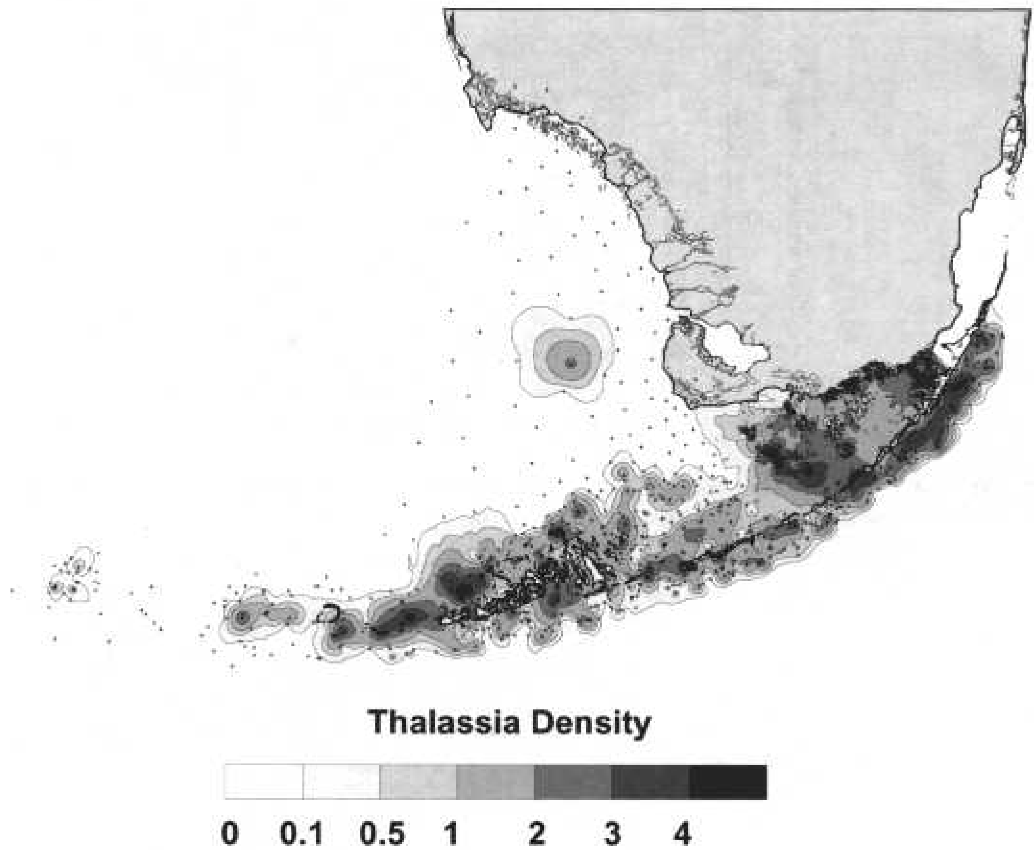

FIGURE 18.6 Spatial distribution of the density of *Thalassia testudinum* across the South Florida hydroscape. Small crosses indicate sampling points. Density scale is in Braun–Blanquet density units (see text and Table 18.1).

The only other species of seagrass that covered a large proportion of the surveyed area was *Halodule wrightii*; it occupied 3540 km^2, or 18.2% of the surveyed area. While *H. wrightii* was found sporadically throughout the region, it was most common in Florida Bay, on the Gulf of Mexico side of the Florida Keys, and in an area west of Key West known as the Quicksands (Figure 18.9). Of all of the area supporting *H. wrightii*, 83% had $D < 1$. The other two species encountered, *Halophila engelmanni* and *Ruppia maritima*, were found to be very limited in spatial extent. In the extreme upper estuaries of Florida Bay, *R. maritima* occupied 73 km^2 (Figure 18.10). *Halophila engelmanni* was occasionally observed, found in 143 km^2 scattered around the survey area (Figure 18.10).

The individual species distributions combine to produce a very large area of almost continual seagrass cover (Figure 18.11). 75.4% of the total surveyed area supported seagrasses, resulting in a total area of seagrass beds in the region of 14,622 km^2 (Table 18.6). Of this total area, 5197 km^2 was very sparse, with $D < 1$. Most of these sparse areas were dominated by *Halophila decipiens*, such as the southwest Florida Shelf area north of Key West and the relatively deep water between the Quicksands and Dry Tortugas National Park. The densest areas of seagrass were generally on the Gulf of Mexico side of the Florida Keys. On the Atlantic Ocean side of the Keys, seagrass beds were more dense in the Upper Keys than farther west.

