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Seagrass transect data summary and analysis from a six-year period: 1999 - 2004

Charlotte Harbor Environmental Center, Inc
Charlotte Harbor Aquatic Preserves Florida Department of Environmental Protection

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Seagrass Transect Data Summary and Analysis
From A Six-Year Period: 1999 – 2004

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Executive Summary

This report contains a summary and analysis of data from a seagrass transect monitoring project begun in 1998 by the Charlotte Harbor Aquatic Preserves, Florida Department of Environmental Protection. Seagrass abundance and distribution data at twenty-six locations around Upper Charlotte Harbor, Gasparilla Sound / Lemon Bay, and the Peace and Myakka Rivers have been collected annually each year since 1999 to characterize the local and regional abundance of seagrasses. The purpose of this report is to summarize the dataset, to detect changes (if any) in seagrass abundance and distribution which may have occurred over time, to suggest mechanisms that may be associated with observed seagrass variability (i.e. regional water quality, meteorological events), and to develop a relationship between seagrass transect data and seagrass habitat maps based on aerial photographs.

To accomplish these tasks, this report contains information on species abundance and distribution, as well as quadrat and transect abundance trends in four geographic basins associated with Water Management District basin boundaries, several descriptions of the relationships between water quality variables and seagrass abundance and distribution, an examination of the potential for major meteorological events to affect the abundance of Upper Charlotte Harbor seagrasses, and a method for combining transect data with seagrass maps from aerial photographs to expand the utility of each method of characterizing seagrass resources.

While seagrass abundance measured on a scale of square meters in the basins associated with Upper Charlotte Harbor, Lemon Bay, and the Peace and Myakka rivers seems to be declining, persistent trends in transect length and deep edge depth are not immediately obvious.

Hence, we examined six water quality variables for association with seagrass abundance: chlorophyll (i.e. phytoplankton abundance), color, salinity, salinity variability, secchi depth (i.e. water clarity), and total nitrogen. Researchers have demonstrated how each of these variables affects seagrass abundance and distribution, either in Upper Charlotte Harbor, Lemon Bay, and/or other estuaries in Florida. We found significant correlations between seagrass abundance and each of these variables in at least one of the basins included in this study. We also constructed a linear model containing some combination of these variables to predict seagrass abundance in each geographic basin. The relationship between seagrass abundance and each variable in the model was significant, and salinity or variability of salinity was the most common, appearing in each model. However, models based on monthly water quality data alone were not sufficiently powerful to explain variation in seagrass abundance based on annual surveys.

One of the best known effects of El Nino in southwest Florida is increased rainfall. As salinity or salinity variability exhibited the greatest degree of association with seagrass abundance and
distribution, we suggested that increases rainfall during El Nino years would decrease salinity in Upper Charlotte Harbor, and may help explain changes in seagrass abundance. However, we found that the magnitude of the El Nino phenomenon was not a reliable predictor of surface water salinity in the estuary, making quantification of its impact on seagrass abundance and distribution difficult.

Finally, to expand the potential for analyses of environmental data, the transect data were analyzed in conjunction with maps describing seagrass habitats. To do this, we compared habitat classes as defined by aerial photograph interpretation to seagrass quadrat data, and we applied a method describing seagrass distribution along transects using a “moving window”. In this way, combining datasets may help improve the thematic accuracy and precision of the maps, as well as providing quantitative statements on seagrass abundance across the entire region.

Project deliverables include a geodatabase (ESRI) with the following components: shapefile of transect locations, a table of quadrat seagrass information, and a table of environmental site data (depth, salinity, temperature, water clarity).

From its inception, this annual seagrass transect monitoring project was designed to characterize baseline seagrass abundance and distribution throughout the Charlotte Harbor Aquatic Preserves for the purpose of change detection. We believe this report provides a six-year summary of the dataset, addresses several specific topics related to seagrasses and water quality, and presents a method to aid in relating these data to seagrass maps based on aerial photographs. In summary,

1. seagrass abundance (amount of seagrass per quadrat) has decreased throughout much of the study area, but not in all areas;
2. seagrass distribution (quadrats with seagrass along a transect) is also decreasing throughout much the study area;
3. the water quality variables most frequently associated with variability in seagrass abundance were total nitrogen, salinity, and water clarity, while the variables with the greatest influence were salinity, salinity variability, color, and water clarity, depending on the basin;
4. yet while significant, most water quality variables in most areas accounted for less than 25% of seagrass variance when considered individually;
5. benthic habitat maps based on aerial photography describing seagrasses as “patchy” or “continuous” in distribution did not consistently correspond to seagrass abundance classes estimated in situ by Braun-Blanquet index,
6. yet in some areas, the use of a “moving window” analysis provided a degree of predictability between quadrat data and the location and classification of benthic habitat classes from habitat maps.
Introduction

**Seagrass Transects.** The State of Florida established the Charlotte Harbor Aquatic Preserves (CHAP) in 1975. The Florida Department of Environmental Protection, through the Charlotte Harbor Aquatic Preserves office in Punta Gorda, Florida, has jurisdiction and management responsibilities in five aquatic preserves, defined as submerged lands of exceptional biological, aesthetic, and scientific value; including Gasparilla Sound / Charlotte Harbor, and Cape Haze (Figure 1). A seagrass monitoring program at 26 permanent locations within Southwest Florida Water Management District (SWFWMD) boundaries began in 1999 (Table 1). The twenty-six transects are located in the receiving waters of four drainage basins identified by SWFWMD: Peace River, Myakka River, Charlotte Harbor/Gasparilla Sound, and Southern Coastal/Lemon Bay (Table 2).

**Table 1.** Summary of DEP seagrass monitoring transects included in this study.

<table>
<thead>
<tr>
<th>Transect Abbreviation</th>
<th>Locality</th>
<th>Number of Transects</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAS</td>
<td>Gasparilla Sound</td>
<td>4</td>
</tr>
<tr>
<td>ICW</td>
<td>Lemon Bay</td>
<td>5</td>
</tr>
<tr>
<td>MC</td>
<td>Charlotte Harbor</td>
<td>8</td>
</tr>
<tr>
<td>MYR</td>
<td>Myakka River</td>
<td>5</td>
</tr>
<tr>
<td>PR</td>
<td>Peace River</td>
<td>4</td>
</tr>
</tbody>
</table>

**Table 2.** Occurrence of DEP seagrass monitoring transects in the receiving waters of four SWFWMD basins, and assignment to basins as analyzed in this report.

<table>
<thead>
<tr>
<th>SWFWMD Basin</th>
<th>Transects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lemon Bay / Southern Coastal</td>
<td>All ICW transects (5), and GAS transects (4)</td>
</tr>
<tr>
<td>Charlotte Harbor / Gasparilla Sound</td>
<td>All MC transects (8)</td>
</tr>
<tr>
<td>Myakka River</td>
<td>All MYR transects (5)</td>
</tr>
<tr>
<td>Peace River</td>
<td>All PR transects (4)</td>
</tr>
</tbody>
</table>

**El Nino/ Southern Oscillation (ENSO).** In southwest Florida, strong El Nino years are characterized by below average temperatures and above average rainfall and flooding, particularly in the early months of the year (NOAA 2003). In contrast, strong La Nina years are characterized by below average rainfall. These seagrass surveys include data collected during the full range of ENSO-styled conditions. As rainfall can affect estuarine salinity and salinity variability, it is possible that seagrass abundance may be impacted by various ENSO conditions.
We suggest the most likely mechanism of an ENSO influence on seagrass abundance in Charlotte Harbor is by the negative effect of decreased salinity on seagrass productivity. Based on NOAA (2003) and NASA (2006) classification of ENSO effects during 1999-2004, we hypothesized that surface salinity would be higher during La Nina years, and lower during El Nino years. If this relationship is present, it may be reasonable to expect greater SAV abundance during the La Nina years when rainfall is below average, and stress from low and/or more variable salinity is minimized. Alternatively, increased rainfall during El Nino years may decrease SAV abundance, either by lowering estuarine salinity or increasing salinity variability, causing physiological stress to seagrasses.

