SEAGRASS SPECIES COMPOSITION AND DISTRIBUTION TRENDS IN RELATION TO SALINITY FLUCTUATIONS IN CHARLOTTE HARBOR, FLORIDA

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Abstract: *Seagrass species composition and distribution reflect environmental changes, making these measures potentially useful estuarine indicators. An annual seagrass transect and quadrat monitoring survey program including 50 locations in Charlotte Harbor, Florida, began in 1999. This six-year data set was analyzed in conjunction with a monthly water quality monitoring program covering the same time period to examine trends in seagrass species composition and distribution. Analyses of the maximum depth of seagrass distribution for each transect did not indicate any large-scale changes in seagrass depth distribution. This suggests a stable overall area of seagrass distribution in the Charlotte Harbor area during the study period. However, abundance of* Halodule wrightii *and* Thalassia testudinum *has significantly declined, along with the overall frequency of seagrass occurrence among quadrats. Finally, the distribution of the three dominant seagrass species,* H. wrightii, T. testudinum, *and* Syringodium filiforme, *appear to be influenced by low, wet-season salinity and high variation. This study highlights the value of research into seagrass species abundance and distribution on a meter-to-meter scale to recognize the effects of water quality or environmental variables such as salinity on a small scale, prior to large scale loss.*

Key Words: Salinity, salinity variability, water quality, *Syringodium filiforme*, *Thalassia testudinum*, *Halodule wrightii*, species shift

The human population in Florida is increasing rapidly, with over a five-fold rise over the fifty-year period 1950–2000 (Dawes et al., 2004). Along with this rise in population and development of the coast lines comes anthropogenic affects on the coastal estuaries. As in many other areas around the world (Short and Wyllie-Echeverria, 1996), large-scale, wide-spread seagrass losses from anthropogenic degradation of water quality have occurred along the west coast of Florida within the last century, including up to a 46% loss in Tampa Bay, and a 28% loss in Sarasota Bay (Tomasko et al., 2005).

A state-wide loss of 3 million acres, an estimated 60% of historical seagrass coverage, corresponds to this increase in Florida's population (Dawes et al., 2004). Despite this large loss of habitat, seagrass beds continue to cover a large portion of the shallow coastal zone of Southwest Florida (Tomasko et al., 2005; Corbett, 2006), providing critical habitat to fish and invertebrates (Green and Short, 2003). Moreover, seagrass beds act as sediment stabilizers (Duarte et al., 1999), are an important food source, and contribute greatly to the nutrient cycle (Phillips and Meñez, 1988) in near-shore coastal ecosystems. The importance of seagrasses to the ecological function of the coastal estuaries highlights the need to understand the factors limiting this natural resource.

Seagrass depth distribution is limited by the amount of light reaching the benthos (Duarte, 1991; Gallegos and Kenworthy, 1996), while the seagrass species composition is also strongly influenced by the long-term salinity regime (Iverson and Bittaker, 1986; Montague and Ley, 1993; Fourqurean et al., 2003). Nutrient loading, often linked to population growth and the resultant decline in water clarity, is one of the leading causes of seagrass loss worldwide (Short and Wyllie-Echeverria, 1996) by limiting the depth at which seagrasses receive adequate light for sustained growth. For example, predicted increases in nitrogen loading into the Northwest portion of Charlotte Harbor, Lemon Bay, could potentially cause a reduction in *Thalassia testudinum* (Banks ex König) depth limit by 24% by 2010 (Tomasko et al., 2001).

Such large scale losses are detectable with aerial photography used to estimate total seagrass coverage. However, maps based on aerial photographs are not sensitive enough to discriminate small scale changes in seagrass species distribution (e.g., Frazer and Hale, 2001), particularly when seagrass meadows are composed of several species, as is often the case along the west coast of Florida (Iverson and Bittaker, 1986; Staugler and Ott, 2001; Frazer and Hale, 2001; Hale et al., 2004). Seagrass species composition and percent-cover are a reflection of biotic and abiotic environmental characteristics, thus making these measures potential indicators of estuarine health (Phillips and Meñez, 1988; Fourqurean et al., 2003; Hunt and Doering, 2005). Furthermore, species-specific seagrass responses to certain water quality variables are predictable (Fourqurean et al., 2003).

