CHANGE ANALYSIS OF SUBMERGED AQUATIC VEGETATION IN THE CHASSAHOWITZKA NATIONAL WILDLIFE REFUGE 1996-2000

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ABSTRACT

The present study was performed to describe changes and recovery to submerged aquatic vegetation (SAV) following an extended algal bloom in coastal Florida waters, including the Chassahowitzka National Wildlife Refuge. SAV were defined as vascular plants and rhizophytic algae. Five years of sampling for SAV (using rapid assessment Braun-Blanquet techniques) and water quality resulted in seven surveys of submerged aquatic vegetation and 17 water surveys between 1996 and 2000. Extremes of both wet and dry conditions were sampled. A GIS was created to store and display the data collected during the project and to help facilitate the comparisons of water quality change and vegetation change. Spatial relationships between water quality and vegetation were examined in order to determine possible factors associated with SAV change in the Refuge. Submerged aquatic vegetation formed a nearly continuous cover within the Refuge in 1996. Species diversity was high. The alga Caulerpa paspaloïdes was the most frequently observed, appearing in 33% of all coastal stations. In 1998, high flow events were followed by a coastal algal bloom and water clarity declined substantially, with co-occurring declines in some species of algae. The number of unvegetated quadrats during a given sampling increased as well. By May 2000, some species had recovered to 1996 levels, whereas others remained reduced in cover, despite restoration of former water clarity and salinity values.

ACKNOWLEDGEMENTS

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MOTe MARine LABORATORY
Change Analysis of Submerged Aquatic Vegetation
In the Chassahowitzka National Wildlife Refuge 1996-2000
INTRODUCTION

The Chassahowitzka National Wildlife Refuge (NWR), under the management of the U.S. Fish and Wildlife Service (USFWS), is a 124 km² area that encompasses the mouth and a portion of the Chassahowitzka River as well as numerous islands and near-shore marine waters out to a distance of 1 to 3 km offshore. Located on the central west coast of Florida, this shallow oligotrophic portion of the Gulf of Mexico is receiving more attention as trends of increasing nutrients in groundwater discharges are documented due to increased development (Jones et al., 1997; Dixon, 1997). Localized atmospheric loadings of inorganic nitrogen in wet deposition have also increased in recent years (Dixon and Estevez, 2002) and are comparable in magnitude to riverine loadings from spring discharges. Unquantified diffuse groundwater discharges and the influence of higher nutrient offshore waters undoubtedly contribute additional nutrient loads to the Refuge. Concern over possible nutrient-related changes in the Refuge led to the initiation of a sampling program in 1996. All samplings have been carried out by Mote Marine Laboratory (MML) with logistic assistance from Refuge staff and USFWS.

This report forms a data summary and GIS analysis of submerged aquatic vegetation (SAV) from five years of the sampling program, over a period when water clarity was adversely impacted due to an extensive coastal algae bloom. Vegetation samplings analyzed in this report include periods before, during and after the water quality impairment. Relationships are examined spatially, both with respect to seasonal and inter-annual changes. Portions of the report (methods, regional descriptions, etc.) are reproductions of prior documents which are incorporated in the interest of clarity.

STUDY AREA SETTING

Chassahowitzka Bay and adjoining inshore waters are bounded by an extensive system of tidal wetlands, intertidal karst shoals and oyster reefs, and include extensive, shallow, subtidal beds of SAV. Geologically, the area represents a mixture of marsh archipelago and shelf embayment situated along a low energy, low-gradient, micro-tidal, and non-barrier coast (Hine and Belknap, 1986).

Coastal hydrology of the Chassahowitzka NWR is dominated by the discharge of several spring groups (Homosassa, Hidden River, Halls River, Chassahowitzka) together with runoff from a poorly delimited coastal basin area. Depending on their depths, individual spring vents discharge variable mixtures of fresh and saltwater and both the quality and quantity of discharge can vary tidally (Yobbi, 1992). A groundwater and spring discharge monitoring program together with other trend analyses conducted by the Southwest Florida Water Management District (SWFWMD, 1994; Jones et al., 1997; Dixon, 1997) has documented increasing trends of nitrogen in spring discharges with sources attributed to inland development and subsequent residential and golf course fertilization (Jones, et al., 1997). Nitrate levels in the discharge are presently near 0.4 – 0.5 mg L⁻¹ or between 40 and 50 times background groundwater concentrations. Other rivers nearby include the Crystal River (a spring-fed system 25 km to the north), the Withlacoochee River (primarily a surface drainage river 34 km to the north) and the Weeki Wachee River (also a spring-fed system 18 km to the south).
The inshore bathymetry is shallow and low in relief. Bottoms are limestone covered by veneers of organic and carbonate sediments and lacking quartz sand (Hine and Belknap, 1986). Submerged aquatic vegetation (SAV) is extensive. Historically, contiguous beds of dense, SAV cover more than 90% of inshore (<2 m depth) areas (McNulty et al., 1972; Wolfe, 1990). Dominant vascular plants of the coastal waters are turtle grass (Thalassia testudinum) and shoal grass (Halodule wrightii), together with manatee grass (Syringodium filiforme), (Iverson and Bittaker, 1986). Widgeon grass (Ruppia maritima) grows in lower salinity inshore water.

Clear, mineralized flows in the spring runs have historically permitted luxuriant growth of tape grass (Vallisneria neotropicalis) although long-time residents report that filamentous forms of algae are becoming more prevalent. Other common submerged fresh to brackish water species include sago pondweed (Potamogeton pectinatus), watermilfoil (Myriophyllum spicatum), hydrilla (Hydrilla verticillata), and naiad (Naja guadalepensis), with Potamogeton illinoensis occurring near the spring head. Midriver, floating rafts of both P. pectinatus and Myriophyllum are mixed with Enteromorpha spp. with abundance varying between years. Filamentous algae are common in the upper river, particularly in areas of low current velocity. Filamentous algae (Cladophora gracilis, Chaetomorpha spp., Lyngbya gracilis, and Schizothrix mexicana) form nuisance level mats on the sediment, particularly in the upper river and at the main spring.

MATERIALS AND METHODS

Station Selection

The Study area was identified as the near coastal waters of the Wildlife Refuge outside of the mouths of the Chassahowitzka and Homosassa Rivers. Assistance with station selection was performed by the U.S. Environmental Protection Agency (Dr. Kevin Summers) following EMAP (Environmental Monitoring and Assessment Program) protocols. From the area bounded by the Refuge, 30 polygons were selected for SAV sampling (Figure 1), and a subset (generally those nearer shore) was identified for water chemistry samplings (Figure 2). Of the potential stations identified within the polygons, sites were visited in order until SAV was observed, at which time that location became the established station location. In addition to the polygon-based stations, additional salinity-based stations were established in the Chassahowitzka River in 1997, extending up as far as the largest observed spring boil (station R0.0, Figure 2). Table 1 lists station locations.
Figure 1. Study area, Chassahowitzka National Wildlife Refuge, Florida. Thirty coastal stations and eight riverine stations.
Figure 2. Subset of twelve coastal and eight riverine water chemistry stations.
Table 1. Geographic locations of core stations; degrees and decimal minutes.

