SEAGRASS COVERAGE CHANGES IN CHARLOTTE HARBOR, FL

Catherine A. Corbett

Charlotte Harbor National Estuary Program,
1926 Victoria Avenue, Fort Myers, FL 33901

Abstract: *Seagrass areal coverage is estimated through seagrass polygon maps created almost biennially in Charlotte Harbor, Florida by photo-interpreting aerial photographs. This effort reports and analyzes coverage data for 1982–2003 for Upper and Lower Charlotte Harbor regions and 13 seagrass segments. Analyses did not detect trends in Upper or Lower Charlotte Harbor regions from 1982–2003. The Placida and Pine Island segments displayed increasing trends from 1982–2003, while the Peace River segment demonstrated a decreasing trend. From 1988–2003 the Placida segment displayed an increasing trend in areal extent, while the nearby South Harbor segment demonstrated a decreasing trend. Several segments demonstrated trends in seagrass polygon classification from "patchy" to "continuous" or vice versa, whereas these segments displayed no trend in areal extent. Relatively large changes occurred between the 1996 and 1999 mapping events, potentially a result of above-average rainfall with the 1997–1998 El Niño. This effort proposes that the changes may also be resultant in part from changes in the timing of data acquisition. Despite regional stability in seagrass coverage, declining water quality in some areas and the potential for future declines in others give reason for concern for the long-term maintenance of seagrass coverage in the Charlotte Harbor area.*

Key Words: Seagrass coverage, seagrass extent, Charlotte Harbor, estuaries, seagrass maps

Charlotte Harbor, one of Florida's largest estuaries, is located in southwest Florida near Sarasota and Tampa Bays. The Charlotte Harbor estuarine complex includes numerous interconnected estuaries from northern Coastal Venice and Lemon Bay south to Estero Bay. The Charlotte Harbor watershed extends approximately 210 km (130 mi) from the northern headwaters of the Peace River to southern Estero Bay. Three large rivers, the Peace (6,090 km^2 basin), the Myakka (1,560 km^2 basin) and the Caloosahatchee River (3,570 km^2 basin extending to Moore Haven), serve as the major sources of freshwater to the Charlotte Harbor estuary (Hammett, 1990).

Resource managers in the south Florida region, including Indian River Lagoon and Tampa and Sarasota Bays, have focused on seagrass meadows as environmental indicators of coastal environmental conditions. Managers have established systematic coverage maps and fixed transect monitoring to estimate changes in the extent and species composition and abundance of seagrass beds over time. Through seagrass coverage mapping efforts, a 46% loss of seagrass coverage in Tampa Bay from 1950 to 1982 followed by a 24% increase from 1982 to 1996 was documented (Tomasko et al., 2005). A similar trend in Sarasota Bay was documented with a 28%

loss from 1950 to 1988 followed by a 19% increase from 1988 to 1996 (Tomasko et al., 2005). These trends are thought resultant from changes in water quality and policies regulating pollutant loads (see Tomasko et al., 2005).

The Southwest and South Florida Water Management Districts (WMDs) have photo-interpreted 1:24,000 aerial photographs to develop seagrass polygon maps for Upper and Lower Charlotte Harbor approximately every 2 years since 1988 and 1999, respectively, and these data are reported by regions, Upper and Lower Charlotte Harbor, and by 13 seagrass segments (FIG. 1). Also, the Florida Department of Environmental Protection Aquatic Preserves monitor seagrass species composition and abundance annually at 55 fixed transects throughout Charlotte Harbor and Lemon and Estero Bays, documenting six species of seagrasses: *Halodule wrightii* (Ascherson), *Thalassia testudinum* (Banks ex König), *Syringodium filiforme* (Kützing), *Halophila englemanni* (Ascherson), *Halophila decipiens* (Ostenfeld) and *Ruppia maritima* (Linnaeus).

Previous analyses demonstrated that seagrass coverage estimates in Upper Charlotte Harbor are stable since 1988 (Kurz et al., 1999; Corbett et al., 2005; Tomasko et al., 2005; Corbett and Madley, *In Press*). However, losses in seagrass areal extent have been documented in Charlotte Harbor. Harris and co-workers (1983) compared seagrass extent derived from 1946 to 1951 black and white photographs to data derived from 1982 color photographs and documented a 29% decrease in seagrass, from 33,572 ha (82,959 acres) to 23,672 ha (58,495 acres) between 1945 and 1982, excluding Lemon and southern Estero Bays. All areas within the Charlotte Harbor study area demonstrated losses, ranging from 6–87%; however, the effort determined that over 57% of the total Charlotte Harbor region-wide loss was located solely within the Pine Island Sound, Matlacha Pass and San Carlos Bay segments (FIG. 1) of the Lower Charlotte Harbor region (Harris et al., 1983). Losses in Pine Island Sound alone accounted for more than 40% of the 29% region-wide loss. A subsequent effort, Corbett and co-workers (2005), reported seagrass extent through 2002, excluding Lemon and Estero Bays, and documented an overall 6% decrease between 1982 and 1999, from 23,127 ha in 1982 to 21,802 ha in 1999. The majority of the loss from 1982 to 1999 was found in the Lower Charlotte Harbor region within the Matlacha Pass, San Carlos Bay and Caloosahatchee River segments. During the same time period, the Pine Island Sound segment demonstrated an increase of 631 ha (Corbett et al., 2005).

Whereas water clarity and resultant changes in seagrass coverage in Tampa and Sarasota Bays have been linked to nutrient loads (see Tomasko et al., 2005 for references), coverage changes in Charlotte Harbor were largely attributed to other causes. Harris and co-workers (1983) credited the majority of the decreases from the 1940s to 1982 to the dredging of the Intracoastal Waterway and Sanibel Bridge construction in the Lower Charlotte Harbor region in the 1940s and 1960s. The authors also noted an overall decrease in seagrasses in the deep edges of seagrass beds and the deeper portions of the harbor and conjectured this loss was a result of decreasing water clarity from anthropogenic impacts. Corbett and co-workers (2005) observed some variability between sampling events in seagrass coverage estimates within the Upper Charlotte Harbor region and that this inter-mapping variability