Fixed transects, monitored on an annual basis, provide information on percent-cover and species composition, allowing year-to-year comparison and detection of change (e.g., Morris and Virnstein, 2004). Long-term quantitative data on species composition and percent-cover were not available for the Charlotte Harbor area prior to 1999. This paper examines seagrass species abundance, distribution, and meadow composition data collected annually over a six year period (1999–2004) in conjunction with monthly water quality data collected over the same time period. The study (a) describes trends in seagrass abundance and distribution over time, (b) defines the trends in species-specific distribution associated with specific salinity regimes, and (c) characterizes seagrass trends and salinity variability by hydrologic management regions.

MATERIALS AND METHODS—*Study site*—This study was conducted in five designated aquatic preserves of Greater Charlotte Harbor, on the Southwest coast of Florida: Lemon Bay Aquatic Preserve, Gasparilla Sound-Charlotte Harbor Aquatic Preserve, Cape Haze Aquatic Preserve, Pine Island Sound Aquatic Preserve, and Matlacha Pass Aquatic Preserve. The preserves are divided into ten hydrologic

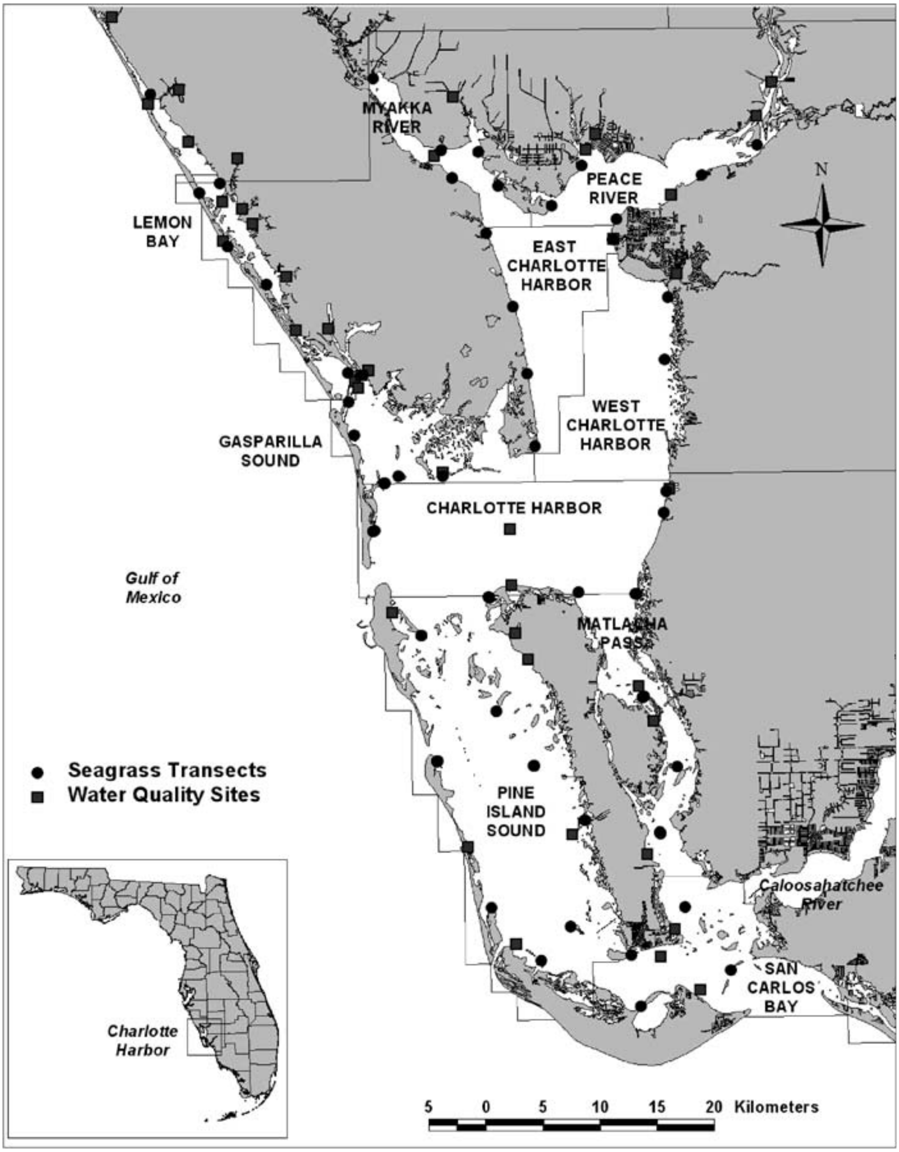

FIG. 1. Map of Greater Charlotte Harbor, on the Southwest coast of Florida, depicting water quality sites, seagrass transect sites, and hydrologic management areas of the Charlotte Harbor Aquatic Preserves.

management regions (FIG. 1). These aquatic preserves – covering more than 165,000 acres (66,773 hectares) – harbor six species of seagrass, three of which are common: *Thalassia testudinum* (turtle grass), *Syringodium filiforme* (Kützing) (manatee grass), and *Halodule wrightii* (Ascherson) (shoal grass).