<table>
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<th>Station</th>
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<th>Minutes</th>
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<td>28</td>
<td>42.9159</td>
<td>83</td>
<td>34.5790</td>
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<tr>
<td>* R1.0</td>
<td>28</td>
<td>42.9844</td>
<td>83</td>
<td>34.7443</td>
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<tr>
<td>* R1.3</td>
<td>28</td>
<td>42.9283</td>
<td>83</td>
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<tr>
<td>* R1.7</td>
<td>28</td>
<td>43.2959</td>
<td>83</td>
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<tr>
<td>* R2.0</td>
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<td>42.8732</td>
<td>83</td>
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</tr>
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<td>28</td>
<td>42.3902</td>
<td>83</td>
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<td>* R3.0</td>
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<td>83</td>
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<td>2</td>
<td>28</td>
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</tr>
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<td>* 3</td>
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<td>83</td>
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<td>* 4</td>
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<td>8A</td>
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<td>83</td>
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<td>83</td>
<td>40.7322</td>
</tr>
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<td>* 26</td>
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<td>40.4980</td>
<td>83</td>
<td>39.9336</td>
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<td>28</td>
<td>39.6817</td>
<td>83</td>
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<tr>
<td>* 28</td>
<td>28</td>
<td>37.4440</td>
<td>83</td>
<td>40.5185</td>
</tr>
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<td>* 30</td>
<td>28</td>
<td>36.9285</td>
<td>83</td>
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<td>39</td>
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<td>44.7503</td>
<td>83</td>
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<td>* 40C</td>
<td>28</td>
<td>38.6682</td>
<td>83</td>
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<td>28</td>
<td>37.0733</td>
<td>83</td>
<td>40.6558</td>
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* Denotes water quality stations
**SAV Sampling Dates**

Sampling dates have emphasized May in order to sample historically dry conditions and optimum early growth conditions for SAV. Of the seven SAV samplings performed between 1996 and 2000, five have been in May, and two were conducted in September (1997 and 1998). The full suite of 30 SAV stations was sampled in all but the two 1998 samplings. Coverage in that year was reduced to permit a more intensive water quality sampling program. A core group of twelve nearshore stations has been sampled during each SAV effort. In May 1997, data were collected at eight stations in the Chassahowitzka River and subsequent samplings have collected vegetation cover and abundance data at the riverine stations.

**SAV Survey Methods**

Cover and abundance of submerged aquatic vegetation (SAV) were measured using a rapid-survey technique (Braun-Blanquet, 1932). At each pre-determined station, an observer surveyed two quadrats haphazardly cast on each side of the vessel for a total of four quadrats. Quadrats were 0.25 m² in area. The observer listed species of vascular plants and rhizophytic algae, as well as cover of all drift algae species combined, and assigned a cover-abundance value for each taxa or group (Table 2). Upper scale values (5-2, inclusive) pertain to cover only. Lower scale values are estimators of abundance (number of individuals per species). Four replicate quadrats were used to assess within and between station variability. Attributes were calculated as follows:

- Frequency = \( N_0N_t \)
- Abundance = sum of B-B scale values/\( N_0 \)
- Density = sum of B-B scale values/\( N_t \)

where \( N_0 \) was the number of occupied quadrats and \( N_t \) was the total number of quadrats. Secchi depths were recorded during SAV surveys. Reported depths were not tidally correct. In the coastal waters, unattached algae were categorized as 'Drift/Filamentous' species and included *Digenia simplex*, *Laurencia poitei*, *Laurencia intricata*, *Spyridea filamentosa*, *Chondria tenissima*, etc. At lower salinity stations, other non-rhizophytic algae were observed and included in the same 'Drift/Filamentous' category. While not identified to species level, they appeared to be filamentous chlorophytes and cyanophytes.
Table 2. Scalars used for Braun-Blanquet cover-abundance ratings of submerged aquatic vegetation in Chassahowitzka Bay.

<table>
<thead>
<tr>
<th>Value</th>
<th>Relative Number</th>
<th>Percent Cover</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>any number</td>
<td>greater than 75%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>any number</td>
<td>50%-75%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>any number</td>
<td>25%-50%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>any number</td>
<td>5%-25%</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>numerous</td>
<td>less than 5% or</td>
<td></td>
</tr>
<tr>
<td>+</td>
<td>few</td>
<td>small</td>
<td>assigned 0.5 value</td>
</tr>
<tr>
<td>r</td>
<td>solitary</td>
<td>small</td>
<td>assigned 0.1 value</td>
</tr>
</tbody>
</table>

Water Quality Samplings

Water quality samplings were generally limited to twelve nearshore stations and eight riverine stations. In situ measurements consisted of depth, temperature, conductivity (salinity), dissolved oxygen, percent saturation of oxygen, and Secchi depths. Water quality analyses consisted of nutrients (nitrate-nitrite-nitrogen, ammonium-nitrogen, total Kjeldahl nitrogen, orthophosphate, total phosphorus), chlorophyll, (chlorophyll a corrected for phaeophytin). Analytical methods and detection limits are detailed in Table 3. The analytical method for chlorophyll was changed from spectrophotometric to fluorometric for improved sensitivity in August 2000. Instrumental readings, collection, preservation and analysis of water quality samples were performed according to MML’s Florida Department of Environmental Protection-approved Comprehensive Quality Assurance Plan prior to Fall 2001 and subsequently according to MML’s NELAC certified Quality Plan. A total of 17 water quality samplings were conducted between May 1996 and May 2000.

Table 3. Detection limits, analytical methods, and data quality objectives for water quality samples; Chassahowitzka River and the coastal region.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Detection Limit</th>
<th>Method Number</th>
<th>Precision (%RSD)</th>
<th>Recovery Limits (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ortho-Phosphorus</td>
<td>0.005 mgL⁻¹</td>
<td>4500-PF</td>
<td>15</td>
<td>87-115</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>0.05 mgL⁻¹</td>
<td>365.4</td>
<td>13</td>
<td>80-111</td>
</tr>
<tr>
<td>Ammonium Nitrogen</td>
<td>0.05 mgL⁻¹</td>
<td>350.1</td>
<td>20</td>
<td>86-113</td>
</tr>
<tr>
<td>Nitrate-Nitrite-Nitrogen</td>
<td>0.005 mgL⁻¹</td>
<td>353.2</td>
<td>15</td>
<td>81-116</td>
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<tr>
<td>Total Kjeldahl Nitrogen</td>
<td>0.05 mgL⁻¹</td>
<td>351.2</td>
<td>18</td>
<td>86-119</td>
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<tr>
<td>Chlorophyll</td>
<td>0.5 µgL⁻¹</td>
<td>10200H(1,2)</td>
<td>28</td>
<td>Not Appl.</td>
</tr>
<tr>
<td>Chlorophyll, fluor</td>
<td>0.05 µgL⁻¹</td>
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Mapping Methodology

A GIS was created to store and display all the relevant information to help assess the changes in vegetation and water quality. The basemap used a shoreline that was digitized by the Florida Marine Research Institute (FMRI). It contained the necessary level of detail and was cropped and reprojected to UTM Zone 17 for ease of use. In addition to the shoreline, the sampling regions and point locations were also included. A hexagonal grid was created as part of the basemap to reflect the original EMAP sampling design.