TABLE 18.6
Area Inventory of Seagrass Species in the Surveyed Region[a]

Species	Density Class (D)							
	$0 \le D \le 0.1$	$0.1 < D \le 0.5$	$0.5 < D \le 1$	$1 < D \le 2$	$2 < D \le 3$	$3 < D \le 4$	$D > 4$	$D > 0.1$
Area in a Density Class (km²)								
Thalassia testudinum	10920	2193	1734	2657	1370	472	55	8482
Syringodium filiforme	14523	2421	1116	718	249	196	179	4879
Halodule wrightii	15862	2163	772	554	49	1	0	3540
Halophila decipiens	11992	2984	1668	1838	780	138	2	7410
Halophila engelmanni	19259	132	10	1	0	0	0	143
Ruppia maritima	19329	43	20	10	0	0	0	73
ΣD for all seagrasses	4780	3052	2145	4183	3112	1473	657	14622
Fraction of Surveyed Area (%)								
Thalassia testudinum	56.3	11.3	8.9	13.7	7.1	2.4	0.3	43.7
Syringodium filiforme	74.9	12.5	5.8	3.7	1.3	1.0	0.9	25.1
Halodule wrightii	81.8	11.1	4.0	2.9	0.3	0.0	0.0	18.2
Halophila decipiens	61.8	15.4	8.6	9.5	4.0	0.7	0.0	38.2
Halophila engelmanni	99.3	0.7	0.0	0.0	0.0	0.0	0.0	0.7
Ruppia maritima	99.6	0.2	0.1	0.1	0.0	0.0	0.0	0.4
ΣD for all seagrasses	24.6	15.7	11.1	21.6	16.0	7.6	3.4	75.4

[a] Total area of the survey was 19,402 km² (Figure 11.1).

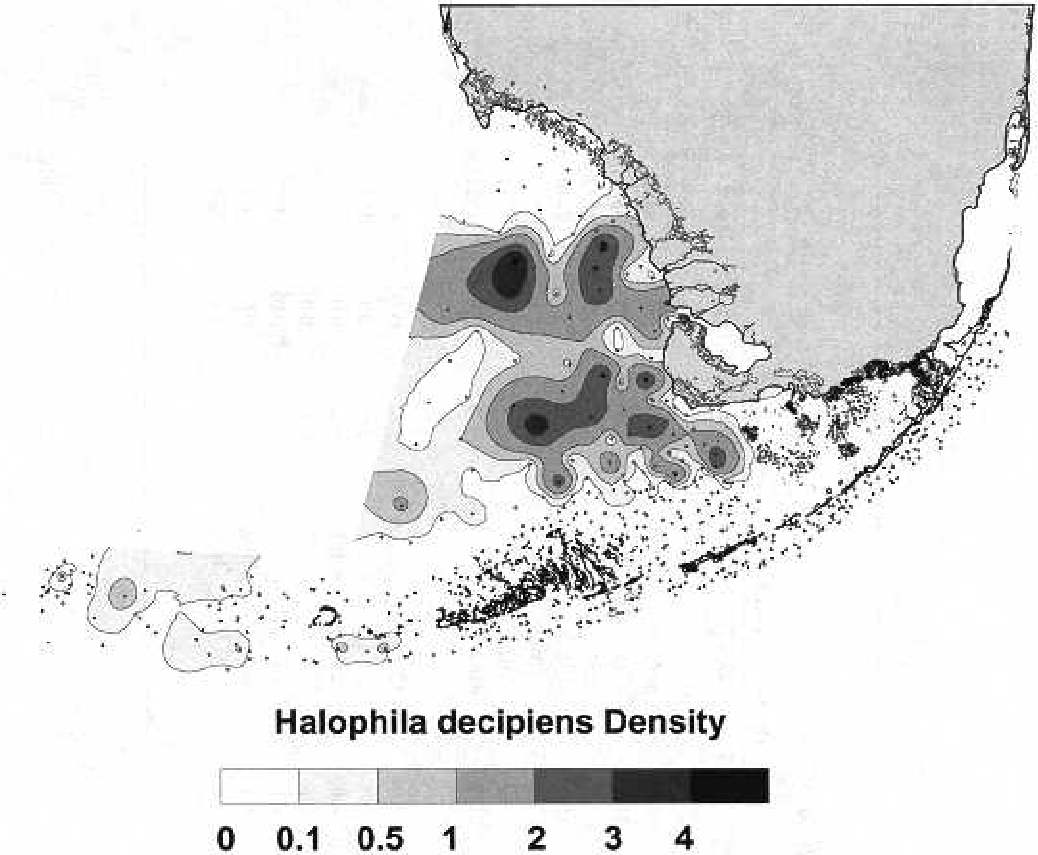

FIGURE 18.7 Spatial distribution of the density of *Halophila decipiens* across the South Florida hydroscape. Small crosses indicate sampling points. Density scale is in Braun–Blanquet density units (see text and Table 18.1).