Seagrass transects—Transect monitoring began in 1999 and has continued to the present. Annual samplings are conducted every fall (September–December) to characterize seagrass health at the end of its growing season (Staugler and Ott, 2001). The locations of the 50 transects were chosen to reflect a variety of seagrass bed sizes and, where possible, have a steep depth gradient to facilitate determination of a distinct offshore bed edge. Transects were widely distributed to span the five designated aquatic preserves. Beginning at the near-shore bed edge, transects extend to the offshore bed edge, perpendicular to shore.

Quadrats were typically located every 50 m along transects beginning at the edge of the seagrass bed, except on relatively short transects (<50 m), where they were spaced every 10 m. In addition, quadrats were located at the end of the seagrass beds. Each year approximately 350 quadrats were surveyed among all transects. Of those sampled, 192 quadrats were sampled consistently for each year of the study period (1999–2004).

The data collected at each quadrat and used in these analyses consists of: water depth (in cm, and corrected to mean water), presence/absence of seagrass species, and a modification of the Braun-Blanquet (BB) percent-cover class estimate of abundance (Braun-Blanquet, 1965) (i.e., 0 = no vegetation, 0.1 = solitary shoot, 0.5 = <1%, 1 = 1–5%, 2 = 6–25%, 3 = 26–50%, 4 = 51–75%, 5 = 76–100%) for each species present.

Salinity data—Salinity data, provided by the Charlotte Harbor Volunteer Water Quality Monitoring Network, a program initiated and supported by the CHAP since 1998, were collected on the first Monday of every month at sunrise from 36 fixed sites distributed throughout the Greater Charlotte Harbor estuaries (FIG. 1).

Analyses—Analyses to examine the depth of the deep edge of persistent seagrass beds, used 38 transects with abundance data collected for all years during the 1999–2004 study period. A non-parametric repeated-measures ANOVA (i.e., Friedman test) was used to test for differences in deepest depth of seagrass occurrence among years. When a significant difference among years was detected, pair-wise analyses were performed to determine if the changes were significant between consecutive years ($p < 0.05$).

Seagrass species composition and percent-cover class (BB) collected at quadrats sampled all six years ($n = 192$) were examined for annual variation by species. Only quadrats sampled all years were used in these analyses so as not to bias data. A non-parametric repeated-measures ANOVA (i.e., Friedman test) was used to test for differences in percent-cover class among years. When there were significant differences among years, pair-wise analyses were done to determine if the changes were significant between consecutive years ($p < 0.05$).

Seagrass occurrence was characterized by the number of quadrats containing a single seagrass species, a mix of multiple seagrass species, or no seagrass, and was calculated for each year of data. Regression analyses were used to determine if there was a temporal trend in the frequency of occurrence of these three categories throughout the study area. The temporal variation in seagrass species composition was examined by comparing the percent of quadrats exhibiting changes in composition among years. Hence, the types of quadrat composition change were analyzed as a change in the presence or absence of seagrass (or seagrass species), and grouped into four mutually exclusive categories: no change in composition, loss of seagrass (i.e., change from seagrass to no seagrass present), gain of seagrass (i.e., change from no seagrass to seagrass present), and species shift. These categories were used to detect patterns specific to individual hydrologic regions.

Monthly salinity averages, combining all sites throughout the Greater Charlotte Harbor study area during the study period were analyzed to determine the wettest and driest months immediately preceding the seagrass evaluation beginning in September. Salinities from the three consecutive driest months and three consecutive wettest months were averaged for each location for each year to provide estimates of the average high and low salinity values at each site throughout the study area. The average salinity for the wet months and dry months were used to represent each of the sample locations.