The GPS waypoint file that contained coordinates for the sampling stations was imported, projected and overlaid. The resulting on-screen product was carefully compared to the original station chart. The data are being used for comparison at a large scale, so the resulting hexagon and station placements were suitably accurate. While the actual coordinate locations are retained in the attribute tables, the "ideal" waypoints of the stations were used to assign the polygons. The vegetation layers were created by importing the vegetation tables for each year and attaching the values to the appropriate hexagons. Displaying the vegetation data as polygons de-emphasized the scarcity of the data and was suitable to investigate regional patterns and trends. Density was chosen to represent species presence because it incorporates data from all the sampled quadrats, even when the species is not present. Therefore, density represents a more complete description of the SAV growth in an area than abundance, which is calculated using only the number of quadrats where a species was present. It should be noted that the sampling stations had slight variations between samplings, so only areas that were sampled are shown in the display for clarity. Care should be taken when comparing displays from other years with 1998. A large loss in density, or change in shading, should not be confused with the display showing fewer polygons.

To maximize the temporal aspect of the density maps, a layout was designed to show separate maps for each May sampling together on one page. A second layout was created to illustrate the differences between the May and September samplings in 1997 and 1998. The layouts for each species were exported as images and a library created for them in a shared directory. Users were then able to access and use the layouts without the need to use the GIS directly.

Water quality data were treated in much the same way as the vegetation data. Median values were calculated for the station using the data collected from 1996 through 2000. Compiled in a separate table, computed values were shown as graduated symbols. Also combined in the table were median values for each year, which were then displayed as polygons for compatibility with the vegetation maps. Some flexibility in visualization is retained for water quality parameters because contours, points, polygons or surfaces can be generated from a single table.
RESULTS AND DISCUSSION

Study Area

The largest discharge for the Chassahowitzka River appeared to be the main boil (Station R0.0) immediately to the northeast of the Citrus County boat launching facility. Numerous smaller vents were also observed upstream. Based on Florida aquifer potentiometric surface data, discharges were near normal in 1996, below normal in 1997, above normal in 1998, with declining levels since 1998. Rainfall received in late 1997 and early 1998 produced cumulative rainfall values well in excess of historical means and groundwater levels recovered as well. The effect of this rainfall on surface flows is also apparent in the records from the Withlacoochee River at holder, Florida, (U.S. Geological Survey Station 02313000) and the Suwannee River, in which mean monthly flows were approximately four time historical means for a number of months. By February 2000, however, a pattern of continuing drought throughout the state had resulted in regional rainfall deficits of 26 to 42 cm and near-record lows for groundwater levels. Surprisingly, local rainfall records (National Atmospheric Deposition Program Site FL05, located at the Chassahowitzka National Wildlife Refuge) recorded comparable wet season rainfalls in 1998, 1999, and 2000.

Downstream of the main spring area, confluences with a number of creeks deliver discharges from other smaller vents. Floating mats of senescent filamentous vegetation, cattails (Typha spp.), and reeds (Phragmites sp.) lined the sides of the river in places. Beds of tapegrass (Vallisneria) and pondweed (Potamogeton pectinatus, Potamogeton illinoensis) were visible on the bottom with some Hydrilla verticillata, as well. Over time, qualitative observations indicate a reduction in floating mats of algae and SAV canopies with an increase in submerged filamentous algal species. The upper 4 km of the river are surrounded by a deciduous flood plain forest down to the eastern boundary of the Chassahowitzka National Wildlife Refuge (Station R2.0). At the boundary, sawgrass (Cladium jamaicensis) and cattail (Typha spp.) dominate the bank vegetation, cabbage palm (Sabal palmetto) hammocks and Juncus appear, and the flood plain forest ends. Floating mats of Enteromorpha-like algae, Eurasian water milfoil (Myriophyllum spicatum), and Hydrilla verticillata were very dense here in 1996, but by May 2000 were much reduced. Water clarity typically decreased by this location. The lower River is lined with sawgrass, while Juncus dominates the interior marsh. Some cattails remain and the seagrass Ruppia maritima is occasionally present in the river. At the mouth of the river, clarity generally improved and the remaining coastal waters typically experienced high water clarity. The remaining coastal stations were within and offshore of a dense archipelago of marsh (Juncus) islands. Mangroves (Rhizophora mangle) were not numerous in 1996, being near the northern limits of cold tolerance for this species, and were evident chiefly as either dead and weathered stumps, or as small seedlings in the 20-50 cm size range.

Submerged Aquatic Vegetation

Of the 30 polygons identified for sampling, vegetation was found at all but one of the primary sites within each polygon during the initial 1996 sampling. For Polygon 8, the primary site had no vegetation and the first alternate site, Station 8A, was sampled instead. Data on frequency, abundance, and density were computed on the 30 vegetated stations, and so represent an
assessment of the vegetated regions only, rather than an assessment of the entire submerged study area. The fact that only one of the 30 primary stations was unvegetated indicates that coverage by SAV was extensive and almost continuous. Station 40 C was the primary site for Polygon 40, as the first randomly selected sites fell on land.) Since the initial sampling, station locations have not been altered.

A summary of species per sampling present in both coastal and riverine stations appears in Table 4. It is important to keep in mind that riverine stations were not sampled in 1996 and May 1997 and so freshwater species did not appear. Also, the further offshore stations were not sampled in 1998, possibly affecting the species found. Tables 5 and 6 give regional statistics on frequency, abundance and density for the coastal stations, either for the entire coastal study area (30 coastal stations) or for the inshore subset of 12 nearshore stations which were sampled during each SAV survey. Statistics are not comparable between these two tables due to the differing regions represented.

By May of 1998 the Refuge was affected by a phytoplankton bloom that was part of a larger bloom documented between the Weeki Wachee and Crystal Rivers (Dixon and Estevez, 2001). The bloom involved higher chlorophyll values and was attributed to the dominance of a blue-green algae, followed by a diatom (FDEP, 1999). The bloom occurred following the large surface water flows experienced in 1998 and was coincident with depressed salinities in the region. Within the refuge, the bloom was more concentrated at the stations between the Chassahowitzka and the Homosassa Rivers where marsh islands are abundant. At the time of the May 1998 sampling, the bloom dominated at least a 50 km portion of the coast. Trophic State Indices (TSI), which use nutrients, chlorophyll and water clarity measurements to rate water quality, nearly doubled for the refuge and persisted through October 1998 (Dixon, 1999).

An overview map displaying mean density over time for all species at the stations in the refuge was created to serve as a guide for visual analyses (Figure 3). Previous analyses showed that turbidity was generally higher in the area to the north of the mouth of the Chassahowitzka River and that values of both turbidity and chlorophyll increased during the phytoplankton bloom of 1998 (Dixon and Estevez, 2002). The mean density of Stations 18 and 21 reached their lowest values in May 1998, which corresponds to the highest chlorophyll and turbidity values over the course of the study. At the coastal stations sampled for all May events, mean densities generally decreased across the refuge during the May 1998 sampling. A second map was produced showing the mean density of the species that were present at each station over time (Figure 4). The stations at the mouth of the River, such as 23 and 26, showed a mean density of 5 among those species present and a large decline in May 1998. Station 23 showed variations, but overall recovery in the mean density of those present. However, Station 26 continued to decline through September 1998, and by May 2000 had still not shown significant recovery.
Table 4. Submerged aquatic vegetation species observed by sampling.

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* - No riverine stations sampled; no low salinity species
** - Twelve nearshore stations rather than thirty coastal

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In the Chassahowitzka National Wildlife Refuge 1996-2000
Table 5. Regional Braun-Blanquet statistics by sampling for the entire coastal study area (30 stations.) OBS – number of quadrats in which species was observed, FREQ-frequency, ABUN-abundance, DENS-density (See text.)