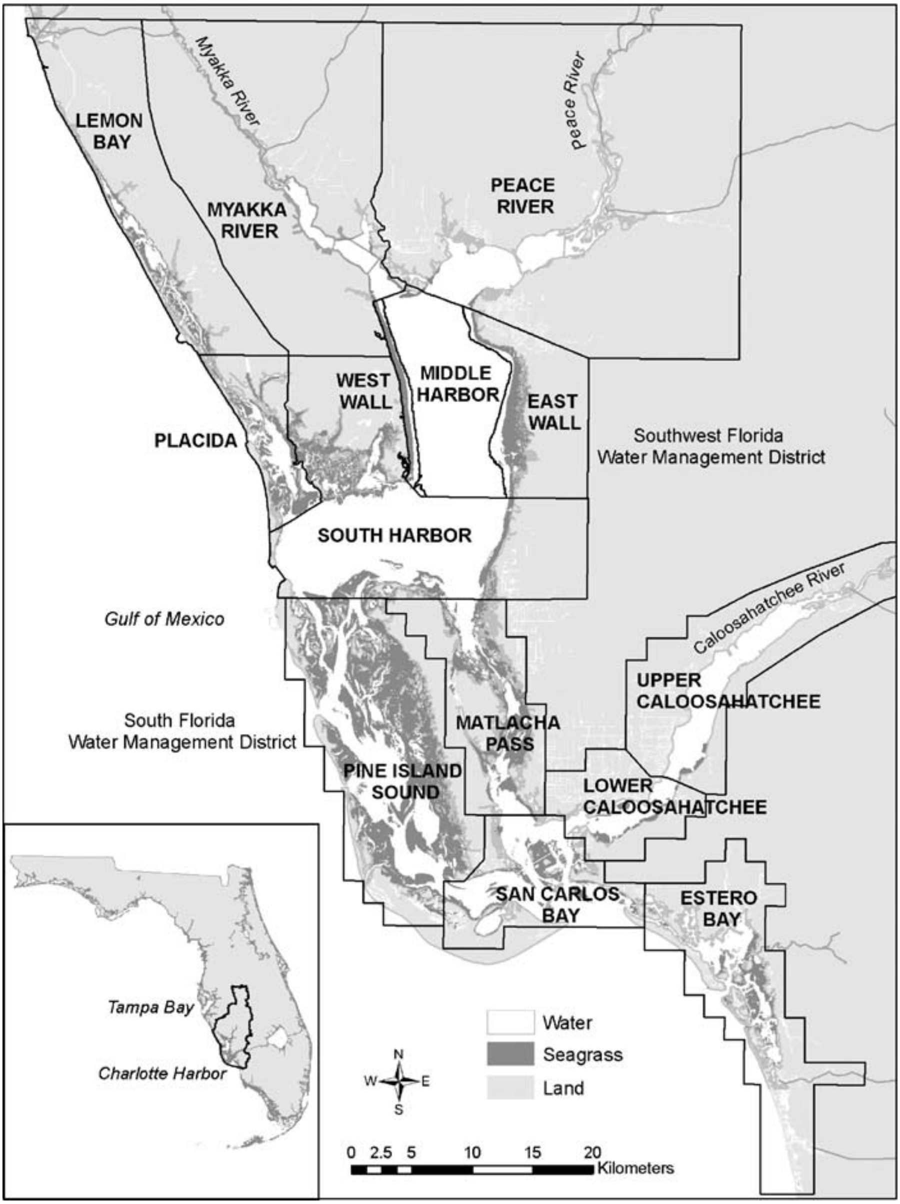

FIG. 1. Upper and Lower Charlotte Harbor Seagrass Segments. Seagrass Segments & 1999 Areal Coverage Provided by SWFWMD and SFWMD.

probably stemmed from inter-annual changes in freshwater inflows from the 3 major tributaries. The authors postulated the decreases detected in the 1999 mapping effort probably stemmed from the 1997–1998 El Nińo event, during which above average rainfall resulted in high inflows of stormwater runoff. In turn, salinity stress and

TABLE 1. Seagrass datasets for Charlotte Harbor and Lemon and Estero Bays.

Dataset	Date of Aerial Photography Acquisition
1982	April 1982
1988	October 1988
1992	March 1, 1993
1994	Upper Charlotte Harbor on March 1, 1995
	Lemon Bay in January 1995
1996	Upper Charlotte Harbor on April 24 and May 8–9, 1997
	Lemon Bay on January 31 and May 8, 1997
1999	Upper Charlotte Harbor December 1, 1999
	Lower Charlotte Harbor December 9 and 26, 1999
2001	January 9–10, 2002
2002	January 2003
2003	January 12–13, 2004

reduced water clarity from increased dissolved organic matter (Dixon and Kirkpatrick, 1999; Tomasko and Hall, 1999), likely caused a die-back of above-ground biomass before the 1999 mapping event (Corbett et al., 2005; Tomasko et al., 2005). Thus, changes in nutrient loads have not been linked to seagrass coverage changes in Charlotte Harbor.

Nonetheless, recent analyses of water quality data for Charlotte Harbor and Lemon and Estero Bays demonstrate a reason for concern for the future maintenance of seagrass extent and compel further scrutiny of seagrass coverage estimates. Analyzing water quality collected though 2001, Janicki Environmental Inc. (2003) documented increasing total suspended solids in Lower Charlotte Harbor and Upper Charlotte Harbor and increasing turbidity in Lower Charlotte Harbor. As suspended matter in the water column can at times account for over half of light attenuation in Charlotte Harbor (McPherson and Miller, 1987; McPherson and Miller, 1994; Dixon and Kirkpatrick, 1999), the increasing trends of these constituents give reason for a more thorough evaluation of seagrass coverage estimates. In addition, previous trend analyses for seagrass coverage estimates in Upper Charlotte Harbor (i.e., Kurz et al., 1999; Corbett et al., 2005; Tomasko et al., 2005), failed to analyze data by individual seagrass segment. Corbett and co-workers (2005) completed a change analysis comparing 1982 to 1999 data by region and seagrass segment but did not undertake a trend analysis by individual segment. This effort, therefore, updates previous analyses by reporting 2002 and 2003 coverage data for the Charlotte Harbor area and then examines the data for trends by region and by seagrass segment.

METHODS—*Seagrass maps*—In Upper Charlotte Harbor, the Southwest Florida Water Management District (SWFWMD) has created seagrass polygon maps to estimate seagrass coverage on a roughly biennial basis since 1988, while the South Florida Water Management District (SFWMD) initiated efforts within their jurisdiction of Lower Charlotte Harbor in 1999. The two Districts use approximately the same methodologies in their mapping efforts differing only slightly in the minimum mapping units, map accuracy standards and classification of "patchy" versus "continuous" seagrass coverage (see Corbett et al., 2005 for explanation).