Salinity data from each year and from each season (wet and dry) were interpolated and contoured; salinity contour intervals were set at 1 psu. Seagrass transect locations were overlaid onto the contour shapefiles and were assigned the salinity values of the nearest contour line, providing estimates of the wet and dry-season salinity for each of the 50 seagrass transect locations for each of the six study years. The coordinates of the beginning of the transects were used to represent the transect, and corresponding quadrat locations in GIS analyses. Descriptive statistics were calculated for each of the three dominant seagrass

TABLE 1. Descriptive statistics of salinity (psu) in the ten hydrologic management areas throughout the study period (1999–2004).

	Peace River	Myakka River	East Charlotte Harbor	West Charlotte Harbor	Charlotte Harbor	Gasparilla Sound	Lemon Bay	Matlacha Pass	Pine Island Sound	San Carlos Bay
N	60	60	24	60	60	60	72	48	108	48
Min.	4	5	14	10	11	22	16	9	18	19
Max.	34	33	36	37	38	38	39	38	41	37
Mean	20.07	17.98	24.42	24.47	29.10	32.21	30.63	24.88	32.52	29.67
Std. Dev	8.68	9.39	7.63	7.94	6.82	4.40	5.79	7.75	4.51	5.71
C.V.	0.43	0.52	0.31	0.32	0.23	0.14	0.19	0.31	0.14	0.19

species, *Halodule wrightii*, *Thalassia testudinum*, and *Syringodium filiforme* to define the salinity in which they were found in the study area. Descriptive statistics of the salinity data were also calculated for each of the ten hydrologic management regions. Analysis of variance was used to test for significant difference in salinity among years and regions. Follow up pair-wise analyses were done using Tukey's test.

All statistics were done using Systat v 9.0, using the significance level of $\alpha = 0.05$. The GIS program ArcGIS v 9.0 (with the Spatial Analyst extension) was used for salinity interpolation, contouring, and spatial relates.

RESULTS—There were a few examples of transects in the Peace River and Myakka River hydrologic management areas where complete loss of seagrass persisted for several years. When these transects did support seagrass it was generally of less than 5% cover and consisted of one of two species: *Halodule wrightii* or *Ruppia maritima* (Linnaeus). The Peace River site furthest upstream exhibited only a single sparsely covered quadrat in 1999 and was devoid of seagrass throughout the remainder of the study period. The adjacent site, further downstream, exhibited only two quadrats with sparse abundance in 1999 and 2003. The transect furthest upstream in the Myakka River supported seagrasses in 4 of 6 years. The next transect downstream supported seagrass in all years except 2001. The Peace River and Myakka River regions had significantly lower salinities than all other regions, and the highest coefficient of variation (Table 1).

All other transects were classified as "persistent" beds, meaning they exhibited at least some seagrass cover during each sampling event. There were no significant differences in the deepest occurrence of seagrasses in persistent beds over the six-year study period.

There were significant decreases in seagrass abundances among years as measured by categorical Braun-Blanquet scores of *Halodule wrightii* and *Thalassia testudinum* (FIG. 2). Significant declines in *H. wrightii* occurred between 2000 and 2001, and between 2001 and 2002. In contrast, the decline in *T. testudinum* occurred gradually over time, with no significant differences between consecutive years, but an overall difference among years. The year of highest abundance, 2000, for all three species was also the year of highest average salinity.

There was a significant increase in the number of quadrats without seagrass, while the number of quadrats with a single species of seagrass significantly declined. The number of quadrats with more than one species remained relatively steady (FIG. 3).