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Table 6. Regional Braun-Blanquet statistics by sampling for the nearshore stations (12 stations). OBS - number of quadrats in which species was observed, FREQ-frequency, ABUN-abundance, DENS-density (See text).

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*Mote Marine Laboratory*

*Change Analysis of Submerged Aquatic Vegetation*

*In the Chassahowitzka National Wildlife Refuge 1996-2000*
Table 6. Continued

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Figure 3. Mean density for all species. Excludes unvegetated areas.
Figure 4. Mean density for all species present by year. Excludes unvegetated areas and drift/filamentous algae.
Mean density was broken down further to show vascular SAV (Figure 5) and rhizophytic algae (Figure 6) separately. For vascular SAV species, assemblages at riverine stations were salinity intolerant and differed from the species found at coastal stations. Coastal vascular SAV appears concentrated in the northern part of the Refuge. The difference in vascular SAV densities between the river and coast also represents species with varying salinity tolerances. The mean density of rhizophytic algae is higher than for vascular SAV along the coast, but the species are restricted from riverine stations by low salinity. The coastal algal species showed a decline in 1998, followed by recovery in 1999 and 2000, especially in the central part of the refuge.

During the bloom year, unvegetated areas increased dramatically. The percent of four quads that were bare in each May sampling are shown in Figure 7. There was little change in the number of nearshore bare quadrats in September 1997 and May 1998 with 2 and 3, respectively. However, there was an increase from 3 in May 1998 to 13 in September 1998. Fewer bare quadrats were found in 1999 and 2000, but the area has not yet returned to 1996-1997 levels.

The density map for drift and filamentous algae (Figure 8) showed drift algae were generally present in higher densities offshore, although data were not available for the bloom year. Again, riverine and coastal stations contain different and generally non-overlapping species assemblages. The May 1998 sampling yielded the highest densities for drift algae at the mouth of the river and the lowest densities in the southern nearshore stations. Density of filamentous algae in the river has generally increased since 1998.

The number of species per station for each sampling was also color coded to highlight areas with higher species diversity (Figure 9). Between May 1997 and May 1998, 2/3 of the stations showed a decrease in the number of species and only Station 40C showed an increase from 3 to 5 species. This station had the highest species diversity observed in the refuge in 1998. Since then, the species count has increased at many stations, especially offshore and in the northern part of the refuge. The number ranged up to 10 species at Station 9 in May 1999 and 3 stations in May 2000 reported 9 species. These stations have also increased their overall mean density.
Figure 5. Mean density for vascular SAV species by year.
Figure 6. Mean density for rhizophytic algal species by year.
Figure 7. Percent unvegetated of four quadrats by year.
Figure 8. Density of drift and filamentous algae by year. Includes fresh and saltwater species.
Figure 9. Number of species present per sampling by year.
Time series of the densities of individual species during the May samplings were also prepared (Appendix A). Density maps for abundant species such as *Acetabularia crenulata* (Figure 10) and *Caulerpa paspaloides* highlight the fluctuations in values and locations, decline and recovery of the species over time. In 1996, *Acetabularia* was a common species, observed in nearly one third of all quadrats and at a mean abundance of over 2.00 (greater than 5-25% cover) when present. Of the 12 nearshore stations, it was present in 17% of all quadrats. By 1998, *Acetabularia* had declined and was present in only 6% of all quadrats. Since 1998, recoveries have been observed. The recovery of *Acetabularia* does not, however, appear to be constant over the entire refuge. Since the losses noted in 1998, the density increased first at the area near the mouth of the Chassahowitzka River in May 1999, followed by the increase in May 2000 of the northern and southern parts of the refuge. By 2000, *Acetabularia* was present in 29% of the nearshore quadrats and in 36% of all quadrats.

*C. paspaloides*, the most dominant SAV species in the refuge, exhibited declines at the mouth of the River in 1998 (Figure 11). Loss of density continued into May 1999 in this region. Some recovery was evident by May 2000 but still did not return to 1996 levels. In contrast, the southern coast (Station 40C) showed recovery back to 1996 and 1997 levels, although not at the offshore stations. While the density, where present, has generally remained comparable over time, the number of quadrats containing *C. paspaloides* has declined to about two thirds of 1996 levels in the near-shore stations. Other species which exhibited declines in 1998 and which have not returned to 1996 levels included *Caulerpa prolifera* at the nearshore stations, although declines predated the 1998 bloom.

Also of note are the maps that show the first collection of isolated species such as *Padina* sp. (Figure 12). *Padina* was first documented in May 2000 at stations 18 an 22, offshore and just north of the mouth of the Chassahowitzka River. While Station 22 was not sampled for vegetation in 1998, Station 18 was included in all samplings. The maps also provide a geographic reference for other isolated appearances such as *Caulerpa ashmeadii* in May 1996 and presence of *Chara* spp. In May 1997. *C. ashmeadii* was found only once in the northern part of the refuge and was not seen again in any sampling. *Chara* was found near the mouths of both the Chassahowitzka and Homosassa Rivers in May of 1997. A second sampling in September 1997 showed a decline in density near the mouth of the Homosassa River, but the species was not seen again near the mouth of the Chassahowitzka River.

A second set of maps (Appendix B) was developed to show seasonal variability, comparing May and September samplings. The example of the disappearance of *Chara* given above is shown clearly by this method (Figure 13). The display for May 1997 shows the location of the two areas with densities of 3.275 in the southern station and 3.75 to the north. In the corresponding locations for September, *Chara* is not present, although a density of 0.75 is reported at the station upriver in the Homosassa area.
Figure 10. Density of *Acetabularia crenulata* by year.
Figure 11. Density of *Caulerpa pascaloides* by year.
Figure 12. Density of *Padina* sp. by year.
Figure 13. Density of Chara sp. during seasonal samplings in 1997 and 1998.
The seasonal map for drift/filamentous algae shows the best example of seasonal changes (Figure 14). Declines in density can be seen in both September samplings. Most of the species did not show a clear, seasonal repetitive pattern, but it should be noted that the phytoplankton bloom during 1998 could be responsible for masking seasonal signals in the observations.

Since the change in density was important to visualize, maps were designed to show change between years. Change in density was computed as the difference between BB values for a given species and over the identified time period. To improve clarity, only stations that had a reported instance of a species during any year were displayed. Polygons which showed no change could therefore be distinguished from areas where a species had never been reported. If a species was no longer present at a station, successive observations of zero density were illustrated as ‘no change’. The polygons were shaded to display loss or gain in density, or no change where the value was constant. Some species do not display polygons for some years, if the station was not sampled at both the beginning and end of the time span.

Detailed density change maps illustrated changes from May sampling to the following May 9 (Appendix C). The second set (Appendix D) showed the change between consecutive seasonal samplings and made the direct comparison between September samplings and the following May for sampling in May 1997 to May 1999. The two sets used together presented a geographic representation of areas and general change for the entire time frame. It should be noted that small changes were represented the same as large changes, so these maps were best used as supplements to the original density maps and to highlight areas of interest.