**Hurricane Charley.** Hurricane Charley dramatically impacted parts of the Charlotte Harbor ecosystem on 13 August 2004. Transect surveys for 2004 began on 8 September, less than four weeks later, and have presented an opportunity to compare estimates of seagrass abundance collected during the years before this storm to those collected soon after.

In addition to this storm in particular, the remainder of the 2004 hurricane season was particularly active. Increased wind and rain may have caused a decrease in seagrass abundance and distribution by any number of mechanisms, including increased freshwater delivery to the estuary, decreased light availability by sediment resuspension, increased color from river and overland flow, or increased phytoplankton abundance.

**Benthic Habitat Classes and Aerial Photography.** Maps of seagrass distribution based on aerial photography categorize benthic habitat with potential to support seagrasses into three classes: patchy, continuous, and tidal flat/unvegetated. The former two classes are distinguished by (1) the amount of bottom visible within an area at least as large as the stated minimum mapping unit (typically 0.2 ha for maps developed from 1:24,000 scale imagery), or (2) the dominant bottom cover, vegetated or unvegetated. As a result, the spatial resolution of habitat estimates is at best on the order of thousands of square meters. By definition, however, the patchy-continuous scale is a measure of variability, not abundance, and calculations of macrophyte abundance cannot be made with this type of data. The benefit of this method, of course, is that information across hundreds of square kilometers is collected in a relatively short period of time.

In contrast, the seagrass transect monitoring program collects relatively explicit abundance data at a resolution of 1 square meter. This spatial scale can be expanded to cover tens of meters when data are collected from several quadrats arranged along a transect. Combining seagrass transect data with seagrass maps based on aerial photography would provide a valuable tool in several respects. First, it may allow a quantitative estimate of seagrass abundance based on map data in some circumstances, i.e. where both methods describe a region of even or consistent SAV coverage. Second, analyses requiring a more refined spatial precision would be possible than when using the seagrass maps alone. An example of this is collecting and verifying ground truth data required to assess the accuracy of seagrass maps. Finally, a more complete analysis of landscape ecology issues such as patch size and spacing can be made using the improved spatial resolution of transect data in combination with expanded spatial extent of seagrass maps.
However, there are at least two reasons to expect a poor correlation between data from seagrass abundance measured along transects and map classification based on aerial photography. First, the benthic habitat classifications are not based on seagrass abundance. The "patchy" and "continuous" categories refer to continuity and variation within mapped polygons relative to the size of the polygon, not absolute areal coverage, as is the case in quadrats along a seagrass transect. Second, aerial photographs are routinely acquired during times of the year when water clarity is highest, that is, between late December and March. This corresponds with the annual seagrass biomass minimum (see Figure 8 in Tomasko and Hall 1999). Conversely, transects are surveyed to coincide with the period of maximum seagrass abundance, generally between September and early November.

Finally, the positional accuracy of quadrat locations is measured in centimeters, while film resolution and the registration/rectification processes involved in aerial photograph interpretation may produce images generally restrict positional accuracy measured to a scale of tens of meters. Hence, precise (e.g. 1-meter) relocation of SAV quadrat data on maps from aerial photographs is not possible. However, given judicious choice of transect and mapped polygon location, comparisons of these two types of data, in both spatial and thematic context, can be made.

We approached this topic in two ways. First, we examined the distribution of Braun-Blanquet abundance estimates from the SAV transects across two and three benthic habitat categories. Next, we developed a transect-specific estimate of seagrass distribution sensitive to the rate of change in seagrass abundance from quadrat to quadrat, known as a moving window estimate of the coefficient of variation.

**Water Quality Data.** Seagrass condition in Florida and elsewhere has been related to water clarity (i.e. depth of light penetration, Duarte 1991), chlorophyll and nitrogen (Tomasko et al. 2001), color (Gallegos and Kenworthy 1996), salinity and salinity variability (Montague and Ley, 1992), and combinations of these variables (Dixon and Kirkpatrick 1999, Tomasko and Hall 1999). To explore the possibility of influence of water quality on seagrass, we calculated two coefficients of correlation between seagrass abundance and each of these six water quality variables. We also composed a generalized linear model to predict seagrass abundance as a function of combinations of these water quality variables for each basin of the study area.

The goal of this data summary and analysis project was to approach the above topics by answering the following questions:

1. What is the mean abundance or density of seagrass species in each basin, and have abundances changed during the study period, from 1999 - 2004?
2. Have there been changes in transect length (distance to bed edge) or depth of "deep edge"?
3. Do any water quality variables influence the abundance and distribution of seagrasses?
4. Did El Nino or Hurricane Charley affect seagrass abundance?
5. Is there a relationship between seagrass transect data and benthic habitat classes based on aerial photograph interpretation?
**Methods**

**Basin.** Twenty-six transects within the boundaries of SWFWMD were visited once per year between September and November, from 1999 to present. Between 1999 and 2003, transects were relocated using GPS, flagging tape, stakes, and landmarks. During this time, quadrat locations were relocated along each transect using fiberglass tape and compass bearing, and permanent marking stakes. In 2004, the positions of all quadrats visited were recorded using a Trimble GEO XT GPS.

**Transects.** Transects generally extended from near the vegetated (e.g. mangrove) shoreline perpendicular toward open water on a compass bearing. Small PVC stakes marked most quadrat positions, which were relocated using a 50-m fiberglass tape, compass bearings, and landmarks.
The end of each transect was generally defined as the furthest distance from shore where seagrass could be found after a brief search by snorkel or SCUBA. This was defined as the "deep edge" of the bed, and no minimum abundance was used to define bed edge.

**Quadrats.** Sampling stations were generally spaced every 10 meters along transects less than 50 meters total length, and every 50 meters along transects greater than 50 meters in length. A 1-square meter PVC quadrat divided into a 10x10 grid was placed on the bottom at each station. Two observers agreed on an estimate of abundance using the Braun-Blanquet vegetation index (Table 3, modified from Braun-Blanquet (1965)) for each species of seagrass present in the quadrat. In this context, the terms abundance, coverage, and the values of the Braun-Blanquet index are used as synonyms of areal coverage. Because this index estimates areal coverage and not biomass, it cannot estimate density (amount of biomass per unit area). This report includes abundance and distribution information on the most common species of seagrass in the survey. *Thalassia testudinum*, *Syringodium filiforme*, and *Halodule wrightii*, were the most commonly observed seagrasses. *Ruppia maritima* is a freshwater angiosperm that is particularly tolerant of lower to mid-salinity conditions (e.g. Zieman and Zieman 1989). Therefore, *Ruppia* is included in this report because its distribution overlaps those of seagrasses, particularly in areas of low salinity, i.e. transect MYR05, near the Myakka River mouth.

The Braun-Blanquet index is a generalization of percent cover, and technically requires the use of non-parametric statistics, i.e. for ranked data, not interval or continuous data. The reason for this is that a quadrat with vegetation abundance estimated at a Braun-Blanquet index of 4 (between 50 and 75% cover) does not necessarily indicate twice the coverage of one estimated at a score of 2 (between 5 and 25% cover). However, some authors calculate "mean" and "standard deviation" abundance values for these types of data, and use statistics intended for normally distributed data (e.g. Ferdie and Fourqurean 2004). In general, we rely on non-parametric statistics and tests in this report, and apply the Poisson distribution to model count data, though we also calculate some parametric statistics using the Braun-Blanquet index where noted. Mean SAV abundance using the Braun-Blanquet scale was calculated as the sum of Braun-Blanquet scores divided by the number of quadrats where the species was present.

Water quality variables collected at the deepest quadrat during each transect visit include tide stage, water clarity, PAR, temperature, salinity, and dissolved oxygen. Water depth was recorded at each quadrat and later corrected for tide stage.