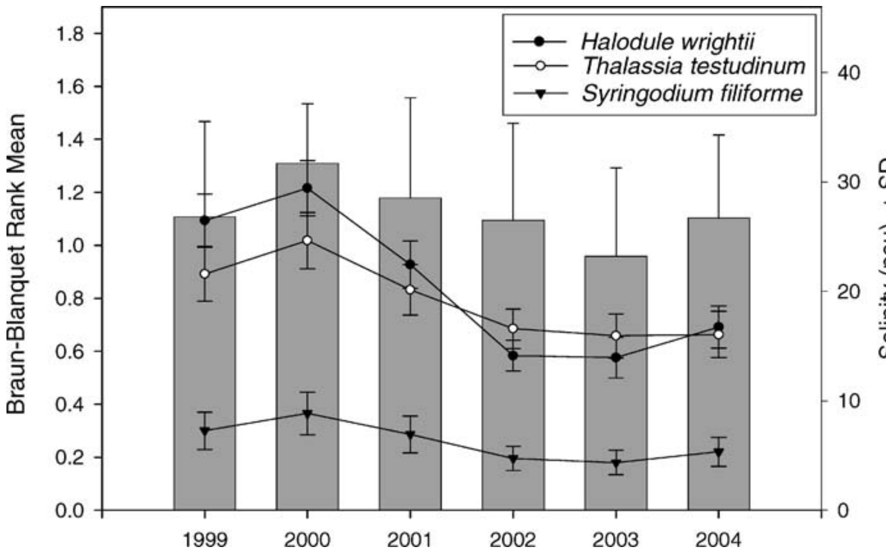

FIG. 2. The mean Braun-Blanquet percent-cover score (± standard error) for three seagrass species, and the mean salinity (± standard deviation) over the six-year study period. Salinity is represented by bars, seagrass is represented by lines.

Most quadrats (66%) did not exhibit any changes in presence, absence, or species composition between consecutive years. In fact, 55.2% of the quadrats had the same species composition in 1999 and 2004, while 23.4% of quadrats with grass lost all abundance at some point during the study, 15.1% gained grass after having none previously, and 6.3% maintained seagrass presence, but experienced a shift in species. These changes in composition were grouped by hydrologic regions (FIG. 4). The northeast portion of the study area (i.e., Peace River, Myakka River, East Charlotte Harbor, and West Charlotte Harbor) experienced a net loss of seagrass. Charlotte Harbor and Gasparilla Sound showed net increases in seagrass. Conditions in the remaining regions (i.e., Lemon Bay, Pine Island Sound, San Carlos Bay, and Matlacha Pass) remained relatively stable. In addition, seagrass stability appears to correspond to low salinity variation, while loss of seagrass corresponds to regions of high salinity variation (Table 1).

Patterns in salinity data were used to define the wet and dry month categories used for analyses (FIG. 5). The average salinity of the dry months (April, May, and June) were consistently above 25 psu. The beginning of the wet season (July, August, and September) was signified by consistently sharp declines in salinity between June and July. Although October also demonstrated low salinity values, this month was not used in analyses because it does not reflect conditions prior to seagrass data collection beginning in September. *Halodule wrightii* is the most common species in areas with the widest range of salinities, while *Syringodium filiforme* is found generally only in areas of consistently higher and less variable salinity (FIG. 6, Table 2).

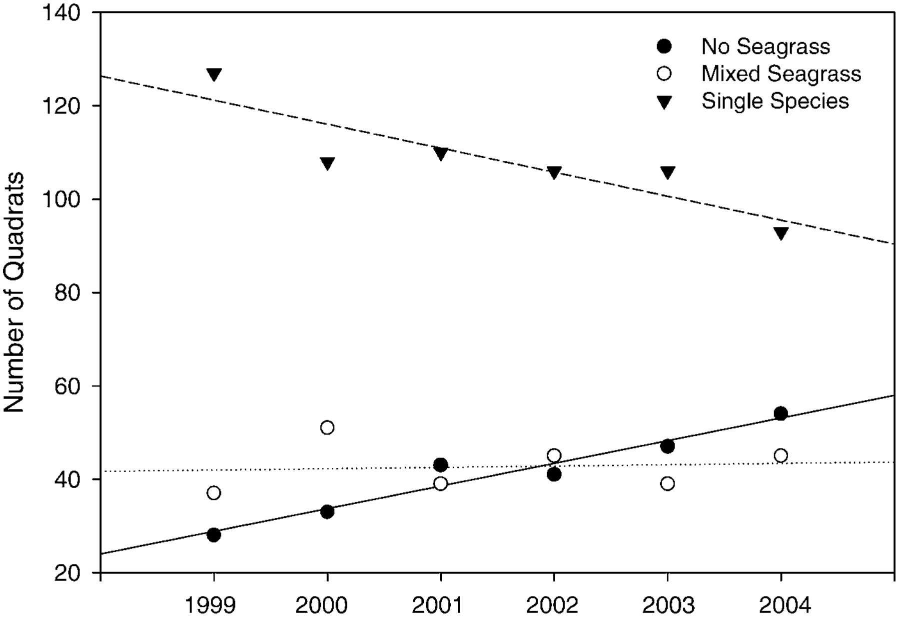

FIG. 3. Regression analyses of number of quadrats for the three categories; no seagrass, mixed seagrass, and single species over the six-year study period. Frequency of no seagrass quadrats increased significantly over time ($y = 4.86x + 24$; $R^2 = 0.93$), while frequency of single seagrass species quadrats decreased significantly over time ($y = -5.14x + 126.3$; $R^2 = 0.78$).