DISCUSSION

The 14,622 km^2 of seagrasses in South Florida ranks this area among the most expansive documented seagrass beds on Earth, comparable to the back-reef environment of the Great Barrier Reef in Australia (Lee Long et al., 1996) and the Miskito Bank of Nicaragua (Phillips et al., 1982). Accordingly, the economic impact and ecological importance of the South Florida seagrass beds are significant (Zieman, 1982). Fisheries landings in the Florida Keys total over $12 \cdot 10^6$ kg annually of mostly seagrass-associated organisms (Bohnsack et al., 1994), and over half of all employment in the Florida Keys is dependent on outdoor recreation (NOAA, 1996). For the larger part, these outdoor activities are reliant on the clear waters and healthy marine habitats of the marine environment.

Proper environmental stewardship requires accurate data on the present state of resources. Prior to the initiation of the three monitoring programs that supplied data for this chapter, there was only a general understanding of the magnitude and composition of the seagrass beds of South Florida. Our work has provided baseline data that will be required for assessing the efficacy of management of the marine environment in South Florida. In terms of areal extent, seagrasses are, by far, the most commonly encountered habitat type in the survey area. At 87.5% of randomly selected stations, at least one species of seagrass was present; on an areal basis, this translated to seagrass present over 75.4% of the surveyed area. The remaining area was predominantly unvegetated soft-bottom

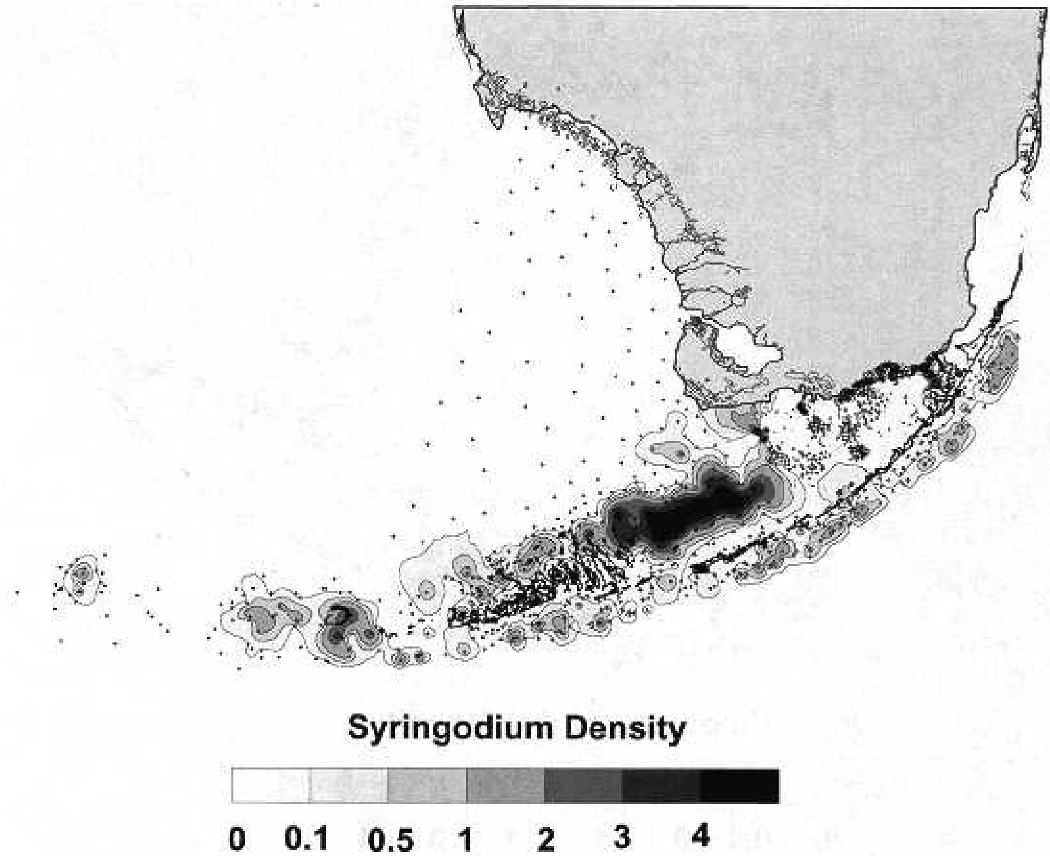

FIGURE 18.8 Spatial distribution of the density of *Syringodium filiforme* across the South Florida hydroscape. Small crosses indicate sampling points. Density scale is in Braun–Blanquet density units (see text and Table 18.1).

communities. Coral reef communities, while in many respects the most valued and visible benthic habitat type in the region, make up only a small percentage of the total bottom cover in the survey area (Porter, 2002).

