FLORIDA KEYS NATIONAL MARINE SANCTUARY

WATER QUALITY PROTECTION PROGRAM

SEAGRASS STATUS AND TRENDS MONITORING

ANNUAL REPORT
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Volume I

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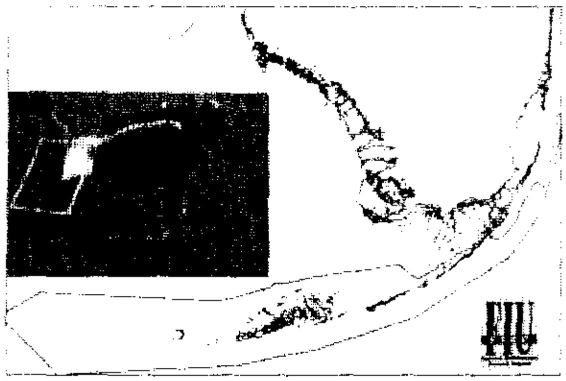

Seagrass Status and Trends Monitoring Program

EPA Water Quality Protection Program for the Florida Keys National Marine Sanctuary

Executive Summary - FY 1998

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PROJECT OVERVIEW

The general objective of seagrass monitoring in the Florida Keys National Marine Sanctuary (FKNMS) is to measure the status and trends of seagrass communities to evaluate progress toward protecting and restoring the living marine resources of the Sanctuary. The scope and depth of this monitoring effort are without precedent or peer for seagrass ecosystems throughout the world. Specific objectives are: 1) To provide data needed to make unbiased, statistically rigorous statements about the status and temporal trends of seagrass communities in the Sanctuary as a whole and within defined strata; 2) To help define reference conditions in order to develop resource-based water quality standards; and 3) To provide a framework for testing hypothesized pollutant fate/effect relationships through process-oriented research and monitoring. In order to meet these objectives, we have developed these goals for the project:

- Define the present distribution of seagrasses within the FKNMS
- Provide high-quality, quantitative data on the status of the seagrasses within the FKNMS
- Quantify the importance of seagrass primary production in the FKNMS
- Define the baseline conditions for the seagrass communities
- Determine relationships between water quality and seagrass status
- Detect trends in the distribution and status of the seagrass communities

To reach these goals, four kinds of data are being collected in seagrass beds in the FKNMS:

- Distribution and abundance of seagrasses using rapid assessment Braun-Blanquet surveys
- Demographics of the seagrass communities using leaf-scar counting and population demographics techniques
- Seagrass productivity of the dominant species of seagrass in the FKNMS (*Thalassia testudinum*) using the leaf-mark and harvest method
- Seagrass nutrient availability using tissue concentration assays

These data are being collected at three different types of sites within the FKNMS:

- **Level 1 Stations**: Sampled quarterly for seagrass abundance, demographics, productivity and nutrient availability. These stations are all co-located with the water quality monitoring project's stations (Figure 1)
- **Level 2 Stations**: Randomly selected locations within the FKNMS, sampled annually for seagrass abundance, demographics and nutrient availability. Each year, new locations for Level 2 stations are chosen.
- **Level 3 Stations**: Randomly selected locations within the FKNMS, sampled annually for seagrass abundance. Each year, new locations for Level 3 stations are chosen.

We are assessing both inter-annual and intra-annual trends in seagrass communities. The mix of site types is intended to monitor trends through quarterly sampling at a few permanent locations (Level 1 sites) and to annually characterize the broader seagrass population through less intensive, one-time sampling at more locations (Level 2 and 3 sites).

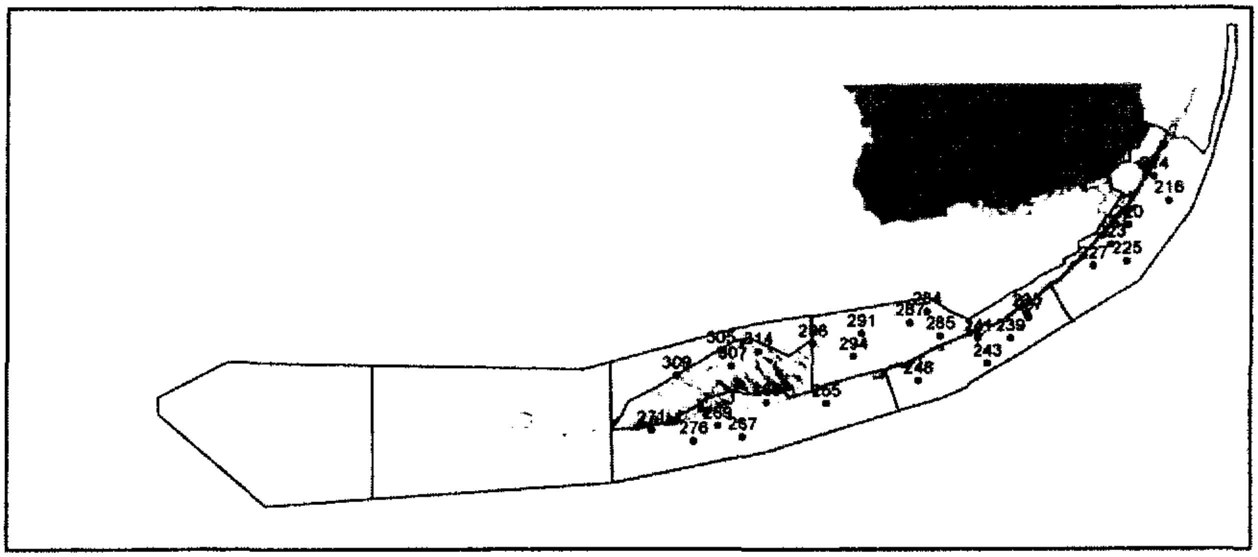

Figure 1. Location of Level 1 seagrass status and trends monitoring sites in the Florida Keys National Marine Sanctuary. Site numbers correspond to water quality monitoring locations.

PROJECT ACCOMPLISHMENTS FY 1998

In 1997, we reported data from quarterly collections from 28 permanent (Level I) stations. In cooperation with the FKNMS Special Permitting Areas monitoring program, two additional permanent Level I stations were established in the Western Sambos and Carysfort Ecological Reserves, bringing the total number of permanent monitoring stations to 30. During both FY 1996 through FY 1998 summer sampling of Level 2 and Level 3 stations was conducted in May - August, and the number of sites visited each year is listed below:

	1996	1997	1998
No. Level 2 Stations	65	87	82
No. Level 3 Stations	141	187	191
Total No. Stations	206	274	273

Station locations for all sites visited in 1996 through 1998 are shown Figure 2. When the results from these EPA-funded surveys are combined with comparable data from Florida Bay funded by the South Florida Water Management District and Everglades National Park, it is possible to make regional maps of seagrass distribution for the entire south Florida Region. Combining all projects, we sampled 1207 randomly-selected stations in the area from Cape Romano to the Dry Tortugas to North Key Largo; 87.5% of all sites supported seagrasses. When projected to an areal basis, 75.4% of the survey area, or 14,662 km^2, supported seagrasses.

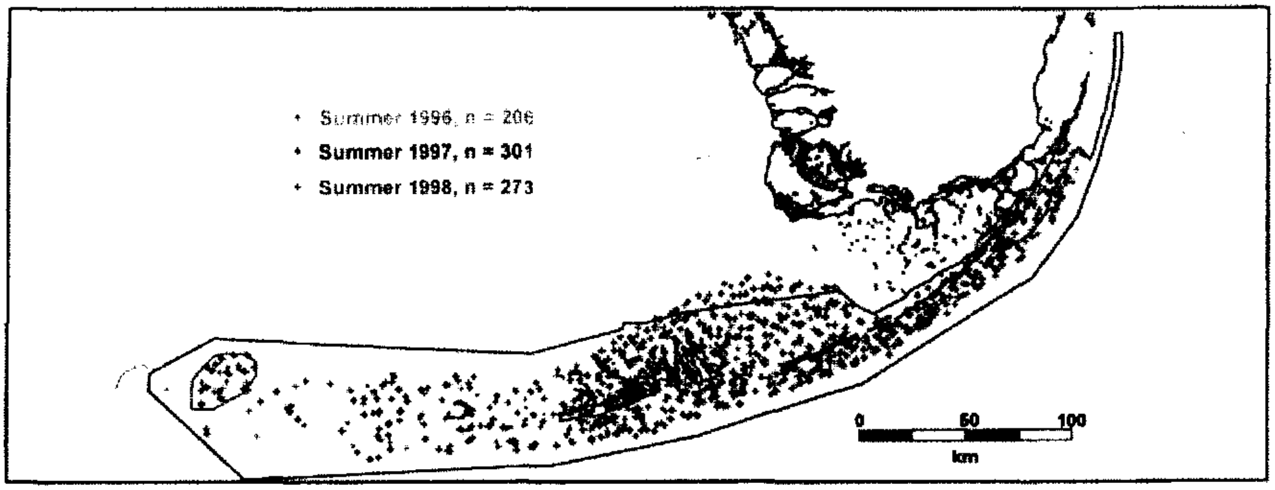

Figure 2. Locations of Level 2, and 3 sites sampled in the FKNMS during FY1996 - FY 1998.

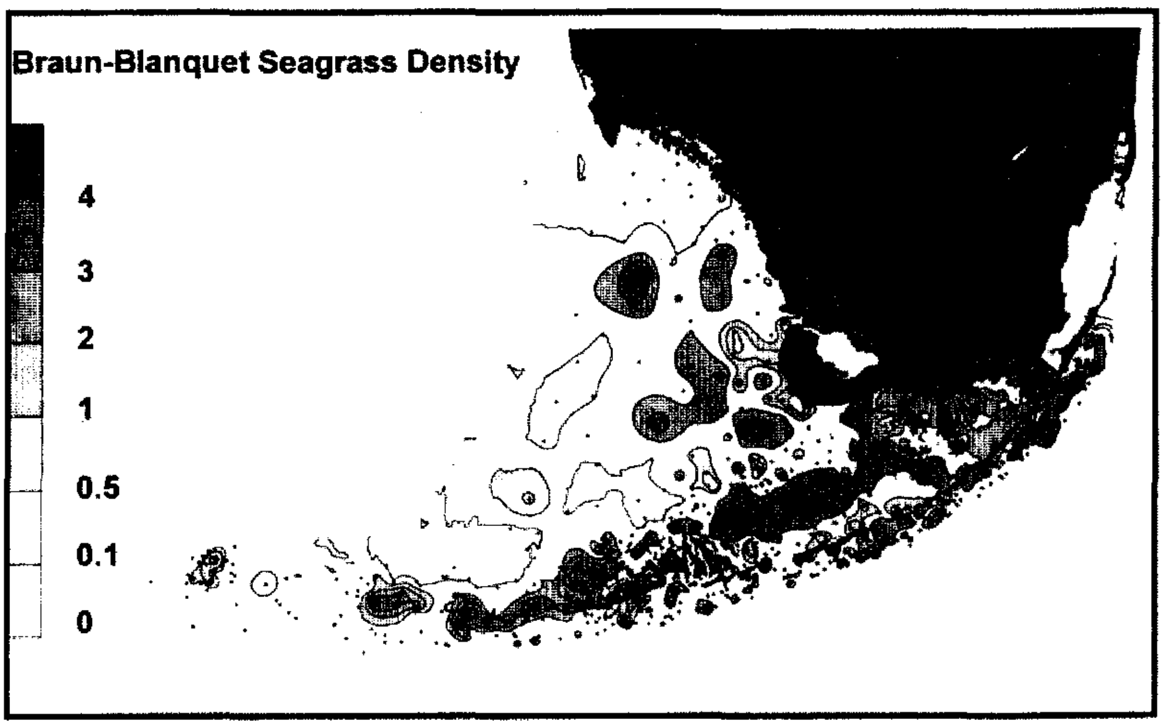

Figure 3. Seagrass distribution in south Florida. Seagrasses occupy more than 14,000 km^2 of benthic habitat. Density scale is in Braun-Blanquet cover class; 0 = not present, 5 = 75-100% cover.