Acetabularia (Figure 15) showed declines at the stations near the mouth of the Chassahowitzka River between 1996 and 1997, followed by increases from May 1998 to May 1999 and declines again from May 1999 to May 2000. Much of the loss for the deeper coastal region apparently preceded the bloom year, as it was apparent in the May 1996-1997 comparison. Figure 16 indicates that the losses continued from May to September 1997, which recovery apparent from May 1998, September 1998, May 1999 and May 2000. Similar fluctuations were seen in the map pair for C. paspaloides at stations in the same region. The Halimeda density changes showed that the declines started between May and September 1997 and gains began after May 1999.

The change maps show density relationships between riverine species more clearly than the density maps, due to the smaller amount of information being displayed. Species such as Naja guadalupensis and Vallisneria americana were viewed more clearly by this method, but there is less vegetation data available for the river, so the change maps appeared less complete.
Figure 14. Density of drift and filamentous algae during seasonal samplings in 1997 and 1998.
Figure 15. Density change of *Acetabularia crenulata* during May samplings.
Figure 16. Density change of *Acetabularia crenulata* during consecutive seasonal samplings.
Water Quality

In an effort to investigate probable causes for some of the changes in vegetation, two approaches were employed. Previous study had shown that the phytoplankton bloom accompanying the reduced salinity in 1998 also reduced ambient light levels at depth (Dixon and Estevez, 2001) and so parameters of primary importance were salinity, color, turbidity and chlorophyll.

Graphically, changes in density were compared to a variety of calculations of water quality parameters. X-Y plots were created to check for relationships between salinity and light-related parameters and the change in density for two species that showed the most prominent change over the sampling record. Density changes for Acetabularia crenulata and Caulerpa paspaloides were plotted against salinity, turbidity, color (apparent) and chlorophyll a.

Density changes were calculated by station and by species, subtracting the density value for that station from the previous May sampling. Therefore, density changes of 0 represent "no change" and may show a station where the density remained at 5 for both samplings or at 0. However, only stations where the species had been reported as present in any sampling are used.

The water quality values were calculated for each sampling year spanning from May to May, inclusive. The 1996 values for SAV change and water quality were not used because only one sample set was available. The year 1997 to 1998 includes 3 samplings (May 1997, Sept. 1997 and May 1998). The year from 1998 to 1999 includes 7 samplings (May 1998, July 1998, Sept. 1998, Nov. 1998, Jan 1999, March 1999 and May 1999). The year from 1999 to 2000 includes 5 samplings (May 1999, Aug. 1999, Nov. 1999, Feb 2000 and May 2000). Median values were calculated, in addition to the means, to lessen the effect of extreme values on the calculations. Standard deviations were also plotted to gauge the effect of variations on the change in density. Maximum values for turbidity, color and chlorophyll a were plotted versus density change, but minimum salinity was used to better visualize the effect of depressed salinity values.

Density change during a year was plotted against the water quality calculation for the same time period. Even though change over time is clear for these two species, none of the graphs showed a correlation between any one parameter and density change. Figure 17 shows the graph of C. paspaloides density against chlorophyll a values. While the graph is not conclusive, there is a group of stations with concurrent higher chlorophyll values and density loss, especially during the May 1997 to May 1999 timeframe, although density losses also occurred where chlorophyll values remained low. Finally, the density of all the stations was plotted against the median values of the prior year to show the water quality ranges where the species were present.
Median water quality values for each station were calculated using all samplings and mapped with graded symbols (Appendix E). These maps were helpful in illustrating where in the refuge certain conditions prevailed. Of all the coastal stations, the stations in the north showed higher chlorophyll $a$ values and generally higher TSI values. The only station to have a median total phosphorus value higher than the limit of detection was located in the area of highest median turbidity.

Median values of salinity and chlorophyll $a$ were calculated by sampling year, with the exception of 1996-1997 where the mean was used ($n=2$). Color and turbidity were begun in 1998 and calculated for 1998 to 2000. These yearly medians were mapped and displayed in the same format as the density maps (Appendix F). Medians mapped by sampling years, did not seem to show high and low values, so means and maximum values were also mapped, although the minimum value for salinity was used, rather than the maximum. Median values by calendar year were mapped, but it should be noted that $n=1$ for 1996. These maps show the bloom year effects much clearer, but are not comparing the same time span as the density change maps.

Figure 18 illustrates the median salinity values for each sampling year. The map supports the previous conclusions about the role of salinity in the region. For the upper river, diurnal variations in salinity were comparable to those experienced over the course of the study. Discharge from the main spring ranged between 0.2 and 4 PSU with the lowest salinity observed in September 1998 and the highest in May 2000, generally reflecting rainfall and groundwater
surpluses and deficits for the region. The rainfall departures and groundwater indices were also reflected in the coastal salinity data. Depressed salinities occurred in May, July, and September 1998 and followed the extreme discharge events of early 1998. During these three samplings, while reduced salinity was present near the mouth of the Chassahowitzka, lowered salinities were also observed at the northern boundary of the Refuge (Stations 3 and 4), and indicated a variety of freshwater influences to the region. This parallels the data showing the loss of rhizophytic algae in these regions and shows salinity could be at least partially responsible for these declines.

Color and turbidity were not sampled until after the initiation of the phytoplankton bloom in 1998. Median maps were created to display 1998-1999 and 1999-2000 data. Within the river, contributions of dissolved humics from wetland forests and marshes clearly appeared as increased color values between Station R1.7 and R4.0. Precipitation of humics on exposure to salt resulted in a similar distribution of turbidity within the river. Outside the mouth of the river, color values declined with increasing salinity. The highest colors were observed in September 1998, followed by lesser highs in August 2000, and were associated with reduced salinity values. Local rainfall in September 1998 and July 2000 were most likely responsible for increased surface and marsh drainage to the waters of the River and Refuge.
SUMMARY

The present study was performed to map previously sampled submerged aquatic vegetation and water chemistry and to establish spatial links between them in the Chassahowitzka National Wildlife Refuge. Mote Marine Laboratory conducted all sampling and analysis with sampling assistance from Refuge personnel and vessels.

Five years of sampling for SAV and water quality have resulted in seven surveys of submerged aquatic vegetation and 17 water quality surveys. SAV survey techniques employed the Braun-Blanquet technique for rapid assessment of cover and abundance by species. While there are some interannual differences, surveys generally included 30 stations for SAV and 20 stations for water quality in both the coastal waters of the Refuge and within the Chassahowitzka River. The number of water quality samplings conducted varied by year. The period of study has included extremes of both wet and dry conditions. Of particular note was the high rainfall in late 1997 and early 1998 and subsequent high discharges from nearby surface drainage rivers (Withlacoochee and Suwannee Rivers). An extended period of drought through 2000 depressed groundwater levels, but local rainfall appeared near normal. The salinity of the discharge from the main spring appeared inversely correlated to regional groundwater levels.

During 1998, however, the May through September samplings detected an extensive phytoplankton bloom in the coastal water of the Chassahowitzka Refuge. Chlorophyll concentrations increased to near 20 μg L⁻¹ and water clarity declined. The highest chlorophyll concentrations were in the north-central portion of the refuge, among the numerous marsh islands. During the bloom condition, orthophosphorus and organic nitrogen more than doubled, and inorganic nitrogen increased slightly, producing strongly nitrogen limited conditions. Organic phosphorus concentrations were much reduced, however, in the bloom water mass. The high organic nitrogen noted was attributed to compounds entrained in a water mass of riverine origin rather than phytoplankton biomass since organic concentrations were low. Correlation of chlorophyll with organic nitrogen during the bloom was attributed to an essential growth factor that covaried with the organic nitrogen and may have been of terrestrial origin. Trophic state indices were considered “GOOD” for the refuge as a whole, except during the 1998 bloom when almost all coastal stations recorded values in excess of 50, or a ‘FAIR’ designation.