Analyses of the spatial scope required for this assessment are often impossible because of the magnitude of the task of collecting the data and because of overlapping jurisdictional boundaries. Careful coordination between management agencies and research groups ensured that data collected by different principle investigators, for different goals funded by different agencies, could be pooled and analyzed as a whole. This type of cooperation should serve as a model to other groups embarking on the assessment of resources over large geographic ranges.

In the nearshore environments of the survey area, *Thalassia testudinum* was the dominant seagrass. *T. testudinum* may be limited to shallow water because of its high light requirement. This requirement is a consequence of its relatively low proportion of leaves to roots and rhizomes compared to the other seagrass species found in the area (Fourqurean and Zieman, 1991). Nutrient availability also plays a role in *T. testudinum* distribution. This species is the competitive dominant in the high-light, low-nutrient environment of Florida Bay (Fourqurean et al., 1995). Phosphorus availability, which limits the biomass of *Thalassia testudinum*, increases from east to west in Florida Bay (Fourqurean et al., 1992; Fourqurean et al., 1993); it also increases from onshore to offshore on the ocean side of the Florida Keys (Szmant and Forrester, 1996). Experimental increases in phosphorus availability have resulted in other seagrasses outcompeting *T. testudinum* and become

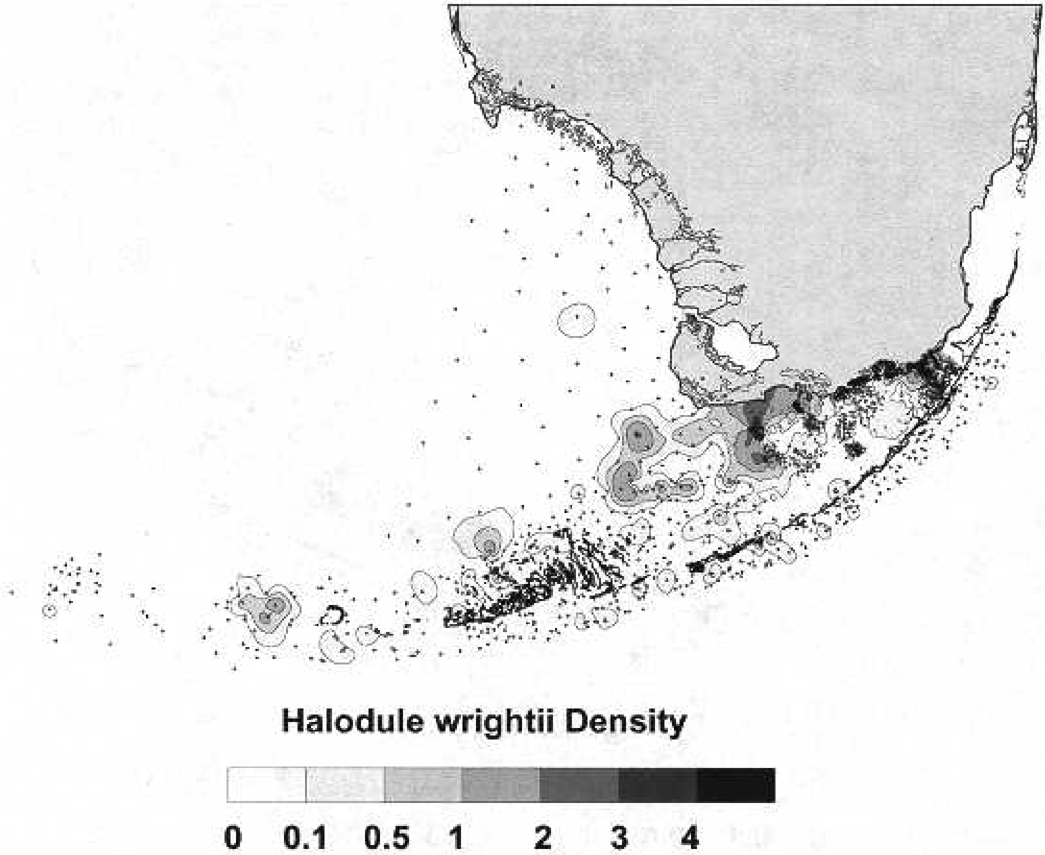

FIGURE 18.9 Spatial distribution of the density of *Halodule wrightii* across the South Florida hydroscape. Small crosses indicate sampling points. Density scale is in Braun–Blanquet density units (see text and Table 18.1).