**Table 3.** Estimates of SAV coverage and the modified Braun Blanquet index used in this report.

<table>
<thead>
<tr>
<th>Estimated Areal Coverage</th>
<th>Modified Braun-Blanquet Index Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>not present</td>
<td>0</td>
</tr>
<tr>
<td>single or rare</td>
<td>0.1</td>
</tr>
<tr>
<td>very few</td>
<td>0.5</td>
</tr>
<tr>
<td>less than 5%</td>
<td>1</td>
</tr>
<tr>
<td>5 - 25%</td>
<td>2</td>
</tr>
<tr>
<td>25 - 50%</td>
<td>3</td>
</tr>
<tr>
<td>50 - 75%</td>
<td>4</td>
</tr>
<tr>
<td>75 -100%</td>
<td>5</td>
</tr>
</tbody>
</table>
**Transect Length And The “Deep Edge”**. As defined in this project, transects extend perpendicularly from the shoreline into deeper water. Therefore, monitoring the length of a transect and the depth of the deepest occurrence of SAV along a transect can, over the course of several years, give an indication of a local response of SAV to changing water quality variables.

**Water Quality Data.** Although numerous agencies have collected water quality data around the Upper Charlotte Harbor estuarine complex for decades, the volunteer water quality monitoring program initiated by the CHAP office in 1998 provides a complimentary set of water quality variables collected each month throughout the duration of this seagrass survey. Ott et al. (2006) describe data collection procedures, and summarize data collected since the beginning of the program (see Fig. 1 for water quality sampling locations).

Mean water quality values for the six months preceding the start of each annual seagrass survey (April through September), and corresponding with seagrass growing season for this area (see Tomasko and Hall 1999), were calculated for the following water quality variables: water clarity (as secchi depth), chlorophyll, total nitrogen, color, and salinity (Table 4). In addition, the standard deviations of salinity during the same six-month periods were also calculated. Bivariate scatter plots of all combinations of variables pooled for all years and basins were visually examined for co-variation. To estimate the values of each water quality variable throughout Charlotte Harbor, mean values were interpolated using methods described by CHEC (2005). Next, interpolated values for each variable were assigned to each quadrat location for each year.

**Correlation Coefficients.** Two measures of association were calculated between the means of the six water quality variables and SAV abundance in quadrats in each of four basins, Spearman’s ρ (rho) and Kendall’s τ (tau). These are the ranked-data equivalents to the familiar Pearson’s correlation coefficient, r. Spearman’s statistic is sensitive to the magnitude of difference between samples, while Kendall’s statistic is less so. Hence, comparison of these different calculations of correlation can give extra insight to degree of the association between seagrass and water quality. It is important to remember that neither of these coefficients determines a cause-and-effect relationship. A significant positive value means only that an increase in one variable (e.g. mean salinity) is associated with an increase in seagrass abundance. Similarly, a significant negative value means that an increase in one value (e.g. mean color) is associated with a decrease in seagrass abundance.

**Generalized Linear Model.** A linear model may be used to predict (correlate) SAV abundance in each basin as a function of combinations of certain water quality variables. Water quality variables indicated as significantly associated with seagrass abundance in a particular basin by Kendall’s tau calculations were used as initial parameters in a general linear model based on a Poisson distribution of seagrass abundance data. Model terms not significant at p < 0.05 were dropped, and new ones added until a combination of significant terms and intercept was found. Given significant model terms, the combination which produced the model with the highest F-ratio was selected to represent the basin. The F-ratio is the proportion of model variance to null (random) variance, and is significant at high sample size when F ≥ 1.0.
Table 4. Annual mean water quality values for variables used in this report, summarized by basin. Data collected by the Charlotte Harbor Volunteer Water Quality Monitoring Network, Charlotte Harbor Aquatic Preserve, Punta Gorda, Florida. Abbreviations: CH, chlorophyll (ug/l); CO, color (PCU); SA, salinity (ppt); SE, secchi depth (m, excluding “greater than bottom” readings); SV, standard deviation of salinity (ppt); TN, total nitrogen (mg/l).

<table>
<thead>
<tr>
<th>Southern Coastal / Lemon Bay Basin</th>
<th>CH</th>
<th>CO</th>
<th>SA</th>
<th>SE</th>
<th>SV</th>
<th>TN</th>
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</thead>
<tbody>
<tr>
<td>1999</td>
<td>5.1</td>
<td>20.4</td>
<td>31.8</td>
<td>1.4</td>
<td>3.3</td>
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<td>15.1</td>
<td>15.2</td>
<td>35.1</td>
<td>1.2</td>
<td>2.9</td>
<td>1.3</td>
</tr>
<tr>
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<td>4.7</td>
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<td>30.9</td>
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<tr>
<td>2002</td>
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<td>30.1</td>
<td>1.4</td>
<td>6.5</td>
<td>0.5</td>
</tr>
<tr>
<td>2003</td>
<td>6.9</td>
<td>26.6</td>
<td>28.5</td>
<td>1.2</td>
<td>7.2</td>
<td>1.2</td>
</tr>
<tr>
<td>2004</td>
<td>3.9</td>
<td>31.6</td>
<td>32.2</td>
<td>1.5</td>
<td>4.3</td>
<td>0.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Charlotte Harbor Basin</th>
<th>CH</th>
<th>CO</th>
<th>SA</th>
<th>SE</th>
<th>SV</th>
<th>TN</th>
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<tr>
<td>1999</td>
<td>6.4</td>
<td>60.8</td>
<td>20.6</td>
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<td>6.0</td>
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<td>28.9</td>
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<td>5.7</td>
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<tr>
<td>2001</td>
<td>5.3</td>
<td>62.6</td>
<td>26.8</td>
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<td>10.2</td>
<td>0.9</td>
</tr>
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<td>NA</td>
<td>25.9</td>
<td>23.5</td>
<td>1.1</td>
<td>9.3</td>
<td>0.5</td>
</tr>
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<td>2003</td>
<td>9.2</td>
<td>58.9</td>
<td>19.0</td>
<td>1.1</td>
<td>7.9</td>
<td>1.1</td>
</tr>
<tr>
<td>2004</td>
<td>5.1</td>
<td>68.8</td>
<td>24.1</td>
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**El Nino/ Southern Oscillation.** Annual interpretations of the intensity of ENSO were collected from from NOAA (2003) and NASA (2006), and the years included in this study were characterized in terms of strong, weak, or neutral ENSO conditions. Mean surface water salinity of data collected by the Charlotte Harbor Volunteer Water Quality Monitoring Program (managed by CHAP) was calculated.

**Hurricane Charley.** On 13 August 2004, Hurricane Charley brought winds in excess of 200 kph directly over a number of seagrass transect sites. All MC and PR transects were within 15 km of the storm track, and so are the basins most likely to exhibit an effect due to storm-force winds. We examined mean annual seagrass abundance along MC and PR transects in light of this timeline.

**Benthic Habitat Classes.** We compared maps of seagrass habitat distribution based on interpretations from aerial photography acquired in December 1999, January 2002, and January 2004, to seagrass transect data collected in 1999, 2001, and 2003, respectively. (In spite of the dates of acquisition, it should be noted that the seagrass maps are popularly known by the dates “1999”, “2001”, and “2004”, respectively.) In each case, transect data reflects seagrass conditions up to a few months prior to aerial photograph acquisition. Metadata and descriptions of seagrass maps are available from the SWFWMD website at www.swfwmd.state.fl.us/data/gis/libraryis/swim.htm. Briefly, polygons representing various benthic habitats were delineated from 1:24,000 true color photographs. Benthic habitats capable of supporting seagrass were classified as either tidal flats and unvegetated (6150), patchy seagrass (9113), or continuous seagrass (9116).

Abundance of seagrass in quadrats was pooled for the three map categories for each year of habitat data. The distribution of Braun-Blanquet abundance estimates into the three map categories was examined for pattern. The distribution of abundance between the two vegetation categories “patchy” and “continuous” was tested using a Kruskal-Wallis test for all data, and by year (p < 0.05, n = 530, 172, 173, and 185, respectively).