DISCUSSION—Transect survey and aerial survey programs were initiated in the Greater Charlotte Harbor area to detect large-scale changes in seagrass spatial distribution over time. Aerial surveys from the same region show relatively stable spatial distribution of seagrass beds since the initiation of regularly conducted surveys in the 1980s (Tomasko et al., 2005; Corbett, 2006), and analysis of maximum depth of seagrass distribution in this study found no wide-spread shifts in the Charlotte Harbor area. Thus, on a watershed scale, both methods suggest that the overall areal extent of seagrass coverage has been stable over their respective time periods. However, both surveys have identified the Peace River as an area of seagrass loss (see Corbett, 2006 for discussion).

In contrast to areal coverage and transect-level surveys, quadrat surveys were used to detect small-scale changes, such as shifts in species composition and decreasing seagrass abundance. These data suggest that there has been a significant reduction in the percent-cover of *Halodule wrightii* and *Thalassia testudinum* over the six-year study harbor wide, corresponding to salinity fluctuations over the same time period. Productivity of *T. testudinum* has been shown to be reduced significantly at salinities lower than 10 psu in the Charlotte Harbor watershed (Tomasko and Hall, 1999; Doering and Chamberlain, 2000). Growth of this species ceases at salinities at or below 6 psu, even under laboratory conditions with ample light (Doering and Chamberlain, 2000).

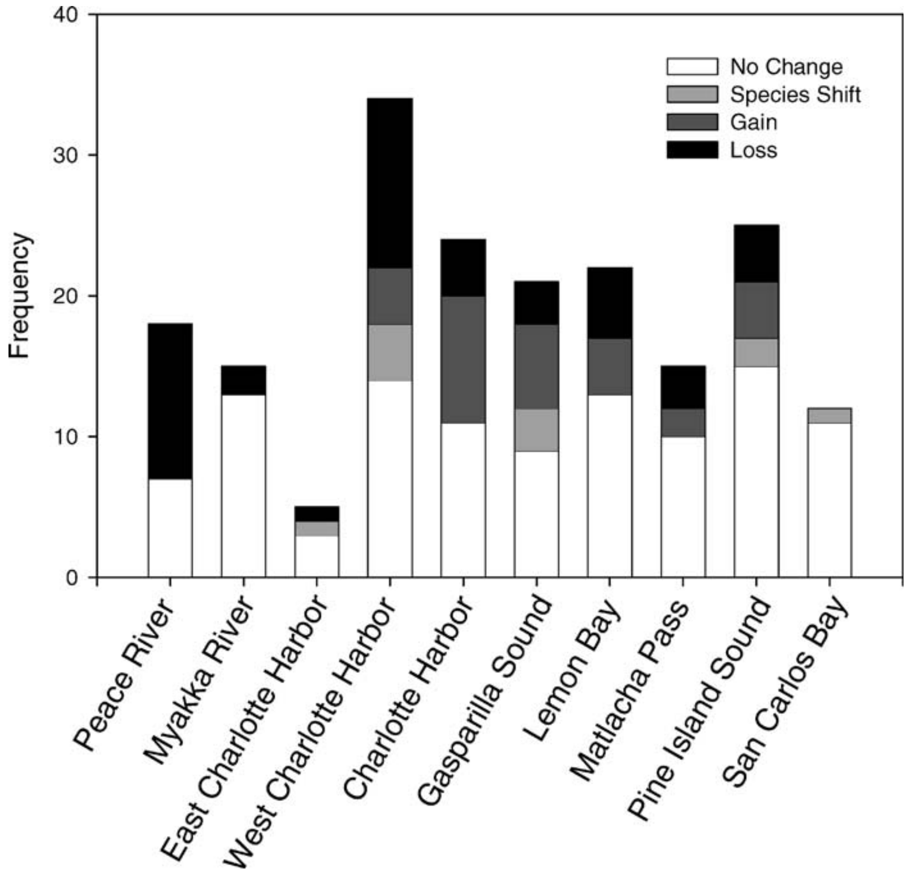

FIG. 4. Frequency of quadrats surveyed over the entire study period, exhibiting *no change, species shift, gain of seagrass,* and *loss of seagrass*, grouped by estuarine region reflecting how composition compared at the beginning and end of the study period.