Existing seagrass datasets and the dates of aerial photography acquisition are listed in Table 1. Seagrass maps are produced through a multi-step process by photo-interpreting 1:24,000 aerial photographs using stereoscopes or analytical stereo plotters (for details see Kurz et al., 1999; Corbett et al., 2005; Tomasko et al., 2005; SWFWMD, 2006; Corbett and Madley, *In Press*; Tomasko and Greening, *In Press*). Maps are checked for accuracy by post-production field verification, and both WMDs require a photo-interpretation classification accuracy of over 90%. Seagrass signatures are divided into two classes: 9116 "continuous" coverage (approximately 75%–100% seagrass cover visible within a polygon) and 9113 "patchy" (approximately 25%–75% seagrass cover visible within a polygon). Both polygon classes are combined for 911 "total" seagrass coverage. Other map categories are polygons with approximately 0–25% seagrass cover, classified as 6510 "tidal flat" or 5400 "open water" depending on depth. Non-vegetated areas that are periodically exposed or are capable of supporting seagrass, defined as approximately 2 meters in depth or shallower, are classified as "tidal flat"; they are usually found on the shallower edges of seagrass beds, either along the shoreline or on the crest of a seagrass bed (SWFWMD, 2006). Lastly, 7100 "beaches other than swimming" are isolated strands of non-vegetated sand found along mangrove and spoil islands (SWFWMD, 2006).

The 1982 data were collected by the Florida Fish and Wildlife Conservation Commission in April 1982 using similar methods to SWFWMD in 1988 that included field verification of signatures; however, seagrass coverage was classified to three categories (i.e., sparse, dense, patchy) (see Harris et al., 1983 for details). Because the 1982 polygon classifications are not easily comparable to subsequent mapping efforts harbor-wide, the 1982 data are not included in the analysis of "patchy" and "continuous" coverage described below. Also, the 1982 data did not include Lemon or southern Estero Bays, and because of this, analysis of 1982 Lemon and Estero Bays areal extent is not included here. Data for the Caloosahatchee River are reported for the Lower Caloosahatchee River segment (FIG. 1) only.

Data analysis—All statistical analyses were completed using Statistica® v 7.0, with the significance level of α=0.05. All trend analyses were completed using linear regression analysis (i.e., Pearson r). Mann-Whitney U tests were performed to compare 1988–1996 coverage data with 1999–2003 coverage data.

Total seagrass coverage—Seagrass areal extent data were first examined by combining the "patchy" (9113) and "continuous" (9116) polygon categories for total areal extent, called "total", for each mapping effort. A mean-error plot was created of the mean areal extent by seagrass segment for 1982–2003 (1988–2003 for Estero and Lemon Bays). To account for differences in the segments such as segment size and water depth, a uniform estimate of potentially-available seagrass habitat for each segment was made by adding the "tidal flat" (6510) coverage to the "total" seagrass coverage. The plot was then created for the ratio of "total" seagrass coverage to this estimate of "available habitat" by segment.

"Total" seagrass areal extent data for the Upper and Lower Charlotte Harbor regions, excluding Estero and Lemon Bays, were examined for temporal trends for 1982–2003 data by linear regression analysis. "Total" seagrass areal extent data for the 13 individual seagrass segments were also examined for trends for 1982–2003 data by linear regression analysis. For comparison purposes with the "patchy" and "continuous" analyses described below, linear regression analysis was also performed on 1988–2003 "total" seagrass areal extent data by segment.

Polygon category comparisons—Seagrass data for each seagrass segment were next analyzed by polygon category, "patchy" and "continuous", for each sampling effort between 1988–2003. The 1982 data were not used in these analyses. Linear regression analysis was performed on "patchy" and "continuous" data separately for each seagrass segment for 1988–2003 to look for temporal trends in coverage by polygon categories.

Next, to quantify changes in the relationship of seagrass coverage mapped as "patchy" or "continuous", the percent of "total" areal extent mapped as "patchy" and then "continuous" was determined by segment and sampling effort from 1988–2003. A mean-error plot of mean percent "continuous" coverage by segment was created. These data were then analyzed by seagrass segment for trends between 1988–2003 using linear regression analysis. For comparison purposes, the linear regression analyses were also performed on data collected by SWFWMD in Tampa Bay for 1988–2003 for the following segments: Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay, Boca Ciega Bay, Lower Tampa Bay, Terra Ciea Bay and Manatee River.

TABLE 2. Seagrass coverage in hectares by region and by segment by year since 1982. These coverages reflect segment boundary changes made in 2003 by the SWFWMD and SFWMD.

		Upper Charlotte Harbor							
Year	Lemon Bay	Placida	South Harbor	West Wall	East Wall	Middle Harbor	Myakka River	Peace River	Subtotal (Except Lemon Bay)
1982		957	3,544	665	1,548	70	218	397	7,399
1988	1,055	1,416	3,710	580	1,372	50	161	158	7,448
1992		1,384	3,662	490	1,361	50	130	167	7,244
1994	1,067	1,344	3,659	671	1,416	60	189	196	7,535
1996	1,054	1,460	3,648	790	1,371	76	203	232	7,781
1999	1,049	1,503	3,340	699	1,452	62	191	109	7,356
2001	1,046	1,531	3,313	699	1,454	64	185	138	7,384
2003	1,110	1,625	3,488	646	1,315	43	118	106	7,341
Mean	1,064	1,402	3,545	655	1,411	60	174	188	7,436

	Lower Charlotte Harbor					
Year	Pine Island Sound	Matlacha Pass	San Carlos Bay	Caloosahatchee River	Estero Bay	Subtotal (Except Estero Bay)
1982	9,857	3,247	2,420	242		15,766
1999	10,483	2,456	1,504	1	1,008	14,445
2002	10,647	2,784	1,768	42	975	15,241
Mean	10,329	2,829	1,898	95	991	15,151

Time series comparison—To determine if seagrass coverage estimates were significantly different between 1988–1996 and 1999–2003, a Mann-Whitney U test was performed on "total" seagrass coverage by segment and by region for 1988–1996 and 1999–2003 periods. A Mann-Whitney U test was also performed on the percent "continuous" coverage by segment to compare 1988–1996 and 1999–2003 percent "continuous" coverage data.

RESULTS—*Seagrass coverage*—Table 2 lists estimates of "total" seagrass areal for 1982–2003, and Table 3 lists coverage estimates for "patchy" and "continuous" categories by segment for 1988–2003. The spatial extents of several segments within the Upper Charlotte Harbor region were modified in 2003 by SWFWMD; thus, the data reported in Table 2 differ slightly from earlier efforts (i.e., Kurz et al., 1999; Corbett et al., 2005; Tomasko et al., 2005; Corbett and Madley, *In Press*).