Quarterly Station Summary Data

Now that we have collected three years of monitoring data from our permanent monitoring sites, we can document the degree of intra- and interannual variability in the seagrass beds of the FKNMS. The degree of temporal variation is site-specific, and seasonal increases in seagrass abundance and productivity appear to be related to water depth--where shallow sites are most affected by colder temperatures during winter months. In general, the productivity of seagrasses is more variable on an interannual scale than measures of seagrass abundance. *Thalassia testudinum* appears to be the most stable and consistent of the seagrasses. *Syringodium filiforme and Halodule wrightii* exhibit more dramatic seasonal patterns at most sites relative to T *testudinum.* No obvious patterns have been observed with calcareous green algae, where frequencies and densities are constant over time at some sites and not others.

Density & Standing Crop Estimates: Short shoot density, standing crop, and leaf mass of *Thalassia testudinum* were estimated from seagrasses harvested from the 6 quadrats used in our productivity studies. Short shoot densities ranged between 66 - 1025 SS m^{-2} for all sites for both years. Standing crop ranged between 5 - 93 g m^{-2}. Leaf mass exhibited a high degree of variation, with values ranging between 21 - 415 mg SS^{-1}.

Productivity: Productivity of *Thalassia testudinum* was calculated on a short shoot (SS), mass-specific (MS), and areal basis. Short shoot productivity ranged between 0. 18 - 8.31 mg SS^{-1} d^{-1}, with higher values recorded for seagrasses in Florida Bay (FKNMS segments 4 and 6) relative to seagrasses on the ocean-side (FKNMS segments 5, 7, and 9). Mass-specific productivity ranged between 3.21 - 49.47 mg g^{-1} d^{-1}, with the highest value recorded at site 271 in 97-3. Areal productivity ranged between 0.07 - 3.37 g m^{-2}. Strong seasonal patterns were observed for all three measures of productivity, especially for shallower sites in Florida Bay; where high, negative residuals were calculated for winter and spring, and high positive residuals were calculated for summer and fall.

Leaf C:N:P Ratios: Carbon and nitrogen contents of all quarterly samples collected through 97-3 have been analyzed. The nature of the laboratory analyses for phosphorus content has allowed the inclusion of P data for the sampling events through 96-4; the rest of the P samples will be analyzed by January 15, 1998. The elemental content of the leaves of *Thalassia testudinum* from the FKNMS varied greatly in the FKNMS. In fact, 95% of the total range in published seagrass nitrogen and phosphorus contents from all seagrasses from around the world was found within samples of *T. testudinum* from the Sanctuary. The C:N ratio ranged from 15.6 to 38.6, with a grand mean of 23.1. These values indicate that, on average, there is sufficient N available to support the growth of T *testudinum* in the Sanctuary. C:N was generally higher in summer-fall than in winter-spring, which reflects the role of seagrass growth rate in determining N demand, and therefore N availability in the environment. C:P ratios varied form 41 to 1823. The grand mean of all samples processed to date was 860, which indicated the important role that P availability had in determining seagrass distribution in the FKNMS.

Relationships between seagrasses and water quality: Water quality, water depth, and the composition of the substratum are the primary factors determining the composition of the benthic communities in shallow water marine systems. In the south Florida hydroscape, the shallow water benthos is a mosaic of seagrass-dominated habitats, coral reefs, and other hard bottomed habitats. Strong spatial pattern in the species composition, density, and N and P content of seagrasses correspond to patterns in water quality in these areas. The distributions of the four major species of seagrasses (*Thalassia testudinum, Syringodium filiforme*, *Halodule wrightii* and *Halophila decipiens*) are independent of one another, suggesting that the distributions of the species may be controlled independently or that biotic interactions may be important. Water quality varies as a consequence of the relative importance of the different sources of nutrients in the hydroscape. PCA indicates that there are six main influences on water quality: concentration of DIN; TN:TP; concentration of DIP, continental runoff, attenuation of light, and organic N in surface water The runoff from terrestrial systems is relatively rich in N in south Florida; while the primary P sources are oceanic. N:P ratios of seagrass biomass generally mirror the TN:TP of the overlying water column. For the most part, biomass of algal competitors of seagrasses is limited by P availability; phytoplankton chlorophyll concentrations, turbidity, and attenuation coefficients are all correlated to the total P concentration in the water column. Light penetration to the bottom is strongly correlated to the seagrass community in the FKNMS, with the distribution of *T. testudinum*, the dominant seagrass species, limited to areas where greater than 10% of surface light reaches the bottom (Figure 3). If less than 10% of incident light reaches the bottom, seagrass communities are dominated by *Halophila*

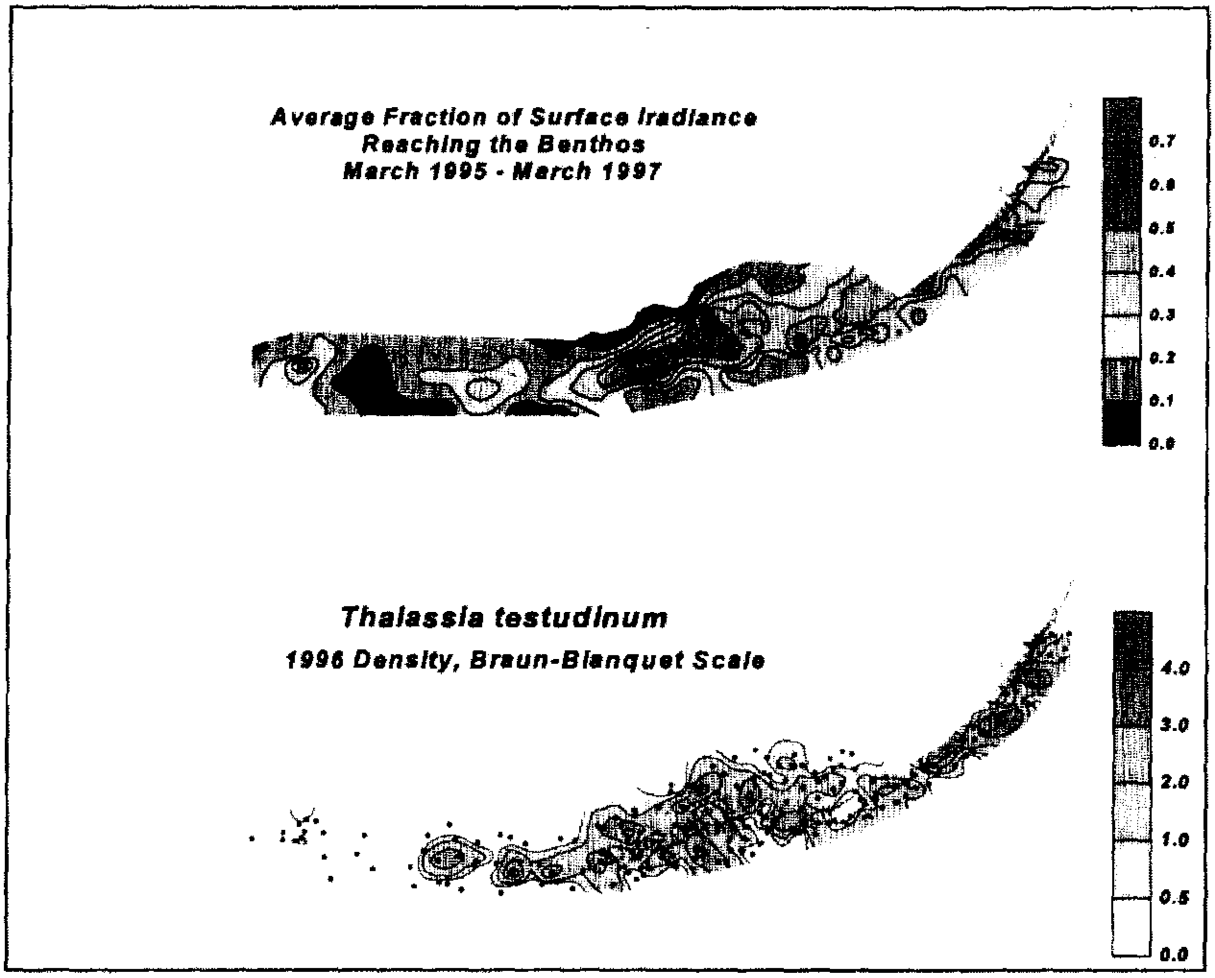

Figure 4. Top: Average fraction of surface irradiance reaching the seagrass community in the FKNMS. Bottom: Density of the seagrass, *Thalassia testudinum*, in the FKNMS.

decipiens. In areas receiving more light, Syringodium density is correlated to P availability, and Thalassia is the dominant seagrass in N-rich environments. Changing the relative importance of the nutrient sources in the hydroscape may lead to large changes in the seagrass distribution.

Effect of Hurricane Georges on seagrasses in the FKNMS: Hurricane Georges hit the lower Florida Keys during our FY1998 fourth-quarter data gathering excursion. This allowed us to directly measure the changes in the plant communities at our 30 permanent monitoring sites (Figure 1) immediately before and after the passing of the storm. At most sites, seagrasses were unaffected by the storm; however, at two sites there was a loss of seagrass cover. At site 243 (near the reef line south of long Key), much of our site was eroded away in the storm, causing a loss in seagrass cover of 1 Braun Blanquet density unit (roughly equivalent to a 25% reduction in seagrass cover). In contrast, our site 309 (north of Key West) experienced a complete loss of seagrass cover because 10-30 cm of muddy sand was deposited on the site. Other plants fared worse in the storm than the seagrasses: there was a general decline in calcareous macroalgae from all sites in the lower keys caused by the storm. We will continue monitoring these sites to assess the long-tem consequences of the hurricane.

Sea Urchin grazing in the FKNMS: We report observations of intense grazing by unusually high density aggregations of the pink sea urchin, *Lytechinus variegatus*, in a seagrass meadow in outer Florida Bay (USA). Sea urchins, at densities as high as 364 m^{-2}, overgrazed portions of an extensive manatee grass, *Syringodium filiforme*, dominated community. Urchins removed 82 % or 390 g dwt m^{-2} of total seagrass biomass and > 95 % of the short-shoot apical meristems, which we hypothesize will severely limit recovery of seagrasses by vegetative reproduction. Within our study area, at least 0.81 km^2 of vegetated habitat was damaged or completely denuded between September 1997 and May 1998. It is estimated that the total area affected by this grazing event is at least 10 km^2. As a result of seagrass canopy loss, epifaunal-infaunal mollusk assemblages were depleted and resuspension of fine grained (< 64 μm) surface sediments has increased, leading to significant changes in community structure and the physical properties of the sediments. The direct effects of this disturbance include the loss of essential fishery habitat, reductions in primary and secondary production, and degradation of water quality. We hypothesize that if destructive grazing continues, there will be additional, longer-term indirect effects that may extend beyond the boundaries of the grazed areas and into adjacent coastal ecosystems.