Low salinities may account for some of the overall loss of seagrass on the meter scale, i.e., quadrat-to-quadrat. As the percentage of quadrats without seagrass has increased, the number of quadrats containing a single seagrass species has decreased. In contrast, multi-species quadrats show some inter-annual variability, but are generally stable over time. The types of changes vary when viewed across all ten hydrologic areas and highlight that the northeast region of the study area, which experiences high salinity variation, is the most unstable.

Numerous researchers have hypothesized a number of now familiar causes behind changes in seagrass communities. Natural weather patterns occurring across many years or decades, such as droughts and periods of above average rainfall, change estuarine salinity conditions, which in turn influence seagrass composition (Cho and Poirrier, 2005). Overloading of seagrass beds with organic matter, whether natural or anthropogenically induced, may also cause die-off as a result of sulfide

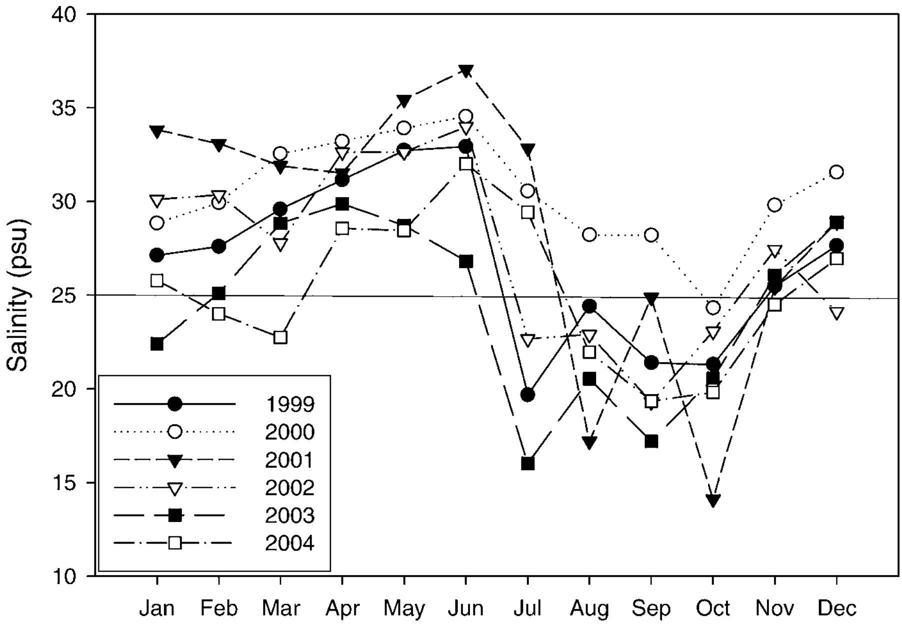

FIG. 5. Average monthly salinity throughout the year for the six-year study period.

toxicity (Morris and Virnstein, 2004). Another cause of seagrass decline may be overcrowding and stress (partially due to hyper-salinity), hypothesized to have triggered a massive seagrass die-off in Florida Bay (Zieman et al., 1999). Lastly, Hale and co-workers (2004) found that species composition changes may have been caused by widespread anthropogenic nutrient loading to the near-shore environment north of Tampa.

In many cases, the causes of seagrass loss cannot be determined, in part due to the lack of data on pre-existing conditions of seagrass and water quality. In some cases, where annual monitoring has been in place and managers have documented trends in species composition prior to seagrass loss (Morris and Virnstein, 2004), researchers were able to more thoroughly assess the causes of change.

Pairing the dependent seagrass variables from quadrat surveys with water quality is useful to describe the conditions in which each species is found within a specific estuary and will allow for future comparison. Temporally extensive water quality data, collected at least monthly, were imperative for summarizing the full range of conditions influencing seagrass composition. Numerous water quality variables influence seagrass composition and distribution (Fourqurean et al., 2003). Spatially and temporally explicit environmental data are essential to determine possible causes of change within seagrass beds.