The ratio of seagrass coverage to available seagrass habitat appeared different in several segments as did seagrass polygon classifications. The most notable result was that the Peace River and Estero Bay segments displayed reduced mean areal extent to available habitat ratios with mean values less than 0.5 (FIG. 2), and the Myakka River, Lemon Bay and Middle Harbor segments displayed ratios less than 0.75. The segments in the Lower Charlotte Harbor region along with the Estero Bay segment generally displayed a greater percentage of seagrass coverage mapped as "continuous" than those segments in the Upper Charlotte Harbor region and the Lemon Bay segment (FIG. 3), which, in turn, had a larger percentage mapped as "patchy".

"Total" areal extent for the Upper Charlotte Harbor region did not demonstrate a trend from 1982 to 2003 (FIG. 4). Mean seagrass coverage in Upper Charlotte Harbor during 1982 to 2003 was 7,436 hectares, and the difference in coverage

TABLE 3. "Patchy" seagrass coverage in hectares by segment from 1988–2003. "Continuous" coverage is in parentheses.

		Upper Charlotte Harbor						
Year	Lemon Bay	Placida	South Harbor	West Wall	East Wall	Middle Harbor	Myakka River	Peace River
1988	673 (382)	804 (612)	2,423 (1,287)	357 (223)	1,175 (197)	42 (8)	132 (29)	157 (2)
1992		853 (530)	2,455 (1,207)	303 (188)	1,215 (147)	49 (1)	105 (25)	167 (0)
1994	541 (525)	853 (491)	2,721 (937)	432 (239)	1,245 (171)	58 (2)	159 (29)	190 (7)
1996	510 (544)	948 (512)	2,587 (1,061)	555 (235)	1,248 (123)	72 (4)	173 (29)	200 (32)
1999	383 (667)	761 (742)	1,713 (1,626)	395 (304)	1,231 (221)	61 (1)	171 (20)	109 (0)
2001	291 (755)	654 (877)	1,468 (1,845)	382 (317)	1,078 (376)	63 (1)	163 (23)	138 (0)
2003	484 (626)	763 (862)	1,249 (2,239)	377 (268)	929 (385)	43 (0)	118 (0)	106 (0)
Mean	480 (583)	805 (661)	2,088 (1,457)	400 (253)	1,160 (231)	56 (2)	146 (22)	152 (6)

	Lower Charlotte Harbor				
Year	Pine Island Sound	Matlacha Pass	San Carlos Bay	Caloosahatchee River	Estero Bay
1999	773 (9,710)	193 (2,263)	112 (1,393)	0 (1)	105 (903)
2002	696 (9,951)	218 (2,566)	230 (1,538)	10 (33)	65 (909)
Mean	735 (9,830)	206 (2,414)	171 (1,465)	5 (17)	85 (906)

estimates between consecutive sampling events was less than 500 hectares. The data for the Lower Charlotte Harbor region also did not demonstrate a trend. Mean areal extent for the 3 mapping efforts in Lower Charlotte Harbor was 15,151 hectares.

Temporal trends were found in several individual seagrass segments when analyzing "total" areal coverage for the 1982 to 2003 period. The Placida and Pine Island segments displayed significant increasing trends estimated to be 26 and 39 hectares per year, respectively, while the Peace River segment demonstrated a significant decreasing trend at a loss approximating 11 hectares per year. The South Harbor segment also demonstrated a decreasing trend from 1982 to 2003 at an estimated rate of 12 hectares per year (FIG. 5), but the trend was not significant ($p=0.15$).

Table 4 lists the results from all trend analyses of 1988–2003 data. From 1988 to 2003, the Placida segment demonstrated a significant increasing trend estimated at 15 hectares per year, while the nearby South Harbor segment displayed a significant decreasing trend at an approximate rate of 25 hectares per year. The South Harbor segment displayed a relatively dramatic loss of 308 ha between the 1996 and 1999 mapping events (FIG. 5). The segment also exhibited a significant decreasing trend from 1988 to 1996 at an approximate rate of 8 hectares per year and an increasing trend that was not significant from 1999 to 2003. A relatively dramatic loss of coverage between the 1996 and 1999 sampling events was also apparent in the Peace River segment. Between 1996 and 1999, coverage declined 53%, while from 1988 to 1996, coverage for the Peace River demonstrated an increasing trend at an approximate rate of 9 hectares per year that was not significant ($p=0.09$). Overall, from 1988 to 2003 the Peace River displayed a decreasing trend that was not significant ($p=0.25$).

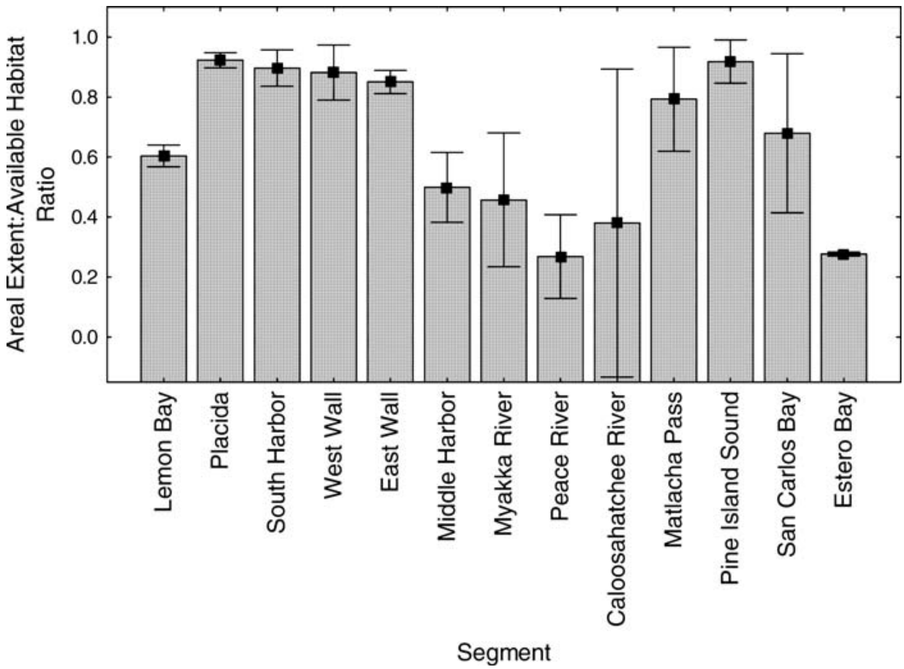

FIG. 2. Mean Areal Extent to Available Habitat Ratio by Segment from 1982 to 2003. Horizontal Bars represent ±0.95 standard deviation.