Submerged aquatic vegetation, including both vascular plants and rhizophytic algae, formed a nearly continuous cover within the refuge in 1996. Species diversity was high in the region. Caulerpa paspaloides was the most frequently observed, and appeared in 33% of all coastal station quadrats, and in 48% of all nearshore station quadrats. Other common species were Acetabularia crenulata, Halodule wrightii, Thalassia testudinum, and Batophora oerstedi. Drift algal species were also prevalent. During the May 1996 sampling, drift algae occurred in approximately 50% of quadrats; frequency and density were generally reduced during both September samplings, indicating a repetitive seasonal pattern.

Mapping available data for the refuge allowed for a visual analysis of change over time, both for density of individual species and for water quality parameters. Sections of the refuge that act as a unit could be grouped together for further study. Overall, the northern part of the refuge acted separately from both the mouth of the River and the southern part of the refuge. The northern part of the refuge was often associated with higher values in turbidity than the coastal stations in...
the south. Color, inorganic nitrogen and chlorophyll concentrations were generally higher near
the mouth of the Chassahowitzka River, except in 1998, when chlorophyll associated with the
extensive phytoplankton bloom was concentrated in the northern part of the refuge.

Having been collected under a wide range of salinity conditions, study data provided information
on SAV species salinity tolerances (and correlated factors such as water clarity). Previous
conclusions about species behavior were confirmed and illustrated. For Caulerpa pascaloides
and Halodule wrightii, declines in density and abundance were noted coincident with the
increased freshwater and reduced water clarity, which have not yet returned to 1996 levels,
despite restoration of former salinity values. Similarly, Acetabularia crenulata and Batophora
oerstedi also recorded abrupt declines in density during 1998. These species, however, have
generally returned to 1996 densities. Unvegetated areas increased sharply in September 1998,
after a number of months of low salinity and low water clarity. While improved, there are still
more unvegetated quadrats than noted in 1996.

As a result of the extended phytoplankton bloom, the Chassahowitzka National Wildlife Refuge
has demonstrated its sensitivity to pulsed freshwater and nutrient loads. Reductions in some
species of SAV and increased frequency of unvegetated bottom were still apparent after two
years. The magnitude of the runoff event and persistence of the reduced salinity and high
nutrient conditions obscured any potential relationship of trophic condition with localized
atmospheric depositions. Since the 1998 bloom, the summers of 1999 and 2000 have had
relatively high atmospheric loads of inorganic nitrogen deposition. Although the seasonally high
atmospheric loads corresponded temporally with increased chlorophyll and increased inorganic
nitrogen noted in the coastal waters in the August sampling of 1999 and 2000, and although the
level of increase in load roughly corresponds to the magnitude of chlorophyll increase, co-factors
such as temperature and salinity cannot be eliminated with the existing data set.
APPENDIX A
Density of *Acetabularia crenulata* from 1996 to 2000

May 1996

May 1997

May 1998

May 1999

May 2000

Kilometers
Denisty of *Anadyomene stellata* from 1996 to 2000

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Kilometers
Density of *Avrainvillea spp.* from 1996 to 2000

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<tr>
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Kilometers
Density of *Batophora oerstedi* from 1996 to 2000

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- 0-1
- 1-2
- 5

Kilometers
Density of *Chara spp.* from 1996 to 2000

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Legend:
- 0
- 1-2
- 2-3
- 3-4
- 4-5
- 5
Density of *Caulerpa pavaşaloides* from 1996 to 2000

- May 1996
- May 1997
- May 1998
- May 1999
- May 2000

**Legend:**
- Density 0
- Density 0-1
- Density 1-2
- Density 2-3
- Density 3-4
- Density 4-5
- Density 5
May 1996

May 1997

May 1998

May 1999

May 2000

Density of *Caulerpa prolifera* from 1996 to 2000

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Kilometers
Density of *Halimeda incrassata* from 1996 to 2000

**Density**
- 0
- 1 - 2
- 0 - 1
- 3 - 4
- 4 - 5
- 2 - 3

**Kilometers**

May 1996

May 1997

May 1998

May 1999

May 2000
Density of Halophila englemannii from 1996 to 2000

Density
- 0
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5

Kilometers
Density of *Halodule wrightii* from 1996 to 2000

Density

- 0
- 1-2
- 3-4
- 4-5
- 5

Kilometers
Density of *Hydrilla verticillata* from 1996 to 2000

May 1996

May 1997

May 1998

May 1999

May 2000

Legend:
- 0
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5

Kilometers
Density of *Myriophyllum spicatum* from 1996 to 2000

Density categories:
- 0
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5

May 1996
May 1997
May 1998
May 1999
May 2000
Density of *Najas guadalupensis* from 1996 to 2000

- **Density**
  - 2-3
  - 3-4
  - 4-5
  - 1-2
  - 5

- **Scale**
  - 2
  - 0
  - 2
  - 4
  - 6
  - 8
  - 10
  - Kilometers
Density of *Padina* sp. from 1996 to 2000

- May 1996
- May 1997
- May 1998
- May 1999
- May 2000

Kilometers

- Density
  - 0
  - 0-1
  - 1-2
  - 2-3
  - 3-4
  - 4-5
  - 5
Density of *Penicillus capitatus* from 1996 to 2000

Density
- 0
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5

Kilometers
Density of *Potamogeton pectinatus* from 1996 to 2000.

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Kilometers
Density of *Ruppia maritima* from 1996 to 2000

May 1996

May 1997

May 1998

May 1999

May 2000

Density

- 0
- 1-2
- 2-3
- 3-4
- 4-5
- 5

Kilometers
Density of Syringodium filiforme from 1996 to 2000

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Kilometers

May 1996

May 1997

May 1998

May 1999

May 2000
Density of *Thalassia testudinum* from 1996 to 2000

Density  
- 2-3
- 3-4
- 4-5
- 5

Kilometers
Density of *Udotea flabellum* from 1996 to 2000
Density of Unvegetated areas from 1996 to 2000

- May 1996
- May 1997
- May 1998
- May 1999
- May 2000

Legend:

- 2-3
- 3-4
- 4-5
- 5

Kilometers
May 1996
May 1997
May 1998
May 1999
May 2000

Density of *Vallisneria americana* from 1996 to 2000

Density

- 0
- 0.1
- 1-2
- 2.3
- 3.4
- 4.5
- 5

Kilometers
APPENDIX B
Appendix B Figure 25

Densities for May and September samplings 1997 and 1998 for *Vallisneria americana*

- May 1997
- Sept. 1997
- May 1998
- Sept. 1998

Legend:
- 0
- 1-2
- 2-3
- 3-4
- 4-5
- 5

Kilometers
Appendix B Figure. 1

Densities for May and September samplings 1997 and 1998 for *Acetabularia crenulata*
Densities for May - September samplings 1997 and 1998 for Anadyomene stellata

Appendix B Figure. 2
Densities for May and September samplings 1997 and 1998 for Avrainvillea spp.

