

COMPARISON OF LIGHT LIMITING WATER QUALITY FACTORS IN SIX FLORIDA AQUATIC PRESERVES

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ABSTRACT: Correlations of Secchi depth to color, turbidity and chlorophyll a within and between eight estuaries comprising the Charlotte Harbor estuarine complex were examined. Secchi depth was used as an indicator of light availability for seagrass growth, a primary habitat in the six Florida aquatic preserves in the Charlotte Harbor region. Six years (1998–2004) of monthly water quality data from the Charlotte Harbor Estuaries Volunteer Water Quality Monitoring Network were examined. Results showed significant differences between the eight estuaries, two seasons and six years for each of the four parameters. Mean Secchi depth values for the eight estuaries ranged from 1.0 m to 1.8 m. Significant correlations were found between Secchi depth and the combination of color, turbidity and chlorophyll a in six of the estuaries, explaining 26% to 53% of Secchi depth change. Color was the strongest predictor of Secchi depth in 6 estuaries and turbidity was the greatest predictor in two of the estuaries. Based on the results, additional water quality questions have been posed which will be addressed in pending status and trends analyses of the data. The volunteer water monitoring program enhances resource management and community involvement in the six aquatic preserves in the Charlotte Harbor region.

Key Words: Charlotte Harbor, aquatic preserves, seagrasses, light attenuation, water quality, water clarity, color, turbidity, chlorophyll *a*, estuary

THIS study examined the correlations of water clarity (as Secchi disc depth) to color, turbidity and chlorophyll *a* (as a measure of phytoplankton) within and between the eight estuaries comprising the Charlotte Harbor estuarine complex in southwest Florida. The three questions asked were: 1) what is the water clarity throughout the estuary region and how does it compare to other Florida estuaries; 2) do color, turbidity and chlorophyll *a* contribute to reductions in water clarity throughout the region; and 3) which of these three factors is the most predictive of water clarity in each estuary.

The aquatic preserves in the region include: Lemon Bay, Gasparilla Sound/Charlotte Harbor, Cape Haze, Pine Island Sound, Matlacha Pass and Estero Bay. Aquatic preserves are areas of exceptional submerged resources, established by the state legislature to be preserved in natural conditions through resource management, research and education. Effective resource management in the aquatic preserves depends on an accurate assessment of resource health, including submerged

resources and water quality. Sustainability of the resources requires identification and prioritization of critical habitat and water quality concerns, locations, trends, sources and needed corrective management actions. Throughout the local aquatic preserves, resource distribution and health, estuary physiography and watershed land use vary widely, requiring the need for thorough water quality monitoring and interpretation. Therefore, resource-based management goals should be developed specifically for each aquatic preserve. Throughout southwest Florida, seagrass distribution and abundance serve as useful indicators of estuarine health (Corbett, et al., 2005; Tomasko, et al., 2005; CHNEP, 2005).

This initial study focused on water clarity as an indicator of light availability for seagrasses. Emphasis was placed on light availability because of its well documented relationship to seagrass health, areal extent and maximum depth of seagrass growth (Miller and McPherson, 1995; Duarte, 2002). Seagrasses comprise one of the largest and most productive submerged habitats in the Charlotte Harbor Aquatic Preserves (FDNR 1983; FDNR 1992; Dawes et al., 2004; Tomasko et al., 2005; Corbett, 2006) and reflect the overall health of the estuaries (Corbett et al., 2005). The average depth at the deep edge of seagrass growth varies throughout the region from approximately 0.8 m near the mouth of the Peace and Myakka Rivers to approximately 1.8 m in Pine Island Sound (Ott et al., 2003).

Light availability for seagrasses was characterized as water clarity measured by Secchi depth (Kirk, 1983; Miller and McPherson, 1995). Previous studies have shown that in southwest Florida primary light attenuating factors in estuaries include color, turbidity and chlorophyll *a* (Dixon and Kirkpatrick, 1999; Kirk, 1983). Therefore, these parameters were used in this study as indicators of light attenuation. In the Charlotte Harbor region, color is a strong indicator of freshwater inflow, and is inversely proportional to salinity (McPherson and Miller, 1987). Turbidity for this study was measured in NTU and includes both algal and non-algal suspended matter (APHA, 1992). Chlorophyll *a*, as measured in $\mu\text{g/l}$, serves as an indirect measure of phytoplankton abundance (Dixon and Kirkpatrick, 1999) and total nitrogen levels (Tomasko et al., 2001).

Six years (1998–2004) of data for Secchi depth, color, turbidity, and chlorophyll *a* were evaluated. Data used for this study were collected by the Charlotte Harbor Estuaries Volunteer Water Quality Monitoring Network (CHEVWQMN). The CHEVWQMN is a long term (since 1998), region-wide (66,773 hectares), monthly, fixed station (46 sites) water quality monitoring program. The monitoring program is a partnership of Florida Department of Environmental Protection's (FDEP) Charlotte Harbor Aquatic Preserves (CHAP), Estero Bay Aquatic Preserve (EBAP), the Charlotte Harbor Environmental Center (CHEC), the Charlotte Harbor National Estuary Program (CHNEP), and local citizens. The program's purpose is to collect consistent, technically sound water quality data throughout the six aquatic preserves to determine baseline conditions and trends in habitat health, which will be used to set resource management goals.