Polygon category comparisons—Linear regression analysis of "patchy" and "continuous" polygons in Upper Charlotte Harbor for 1988–2003 documented trends in several seagrass segments in Upper Charlotte Harbor (Table 4). Four segments, Lemon Bay, Placida, South Harbor and West Wall, displayed significant increasing trends in "continuous" coverage, while the East Wall demonstrated an increasing trend that was not significant ($p=0.06$). The South Harbor segment demonstrated the greatest rate of change with an increase estimated at 68 hectares per year in "continuous" coverage. The South Harbor and Lemon Bay segments demonstrated concomitant significant decreasing trends in "patchy" coverage; the rate of these decreases was approximately 93 hectares and 20 hectares per year, respectively. Three other segments, Placida, Peace River and East Wall, demonstrated decreasing trends in "patchy" coverage also, but these trends were not significant. The Myakka River segment demonstrated a small decreasing trend in "continuous" coverage that was not significant ($p=0.07$) (Table 4) and by 2003 displayed no "continuous" coverage (Table 3). The Middle Harbor and Peace and Myakka River segments also demonstrated no "continuous" coverage in 2003.

An interesting pattern emerges when reviewing these findings and the relationship between "patchy" and "continuous", represented as percent "patchy" or percent "continuous" coverage. The Lemon Bay and South Harbor segments demonstrated significant increasing trends in percent "continuous" coverage and

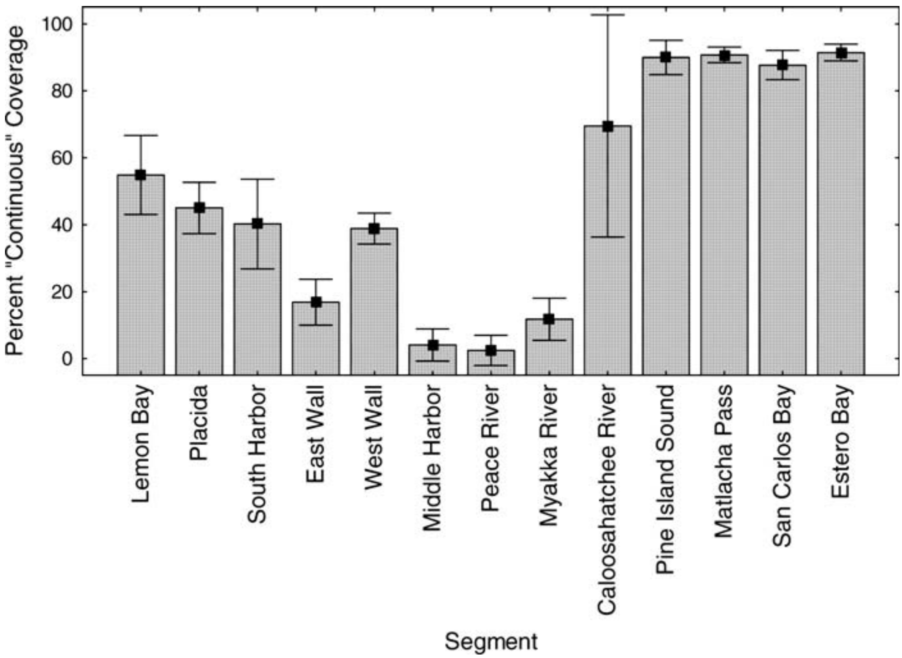

FIG. 3. Mean Percent "Continuous" Coverage by Segment from 1988 to 2003. Horizontal Bars represent ±0.95 standard deviation.

resultant concomitant decreasing trends in percent "patchy". The Placida and East Wall segments demonstrated a similar phenomena, but trends for these segments were not significant ($p=0.09$ and $p=0.06$, respectively). A relatively large increase in percent "continuous" coverage occurred between the 1996 to 1999 sampling events (FIG. 6). Analyses demonstrated the reverse relationship between percent "patchy" and "continuous" for the Middle Harbor and Myakka River segments (Table 4). More than 80% of seagrass coverage in both these and the Peace River segments were classified as "patchy", and in 2003 all 3 segments displayed 100% "patchy" coverage (FIG. 7).

Nonetheless, as mentioned above, only the Placida and South Harbor segments demonstrated "total" coverage trends for the same time period, increasing and decreasing, respectively (Table 4). The South Harbor segment displayed significant trends in all analyses: declining trends in "total", "patchy" and percent "patchy" seagrass coverage and increasing trends in "continuous" coverage and the percent "continuous" coverage. The Placida segment demonstrated significant increasing trends in "total" seagrass coverage and "continuous" coverage. Several of the remaining segments, Lemon Bay, Middle Harbor and Myakka River displayed significant trends in percent "patchy" and percent "continuous" with no concomitant "total" coverage trend. Thus, these data demonstrated a change in the relationship of "patchy" to "continuous" categories.

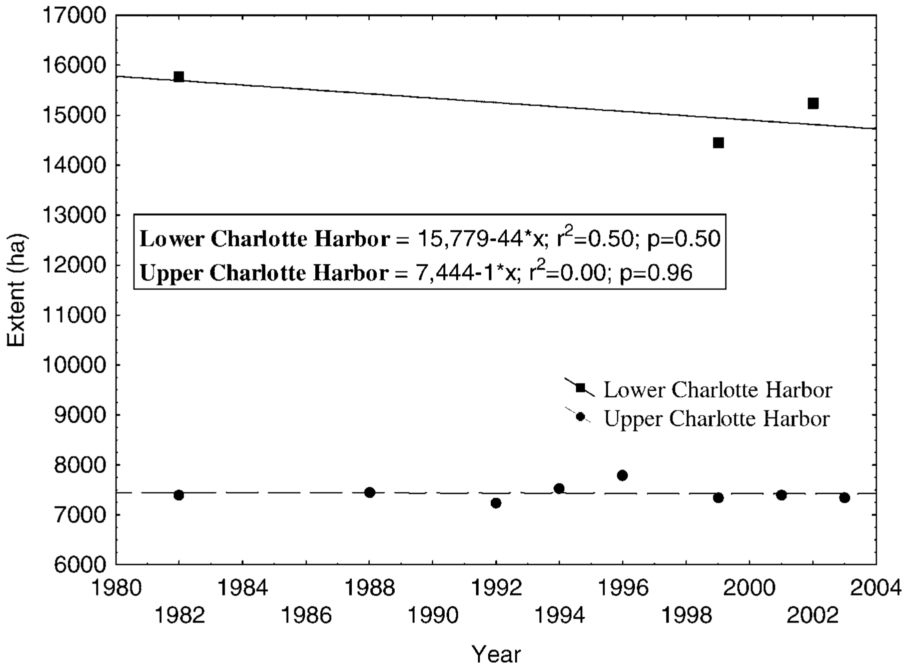

FIG. 4. Areal Extent by Region, excluding Lemon and Estero Bays, from 1982 to 2003.