We chose characteristics of the salinity regime for analysis because of the repeated examples of salinity minimum, range, or variability influencing the abundance and distribution of seagrass species (Montague and Ley, 1993; Tomasko and Hall, 1999; Ziemann et al., 1999; Cho and Poirrier, 2005). Salinity (<20 psu)

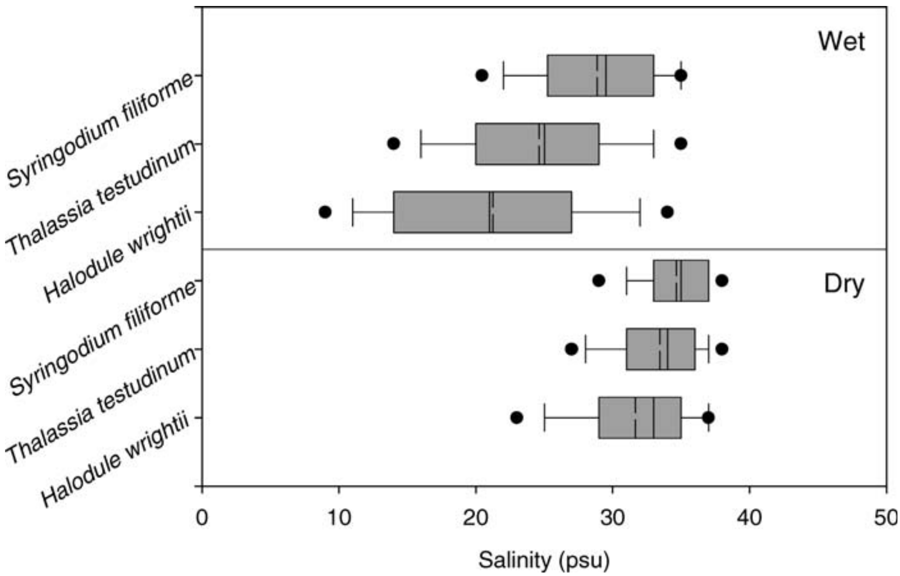

FIG. 6. Box and whisker plots depicting the mean (-), median (- -), 75th percentile, and 95th percentile of salinity during the wet and dry seasons at sites where each of the respective seagrass species were found.

has been positively correlated with water clarity in the northeast portion of our study area (Tomasko and Hall, 1999) and negatively correlated with dissolved matter, one of the contributing factors to light attenuation throughout the study area (McPherson and Miller, 1987). Therefore, although other water quality factors (e.g., color, turbidity, and nutrients) were not considered in these analyses, salinity is used as a proxy for the influence of freshwater flow.

Montague and Ley (1993) also reported relationships between seagrass abundance and variability in salinity, and noted changes in species dominance in areas with high salinity variability. Similarly, the results of our study help define the effects that changes in freshwater flow have on seagrass species composition. For

TABLE 2. Descriptive statistics of salinity (psu) during the wet and dry seasons at quadrats containing each species of seagrass.

	Halodule wrightii		*Syringodium filiforme*		*Thalassia testudinum*	
	Dry Season Salinity	Wet Season Salinity	Dry Season Salinity	Wet Season Salinity	Dry Season Salinity	Wet Season Salinity
N	1228	1228	208	208	699	699
Mean	31.60	21.20	34.70	28.90	33.40	24.60
Std. Error	0.12	0.23	0.19	0.32	0.13	0.23
Std. Dev	4.48	7.94	2.72	4.67	3.48	6.14
C.V.	0.14	0.37	0.08	0.16	0.10	0.25

example, if salinity means or variation changes to the extent that a certain species or percent-cover of seagrass cannot be supported, one of three outcomes may be hypothesized: a shift in dominant species, a decrease in percent-cover, or coverage may be lost altogether. The results presented here demonstrate less stability and lower species diversity in hydrologic regions with highly variable salinity regimes (e.g., Peace River and Myakka River). This study, along with a study by Fourqurean and co-workers (2003) in Florida Bay, demonstrates the wider salinity tolerance of *Halodule wrightii* as compared to the other two dominant seagrass species (i.e., *Thalassia testudinum* and *Syringodium filiforme*). We therefore hypothesize that altered flow leading to higher than normal salinity variation will lead to an overall decline in seagrass abundance and diversity, with a community predominantly composed of *H. wrightii*.

Seagrass species composition and distribution data, collected through transect and quadrat monitoring, have unique and complimentary uses, especially when analyzed in conjunction with one another and with water quality data. Such analyses allow a fuller interpretation of trends on several spatial scales, and can provide an enhanced understanding of estuarine processes. While the Greater Charlotte Harbor estuaries generally show stability in the overall area of seagrass coverage, there is significant thinning and localized loss of single species at the quadrat level of analysis.

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