Demographics of seagrass populations indicate mostly stable seagrass populations: An examination of the population age structure of 131 populations of *Thalassia testudinum* over the extent of the Florida Keys National Marine Sanctuary (FKNMS) over a two year period revealed significant spatial variation in short shoot demographic characteristics and population dynamics. Shoot age was determine for 13544 short shoots. A novel approach to incorporate the seasonal variability in leaf emergence rates was employed by fitting a sine wave function (Figure 5) to the observed quarterly data from our permenent sites (Figure 1) for 1996 and 1997. Using this model, the yearly mean plastochron interval was 34.4 ± 3.8 (d $leaf^{-1}$) and the mean population age was approximately 3 years. A significant relationship between asexual reproductive output and gross recruitment (r^2 = 0.15, p = 0.001) and mortality and gross recruitment (r^2 = 0.72, p < 0.001) existed. Overlapping spatial patterns of high gross recruitment and mortality (Figure 6) were nearly synchronous. Thus, the greatest risk of mortality occurred in areas where gross recruitment was highest. The net population growth for *T. testudinum* within the boundaries of FKNMS was stable (mean = -0.007y^{-1} ± 0.087y^{-1}). However, areas within FKNMS fluctuated between positive and negative net growth rates (-0.20y^{-1} to 0.50y^{-1}; Figure 7). The power of such large scale observations is in its ability to identify areas of management concern and frame questions addressing the controlling mechanisms influencing these regions of fluctuating population growth.

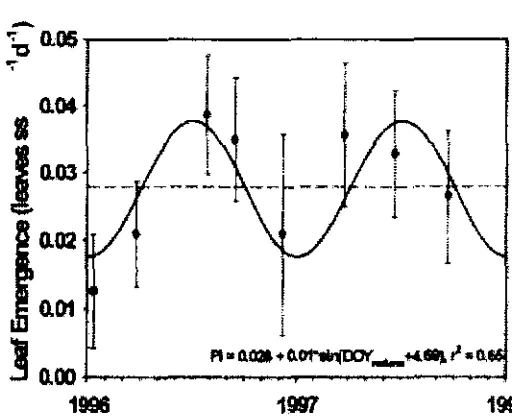

Figure 5. Seasonal pattern in leaf emergence rates at the permanent monitoring sites.

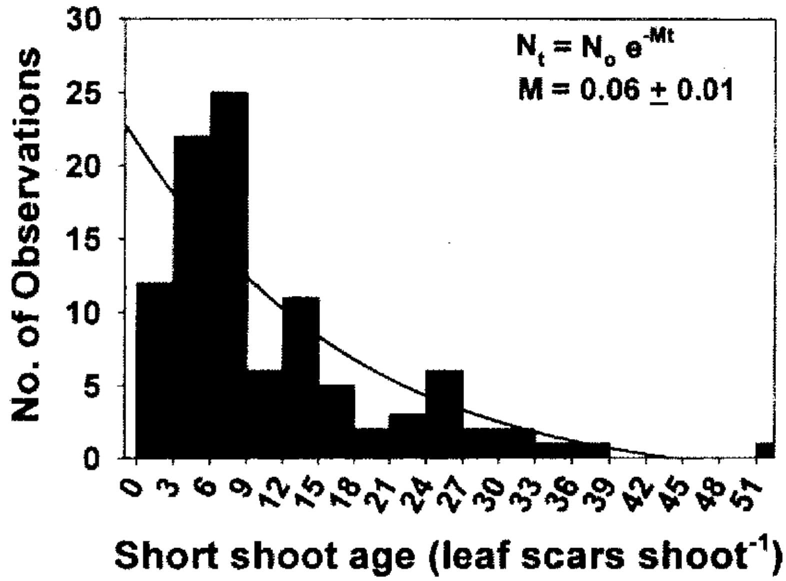

Figure 6. Age frequency distribution of Thalassia short shoots from one site, and the fitted mortality function.

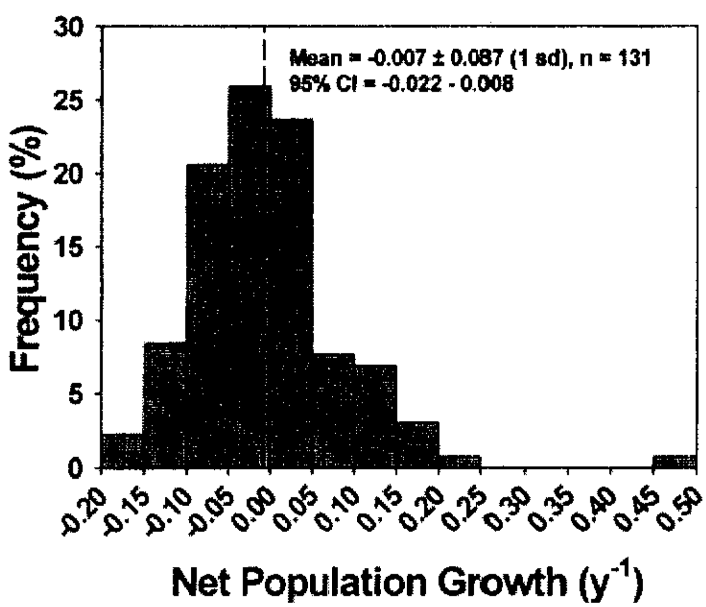

Figure 7. Net Thalassia testudinum population growth from 131 sites in the FKNMS, calculated as the balance between Gross recruitment and

Acknowledgments

This data report represents the dedicated work of many people. Craig Rose, Alan Willsie, Brad Peterson and Leanne Rutten led the field collection efforts and spearheaded the compilation of the data report; Cassandra Furst, Carlos Barroso, Andrés Plata, Braxton Davis, Winston Davis, Kelly Sokol, Vin Difrenna and Brian Machovina collectively put in the thousands of hours in the field and laboratory that went into the collection of these data. Captain Dave Ward and the R/V Magic ensured timely sampling of the permanent sites. The field work was conducted under permits FKNMS-109-98 from the FKNMS, FDEP permit number 97S-774, FDEP Parks and Recreation Permit number 5-98-47, and a permit from the National Park Service.

Section 1

Seagrass Distribution and Abundance in the FKNMS

Section 1.1

Seagrass distribution in south Florida: a multi-agency coordinated monitoring program

Seagrass distribution in south Florida: a multi-agency coordinated monitoring program

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A manuscript intended for publication in the book: Linkages between ecosystems in the south Florida hydroscape: the river of grass continues, edited by J.W. Porter and K.G. Porter.

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. Seagrasses enhance sediment stability, decrease wave energy and increase water clarity (see reviews by Phillips and McRoy 1980, McRoy and Helfferich 1977). 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 effect seagrasses. Dredging and filling of coastal areas for navigation and development can directly remove potential seagrass habitat (Zieman et al. 1989b); alter hydrological conditions that lead to erosion (Giesen et al. 1990; Larkum and West 1990); as well as 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. Cambridge et al. 1986; Orth and Moore 1983). 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 frequent such 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 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 engelmannii* 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 is well-understood (see Zieman 1982; Zieman *et al.* 1989b for review), but specific information on the areal extent of seagrass species in south Florida is lacking. 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. 1989a). Using diver surveys, Iverson and Bittaker (Iverson and Bittaker 1986) estimated that there were an additional 2900 km^2 of seagrass beds in outer Florida Bay (defined as water depths > 2m); 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 there are at least an additional 1029 km^2 of seagrass beds (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 semi-continuous beds.

The near-shore marine and estuarine habitats of south Florida are managed by a diverse group of governmental agencies at local, state and federal levels (Figure 1.1.1). 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 three nautical miles of the shoreline. Some of the marine area controlled by the state is further managed by sub-agencies 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 Environmental Protection Agency 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. While regional-scale deterioration of the seagrass beds has yet to occur in south Florida, there have been many reports of smaller-scale seagrass decline and potential threats to regional water quality. In the south Florida case, the regulatory agencies have taken the opportunity to act in a coordinated effort before large-scale 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 a poorly understood seagrass die-off event that began in Florida Bay in 1987. Communication amongst scientists and resource managers in south Florida has led to the complementary design of these three monitoring programs, so that the programs not only are providing data to address the original question of concern, but they 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.

Three seagrass monitoring programs in south Florida.

Seagrass communities as an indicator 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, 1995). 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. Cambridge *et al.* 1986; Orth and Moore 1983). Concern has been raised over eutrophication and the status of seagrass communities in the waters of the FKNMS (Lapointe and Clark 1992; Lapointe et al. 1990; Lapointe et al. 1994; Tomasko and Lapointe 1991). 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 1.1.2). This program was designed to determine regional-scale gradients in the status of the seagrass communities of the Sanctuary.

Gaging 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 canalization of the Everglades ecosystem directly to the north, altering the pattern of salinity in Florida Bay (Light and Dineen 1994; McIvor et al. 1994; Smith et al. 1989). The present system is one in which hypersalinity is common (Fourqurean et al. 1993; Tabb et al. 1962). It has been hypothesized that changes in the freshwater flow into Florida Bay has 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 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 1.1.3).

Determining the causes and extent of seagrass dieoff in Florida Bay. Florida Bay is currently undergoing an unprecedented modification of its ecosystems. The mass mortality of seagrasses within Florida Bay (Robblee et al. 1991) and the more recent widespread algal blooms (Butler et al. 1995; Phlips and Badylak 1996; Phlips et al. 1995) 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. in press) all play some role in the mortality of the dominant seagrass in Florida Bay, *Thalassia testudinum*. In 1995, the

Florida DEP initiated a monitoring and research program designed to provide spatially comprehensive status and trends information on the benthic communities of Florida Bay while continuing to provide physiological information on seagrass species in the Bay (Figure 1.1.3).

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?; and 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 20^{th} 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 1.1.1). 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 1.1.1. The choice of quadrat size is also very important for this technique; it is important that the quadrat 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 pre-determined random distances along a 50 m transect placed in a N-S direction at each site. In the water management and seagrass dieoff monitoring programs, 4 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 N, S, E and W 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 be greater than 5, because of 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 individual taxa by defining a lower density limit for inclusion in the area. 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 non-uniformly distributed data points. To meet both of these requirements, we have used the systematic random method of hexagonal tesselation, developed by the USEPA'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 sub-unit. These randomly-chosen sites are located in the field using Differential Global Positioning Systems (DGPS); we have found by repeat visits to marked sites that DGPS is reproducible in our area to ± 5 m.

Sites within the boundaries of the FKNMS (Figure 1.1.2) 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 was all collected in the summer of 1998 (Figure 1.1.3): the seagrass dieoff program sampled 378 sites, and the SFWMD/DERM program sampled 228 sites within Florida Bay.

Point data on species density was 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, USA) was used to compute areas of seagrass coverage from these interpolated surfaces.

Since none of the 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 2-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 1.1.1). 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 percent of all sampling sites (Table 2). *Thalassia testudinum* was the most commonly encountered species; it was found at 898 sites. *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 engelmannii* (28 sites).

Differing morphology and life history characteristics are apparent in the comparison of the relative densities of the species (Table 2). With 2 exceptions, only *Thalassia testudinum* and *Syringodium filiforme* were found to occur at very high density (D > 4; 4 ≡ 50 - 75% cover, Table 1.1.1); 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*. Since 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.