The “patchy / continuous” habitat classification scheme describes habitat variability. In other words, “patchy” and “continuous” polygons describe the format of SAV distribution, but not SAV abundance. And although quadrats examined singly describe SAV abundance, quadrats considered in series along a transect may describe variability in habitat. Therefore, to compare SAV transect data with benthic habitat map data, we developed a moving window estimate of variability in quadrat seagrass abundance to characterize the rate of changes in abundance along a single transect. The method calculates the coefficient of variation (CV = ratio of standard deviation to mean) in SAV abundance estimated by Braun-Blanquet in 3 adjacent quadrats. After this calculation, the window moves one quadrat down the transect, and re-calculates the CV (Figure 2). This series of CV values is plotted against position of the moving window, and a curve was fitted to quantify the results for statistical testing. Only transects with a minimum of 14 quadrats were included in this analysis, and transects were not required to coincide with more than one map classification in a single year.
Figure 2. The “CV moving window” used to calculate habitat variability from SAV transect data. Q1 through Q6 represent quadrats along a single transect. CV is the coefficient of variation, and is calculated as the standard deviation of abundance of Braun-Blanquet data divided by the mean abundance of Braun-Blanquet data for each moving window.

“Continuous” polygons are generally characterized by low spatial variability. Conversely, “patchy” polygons may be characterized by high spatial variability, but patches of SAV may be of low or high abundance. When considering the moving window of CV, groups of quadrats along a transect that are high in abundance and low in variability will exhibit low CV values. By contrast, groups of quadrats with either low or highly variable abundance estimates will exhibit higher CV. A series of quadrats with moderate but evenly dispersed abundance will exhibit a median level of CV.

Coefficient of variation values of zero can occur under some conditions. For example, when the standard deviation within a window is zero, that is, all quadrats have the same abundance (high, low, or zero), the CV equals zero. When plotting a series of CV values, a CV of zero surrounded by low CV values corresponds with high, even biomass for several quadrats (small numerator — standard deviation, and large denominator -- abundance). This example would probably correspond with the “continuous” map category. If a zero value CV is surrounded by high values, there are likely a series of low and/or variably distributed abundance. This could be the case in either “patchy” or “tidal flat” polygons. Variable CVs from window to window indicate variation of both abundance and rate of change, and most likely correspond with “patchy” classification.

Next, a spline curve (MathSoft 1999) was fit to the points describing CV along each transect. In this way, an estimate of the position of patchy/continuous boundary may be made. For instance,
a steep increase, from window positions of low CV to high CV, may indicate a transition from high even seagrass abundance (low variance, high abundance) to highly variable distribution of SAV. In this case, the transect crosses from a continuous to a patchy polygon.

Only three transects met the minimum requirements of this procedure: MC03 on the East Wall of Charlotte Harbor, and MC05 and MC06 on the West Wall. Moving window CV plots were generated for each location and all years, and examined in conjunction with seagrass map classification.

The Microsoft Access database containing seagrass and site environmental data was developed by J. Greenawalt and M. Hannan (Sanibel-Captiva Conservation Foundation, Marine Lab, Sanibel, Florida), and K. Fuhr (DEP Charlotte Harbor State Aquatic Preserve). Water quality data are available from the Charlotte Harbor Aquatic Preserve, FL DEP field office in Punta Gorda, Florida, or from CHEC. Seagrass maps based on aerial photography were supplied by SWFWMD. The interpolations of water quality data and other GIS analyses were made using ArcGIS v.9 (ESRI 2004). All statistical summaries, analyses, and the moving window model were made using S-PLUS (MathSoft 1999). Specific or generalized code for all procedures is available on request.

Results

Seagrass Distribution By Basin. Examining the annual proportion of quadrats visited with seagrass (Table 5) gives a sense of the basin-wide distribution of seagrasses. The number of surveyed quadrats has increased since the beginning of the project. However, the proportion of quadrats with seagrass present has declined. If seagrass occurrence had been stable during the course of this program, the proportion of quadrats with seagrass would have been stable, also, and relatively independent of the number of quadrats searched. Hence, while search effort has increased, the observed occurrence of seagrass has actually decreased. This observation suggests a decline in seagrass occurrence that extends throughout Upper Charlotte Harbor. It should be noted that no SAV was present in two or three transects per year in the Peace and Myakka basins.

Another interesting trend has been in the number of seagrasses encountered at a transect. During the course of this monitoring program, the number of transects with one or three species has decreased, while the number of transects with two species has increased.

Trends In Species Abundance In Basins. When viewed as a collection of transects, mean SAV abundance in each basin may have declined during the study period (Fig. 3), although the actual data are highly variable (Appendix A). As noted, mean SAV abundance using the Braun-Blanquet scale was calculated as the sum of Braun-Blanquet scores divided by the number of quadrats where the species was present. Hence, it is important to note that the lower values we may be observing suggest decreased abundance within seagrass patches, not a decrease in distribution.
An interesting observation evident in Figure 3 is the closeness of mean abundances of the three seagrass species in the Lemon Bay/Southern Coastal basin, in contrast with species mean abundances in the Charlotte Harbor/Gasparilla Sound basin. In the latter area, mean *Thalassia* coverage is consistently greater than the other species in all years, generally followed by *Syringodium*, and *Halodule*, when present. However, the mean abundances of all species within and between basins seem to decline at approximately the same rate.

SAV species grow at different rates under different environmental conditions of light availability, salinity, sediment condition, and wave energy (e.g., Dawes 1987). The observation that they occur in different abundances in each basin suggests there may be optimum conditions where one species may exhibit a greater mean abundance than the others. Even so, Figure 3 suggests that on a basin-wide basis, the observed declines in abundance seem to occur for these species equally, independent of their initial mean abundance at the beginning of the study period.

*Halodule* and *Syringodium* are sometimes cited as pioneer species, while *Thalassia* is sometimes viewed as a climax species (e.g., Williams 1990). This model of succession does not seem to be supported by these observations, which suggests the importance of variable environmental factors in structuring the aquatic macrophyte communities of the area. As basin-wide representations of mean abundance where each species occurs, Figure 3 does not account for coexistence of species in individual quadrats. However, a brief examination of SAV abundance in Charlotte Harbor and Lemon Bay (Appendix A and Appendix B) demonstrates how *Halodule* and *Thalassia* are frequently found in the same quadrat. Similar observations have been made in the Big Bend and Springs Coast regions of Florida (Iverson and Bittaker 1986, Hale et al. 2004).

It is therefore important to note that the declines in abundance of these two species are so closely parallel in both the Southern Coastal/Lemon Bay basin, where their mean abundances are approximately equal, and in the Charlotte Harbor/Gasparilla Sound, where mean abundances are not equal, but decline at the same rate nonetheless. This raises the topic of relative species abundances reflecting a balance between the effects of environmental conditions and other ecological processes, such as interspecific competition.

Figure 3 also shows that, when it occurs, *Thalassia* seems to reach a higher abundance than the other species, for all years, in the Charlotte Harbor basin. In contrast, the mean abundances of the three species in the Southern Coastal/Lemon Bay basin are closer to being equal. Differences or variability in environmental conditions, including mean and variability in salinity and water clarity, may be related to these observations.
Table 5. An annual summary of the number of quadrats per transect (“Visited”), proportion of total number of quadrats with any species of SAV Present, which includes *T. testudinum*, *S. filiforme*, *H. wrightii*, and *R. maritima*, and the total number of species observed along the entire transect (“Number of Species”, where 0 = no grasses observed, * = 1 species, ** = 2 species, *** = 3 species). The “Summary” row contains the annual total number of quadrats visited (for “Visited” column), and the annual average proportion of quadrats with seagrass present (for “SAV Present” column). Basins are set off by shading.