dominant (Fourqurean et al., 1995). We hypothesize that the increase in the abundance of *Syringodium filiforme* with distance from shore, as well as the very dense bed of *S. filiforme* north of Marathon, may be partially a response to relatively high phosphorus availability. Only in areas of relatively high phosphorus availability can *S. filiforme* outcompete *T. testudinum*. This hypothesis remains to be confirmed by experimental manipulation.

Interspecific differences in light requirements allow some species of seagrasses to grow in deeper water than others. Most seagrass genera have a minimum light requirement of >10% of surface irradiance (Duarte, 1991). Species in the genus *Halophila*, however, are often found in waters deeper than species of other genera (e.g., Lee Long et al., 1996), suggesting that *Halophila* spp. have lower light requirements. The median depth of sites that supported *H. decipiens* was 6.2 m, compared to 4.6 m for *S. filiforme* and 2.1 m for *Thalassia testudinum*. This lower light requirement of *Halophila* spp. is probably the factor responsible for the expansive beds of *H. decipiens* that we documented in the deeper water areas of our survey area. These areas are deep enough to prevent adequate light from reaching the bottom to support the larger species *Thalassia testudinum* and *Syringodium filiforme*. Of interest is the observation that *H. decipiens* was completely absent from shallow (<2.4 m) areas. Without experimental evidence, we can only hypothesize that *H. decipiens* is competitively displaced from higher light environments by other seagrass species. In contrast to *H. decipiens*, median depth for *H. engelmanni* was a relatively shallow 1.9 m. We never found extensive meadows dominated by *H. engelmanni*; instead, it was