Results from the analyses of Tampa Bay "total", "patchy", "continuous", percent "patchy" and percent "continuous" coverage data from 1988 to 2003 displayed that only one segment, Terra Ciea Bay, of the 7 segments analyzed demonstrated a significant trend in polygon coverage classification without a concomitant overall coverage trend. The pattern in changing coverage classification without overall coverage trends that was found in several segments in Upper Charlotte Harbor was, therefore, not widespread in Tampa Bay.

Time series comparisons—"Total" coverage estimates for 1988–1996 in the Placida, South Harbor and Peace River segments were significantly different from 1999–2003 estimates. The mean coverage for the Placida segment was greater in the 1988–1996 period than the 1999–2003 period, while the opposite was true for the South Harbor and Peace River segments. Percent "continuous" coverage during 1988–1996 was significantly different in all 7 segments in Upper Charlotte Harbor and the Lemon Bay segment from 1999–2003. Lower mean percent "continuous" coverage was detected in 1988–1996 for the Lemon Bay, Placida, South Harbor, West Wall and East Wall segments than in 1999–2003, while the opposite relation was found in the Peace and Myakka Rivers and Middle Harbor segments.

DISCUSSION—Past research has documented that dissolved and suspended matter account for over 90% of light attenuation in Charlotte Harbor (e.g., McPherson

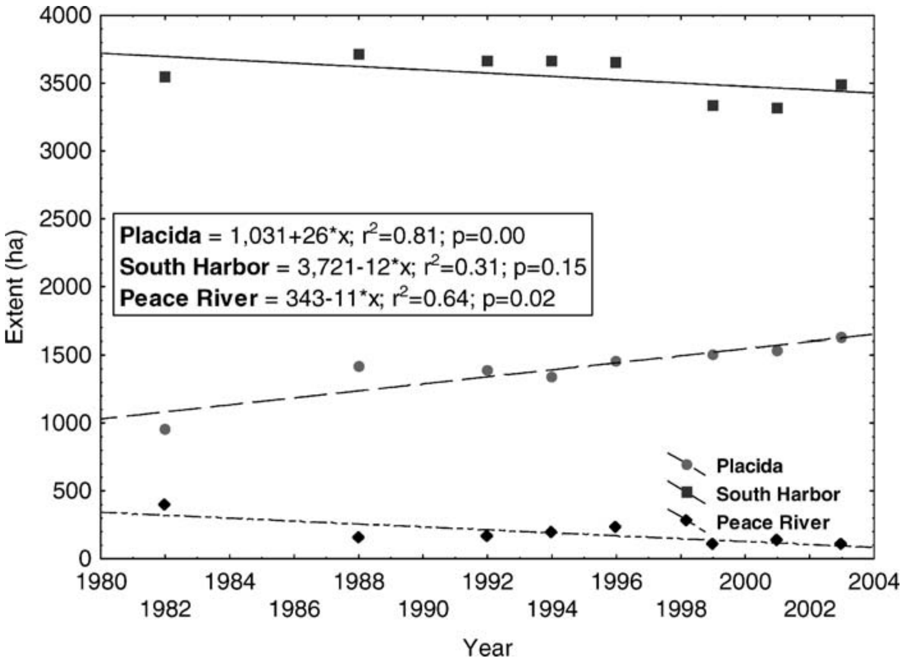

FIG. 5. Areal Extent for Placida, South Harbor and Peace River Segments from 1982 to 2003.

and Miller, 1987; Dixon and Kirkpatrick, 1999) and that water clarity in Charlotte Harbor is strongly, positively associated with salinity (McPherson and Miller, 1987; McPherson and Miller, 1994; Dixon and Kirkpatrick, 1999; Tomasko and Hall, 1999). In turn, water clarity is largely a factor of basin runoff and flows from the three major tributaries (McPherson and Miller, 1987; Doering and Chamberlain, 1999; Tomasko and Hall, 1999). Dixon and Kirkpatrick (1999) found that the maximum depths of seagrass beds in Charlotte Harbor generally increase with increasing distance from the mouths of the 3 tributaries. The analysis in this effort comparing "total" seagrass coverage to available habitat across segments corroborates these previous efforts. Mean areal extent in the river segments, the Peace, Myakka and potentially the Caloosahatchee, appeared lower with respect to available seagrass habitat than in those segments farther away from the tributaries in general. However, Estero Bay also displayed a low mean areal extent to available habitat ratio which suggests that environmental conditions, such as poor water clarity, within this segment are not beneficial for seagrass meadows, a condition that may be worsening. For instance, Janicki Environmental Inc. (2003) found increasing turbidity, total suspended solids and other analytes within the Estero Bay basin.

Similar to previous recent analyses of seagrass coverage estimates for the Upper Charlotte Harbor region (i.e., Kurz et al., 1999; Corbett et al., 2005; Tomasko et al., 2005), seagrass areal extent in the Upper and Lower Charlotte Harbor regions appeared stable in this analysis. This effort did not find a trend in seagrass coverage for 1982 to 2003 for the Upper or Lower Charlotte Harbor region, and estimates for

TABLE 4. Estimated annual rates of change from 1988 to 2003 for seagrass coverage by segment in Upper Charlotte Harbor, expressed as hectares per year or percent by year. Significance levels are enclosed in parentheses with trends significant at p<0.05 shown with an asterisk.

Segment	"Total" Coverage (ha)	"Patchy" Coverage (ha)	"Continuous" Coverage (ha)	Percent "Patchy"	Percent "Continuous"
Lemon Bay	+2 (p=0.43)	−20 (p=0.05)*	+21 (p=0.02)*	−2 (p=0.03)*	+2 (p=0.03)*
Placida	+15 (p=0.02)*	−9 (p=0.25)	+24 (p=0.05)*	−1 (p=0.09)	+1 (p=0.09)
South Harbor	−25 (p=0.03)*	−93 (p=0.02)*	+68 (p=0.04)*	−2 (p=0.03)*	+2 (p=0.03)*
West Wall	+9 (p=0.25)	+2 (p=0.73)	+7 (p=0.05)*	0 (p=0.30)	0 (p=0.30)
East Wall	+1 (p=0.81)	−14 (p=0.14)	+15 (p=0.06)	−1 (p=0.06)	+1 (p=0.06)
Middle Harbor	0 (p=0.86)	+1 (p=0.56)	0 (p=0.05)*	+1 (p=0.04)*	−1 (p=0.04)*
Peace River	−4 (p=0.25)	−4 (p=0.16)	0 (p=0.85)	0 (p=0.81)	0 (p=0.81)
Myakka River	0 (p=0.96)	+1 (p=0.60)	−1 (p=0.07)	+1 (p=0.02)*	−1 (p=0.02)*

the Upper Charlotte Harbor region demonstrated differences between sampling events no greater than 500 hectares. Therefore, existing seagrass coverage estimates demonstrated that region-wide seagrass coverage for Charlotte Harbor was stable between 1982 and 2003.