There were species-specific differences in density tendency (Table 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 engelmannii* 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, like *H. wrightii* and *H. engelmannii*, 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 1.1.3). There was no relationship between the density of *Thalassia testudinum* and *Syringodium filiforme*, but *T. testudinum* density was positively correlated to *Halodule wrightii* density, and negatively correlated to the densities of *Halophila engelmannii*, *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. engelmannii* 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. engelmannii* and *R. maritima*. *Halophila decipiens* and *R. maritima* densities were negatively correlated, while there was no significant relationship between the densities of the two congeners of *Halophila*. No significant relationship was present between *H. engelmannii* 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 engelmannii* (Table 1.1.3). 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 - 2 m; fewer than 10% of the sites were deeper than 10 m (Table 1.1.4). 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 particulary common in the depth range 6-8 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 engelmannii* 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 there were clear differences in the median depth at which each species was recorded (Table 1.1.5). *Ruppia maritima* was never found deeper than 1.4 m, with a median depth of 0.9 m. *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 engelmannii* 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 1.1.4). 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: 3 species were found at 8.6% of sites, and only 1.2% of sites had 4 or more species. There was no clear spatial pattern in species richness; relatively diverse (>3 species) seagrass beds were found on both the Atlantic ocean and Gulf of Mexico sides of the Florida Keys (Figure 1.1.5). The only 2 sites with 5 species (*Thalassia testudinum*, *Syringodium filiforme*, *Halodule wrightii*, *Halophila decipiens* and *Halophila engelmannii*) 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 2) can not 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 the areal extent of the species. In 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 1.1.6). 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 1.1.6).

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 1.1.6). 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 1.1.7). 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* was the most dense species immediately adjacent to the Florida Keys and in Florida Bay (Figure 1.1.6), *S. filiforme* density generally increased in a offshore direction until reaching the reef tract (Figure 1.1.8). 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 km2 of the total area of *S. filiforme* had $D < 1$ (Table 1.1.6).

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 1.1.9). 83 % of all of the area supporting *H. wrightii* had $D < 1$. The other two species encountered, *Halophila engelmannii* 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 1.1.10). *Halophila engelmannii* was occasionally observed, found in 143 km^2 scattered around the survey area (Figure 1.1.10).

The individual species distributions combine to produce a very large area of almost continual seagrass cover (Figure 1.1.11). 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 1.1.6). Of this total area, 5197 km^2 was very sparse, with $D < 1$. Most of these sparse areas were dominated by *Halophila decipiens*, like the southwest Florida Shelf area north of Key West and the relatively deep water between the Quicksands and Dry Tortugas National Park. The most dense 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 further west.

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 large (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 1995). 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 paper, there was only 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 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 et al. This volume).

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.

Very near shore in 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 may also play 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.* 1993; Fourqurean et al. 1992); it also increases from onshore to offshore on the ocean side of the Florida Keys (Szmant and Forrester 1996). Experimental increases in P availability have resulted in other seagrasses outcompeting *T. testudinum* and become 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 P availability: only in areas of relatively high P availability can *S. filiforme* outcompete *T. testudinum*. This hypothesis needs to be confirmed by experimental manipulation, however.

Interspecific differences in light requirements allow some species of seagrasses to grow in deeper water than others. Most seagrass genera have a minium 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. engelmannii* was a relatively shallow 1.9 m. We never found extensive meadows dominated by *H. engelmannii*; instead it was 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. allows *H. engelmannii* to exists as an understory plant, but what is not clear are the life history differences between *H. decipiens* and *H. engelmannii* that allow *H. engelmannii* to be a successful understory species, while its congener *H. decipiens* rarely occurs as an understory. Also, the minimum light requirements for *H. engelmannii* do not appear to be any greater than those for *H. decipiens*, since *H. engelmannii* has been documented growing at 90m depth within the study area (den Hartog 1970), so it is unclear why *H. decipiens* is a meadow-former in deep water, while *H. engelmannii* 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 fresh water. 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* 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 P, *R. maritima* dominates the benthic flora; further 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 1970's 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 1980's (Zieman *et al.* 1989a), and were dominated by *T. testudinum* in our surveys. Zieman (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 presently 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 and Clark 1992; Lapointe *et al.* 1990; Lapointe *et al.* 1994; Tomasko and Lapointe 1991). 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. Since near-shore oceanic water quality is determined by the interaction of coastal influences, marine influences, and man's 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. Since 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 present 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. For this reason, accurate data on the species composition of the seagrass communities needs to 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 south Florida. Because of the close proximity between human development activities and historic seagrass distribution, 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, university scientists and private sector environmental groups. 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 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, since governmental agencies have independent staffs and differing mandates, often leading to disparities among science and monitoring programs. Since 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. There are three major seagrass monitoring efforts ongoing: a U.S. Environmental Protection Agency-funded program addressing status and trends of seagrasses within the Florida Keys National Marine Sanctuary; a State of Florida-U.S. Department of Interior (US Geological Survey and Park Service) funded program assessing the seagrass communities of Florida Bay, and a South Florida Water Management District and Miami-Dade County funded program concentrating 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.

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Table 1.1.1. Braun-Blanquet abundance scale used to assess seagrass density. Cover is defined as the fraction of the bottom that is obscured by the species when viewed by a diver from directly above.

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

Table 2. Distribution of seagrass density D at the 1207 sampling sites.

Species	Density class (D)								
	0	0<D≤0.1	0.1<D≤0.5	0.5<D≤1	1<D≤2	2<D≤3	3<D≤4	4<D≤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 engelmannii	1179	11	12	3	2	0	0	0	0
Ruppia maritima	1166	2	18	10	9	2	0	0	0
$\sum$ 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 engelmannii	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
$\sum$ 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 engelmannii		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
$\sum$ D for all seagrasses		3.0	7.6	7.5	21.1	22.1	18.0	14.7	6.1

Table 1.1.3. Correlations (nonparametric Spearman's ρ) between densities of seagrass species, and seagrass species density and water depth, from the 1207 seagrass sampling sites. Correlation coefficients are below the diagonal; 2-tailed significances are above the diagonal. Significant correlations ($P \leq 0.05$) are in boldface type.

	Depth	*T. testudinum*	*S. filiforme*	*H. wrightii*	*H. decipiens*	*H. engelmannii*	*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 engelmannii	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	

Table 1.1.4. 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 engelmannii*	*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

Table 1.1.5. 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

Table 1.1.6. Area inventory of seagrass species in the surveyed region. Total area of the survey was 19,402 km^2 (Figure 1.1.1)

Species	Density class (D)							
	$0<D\leq0.1$	$0.1<D\leq0.5$	$0.5<D\leq1$	$1<D\leq2$	$2<D\leq3$	$3<D\leq4$	$D>4$	$D\geq0.1$
Area in a density class (km^2)								
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 engelmannii	19259	132	10	1	0	0	0	143
Ruppia maritima	19329	43	20	10	0	0	0	73
$\sum$ D 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 engelmannii	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
$\sum$ D for all seagrasses	24.6	15.7	11.1	21.6	16.0	7.6	3.4	75.4

Figure Captions

Figure 1.1.1 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.

Figure 1.1.2. 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 1.1.3. 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 die-off 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.

Figure 1.1.4. 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 1.1.5. Spatial distribution of species richness of seagrass beds across the south Florida hydroscape. Small crosses indicate sampling points.

Figure 1.1.6. 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 1.1.1).

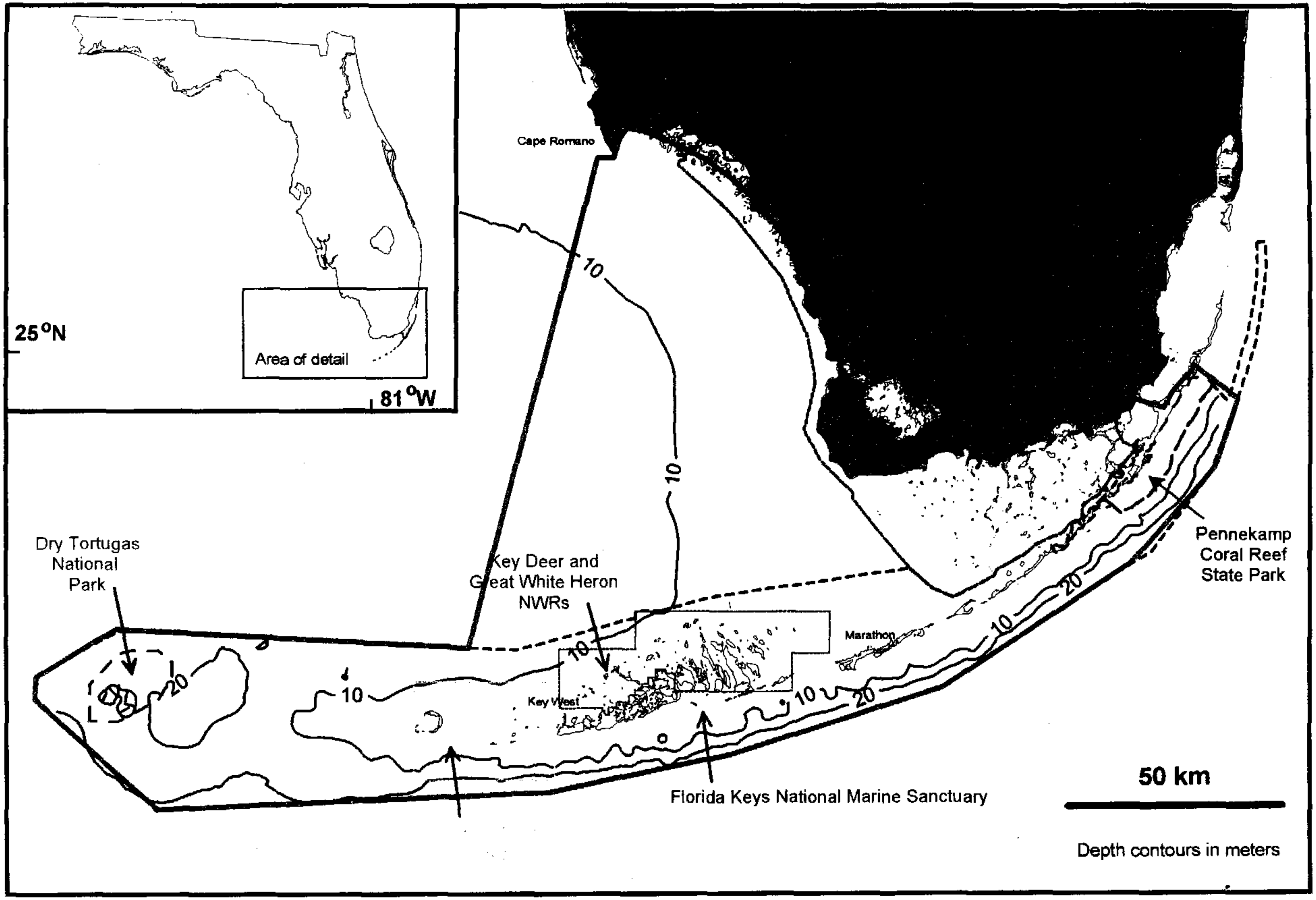
Figure 1.1.7. Spatial distribution of the density of *Halophila decipiens* across the south Florida hydroscape. Small crosses indicate sampling points. Density scale is in Braun-Blanquet density units (see text and Table 1.1.1).