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<td>10 0.20 *</td>
<td></td>
<td></td>
<td>10 0.20</td>
<td></td>
</tr>
<tr>
<td>PR03</td>
<td>7 1.00 *</td>
<td></td>
<td></td>
<td>8 0.75 *</td>
<td></td>
<td></td>
<td>8 0.75 *</td>
<td></td>
<td></td>
<td>8 0.88 *</td>
<td></td>
<td></td>
<td>11 0.36</td>
<td></td>
<td></td>
<td>12 0.33</td>
<td></td>
</tr>
<tr>
<td>PR04</td>
<td>5 1.00 *</td>
<td></td>
<td></td>
<td>5 0.80 *</td>
<td></td>
<td></td>
<td>5 1.00 *</td>
<td></td>
<td></td>
<td>6 0.67 *</td>
<td></td>
<td></td>
<td>8 0.38</td>
<td></td>
<td></td>
<td>8 0.38</td>
<td></td>
</tr>
<tr>
<td>Summary</td>
<td>191 0.86</td>
<td></td>
<td></td>
<td>204 0.80</td>
<td></td>
<td></td>
<td>216 0.69</td>
<td></td>
<td></td>
<td>201 0.74</td>
<td></td>
<td></td>
<td>222 0.65</td>
<td></td>
<td></td>
<td>237 0.59</td>
<td></td>
</tr>
</tbody>
</table>
Figure 3. Annual estimates of SAV species abundance measured by Braun-Blanquet index in each basin of the study area.
Seagrass Species Abundance By Quadrat. Appendix A contains pairs of facing pages which display 6 years of Braun Blanquet abundance data for Thalassia, Syringodium, Halodule, and Ruppia for the quadrats visited at each transect site during the study period. “Meters Along Transect” values represent distance relative to the beginning of seagrass occurrence starting from shore in 1999. Therefore, negative values represent a landward expansion of the seagrass bed.

The transect axes in Appendix A are not scaled to transect length or distance between quadrats. Although quadrats were generally regularly spaced, there was no standard distance of spacing (see Methods), and attention should be paid to the “Meters Along Transect” axis for detailed information on the specific location of stated seagrass abundance. Transect length is the approximate maximum distance perpendicular from shore that seagrasses occurred, and transects were generally ended when seagrass was not detected after a brief search. Therefore, a greater number of quadrats along a transect suggests greater transect length, over 500 meters from shore in several cases. In this way, a sense of changes in seagrass distribution at a single site is suggested by the number of quadrats visited each year for each transect.

Halodule seems to be the most common and widely distributed species. Syringodium abundance and frequency of occurrence is generally highest at GAS and ICW transects, where salinity values are generally both higher, and more consistent than in other basins. Ruppia distribution is generally limited a few sites in or near the Myakka River, where salinity is generally lower. Hence, salinity may dictate the abundance of species in this area as well. Our analyses including salinity and salinity variability do not address the particular environmental requirements of individual species.

Seagrass abundance by basin and transect. Several transects in the Lemon Bay/Southern Coastal basin exhibited relatively low seagrass abundance in 2002 or 2003, while abundances before and after this year were generally higher (Appendix B). However, the “trend” for many of these transects seems to be one of variability in the broadest sense. This basin also seems to have the highest frequency of several seagrass species occurring on the same transect.

Transects associated with the Myakka and Peace Rivers are in contrast to those in Lemon Bay: low abundance across all years, and generally only a single species present.. A monotonic decrease in mean abundance is suggested at downstream transects, while seagrasses were completely absent from more transects in these areas than anywhere else. Because of decreased and variable salinity, as well as reduced water clarity from color, tidal rivers are not favorable places for seagrasses. Yet, there are persistent observations across years of seagrasses in these areas.

SAV abundance in transects in Charlotte Harbor/Gasparilla Sound are located between the Lemon Bay basin and the Myakka and Peace rivers. Not surprisingly, transects in this basin share many of the same characteristics. Abundances at some locations seem to decline during the study period, while in other locations, abundance exhibits minimum seagrass abundance around 2002. A number of transects don’t seem to exhibit a trend at all. Finally, most Charlotte Harbor/Gasparilla Sound transects have two species of seagrass during most years.
Transect Length And The “Deep Edge”. In general, annual transect lengths seem to be consistent, although the lengths of several transects fluctuated considerably (Fig. 4). Furthermore, the maximum depth of seagrass distribution along each transect also seems to be fairly consistent, though, as with transect length, values for some transects oscillated around central values (Fig. 5). This comparison suggests a role that water clarity may play in influencing seagrass abundance, supporting the inclusion of water clarity as a significant argument (with positive sign) in two of four linear models (Table 8, below).

Water Quality Data. A number of water quality variables seem to be related to each other, for instance color and salinity, and water clarity and salinity (Fig. 6, and as noted by Tomasko and Hall 1999). In fact, salinity seems to be related to most other variables to at least some extent in its range. As noted by many other authors, there seems to be a negative relationship between secchi depth and both color and variability in salinity. For instance, higher secchi depths were recorded in areas with low salinity variation. This suggests higher water clarity in areas at both river side and gulf side of the estuary than when compared with that at mid-estuary locations.

It is probable that some relationships between water quality variables may be best expressed by an exponential relationship, as opposed to a linear one. For instance, the spread of points describing the relationship between salinity and color appears to be fairly linear. By contrast, the spread of points of salinity and secchi depth suggests a curve such that rate of change in secchi depth increases with increasing salinity. This suggestion is supported by Tomasko and Hall (1999), who analyzed seagrass abundance at salinities above and below 20 ppt, producing, in effect, a “discontinuous” linear estimate.

In spite of these observations, some relationships between seagrass abundance and water quality variables were detected, as indicated in the following sections.
Figure 4. Transect length (meters), from 1999 to 2004.
Figure 5. Depth (centimeters) of deepest occurrence of seagrass on each transect, from 1999 to 2004.
Figure 6. Pair-wise scatter plots of water quality variables that may be related to seagrass abundance. Abbreviations and units: CH = chlorophyll, ug/L; CO = color, NTU; SA = salinity, ppt; SE = secchi depth, m; SV = salinity standard deviation, ppt; TN = total nitrogen, mg/L.
**Correlation Coefficients.** The idea that differences in local and basin environmental conditions may influence seagrasses is supported by the fact that no single variable was significantly related to SAV abundance across all basins (Tables 6 and 7). Another observation that is immediately apparent is that, while significant, only a few of the single water quality variables explain more than 25% of the variance in seagrass abundance.

Where the Spearman’s $\rho$ and Kendall’s $\tau$ statistics agreed on significance, they also agreed on the direction of association, e.g. negative correlation between SAV abundance and color in the Peace River basin. Only a few of the non-significant statistics did not agree on the direction of correlation.

The water quality variables which exhibited significant associations with SAV abundance most frequently were total nitrogen and water clarity (Spearman’s, Table 6), and total nitrogen and salinity (Kendall’s, Table 7); each was either positively or negatively associated with SAV abundance in three basins.

When all observations are pooled, both measures of correlation found variability of salinity and color as having the greatest influence on SAV abundance. In addition, salinity (Spearman’s, Table 6) and clarity (Kendall’s, Table 7) were also strongly associated with abundance. These results underscore the need for site-specific monitoring and research of SAV resources in the upper Charlotte Harbor estuarine complex.

The relationship between color and seagrass abundance was consistently negative for all basins, though the association was not always significant. Color is cited as a major component of light attenuation in Charlotte Harbor (e.g. McPherson and Miller 1987), and it was strongly associated with variability in seagrass abundance at the Peace River transects. However, color is also frequently associated with salinity, and lower salinity is often cited as a stress to seagrass (e.g., Montague and Ley 1993).