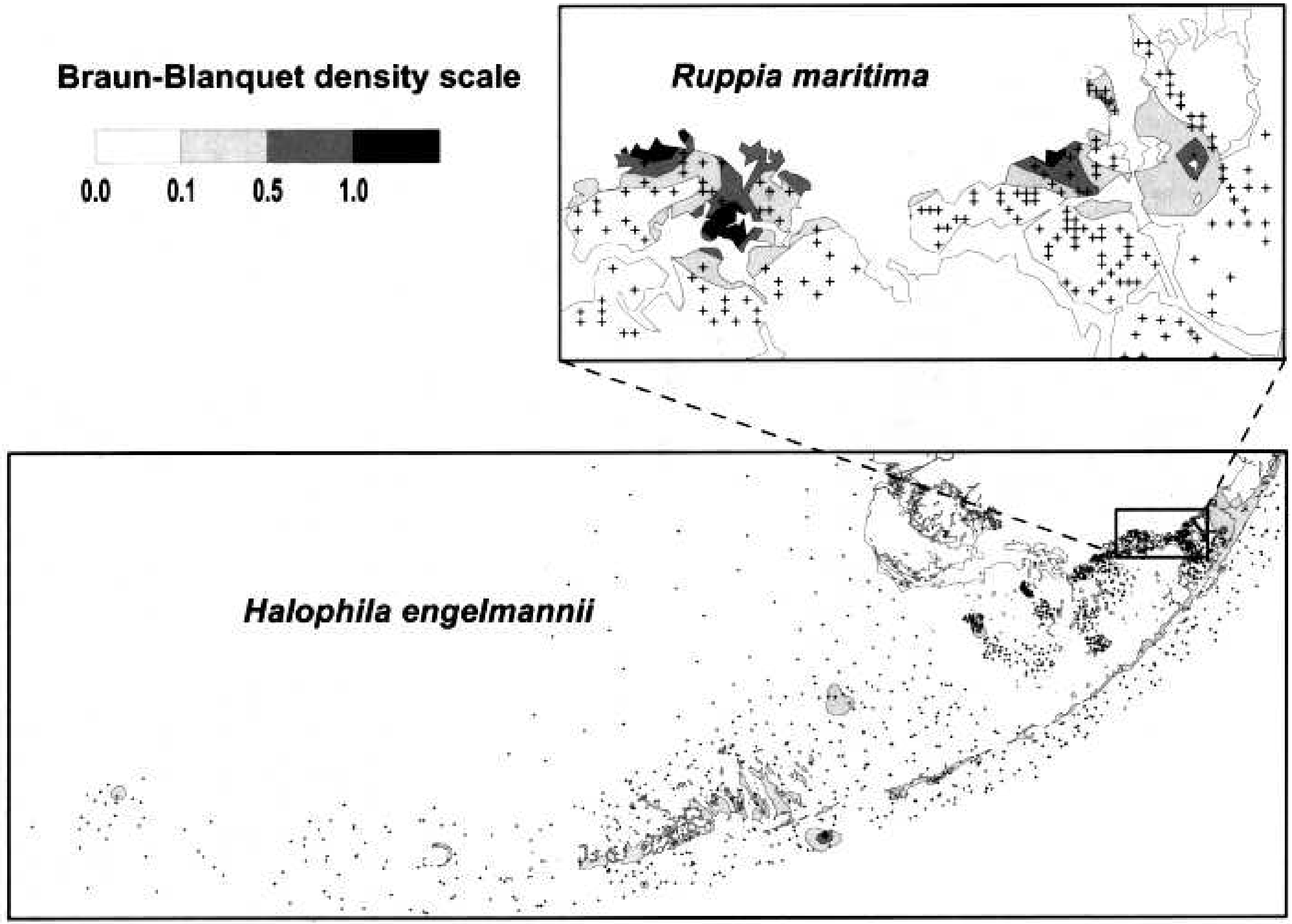

FIGURE 18.10 Spatial distribution of the density of *Halophila engelmanni* (main map) and *Ruppia maritima* (inset) across the South Florida hydroscape. Small crosses indicate sampling points. Density scale is in Braun–Blanquet density units (see text and Table 18.1).

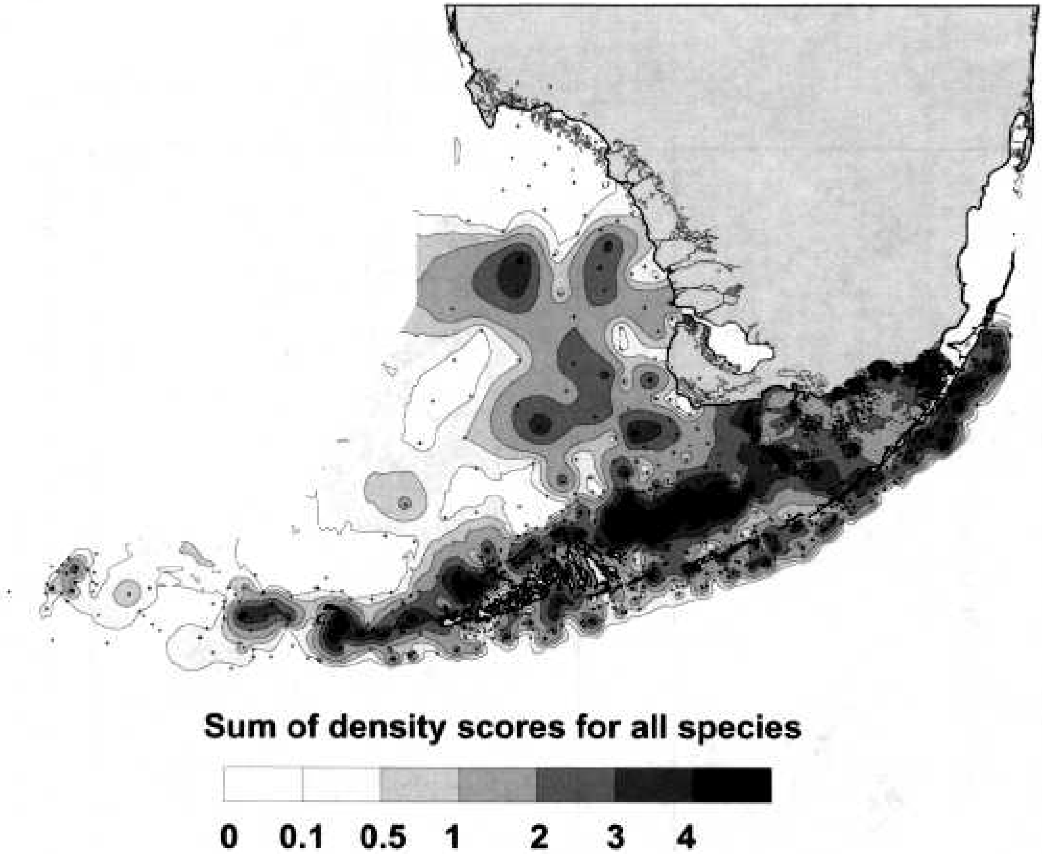

FIGURE 18.11 Spatial distribution of the sum of the density scores for all seagrass species across the South Florida hydroscape. Small crosses indicate sampling points. Density scale is in Braun–Blanquet density units (see text and Table 18.1).