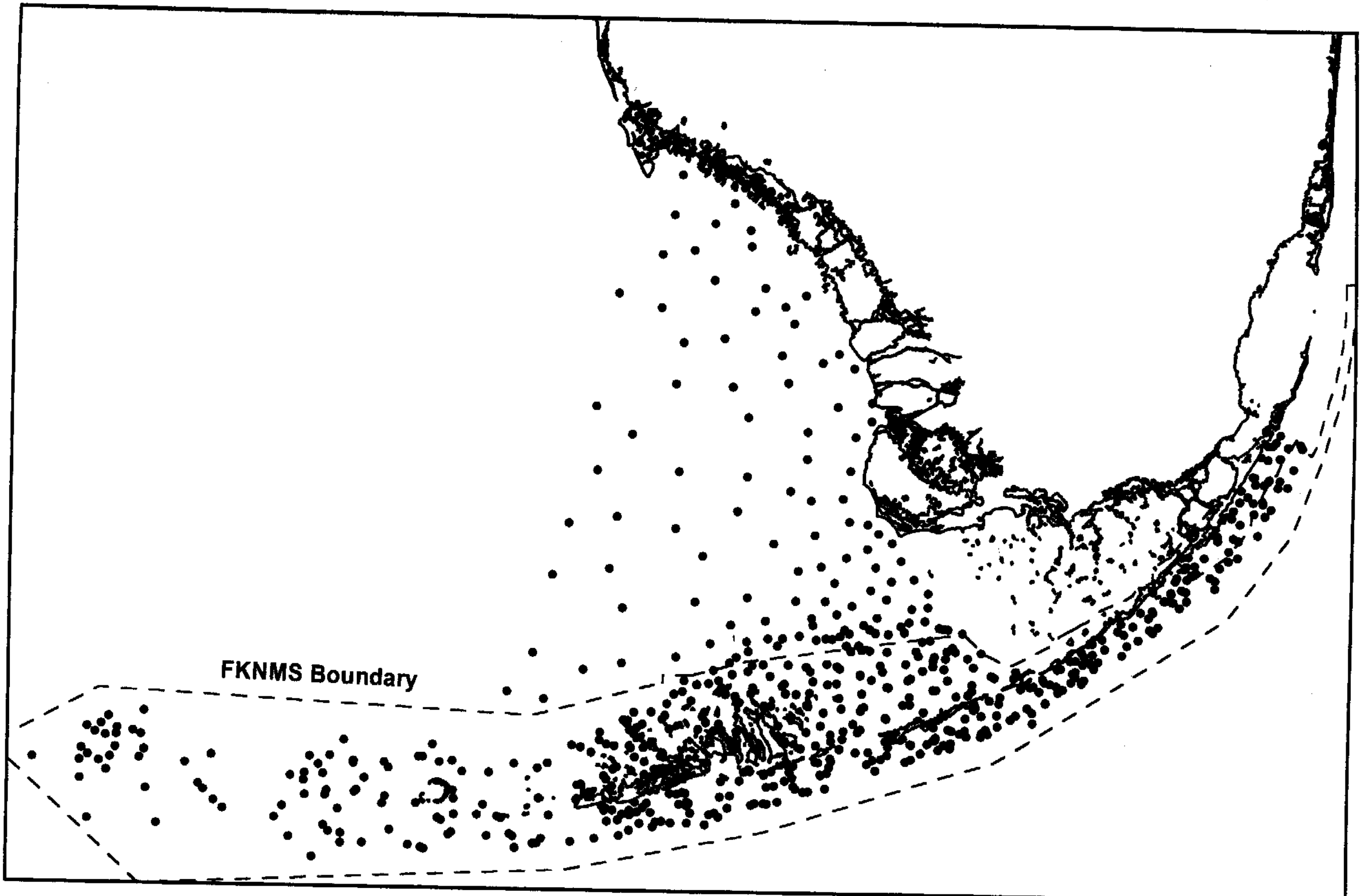
Figure 1.1.8. Spatial distribution of the density of *Syringodium filiforme* across the south Florida hydroscape. Small crosses indicate sampling points. Density scale is in Braun-Blanquet density units (see text and Table 1.1.1).

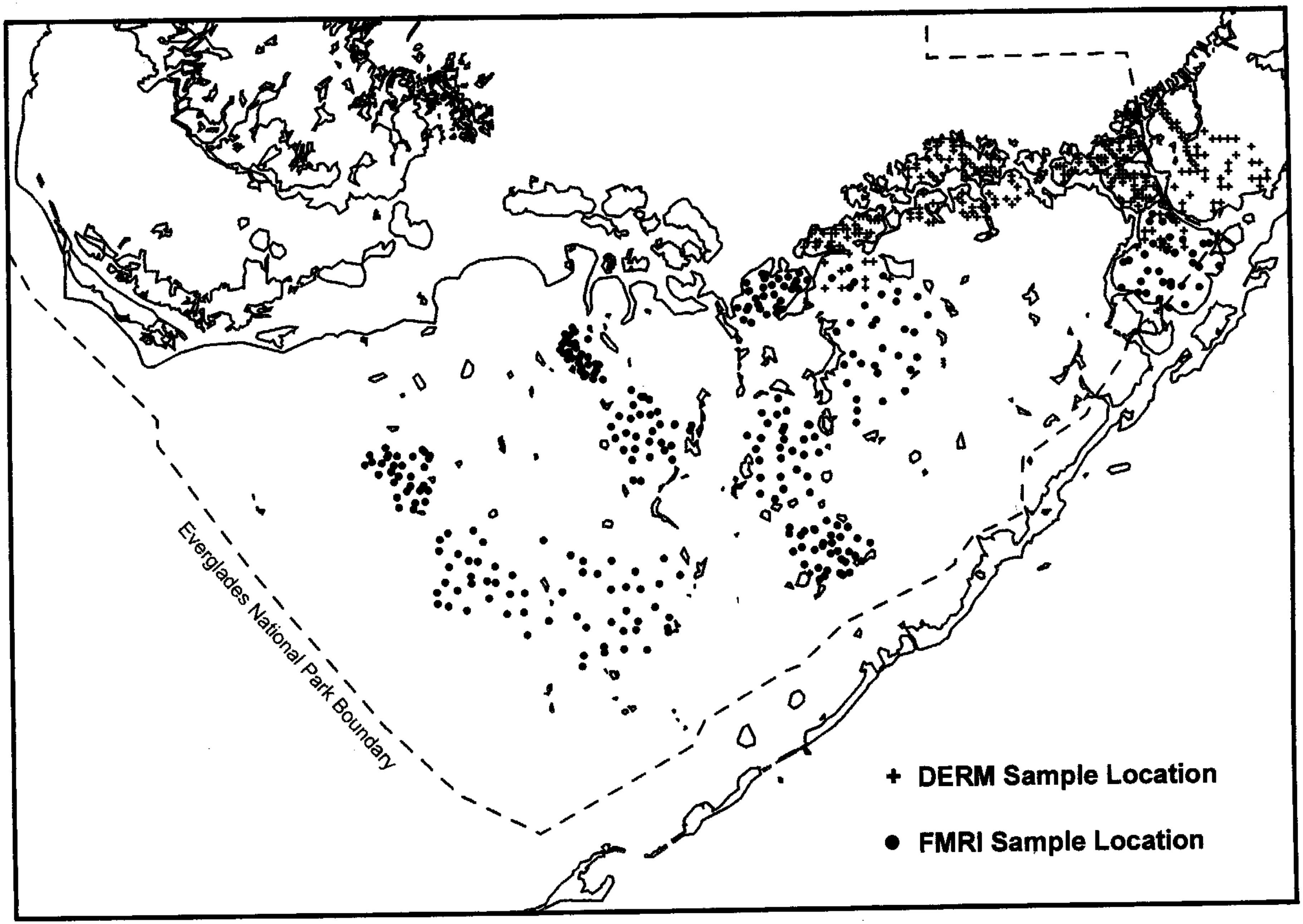
Figure 1.1.9. Spatial distribution of the density of *Halodule wrightii* across the south Florida hydroscape. Small crosses indicate sampling points. Density scale is in Braun-Blanquet density units (see text and Table 1.1.1).

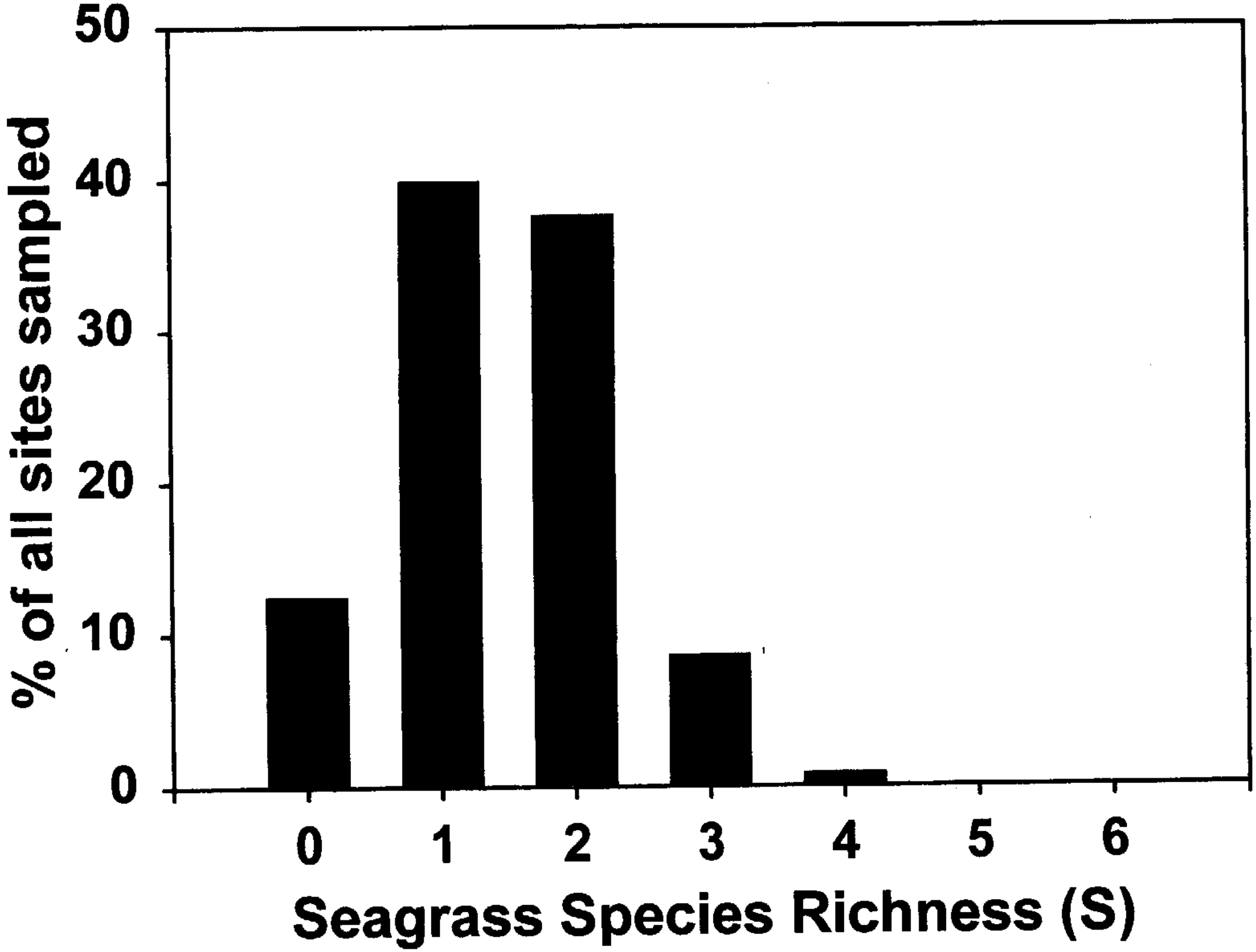
Figure 1.1.10. Spatial distribution of the density of *Halophila engelmannii* (main map) and *Ruppia maritima* (inset) across the south Florida hydroscape. Small crosses indicate sampling points. Density scale is in Braun-Blanquet density units (see text and Table 1.1.1).