Another interesting result is that both methods detected a positive association between seagrass abundance and water column chlorophyll (i.e. phytoplankton abundance) in the Lemon Bay / Southern Coastal basin. This condition is possible when a common factor limits both phytoplankton and seagrass abundance. For instance, total nitrogen is also positively correlated with seagrass abundance, suggesting that inorganic nitrogen, a nutrient required by both phytoplankton and SAV, may limit seagrass production in this area, as it does phytoplankton abundance in Upper Charlotte Harbor (Montgomery et al. 1991).
Table 6. Spearman’s rho statistic describing association between SAV abundance in four basins and six water quality variables (underline indicates significance at $p < 0.05$).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lemon Bay/ Southern Coastal</th>
<th>Charlotte Harbor/ Gasparilla Sound</th>
<th>Myakka River</th>
<th>Peace River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll</td>
<td>0.18</td>
<td>-0.07</td>
<td>-0.22</td>
<td>0.06</td>
</tr>
<tr>
<td>Color</td>
<td>-0.03</td>
<td>-0.17</td>
<td>-0.03</td>
<td>-0.31</td>
</tr>
<tr>
<td>Secchi</td>
<td>-0.25</td>
<td>0.15</td>
<td>-0.16</td>
<td>0.17</td>
</tr>
<tr>
<td>Salinity</td>
<td>0.06</td>
<td>0.12</td>
<td>-0.02</td>
<td>0.33</td>
</tr>
<tr>
<td>Salinity (stdev)</td>
<td>-0.07</td>
<td>0.01</td>
<td>0.31</td>
<td>0.02</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>0.12</td>
<td>0</td>
<td>0.19</td>
<td>-0.27</td>
</tr>
</tbody>
</table>

Table 7. Kendall’s tau statistic describing association between SAV abundance in four basins and six water quality variables (underline indicates significance at $p < 0.05$).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lemon Bay/ Southern Coastal</th>
<th>Charlotte Harbor/ Gasparilla Sound</th>
<th>Myakka River</th>
<th>Peace River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll</td>
<td>0.12</td>
<td>-0.04</td>
<td>-0.15</td>
<td>0.04</td>
</tr>
<tr>
<td>Color</td>
<td>-0.02</td>
<td>-0.11</td>
<td>-0.01</td>
<td>-0.2</td>
</tr>
<tr>
<td>Secchi</td>
<td>0.04</td>
<td>0.08</td>
<td>-0.01</td>
<td>0.2</td>
</tr>
<tr>
<td>Salinity</td>
<td>-0.16</td>
<td>0.1</td>
<td>-0.1</td>
<td>0.11</td>
</tr>
<tr>
<td>Salinity (stdev)</td>
<td>-0.05</td>
<td>0.01</td>
<td>0.2</td>
<td>0.01</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>0.08</td>
<td>0</td>
<td>0.11</td>
<td>-0.17</td>
</tr>
</tbody>
</table>

**Generalized Linear Model.** Although all individual terms were significantly related to seagrass abundance, most were small in magnitude relative to model error, and none of the resulting models we described passed the F-test for significance (Table 8). This suggests that although water quality variables are related to seagrass abundance, finer scale local or temporal variability may influence SAV abundance to a greater degree than can be explained by monthly water quality data collected during the growing season. Alternatively, other ecological processes may be structuring these vegetative communities, including competition or succession.

Salinity (or the standard deviation of salinity) is the only water quality variable that was consistently and significantly included in the linear models of SAV abundance in all basins during this study period, supporting the research of Tomasko and Hall (1999) in Charlotte Harbor, and Montague and Ley (1993) in Florida Bay. It is interesting to note the slight positive effect of salinity variability on SAV abundance in Charlotte Harbor adjacent to the slight negative effect observed in the Lemon Bay/ Southern Coastal basin. Taken individually, these variables were not closely associated with seagrass abundance in these basins, yet they do contribute significant terms to the two models with the highest F-ratios. Hence, the cumulative effects of (sometimes) different water quality variables in the linear models as opposed to single-variable correlations underscore the need for site-specific SAV resource monitoring and research in the Upper Charlotte Harbor estuarine complex.
Table 8. Generalized linear models relating SAV abundance in each basin to water quality variables. All model coefficients and intercepts are significant at \( p < 0.05 \). F-ratio is the proportion of model variance to null variance (significant at \( F \geq 1.0 \)). Abbreviations: CH = chlorophyll, ug/L; CO = color, NTU; SA = salinity, ppt; SE = secchi depth, m; SV = salinity standard deviation, ppt; TN = total nitrogen, mg/L.

<table>
<thead>
<tr>
<th>SAV Abundance</th>
<th>Parameter 1</th>
<th>Parameter 2</th>
<th>Parameter 3</th>
<th>Intercept</th>
<th>F-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lemon Bay/ Southern Coastal</td>
<td>-1.02 * SE</td>
<td>-0.06 * SV</td>
<td>-</td>
<td>2.3</td>
<td>0.91</td>
</tr>
<tr>
<td>Charlotte Harbor/ Gasparilla</td>
<td>0.02 * SA</td>
<td>0.07 * SV</td>
<td>0.65 * SE</td>
<td>-1.5</td>
<td>0.96</td>
</tr>
<tr>
<td>Sound</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myakka River</td>
<td>1.5 * SE</td>
<td>0.46 * SV</td>
<td>-</td>
<td>-6.1</td>
<td>0.80</td>
</tr>
<tr>
<td>Peace River</td>
<td>0.16 * CH</td>
<td>0.13 * SA</td>
<td>-</td>
<td>-4.8</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Conspicuously absent from these models are the effects of total nitrogen and color, while chlorophyll (i.e. phytoplankton) has a significant effect in only one model. This was not expected based on the results of the Spearman’s and Kendall’s calculations. For instance, total nitrogen is significantly associated with seagrass abundance in three out of four basins, and nitrogen from various land uses is discussed extensively by Tomasko et al. (2001). As noted above, many of these water quality variables co-vary to a large extent (Figure 7, and Tomasko and Hall 1999), making it a challenge to interpret these results. Both the Spearman’s statistic and the linear model describing relationships in the Southern Coastal/ Lemon Bay basin include a negative relationship between seagrass abundance and water clarity as estimated by secchi depth. Clearly, secchi depth is not independent of the other variables considered in this report. Tomasko and Hall (1999) point out how environmental conditions of increased water clarity may not necessarily coincide with the height of the seagrass growing season, which was the focus of these analyses. Furthermore, the large intercepts included in each linear model suggest a large amount of error associated with using monthly water quality data alone to characterize seagrass abundance. Therefore, along with site specific SAV monitoring and research, resource management concerns should include

**El Nino/Southern Oscillation.** Salinity and variability of salinity are significantly associated with SAV abundance, both in terms of number of basins and magnitude of the association. The years during the period 1999-2001 were classified as La Nina years (Table 9), and we expected salinity to be consistently higher during these years. Conversely, 2002-2003 were classified as an El Nino period, albeit it variable in intensity, and we expected salinity to be depressed during this time. Yet Figure 7 demonstrates how mean monthly salinity in all years is above 25 ppt in the months before June, but decreases below 25 ppt for the rest of the season for all but one year. ENSO classification alone does not seem to be a reliable predictor of summertime surface water salinity in Charlotte Harbor (Table 10), and thus does not seem to provide a more reliable prediction of SAV abundance than SAV abundance association with water quality variables.

<table>
<thead>
<tr>
<th>Year</th>
<th>El Nino</th>
<th>ENSO “Neutral”</th>
<th>La Nina</th>
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</thead>
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<tr>
<td>1997/1998</td>
<td>Strong</td>
<td>Weak</td>
<td>Weak</td>
</tr>
<tr>
<td>2000</td>
<td>Weak</td>
<td>Strong</td>
<td>Strong</td>
</tr>
<tr>
<td>2001</td>
<td>Weak</td>
<td>Strong</td>
<td>Strong</td>
</tr>
</tbody>
</table>

Figure 7. Mean monthly surface water salinities (ppt) for upper Charlotte Harbor estuarine complex locations monitored by CHVQMN.

Table 10. Qualitative description of salinity values observed in Upper Charlotte Harbor, and those expected based on NOAA and NASA classification of ENSO years. Bold indicates inaccurate forecast of relative surface water salinity.