encountered as a sparse understory species, generally associated with denser beds of *Syringodium filiforme* and *Halodule wrightii*. It is probable that the generally low light requirements of *Halophila* spp. allow *H. engelmanni* to exist as an understory plant, but what is not clear are the life-history differences between *H. decipiens* and *H. engelmanni* that allow *H. engelmanni* to be a successful understory species, while its congener *H. decipiens* rarely occurs as an understory. Also, the minimum light requirements for *H. engelmanni* do not appear to be any greater than those for *H. decipiens*, as *H. engelmanni* has been documented growing at 90-m depth within the study area (den Hartog, 1970). Thus, it is unclear why *H. decipiens* is a meadow-former in deep water, while *H. engelmanni* is not.

While *Halophila* species were restricted to areas of truly marine, near-constant salinity, the other seagrass species were also found in Florida Bay, where salinity is strongly influenced by runoff from mainland Florida and by exchange of oceanic water with the Gulf of Mexico. Florida Bay can be either hypo- or hypersaline, depending on location, season, and year. Deviations from normal seawater salinity are deleterious to most seagrasses, but there is apparently a range in tolerances of species to salinity variation. Of the non-*Halophila* species, *Ruppia maritima* is the most tolerant of hyposalinity events; it is so tolerant of freshwater that it is often found growing in completely freshwater. This fact has led some authors (e.g., den Hartog, 1970) to exclude *R. maritima* from membership within the polyphyletic group of seagrasses. Of the remaining species encountered in our surveys, *Halodule wrightii* is the most tolerant of salinity fluctuation, *Thalassia* *testudinum* has intermediate tolerance, and *Syringodium filiforme* is the least tolerant (McMillan and Moseley, 1967). The extreme northeastern portions of Florida Bay are subject to very large salinity variability; the salinity range for the period 1991–1994 for northeast Florida Bay was 50‰ (Frankovich and Fourqurean, 1997). It is likely that this salinity variation limits the ability of all species but *R. maritima* to flourish in the extreme northeastern parts of Florida Bay. It is not clear, however, why *R. maritima* is not often found in other parts of the survey area. From distributional evidence around point sources of nutrients in Florida Bay, nutrient availability may have a role in determining *R. maritima* distribution. Adjacent to point sources of phosphorus, *R. maritima* dominates the benthic flora; farther from the point sources, *H. wrightii* and *T. testudinum* dominate (Powell et al., 1991). These authors interpreted these observations as evidence that *R. maritima* can only compete with other seagrass species in high-nutrient areas or where salinity variability limits the other species.

It has been suggested that changing water management practices on mainland Florida have led to changes in distribution of seagrasses in Florida Bay. Surveys of Florida Bay from the mid-1970s recorded large areas in central and eastern Florida Bay that were dominated by *Halodule wrightii* (Schmidt, 1979), yet these areas were reported to be dominated by *Thalassia testudinum* in the 1980s (Zieman et al., 1989), and were dominated by *T. testudinum* in our surveys. Zieman (1982) speculated that these changes were the result of changes in timing and amount of freshwater runoff.

Concerns for the state of the seagrass beds of South Florida are well founded. While currently the seagrass beds are nearly continuous and apparently healthy, there is cause for alarm. Localized cases of coastal eutrophication have led to loss of seagrasses in the study area (Lapointe et al., 1990; Tomasko and Lapointe, 1991; Lapointe and Clark, 1992; Lapointe et al., 1994). Seagrass dieoff in Florida Bay is still poorly understood (Fourqurean and Robblee, 1999), and the increase in turbidity that followed the dieoff continues to effect change in western Florida Bay (Hall et al., 1999; Durako et al., 2002). We now have the baseline data against which to measure future changes in these communities.