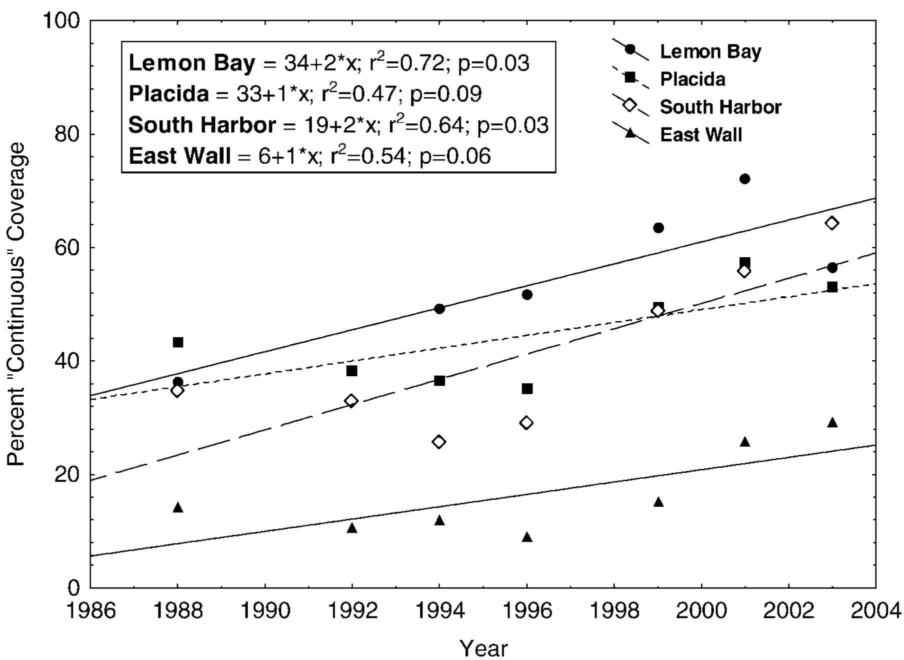

FIG. 6. Percent "Continuous" Coverage in Selected Segments from 1988 to 2003.

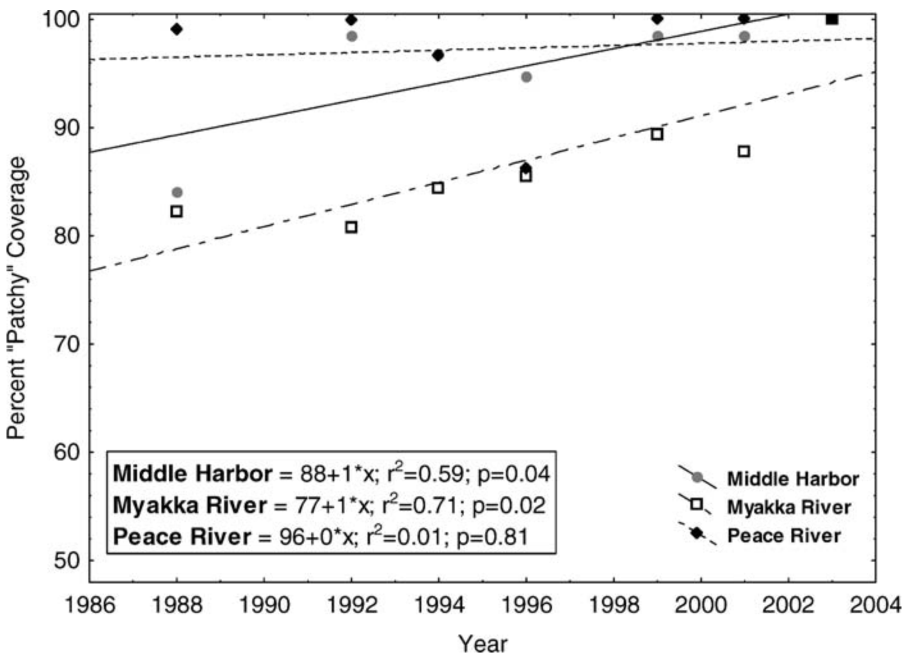

FIG. 7. Increases in Percent "Patchy" Coverage from 1988 to 2003.

Nonetheless, within individual seagrass segments of Charlotte Harbor, there appears to be changes in areal extent and/or classification. Significant trends in seagrass coverage were documented in several segments, such as increasing trends in the Pine Island Sound and Placida segments from 1982 to 2003. The Peace River segment demonstrated an overall significant decreasing trend from 1982 to 2003, but further analysis showed that losses in coverage between the 1982 and 1988 as well as between 1996 and 1999 sampling events could explain that overall trend. Seagrass coverage in the Peace River declined 60% and 53% during those time periods, respectively, while between the 1988 and 1996 periods, the Peace River demonstrated an increasing trend. In addition, the South Harbor segment demonstrated a significant decreasing trend in seagrass coverage from 1988 to 2003. While some of this trend can be explained by a relatively large loss of coverage between the 1996 and 1999 sampling events, this segment also displayed a negative coverage trend between 1988 and 1996.

The 1997–1998 El Niño event occurred between the 1996 and 1999 sampling events and may explain why seagrass coverage in the Peace River and South Harbor segments demonstrated relatively large losses during this time period. Above average rainfall that accompanied the 1997–1998 El Niño resulted in winter and springtime flows as much as 20 times the long-term averages (Dixon and Kirkpatrick, 1999). In turn, salinity stress and reduced water clarity from increased dissolved organic matter (Dixon and Kirkpatrick, 1999; Tomasko and Hall, 1999), likely caused a die-back or sloughing of aboveground biomass documented in the

1999 seagrass maps (Corbett et al., 2005; Tomasko et al., 2005). Conversely, record drought conditions between the 1999 and 2002 seagrass mapping events for Lower Charlotte Harbor probably produced the increase in seagrass coverage documented in the 2002 SFWMD seagrass maps.