<table>
<thead>
<tr>
<th>Year</th>
<th>Classification</th>
<th>Expected Salinity</th>
<th>Observed Salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>strong La Nina</td>
<td>high</td>
<td>median</td>
</tr>
<tr>
<td>2000</td>
<td>strong La Nina</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>2001</td>
<td>weak La Nina</td>
<td>high</td>
<td>median</td>
</tr>
<tr>
<td>2002</td>
<td>weak El Nino</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>2003</td>
<td>weak El Nino</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>2004</td>
<td>neutral</td>
<td>median</td>
<td>median</td>
</tr>
</tbody>
</table>

Hurricane Charley. Although SAV abundance at Charlotte Harbor and Peace River sites was lower in 2004 (post-storm) than the preceding survey, abundance and distribution of SAV at many sites in the area have been declining during the entire period (Appendix A). Therefore, based on the available data, we do not feel that the passage of Hurricane Charley had an impact on seagrass abundance or distribution. However, the hurricane seasons of 2004 and 2005 were particularly active, and the possibility of effects from a series of active hurricane seasons should be considered by future studies.
Figure 8. Trends in salinity (ppt) measured during seagrass sampling visits, 1999 – 2004
**Benthic Habitat Classes And Seagrass Abundance.** Pooling data from 1999, 2001, and 2003, it is clear that there have been more quadrats in patchy seagrass polygons than the other categories (n = 252 versus 165 and 113 respectively). There are also obvious differences between the estimated abundances of seagrass in seagrass polygons versus non-vegetated (Figure 9). Although most quadrats in “tidal flat / non-vegetated” mapped areas exhibited less than 5 % SAV cover, at least a few quadrats contained 25% cover or more. While the bulk of the observations support the definition of “unvegetated”, it appears that some colonization of these areas does occur.

![Bar chart showing distribution of Braun-Blanquet abundance values across tidal flat, patchy, and continuous seagrass polygons as characterized by maps from aerial photographs for combined years 1999, 2001, 2003.](image)

**Figure 9.** Distribution of Braun-Blanquet abundance values across tidal flat, patchy, and continuous seagrass polygons as characterized by maps from aerial photographs for combined years 1999, 2001, 2003.

Less clear is the difference between abundance in patchy vs. continuous coverage classes. Although more quadrats without seagrass occurred in patchy habitat, the shapes of the two distributions are remarkably similar. Indeed, mean quadrant abundance of data pooled for all years in patchy category was 1.6 (s.d. = 1.5), while mean abundance in continuous category was 2.1 (s.d. = 1.5). When examining the distribution of abundances across benthic habitats for each year (Figure 10), the distributions are less smooth, but no less overlapping. Yet differences in abundance between patchy and continuous seagrass polygons were significant for 1999, 2001, and 2003 (Kruskal Wallis; df = 1, p < 0.05), but sometimes just barely (calculated p = 0.025, 0.040, 0.040, respectively).

It is interesting to note the appearance of a familiar trend in Figure 10, the decrease in seagrass abundance during the study period. In these graphs, the trend is visible as the bulk of quadrant counts moves from Braun-Blanquet values 1 or greater in 1999, to values indicating lower abundance corresponding with Braun-Blanquet value of 1 or below in 2003. Also increasing are the numbers of quadrats with no seagrass present.
Figure 10. Distributions of Braun-Blanquet abundance values across three benthic habitat map categories, tidal flats, patchy, and continuous seagrass coverage in 1999 (top), 2001 (middle), and 2003 (bottom).


**Benthic Habitat Classes And Seagrass Distribution.** Only three transects met our criteria for application of the moving window CV. Maps from aerial photos are juxtaposed with each in Figures 11a, 11b, and 11c to illustrate how the two datasets can be related. It is useful to refer to Appendix A from Part 1 to verify certain points in the moving window CV graphs.

The moving windows used to make these graphs were three quadrats wide. That is, quadrats one through three correspond to moving window index = 1 in the CV graphs; quadrats two through four correspond to index = 2 in the CV graphs; quadrats three through five corresponds to index = 3 in the CV graphs, and so on.

The curves plotted in Figure 11 are spline interpolations, intended to aid in visual interpretation. They should not be used for statistical analysis, but were surprisingly accurate in their ability to estimate locations of polygon boundaries and the nature of patchy and continuous polygon classifications.

The first thing to notice when examining the maps of seagrass distribution at site MC05 is the striking stability in the polygon boundaries. Yet a brief look at the histograms of seagrass abundance by quadrat in Appendix A reveals dramatic changes in both the amount of seagrass, and its location along the transect. The positions of the last three data points in each of the moving window CV plots suggest a change in abundance of seagrass at the deep edge of this bed. Two zero CVs following a high value in 1999 suggest an even tapering off of seagrass abundance. The relatively median and high end-transect values in 2001 and 2003, coupled with higher absolute values of CV in these years suggest greater variability and/or decreased biomass in this area. The figures in Appendix A verify this idea. The red lines bisecting each CV curve occur generally at a sharply increasing section of the graph which seems to indicate the boundary between continuous and patchy seagrass map classes.

The CV curve describing conditions at MC06 in 1999 has at least one characteristic in contrast with 2001 and 2003: it is "concave down" early in the transect, and "concave up" later on, suggesting higher, more even abundance at the beginning of the transect in 1999. Even though the boundary between continuous and patchy habitat classes in 1999 occurs earlier in the transect with respect to the number of quadrats, it is still indicated by the steep increase in the CV curve for that year. The slope corresponds with very high abundance for the few quadrats in the "continuous" polygon, followed quickly by a nearly empty quadrat, which is followed by several quadrats with moderate but varying abundance, causing the curve to continue rising after briefly leveling off.

MC03 presents an interesting challenge to interpret. Of the three sites, the greatest amount of between-year change detected by the seagrass maps occurred here. A visual appraisal of the seagrass maps suggests an increase in continuous seagrass habitat category from year to year. Yet the graphs of quadrat abundance in Appendix A document a decrease in abundance, and uncertain variability from 1999 to 2003. The positions of polygon boundaries are not easily identified from the moving window CV graph. Reading from the map, it appears that the first four or five quadrats of the transect (corresponding with the first 3 CV window positions) are very close to the boundary between patchy and continuous. The figures in Appendix A record
several quadrats with very high abundance, followed by a few of moderate or variable abundance.

One interpretation of the changes at MC03 between the 1999 and 2001 maps is that of coalescence, as seagrasses fill in unvegetated spaces between the area’s seagrass patches. There is unquestionably more area in the 2001 frame designated “continuous” than “patchy.” Again, these map categories do not describe SAV abundance, though the implication is an increase in SAV “continuous” habitat from 1999 to 2001. However, it is clear from the figures in Appendix A that seagrasses were substantially less abundant here in 2001 than 1999. This is illustrated in the moving window CV curve as it continues from relatively low values (high abundance) more or less upwards, indicating increasing variability, with a few zero values to suggest consistent, but very thin, seagrass abundance toward the end of the transect. Hence, while the seagrass maps suggest an increase in seagrass, the observations along the transect do not support this.

The map and graphs for 2003 depict similar inconsistencies, but in a different location. Again, the maps suggest increased distribution of SAV habitat in 2003 than 1999, yet the histogram of abundance in each quadrat clearly shows a decrease in abundance. Nor do the map and moving window CV graph agree on the location of the first polygon boundary, from continuous to patchy seagrass categories. Again, transect data do not agree with the changes in habitat implied by the map data, and the moving window CV curve does not agree with the map on the location of the boundary between classifications. It might be helpful to review this portion of the aerial photographs directly.

The moving window CV graphs also contain information on the overall abundance of SAV in the map polygons in which they occur. For example, the range of CV values in Figure 11a (1999) is between 0 and 0.9, while 2001 and 2003 are between 0.5 and 1.5. This suggests that, during this time period, either an increase in SAV mean abundance (larger denominator in CV calculation) or a decrease in variability within each window has occurred.
Figure 11a. 1999 - 2003 seagrass habitat at transect MC05 as estimated by aerial maps and the moving window CV. Black vertical lines approximate location of polygon boundary (Note: maps from 1999 and 2001 look nearly identical, but do come from different data sources).
Figure 11b. 1999 - 2003 seagrass habitat at transect MC06 as estimated by aerial maps and the moving window CV. Black vertical lines indicate approximate location of polygon boundary (Note: maps from 1999 and 2001 look nearly identical, but do come from different data sources).
Figure 11c. 1999 - 2003 seagrass habitat at transect MC03 as estimated by aerial maps and the moving window CV. Black vertical lines indicate approximate location of boundaries of large contiguous polygons. Although steep slopes are evident in the CV graph for 1999, the position of mapped polygon boundaries with respect to transect and quadrat locations is difficult to determine. (Note: CV moving window proceeds from east to west along transect in direction of black arrow).
Project Acknowledgements

The seagrass transect monitoring program summarized by this report was designed and initiated in 1998 by J. Ott and B. Staugler, of the Charlotte Harbor Aquatic Preserves, Florida DEP, now in Punta Gorda, Florida. K. Fuhr managed the project for several years, assisted by M. Schneider. Other Preserve staff and numerous volunteers helped with the field work each year. J. Greenawalt-Boswell and M. Hannan of the Sanibel-Captiva Conservation Foundation's Marine Lab, designed the MS Access database containing the quadrat and site environmental data.