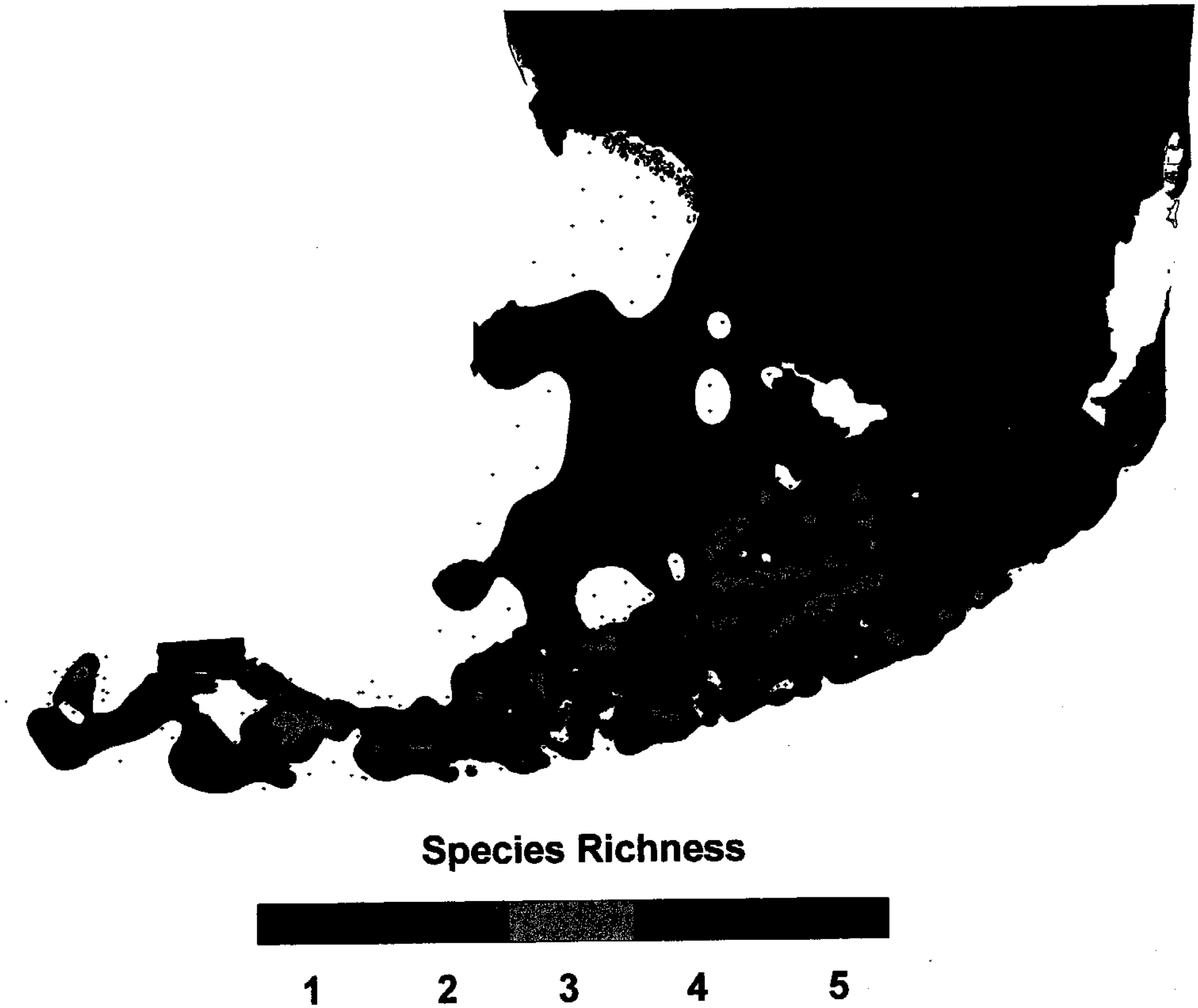
Figure 1.1.11. Spatial distribution of the sum of the density scores for all seagrass species across the south Florida hydroscape. Small crosses indicate sampling points. Density scale is in Braun-Blanquet density units (see text and Table 1.1.1).

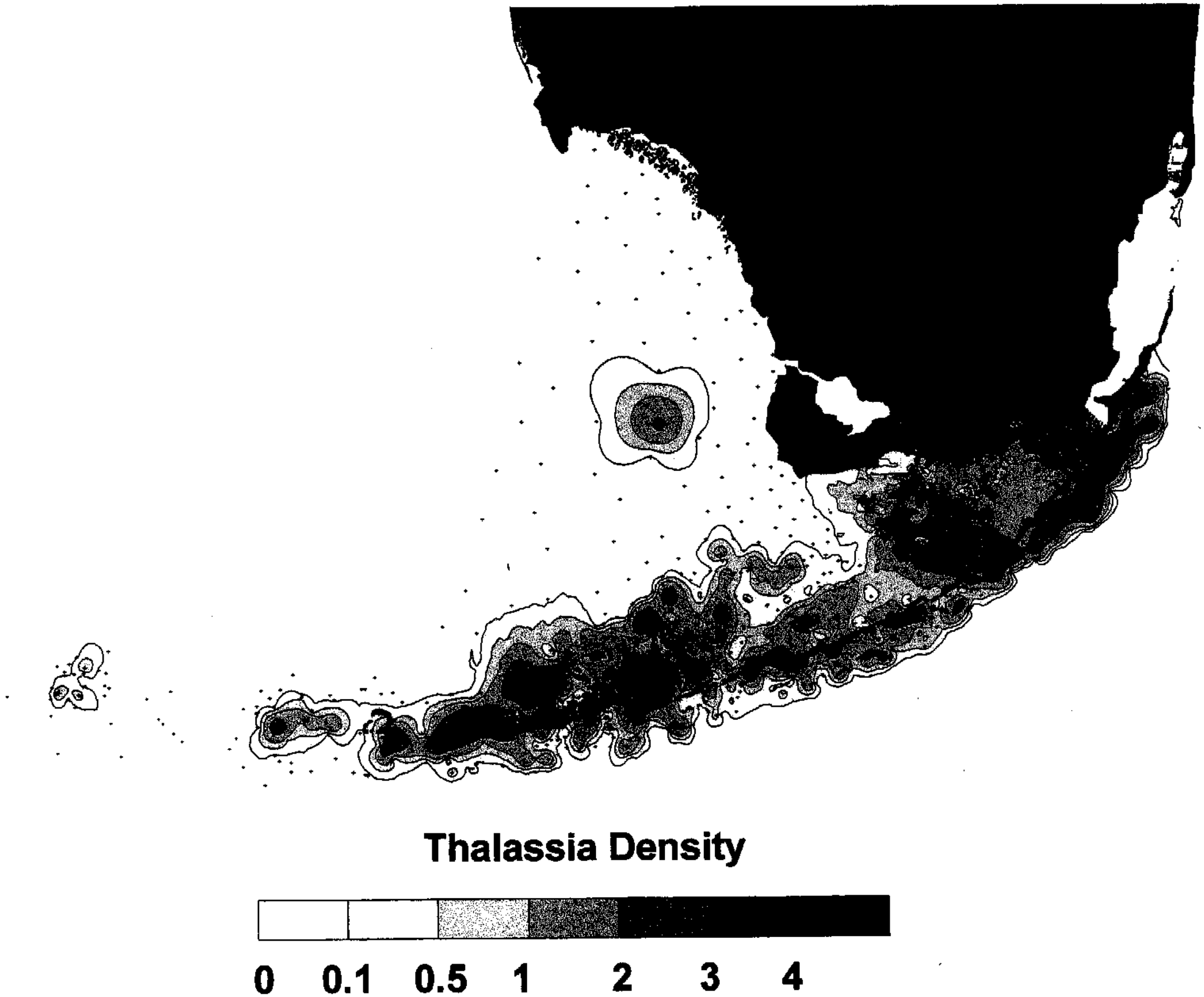

25°N
Area of detail
81°W
Cape Romano
10
10
Dry Tortugas
National
Park
Key Deer and
Great White Heron
NWRs
Pennekamp
Coral Reef
State Park
Marathon
Key West
10
20
10
20
10
20
50 km
Florida Keys National Marine Sanctuary
Depth contours in meters