Appendix B Figure. 3
Appendix B Figure. 4

Densities for May and September samplings 1997 and 1998 for *Batophora oerstedii*
Densities for May and September samplings 1997 and 1998 for *Caulerpa ashmeadii*

Appendix B Figure. 5
Appendix B Figure. 6

Densities for May and September samplings 1997 and 1998 for *Caulerpa papsaloides*
Densities for May and September samplings 1997 and 1998 for Caulerpa prolifera

Appendix B Figure 7
Densities for May and September samplings 1997 and 1998 for Chara spp.

Appendix B Figure. 8
Densities for May and September samplings 1997 and 1998 for *Halimeda incrassata*

Appendix B Figure 9
Densities for May and September samplings 1997 and 1998 for
*Halophila englemannii*

Appendix B Figure 10
Appendix B Figure. 11
Densities for May and September samplings 1997 and 1998 for
*Hydrilla verticillata*

Appendix B Figure 12
Densities for May and September samplings 1997 and 1998 for *Myriophyllum spicatum*

Appendix B Figure 13
Appendix B Figure. 14

Densities for May and September samplings 1997 and 1998 for Misc. Algae (Drift/Filamentous)
Densities for May and September samplings 1997 and 1998 for *Najas guadalupensis*

Appendix B Figure 15
Densities for May and September samplings 1997 and 1998 for 
*Padina* sp.

Appendix B Figure. 16
May 1997

Sept. 1997

May 1998

Sept. 1998

Densities for May and September samplings
1997 and 1998 for
*Penicillus capitatus*

Appendix B Figure. 17
Appendix B Figure 18

Densities for May and September samplings 1997 and 1998 for Potamogeton pectinatus
Densities for May and September samplings 1997 and 1998 for *Ruppia maritima*

Appendix B Figure. 19
Densities for May and September samplings 1997 and 1998 for *Sargassum spp.*

Appendix B Figure. 20
Densities for May and September samplings 1997 and 1998 for
*Syringodium filiforme*

Appendix B Figure. 21
Densities for May and September samplings 1997 and 1998 for *Thalassia testudinum*

Appendix B Figure. 22
Densities for May and September samplings 1997 and 1998 for *Udotea flabellum*

Appendix B Figure. 23
Appendix B Figure. 24

Densities for May and September samplings 1997 and 1998 for Unvegetated areas

Legend:
- Density
  - 0
  - 0 - 1
  - 1 - 2
  - 2 - 3
  - 3 - 4
  - 4 - 5
  - 5

Scale: 0 - 4 Kilometers
Ma y 1996 to May 1997

Ma y 1998 to Ma y 1999

May 1997 to Ma y 1998

May 1999 to Ma y 2000

Density change

Acetabularia crenulata

Density

- Loss
- No Change
- Gain

Kilometers

2.5 0 2.5 5

May 1996 to May 1997

May 1998 to May 1999

May 1997 to May 1998

May 1999 to May 2000
Density change
_Anadyomene stellata_

May 1996 to May 1997

May 1997 to May 1998

May 1998 to May 1999

May 1999 to May 2000

Density
- Loss
- No Change
- Gain

Kilometers

2.5 0 2.5 5
May 1996 to May 1997...

May 1997 to May 1998...

May 1998 to May 1999...

May 1999 to May 2000...

Density change
*Caulerpa ashmeadii*

Density
- Loss
- No Change
- Gain

2.5 0 2.5 5 Kilometers
May 1996 to May 1997

May 1997 to May 1998

May 1998 to May 1999

Density change
Chara spp.

Density

- Loss
- No Change
- Gain

Kilometers

2.5  0  2.5  5
Density change
*Caulerpa pappaloides*

May 1996 to May 1997

May 1997 to May 1998

May 1998 to May 1999

May 1999 to May 2000

Density
- **Loss**
- **No Change**
- **Gain**
Density change
*Halophila englemannii*

May 1996 to May 1997

May 1997 to May 1998

May 1998 to May 1999

May 1999 to May 2000

Density

- Loss
- No Change
- Gain

Kilometers
Density change *Myriophyllum spicatum*

- May 1996 to May 1997
- May 1997 to May 1998
- May 1998 to May 1999
- May 1999 to May 2000

Density
- Loss
- No Change
- Gain

Kilometers

2.5 0 2.5 5
Density change *Najas guadalupensis*

- **May 1996** to **May 1997**
- **May 1997** to **May 1998**
- **May 1998** to **May 1999**
- **May 1999** to **May 2000**

**Density**
- Loss
- No Change
- Gain

**Kilometers**

0 2.5 5
Density change
*Penicillus capitatus*

May 1996 to May 1997

Density
- Loss
- No Change
- Gain

Kilometers

May 1997 to May 1998

May 1998 to May 1999

May 1999 to May 2000
May 1996 to May 1997

May 1997 to May 1998

May 1998 to May 1999

May 1999 to May 2000

Density change
Potamogeton pectinatus

Density
- Loss
- No Change
- Gain

Kilometers

2.5 0 2.5 5

Kilometers
Density change
*Syringodium filiforme*

May 1996 to May 1997

May 1997 to May 1998

May 1998 to May 1999

May 1999 to May 2000

Density
- Loss
- No Change
- Gain

Kilometers
Density change
*Udotea flabellum*

- May 1996 to May 1997
- May 1997 to May 1998
- May 1998 to May 1999
- May 1999 to May 2000

Density:
- Loss
- No Change
- Gain

Kilometers
May 1996 to May 1997

Density change unvegetated areas

May 1997 to May 1998

Density
- Loss
- No Change
- Gain

May 1998 to May 1999

May 1999 to May 2000

2.5 0 2.5 5 Kilometers
APPENDIX D
Density change
*Acetabularia crenulata*

May 1997 to Sept 1997

May 1998 to Sept 1998

Sept 1997 to May 1998

May 1998 to Sept 1998

Sept 1998 to May 1999

Kilometers

- Loss
- No Change
- Gain
Density change

*Anadyomene stellata*

- **May 1997** to **Sept 1997**
- **May 1998** to **Sept 1998**

Legend:
- **Loss**
- **No Change**
- **Gain**

Kilometers

- **2.5**
- **0**
- **2.5**
- **5**

**May 1997** to **Sept 1997**

**Sept 1997** to **May 1998**

**May 1998** to **Sept 1998**

**Sept 1998** to **May 1999**
Density change
Avrainvillea spp.

May 1997 to Sept 1997

Sept 1997 to May 1998

Density
- Loss
- No Change
- Gain

May 1998 to Sept 1998

Sept 1998 to May 1999

Kilometers

2.5  0  2.5  5
May 1~7 to Sept 1~7

Density change
Batophora oerstedi

May 1~8 to Sept 1~8

Density
Loss  No Change  Gain

May 1997 to Sept 1997

Kilometers

Sept 1997 to May 1998

May 1998 to Sept 1998

Sept 1998 to May 1999
May 1997 to Sept 1997

Density change
*Caulerpa pASpaloides*

May 1998 to Sept 1998

Density
- Loss
- No Change
- Gain

Sept 1997 to May 1998

May 1998 to Sept 1998

Sept 1998 to May 1999

2.5 0 2.5 5
Kilometers
May 1997 to Sept 1997

Density change
*Halimeda incrassata*

May 1998 to Sept 1998

Density

- Loss
- No Change
- Gain

May 1998 to Sept 1998

Sept 1997 to May 1998

Sept 1998 to May 1999

Kilometers

0 2.5 5
Density change
_Halodule wrightii_

May 1997 to Sept 1997

May 1998 to Sept 1998

Sept 1997 to May 1998

May 1998 to Sept 1998

Sept 1998 to May 1999

Density

- Loss
- No Change
- Gain

Kilometers

2.5 0 2.5 5
May 1997 to Sept 1997

Density change
Misc. Algae
(Drift/Filamentous)