This report was funded by the SWIM section of the Southwest Florida Water Management District, and completed under the supervision of project manager K. Kaufman. With J. Ott and B. Staugler, C. Corbett (Charlotte Harbor National Estuary Program) and Dr. D. Tomasko (now with PBS&J) provided early inspiration for many of these analyses, as well as comments and suggestions for the manuscript. J. Ott, M. Schneider, and R. Duffey (Charlotte Harbor Aquatic Preserves, Florida DEP) provided water quality data collected by the Charlotte Harbor Volunteer Water Quality Monitoring Network as well as comments on drafts of the manuscript. J. Greenawalt-Boswell (now Charlotte Harbor National Estuary Program) also provided comments on analyses and drafts of the manuscript.
Literature Cited


Appendix A

Braun-Blanquet abundance scores by station of four species of SAV species *Thalassia testudinum, Syringodium filiforme, Halodule wrightii,* and *Ruppia maritima,* collected at 26 transects during the fall season, from 1999 – 2004. For convenience, three tables from the report text are reprinted here.

**Table 1.** Summary of DEP seagrass monitoring transects included in this study.

<table>
<thead>
<tr>
<th>Transect Abbreviation</th>
<th>Locality</th>
<th>Number of Transects</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAS</td>
<td>Gasparilla Sound</td>
<td>4</td>
</tr>
<tr>
<td>ICW</td>
<td>Lemon Bay</td>
<td>5</td>
</tr>
<tr>
<td>MC</td>
<td>Charlotte Harbor</td>
<td>8</td>
</tr>
<tr>
<td>MYR</td>
<td>Myakka River</td>
<td>5</td>
</tr>
<tr>
<td>PR</td>
<td>Peace River</td>
<td>4</td>
</tr>
</tbody>
</table>

**Table 2.** Occurrence of DEP seagrass monitoring transects in the receiving waters of four SWFWMD basins.

<table>
<thead>
<tr>
<th>SWFWMD Basin</th>
<th>Transects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lemon Bay/ Southern Coastal</td>
<td>All ICW transects (5), and GAS transects (4)</td>
</tr>
<tr>
<td>Charlotte Harbor/ Gasparilla Sound</td>
<td>All MC transects (8)</td>
</tr>
<tr>
<td>Myakka River</td>
<td>All MYR transects (5)</td>
</tr>
<tr>
<td>Peace River</td>
<td>All PR transects (4)</td>
</tr>
</tbody>
</table>

**Table 3.** Estimates of coverage and the modified Braun Blanquet index used to quantify seagrass abundance data.

<table>
<thead>
<tr>
<th>Estimated areal coverage</th>
<th>Braun Blanquet Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>not present</td>
<td>0</td>
</tr>
<tr>
<td>single or rare</td>
<td>0.1</td>
</tr>
<tr>
<td>very few</td>
<td>0.5</td>
</tr>
<tr>
<td>less than 5%</td>
<td>1</td>
</tr>
<tr>
<td>5 - 25%</td>
<td>2</td>
</tr>
<tr>
<td>25 - 50%</td>
<td>3</td>
</tr>
<tr>
<td>50 - 75%</td>
<td>4</td>
</tr>
<tr>
<td>75 -100%</td>
<td>5</td>
</tr>
</tbody>
</table>
Braun Blanquet Abundance

1999

2000

2001

Meters Along Transect
Braun-Blanquet Abundance

Meters Along Transect
GAS04

Braun Blanquet Abundance

Meters Along Transect

1999

2000

2001

Meters Along Transect
Braun Blanquet Abundance

GAS04

Meters Along Transect

2002

2003

2004
ICW01

1999

Braun Blanquet Abundance

2000

2001

Meters Along Transect
ICW01

2002

Braun Blanquet Abundance

2003

Meters Along Transect

2004
Braun Blanquet Abundance

ICW02

1999

2000

2001

Meters Along Transect
ICW03

Braun Blanquet Abundance

Meters Along Transect
Braun Blanquet Abundance

ICW03

Meters Along Transect

2002

2003

2004
Braun Blanquet Abundance

ICW05

2002

2003

2004

Meters Along Transect
Braun Blanquet Abundance

Meters Along Transect

MC01

1999

2000

2001
Braun Blanquet Abundance

MC02

2002

2003

2004

Meters Along Transect
Braun Blanquet Abundance

Meters Along Transect

1999

2000

2001

MC03
Braun Blanquet Abundance

Meters Along Transect

2002

2003

2004
Braun Blanquet Abundance

Meters Along Transect
Meters Along Transect

Braun Blanquet Abundance
Braun Blanquet Abundance

Meters Along Transect

1999

2000

2001
Braun Blanquet Abundance

Meters Along Transect
Braun Blanquet Abundance

Meters Along Transect

MC06

2002

2003

2004
Braun Blanquet
Abundance

Meters Along Transect
MC08

Braun Blanquet Abundance

Meters Along Transect

1999

2000

2001
Braun Blanquet Abundance

Meters Along Transect

2002

2003

2004
Braun Blanquet Abundance

Meters Along Transect

2002

2003

2004

MYR02
Braun
Blanquet
Abundance

MYR03

Meters Along Transect
Braun Blanquet Abundance

Meters Along Transect
Braun Blanquet Abundance

Meters Along Transect
Braun Blanquet Abundance

Meters Along Transect
Braun-Blanquet Abundance

Meters Along Transect

1999

2000

2001
Braun Blanquet Abundance

Meters Along Transect
Braun Blanquet Abundance

Meters Along Transect
Appendix B

Mean abundance by transect of three seagrass species estimated by Braun-Blanquet. Graphs are grouped by basins, please refer to Tables 1 and 2 and Figure 1 for transect abbreviations and locations.
Appendix C

GIS Product: Linear referencing and seagrass transects. The GIS products accompanying this report are contained in a geodatabase (ESRI), and include: a shapefile of transect locations (a route file), and tables of seagrass species abundance and environmental conditions collected at each sampling visit. Each of these components is accompanied by a metadata file which complies with SWFWMD GIS standards.

Characteristics of the transect route shapefile. In this context, a “route” is a linear feature (line) with an associated “measure” (point location). Therefore, GPS coordinates need not be collected to identify points, or “route events” along a transect. The only information needed to identify a quadrat is which transect, e.g. MYR02, and the station number, e.g. 45 m. Quadrat GPS data was not collected during most years of this monitoring program, yet all data which have been associated with a position along a transect can be included in any analyses and modeling by using this type of GIS construct.

GPS data collected at quadrats visited in 2004 were used to create the route shapefile. This differs from more common line shapes in the characteristic known as a “measure”. In this use, the measure is a quadrat’s location along a transect, in meters. Locations of all quadrats collected before or since 2004 can be used with this transect shapefile, and their geographic coordinates can be exported by the usual means.

Using the shapefile and related tables. There are several points to remember when displaying and analyzing route data. First, linear referencing tools must be displayed. Second, the data table must be displayed, as well as the transect shapefile. To relate the quadrat information to the transects, the command “Add route events...” will prompt for Route file (“TransectRts”), route ID attribute (“RID”), the route event table, (“QUADDAT”), the route ID field in the table (“SITE”) and measure field, (“STATION”). This creates a point file in the current map (default name “QUADDAT Events”). After creating the route event, a user could change symbology to reflect only quadrats visited in 2003, then in the select by attributes (using the QUADDAT table) only quadrats where Halodule wrightii abundance was greater than 50%.