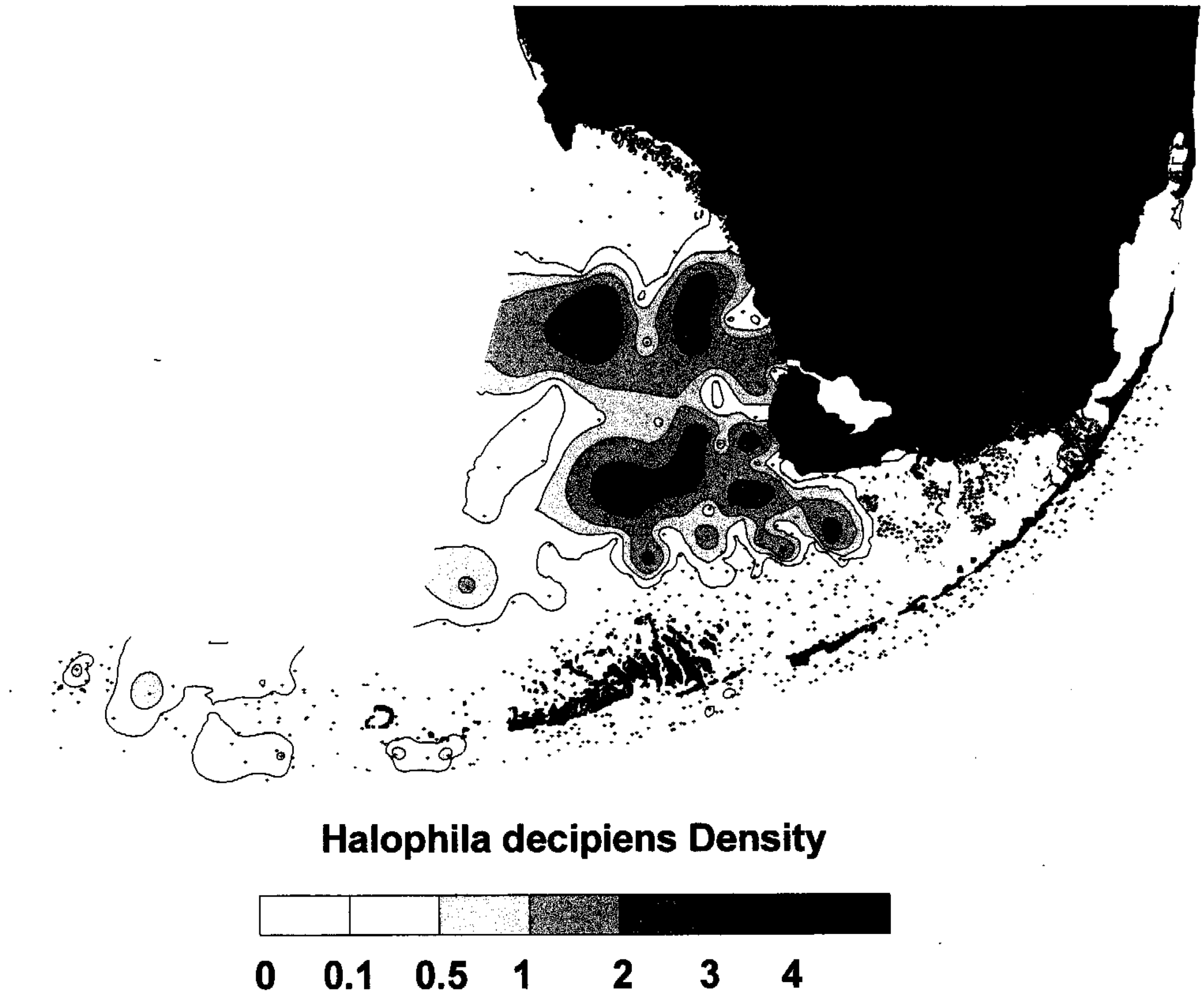

FKNMS Boundary

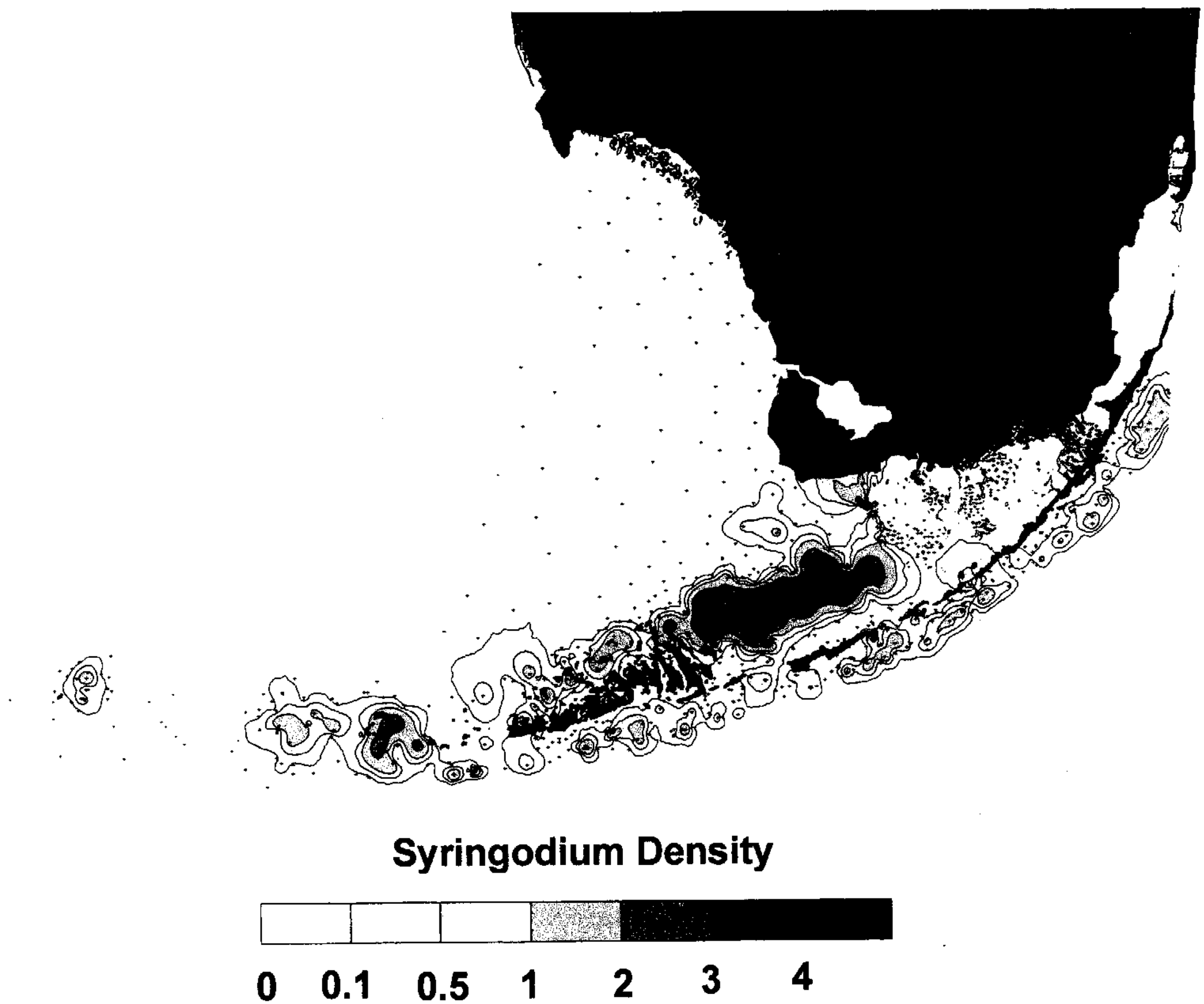

Everglades National Park Boundary
+ DERM Sample Location
● FMRI Sample Location

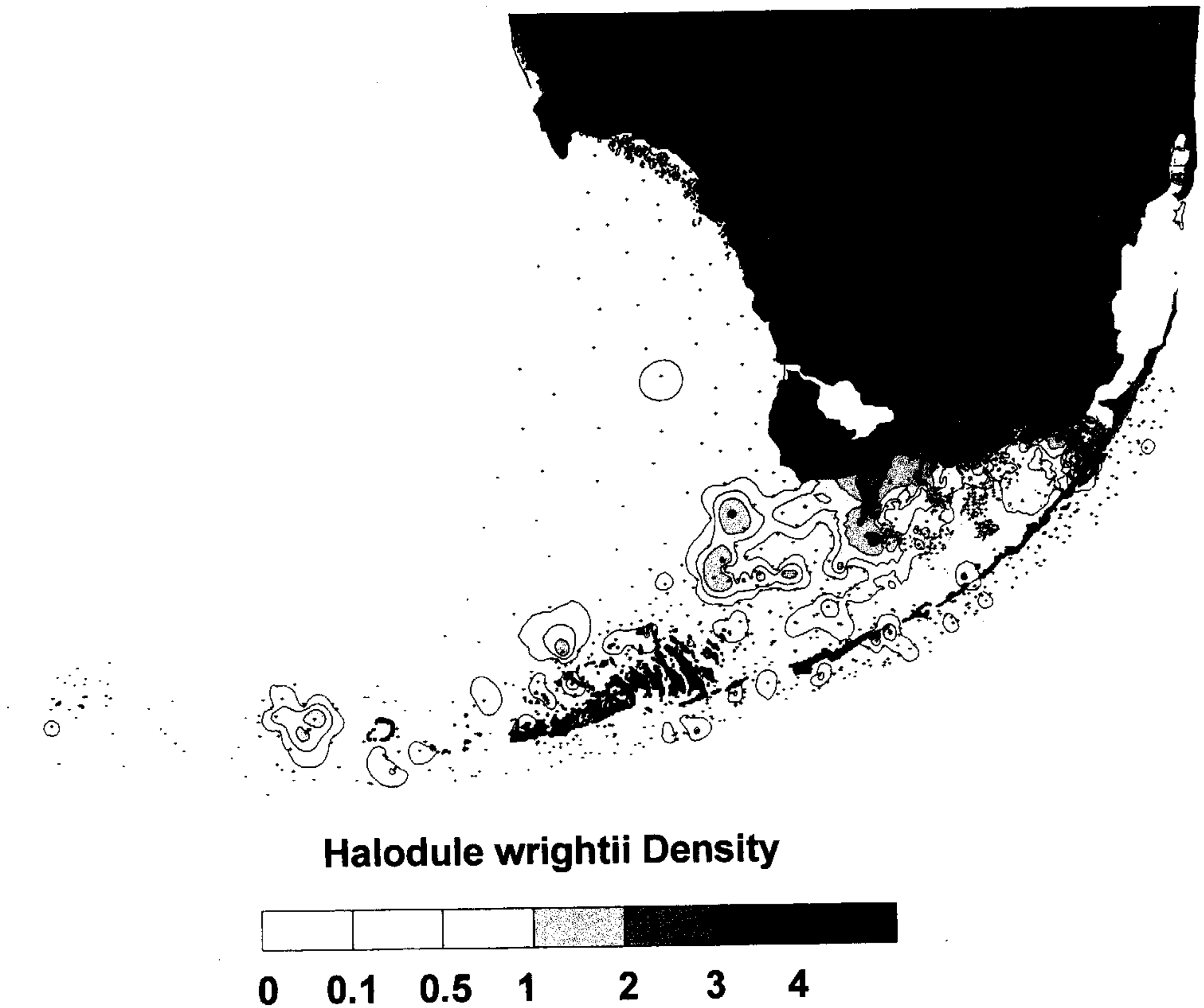

% of all sites sampled
50
40
30
20
10
0
0
1
2
3
4
5
6
Seagrass Species Richness (S)