May 1998 to Sept 1998

Density

- Loss
- No Change
- Gain

Sept 1997 to May 1998

May 1998 to Sept 1998

Sept 1998 to May 1999

Kilometers

2.5  0  2.5  5
Density change
*Myriophyllum spicatum*

May 1997 to Sept 1997

Density
- Loss
- No Change
- Gain

Kilometers

May 1997 to Sept 1997

May 1998 to Sept 1998

Sept 1998 to May 1999


Density change  
*Padina sp.*

May 1997  

Sept 1997  

May 1998  

Sept 1998  

Density  
- Loss  
- No Change  
- Gain  

May 1998  

Sept 1998  

2.5  0  2.5  5  

Kilometers  

May 1998  

Sept 1998  

May 1997  

Sept 1997  

May 1998  

Sept 1998  

2.5  0  2.5  5  

Kilometers  

May 1998  

Sept 1998  

May 1997  

Sept 1997  

May 1998  

Sept 1998  

2.5  0  2.5  5  

Kilometers  

May 1998  

Sept 1998  

May 1997  

Sept 1997  

May 1998  

Sept 1998  

2.5  0  2.5  5  

Kilometers  

May 1998  

Sept 1998  

May 1997  

Sept 1997  

May 1998  

Sept 1998  

2.5  0  2.5  5  

Kilometers  

May 1998  

Sept 1998  

May 1997  

Sept 1997  

May 1998  

Sept 1998  

2.5  0  2.5  5  

Kilometers  

May 1998  

Sept 1998  

May 1997  

Sept 1997  

May 1998  

Sept 1998  

2.5  0  2.5  5  

Kilometers
Density change
*Penicillus capitatus*

May 1997 to Sept 1997

Sept 1997 to May 1998

May 1998 to Sept 1998

Sept 1998 to May 1999

- **Gain**
- **Loss**
- **No Change**

Kilometers
Density change
Sargassum spp.

May 1997 to Sept 1997

Density

Loss
No Change
Gain

Sept 1997 to May 1998

May 1998 to Sept 1998

Sept 1998 to May 1999

Kilometers
Density change
*Syringodium filiforme*

May 1997 to Sept 1997

May 1998 to Sept 1998

Density
- **Loss**
- **No Change**
- **Gain**

Kilometers

2.5 0 2.5 5

May 1998 to Sept 1998

Sept 1997 to May 1998

Sept 1998 to May 1999
Density change
*Thalassia testudinum*

May 1997 to Sept 1997

May 1998 to Sept 1998

Sept 1997 to May 1998

May 1998 to Sept 1998

Sept 1998 to May 1999

Density
- Loss
- No Change
- Gain

Kilometers
Density change
*Udoeia flabellium*

May 1997 to Sept 1997

Density
- Loss
- No Change
- Gain

May 1998 to Sept 1998

2.5 0 2.5 5
Kilometers

Sept 1997 to May 1998

Sept 1998 to May 1999
May 1997 to Sept 1997

May 1998 to Sept 1998

Sept 1997 to May 1998

Sept 1998 to May 1999

Density change
Vallisneria americana
May 1997 to Sept 1997

Density change unvegetated areas

May 1997 to Sept 1997

Sept 1997 to May 1998

Density
- Loss
- No Change
- Gain

May 1998 to Sept 1998

Sept 1998 to May 1999

Kilometers

2.5 0 2.5 5
APPENDIX E
Median salinity (PSU) for 1996 to 2000
Median turbidity (NTU) for 1996 to 2000
Median color, apparent (PCU) for 1996 to 2000
Median chlorophyll $a$ (mg/m$^3$) for 1996 to 2000
Median Trophic State Index (TSI) for 1996 - 2000
Median orthophosphorus (mg/L) for 1996 to 2000
Median total phosphorus (mg/L) for 1996 to 2000
Median total Kjeldahl nitrogen (mg/L) for 1996 to 2000
Median nitrogen as nitrate-nitrite (mg/L) for 1996 - 2000
Median nitrogen as ammonia (mg/L) for 1996 - 2000
Median organic nitrogen (mg/L) for 1996 - 2000
Median inorganic nitrogen (mg/L) for 1996 to 2000
APPENDIX F
Median Salinity by Sampling Year
1996 - 2000

1996-1997

1997-1998

1998-1999

1999-2000

Median Salinity by Sampling Year
1996 - 2000

Salinity (PSU)

0 - 4.9

5 - 9.9

10 - 14.9

15 - 19.9

20 - 24.9

25 - 29.9

30 - 40

Kilometers
Mean Salinity by Sampling Year
1996 - 2000

Salinity (PSU)

- 0 - 4.9
- 5 - 9.9
- 10 - 14.9
- 15 - 19.9
- 20 - 24.9
- 25 - 29.9
- 30 - 40

Kilometers
Minimum Salinity by Sampling Year
1996 - 2000

1996-1997
Salinity (PSU)
- 15-19.9
- 20-24.9
- 25-29.9
- 30-40

1997-1998

1998-1999

1999-2000

Kilometers
Median Turbidity by Sampling Year 1998 - 2000

<table>
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Median Color, Apparent by Sampling Year 1998 - 2000

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Mean Turbidity by Sampling Year 1998 - 2000

Mean Color, Apparent by Sampling Year 1998 - 2000
Maximum Turbidity by Sampling Year
1998 - 2000

- Turbidity (NTU)
  - 0 - 0.9
  - 1 - 2.49
  - 2.5 - 4.9

Maximum Color, Apparent by Sampling Year
1998 - 2000

- Color (PCU)
  - 0 - 9.9
  - 10 - 19.9
  - 20 - 34.9

Median Chlorophyll a by Sampling Year 1996 - 2000

Chlorophyll a, corrected for Pheophytin a

- White: 0 - 0.9
- Light green: 1 - 1.9
- Yellow: 2 - 2.9
- Green: 3 - 3.9
- Dark green: 4 - 4.9
- Orange: 5 - 5.9
- Pink: 6 - 6.9
- Black: 7 - 7.9
- Red: 8 - 8.9

Kilometers
Mean Chlorophyll a by Sampling Year
1996 - 2000

Chlorophyll a, corrected for Pheophytin a

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</table>
Maximum Chlorophyll a by Sampling Year 1996 - 2000
Median Salinity 1996 - 2000

Salinity (PSU)
- 0 - 4.9
- 5 - 9.9
- 10 - 14.9
- 15 - 19.9
- 20 - 24.9
- 25 - 29.9
- 30 - 40

Kilometers
Median Chlorophyll $\alpha$
1996 - 2000

Chlorophyll $\alpha$ corrected for pheophytin $\alpha$
mg/m$^3$

- 0 - 4.9
- 5 - 9.9
- 10 - 14.9
- 15 - 19.9
- 20 - 24.9
- 25 - 29.9
- 30 - 40

Kilometers