Several segments in the Upper Charlotte Harbor region demonstrated trends in "patchy" and "continuous" classification categories. Four segments showed significant increasing trends in "continuous" coverage, and a fifth showed an increasing trend that was not significant. Two of these also showed significant increasing percent "continuous" coverage, while two other segments demonstrated increasing trends that were not significant. Of these segments, only the Placida segment demonstrated a concomitant significant increasing trend in "total" coverage. Moreover, the South Harbor segment demonstrated a concomitant significant *decreasing* trend in "total" coverage. This pattern of increasing "continuous" polygon classification without a simultaneous increase in areal coverage trend seems to signify a "filling in" of gaps between seagrass meadows, although a review of the aerial photographs from which these data are derived is needed for conclusive evidence. The majority of these segments demonstrate a relatively dramatic change between the 1996 and 1999 mapping efforts (FIG. 6). In addition, five segments displayed a higher percent "continuous" coverage in 1999–2003 than in 1988–1996.

The pattern described above—trends in polygon classification with a lack of simultaneous trend in overall coverage—might be indicative of natural variability within the coastal Charlotte Harbor ecosystem or potential evidence of an environmental disturbance. The mosaic of seagrass, oyster bar and unvegetated patches within the coastal Charlotte Harbor landscape probably shifts as environmental constraints, such as salinity, light availability and other water quality variables, vary over time.

Still another likely reason for the significant trends described herein is intersampling differences in aerial photograph acquisition. Between 1988–1996, the data for 2 seagrass maps in the Upper Charlotte Harbor region (i.e., 1992 and 1994) were derived from aerial photography taken in early March, which is towards the end of the seagrass dormant season generally (Robbins, 2006; Ott, 2006), and as late as April and early May for a third dataset (i.e., 1996) (Table 1). Between 1999–2003, the data for the seagrass maps were derived from aerial photography taken in early December or early January, generally the beginning of the seagrass dormant season (Robbins, 2006; Ott, 2006). Tomasko and Hall (1999: FIGS. 6, 8 and 9) found lower *T. testudinum* short shoot density, areal blade biomass and areal blade productivity values in March 1996 than in December 1995. Dixon and Kirkpatrick (1999: FIGS. 12 and 13) also found lower short shoot density in March/April 1998 than December 1997/January 1998 for both *T. testudinum* and *H. wrightii*. Tomasko and Hall (1999) found that *T. testudinum* areal blade biomass and areal blade productivity varied by location and date and that areal productivity was positively related to both water temperature and salinity. A cluster of low areal productivity was documented during low water temperatures ($<20°C$) and intermediate to high salinities (15-35 PPT), and these data were collected from all sample sites during the winter to early spring of 1995–1996 (Tomasko and Hall, 1999). Thus, it is reasonable to expect that the timing of data collection (i.e., aerial photograph acquisition) will have a significant impact on seagrass extent estimates. Indeed, this analysis found that all Upper Charlotte Harbor segments along with Lemon Bay demonstrated significant differences in percent "continuous" coverage between the 1988–1996 and 1999–2003 periods, and three segments displayed significant differences between the periods in areal extent as well.

There have been multiple efforts (references in Robbins, 1997) to quantify the sources of error in the creation of seagrass maps, such as digitization methods and photographic interpretation of habitat categories (see Robbins, 1997; Kurz, 2002; Meehan et al., 2005 for discussion). Seagrass polygons are classified as "patchy" or "continuous" based upon the amount of seagrass coverage within each polygon, and this process is subject to inter and intra-operator error (see Robbins, 1997; Kurz, 2002; Meehan et al., 2005). To reduce these errors, instead of drawing completely new seagrass polygons for each seagrass map, samplers in the southwest Florida region use the previous seagrass map's digital coverage as a baseline and delineate any changes to seagrass extent for the current effort. The size and/or classification of an individual polygon change from sampling event to sampling event, depending on environmental conditions prior to aerial photograph acquisition.

In turn, if above ground biomass is lower in March and April than in December and early January, the trends in changing polygon classifications found herein may not indicate a change in habitat fragmentation. Instead, the coverage within the polygons changed perhaps due to the shift in timing of aerial photograph acquisition to earlier in the "dormant" season. Increasing trends in percent "continuous" coverage without a concomitant coverage trend may be a result of the reclassification of "patchy" polygons in the 1988–1996 datasets to "continuous" in the 1999–2003 because the data for the latter maps were acquired at the beginning of the seagrass dormant season rather than towards the end as in the 1988–1996 datasets. Noteworthy then, is that the Middle Harbor and Peace and Myakka River segments displayed more percent "continuous" coverage in the 1988–1996 datasets than in the 1999–2003 datasets.

Nonetheless, this analysis may suggest potential reasons for concern for the long-term maintenance of seagrass coverage in Charlotte Harbor and a need for further study of seagrass meadows in the region and those factors, such as salinity and water clarity, affecting this essential resource. An important first step would be to review the aerial photographs used to create the seagrass polygon maps to view those areas that displayed losses (i.e., Peace River and South Harbor segments) to determine where the losses occurred. The aerial photographs can be used to verify if seagrass beds within "patchy" polygons are coalescing in those segments that demonstrate polygon classification changes so one may determine if seagrass patch sizes are increasing and habitat fragmentation decreasing or if the classification shifts are potentially due to sampling changes. The aerial photographs can document whether the spatial boundaries of the 13 seagrass segments could better incorporate proper hydrologic, water quality and other ecological variables. For instance, the boundaries of South Harbor segment should probably be changed so those seagrass beds along the East Wall are incorporated into the East Wall segment and those along the northern tip of Pine Island be separate from those in the Cape Haze area. The Placida segment demonstrated an increasing trend in seagrass coverage during the same time period that the nearby South Harbor segment displayed a decreasing trend, and a change to the segment spatial boundaries to reflect *in situ* seagrass bed boundaries might address these opposing trends within the 2 contiguous segments.

Water quality is declining in several areas of Charlotte Harbor and faces potential future declines in many others, raising concerns for the long-term maintenance of seagrass coverage. Total suspended solids are increasing in both Upper Charlotte Harbor and Lower Charlotte Harbor, and turbidity and nutrient levels in Lower Charlotte Harbor show increases through 2001 (Janicki Environmental Inc., 2003). At the same time, the Charlotte Harbor region is facing rapid urbanization pressure along the coast and more intensive landuse changes in its watershed which may result in degraded water quality. In addition, increases in rainfall and freshwater inflows over the previous several decades are projected for the near future (Kelly, 2004), and in turn, pollutant loads that are strongly associated with stormwater runoff will also increase (Tomasko et al., 2005). To understand the impacts of these changes and best protect aquatic resources, it is imperative that resource managers in the Charlotte Harbor region maintain seagrass coverage and species composition and distribution monitoring into the future. In addition, the region should consider developing water quality management strategies protective of seagrass meadows.

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