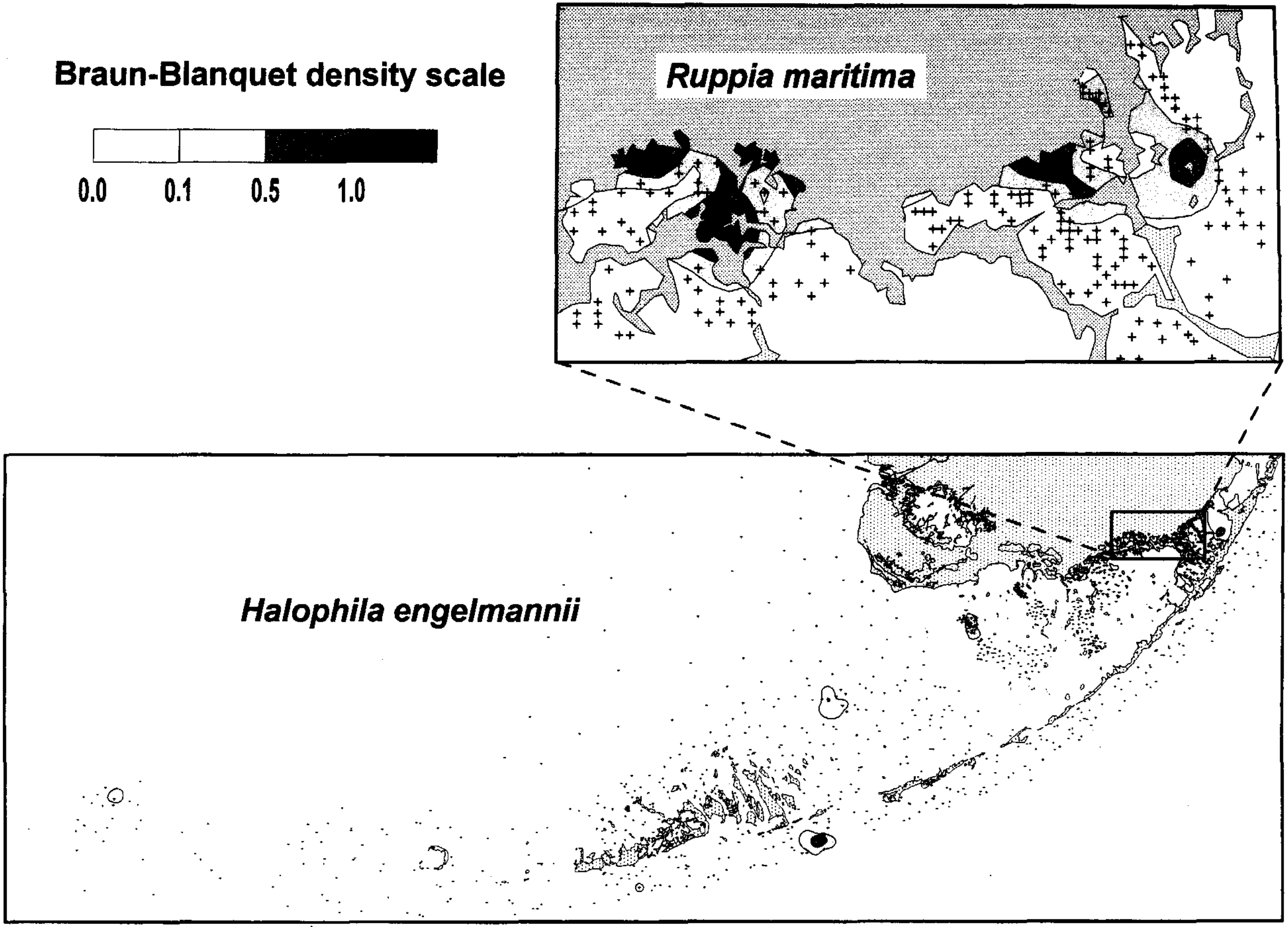

Species Richness
1
2
3
4
5


Thalassia Density
0
0.1
0.5
1
2
3
4

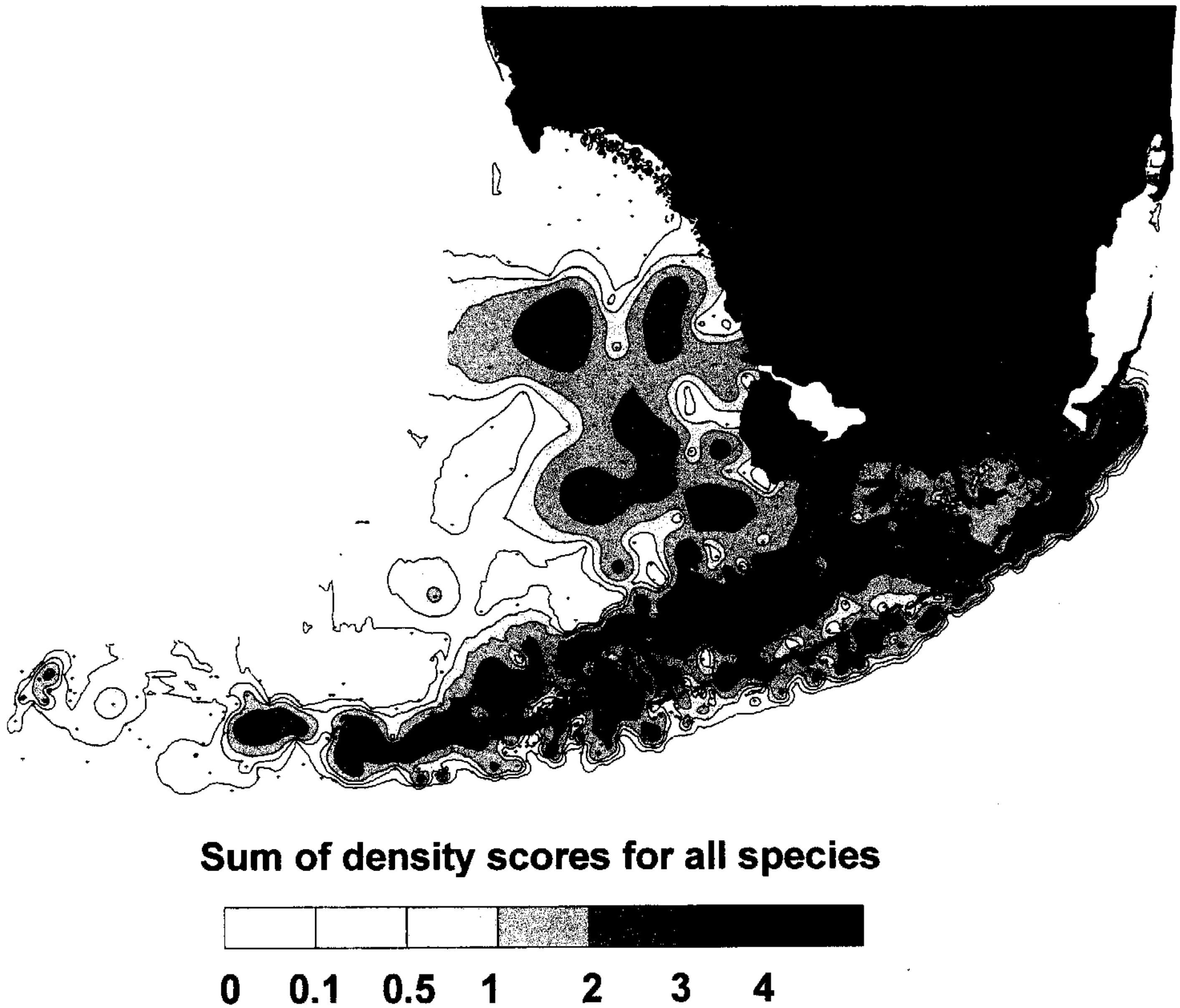

Halophila decipiens Density
0
0.1
0.5
1
2
3
4


Syringodium Density
0
0.1
0.5
1
2
3
4


Halodule wrightii Density
0
0.1
0.5
1
2
3
4



Braun-Blanquet density scale
0.0
0.1
0.5
1.0
Ruppia maritima
Halophila engelmannii


Sum of density scores for all species
0
0.1
0.5
1
2
3
4

Section 1.2

Spatial patterns of seagrass communities

SECTION 1.2

During the last 3 years (1996-1998) we sampled a total of 780 sites during the summers throughout the FKNMS (Figure 1.2.1). Sampling was conducted at all Level II and III sites, and Level I sites sampled in June 1997 (i.e., 97-3). At each site, we sampled benthic macrophyte percent cover in 10 random quadrats placed along a 50 m transect. Visual percent cover was transformed to Braun-Blanquet abundance scores, which were then used to calculate the frequency, abundance, and density of each taxa observed.

Thalassia testudinum is the dominant species in the FKNMS and Florida Bay (Figure 1.1.6 and Figure 1.2.2), mostly in shallow areas with a maximum water depth of 18 m (Table 1.1.5). In the FKNMS, *Syringodium filiforme* is the second most dominant species, and is predominantly found offshore and in outer Florida Bay (Figure 1.1.8 and Figure 1.2.4). *Halodule wrightii* (Figure 1.2.5) and *Halophila decipiens* (Figure 1.2.6) are found with less frequency throughout the FKNMS.

Figure 1.2.1

FKNMS Seagrass Status and Trends Monitoring Program

Benthic Macrophyte Abundance Stations, n = 780

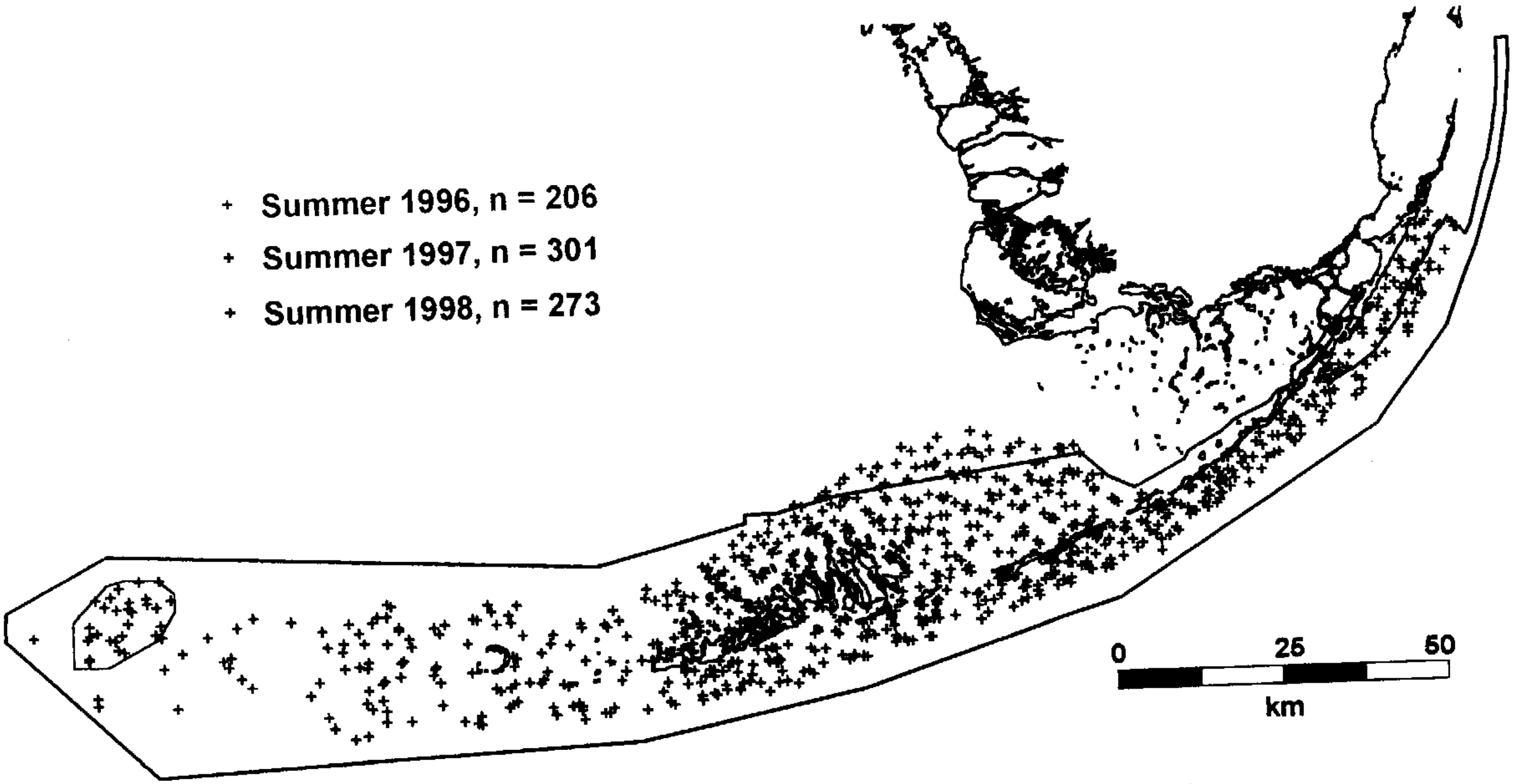


Figure 1.2.2

FKNMS Seagrass Status and Trends Monitoring Program

Thalassia testudinum

Frequency of occurrence, n = 780

Figure 1.2.3

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Thalassia testudinum

Braun-Blanquet density, n = 780

Figure 1.2.4

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Syringodium filiforme

Frequency of occurrence, n = 780

Figure 1.2.5

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Halodule wrightii

Frequency of occurrence, n = 780

Figure 1.2.6

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Halophila decipiens

Frequency of occurrence, n = 780