The present distribution and species composition of seagrasses in South Florida is a result of the interaction of many factors, the most important being water depth, water clarity, and nutrient availability. Changes in the movement and quality of water in the region, whether natural or anthropogenic, are likely to cause changes in the large-scale patterns in abundance and composition of these seagrass beds. Because nearshore oceanic water quality is determined by the interaction of coastal influences, marine influences, and human activities, it is clear that proper management of seagrass beds in South Florida requires holistic knowledge of the entire hydroscape of south Florida. Timing and amounts of freshwater runoff can change coastal salinity. Degradation of water quality of the freshwater runoff can directly effect nutrient availability and water clarity. Restriction of water exchange with the open ocean can alter salinity patterns and nutrient availability. Anthropogenic actions both in the marine and mainland realms can change nutrient availability and water clarity. Because any of these actions has the potential to alter the seagrasses of South Florida, all of these activities must be managed to ensure the continued existence of the seagrass communities in their current state. It is also likely that the first symptoms of a changing coastal environment will be a change in species composition of seagrass beds, not a wholesale loss of seagrass cover (e.g., Hall et al., 1999; Durako et al., 2002). For this reason, accurate data on the species composition of the seagrass communities must be collected periodically as a measure of the state of the coastal environment.

CONCLUSIONS

Seagrass beds are an important, often dominant component in many coastal marine environments; however, there are few locations in the world where seagrasses are as dominant in the hydroscape as in South Florida. Because of the close proximity between human activities and seagrass communities, seagrass beds are being increasingly threatened in many locations worldwide. Seagrass beds are being lost due to the combined effects of dredging, filling, and water quality degradation throughout their range. Often, habitat degradation is only recognized after a vital resource is lost or severely altered. In South Florida, the importance of seagrasses to the economic vitality and ecological integrity of the region has long been recognized; this recognition has led to the development of coordinated seagrass monitoring programs involving government agencies from federal, state, and local levels; academic institutions; and private-sector environmental groups. While smaller scale seagrass declines have been documented, these monitoring programs have been largely implemented *before* regional-scale habitat degradation has severely affected the distribution of seagrasses. The data from these monitoring efforts provide a baseline view of the distribution and abundance of seagrasses of the region that is without precedent.

Clear jurisdictional boundaries in the seagrass-supporting marine areas of South Florida provide both a help and a hindrance to the development of an integrated seagrass monitoring effort. These jurisdictional boundaries — National Marine Sanctuaries, National Parks, National Wildlife Refuges, state waters, state parks, county parks, etc. — clearly define the entity in government that is responsible for proper environmental stewardship and set up clear areas of responsibility. Delineation can also be to the detriment of a coordinated effort, as governmental agencies have independent staffs and differing mandates, often leading to disparities among science and monitoring programs. Because the components of the hydroscape do not respect political boundaries, many resources occur across multiple jurisdictions. Further, the environmental factors controlling the distribution of resources also do not respect jurisdictional boundaries. The regional, cross-ecosystem nature of environmental phenomena make a coordinated effort paramount if proper data are to be collected to address questions of environmental sustainability.

Funding agencies, management groups, and university scientists in South Florida have recognized the need for complementary monitoring of seagrass ecosystems. Three major seagrass monitoring efforts are ongoing: a U.S. EPA-funded program addressing status and trends of seagrasses within the Florida Keys National Marine Sanctuary; a State of Florida–U.S. Department of Interior (U.S. Geological Survey and Park Service)-funded program assessing the seagrass communities of Florida Bay; and a program funded by the South Florida Water Management District and Miami-Dade County that concentrates on seagrass distribution in the upper estuaries of Florida Bay. Together, these programs are producing regional scale maps of the distribution of benthic marine habitats over a 19,402-km^2 area. Seagrasses were found to occur in 75.4% of this total area, or 14,622 km^2.

ACKNOWLEDGMENTS

Monitoring projects of this size would not be possible if not for the hard field and laboratory work of a legion of people. On the FKNMS project, Braxton Davis, Cassie Furst, Leanne Rutten, Brad Peterson, Craig Rose, and Alan Willsie did the lion's share of the field work. The project was greatly facilitated by Captain Dave Ward and the *R/V Magic*. The U.S. Environmental Protection Agency provided funding for the FKNMS through cooperative agreement X994620-94 with Florida International University. The Florida Bay Fish-Habitat Assessment Program (FHAP) has benefited from field and lab assistance from Donna Berns, Scott Daeschner, Nancy Diersing, Scott Fears, Jeff Hall, Manuel Merello, Erica Moulton, and Leanne Rutten. Financial and logistical support for FHAP was provided by the Florida Department of Environmental Protection (#3720-2060-204 D1), U.S. Geological Survey (#98HQAG2186), and Everglades National Park. For the SFWMD/DERM program, Jason Bacon, Forrest Shaw, Kenneth Liddell, Susan Kim, and Martin Roch conduct all of the field work and assist with data management. They are recognized for their commitment and hard work in conducting this program. Cecelia Weaver is SFWMD's project manager and is recognized for her continued guidance and support of this program. This is contribution number 154 of the Southeast Environmental Research program at Florida International University.

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