METHODS—Study site—The Charlotte Harbor estuarine complex is located in southwest Florida. The 46 CHEVWQMN fixed sampling locations are shown in Figure 1. CHEVWQMN sampling sites

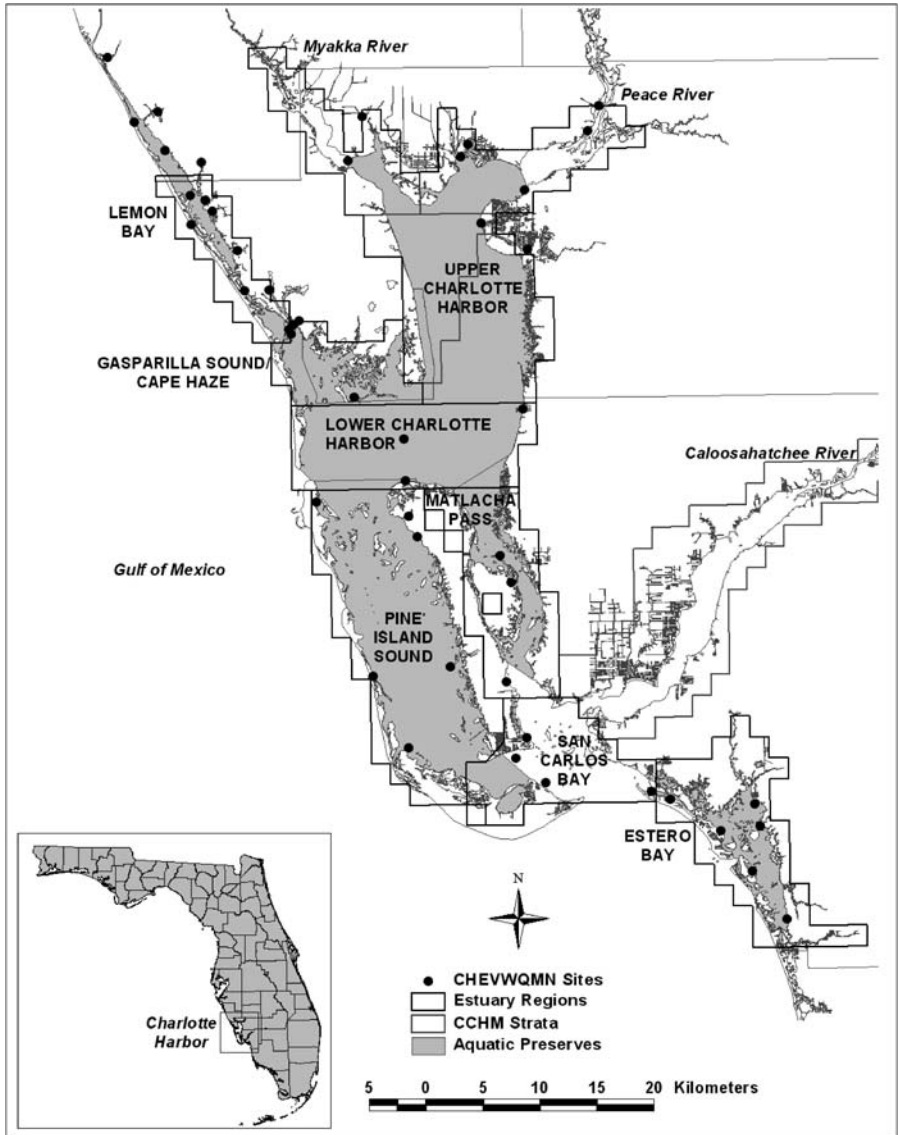


FIG. 1. Sampling Locations of the Charlotte Harbor Estuaries Volunteer Water Quality Monitoring Network (July 1998–Current).

were grouped into 8 estuary regions based on hydrologic strata established by the interagency Coastal Charlotte Harbor Monitoring Network (CCHMN), to describe homogeneous hydrologic regions (CHNEP, 2004). CHEVWQMN sites, estuaries, CCHMN hydrologic strata and aquatic preserves are summarized in Table 1. Sampling locations emphasize near shore coastal areas, with limited sampling in the open water portions of Charlotte Harbor due to sample transport and travel time constraints. Secchi depth values could not be determined for shallow sites and times when water clarity exceeded water depth.

TABLE 1. Sampling Sites in Each Estuary Region for the Charlotte Harbor Estuaries Volunteer Water Quality Monitoring Network (July 1998–Current).

Estuary Region	CHEVWQMN No. of Sites	CCHMN Hydrologic Stratum	Aquatic Preserve
Lemon Bay	12	Upper Lemon Bay Lower Lemon Bay	Lemon Bay
Gasparilla Sound/Cape Haze	3	Cape Haze	Cape Haze
Upper Charlotte Harbor	8	Tidal Myakka R Tidal Peace R East Wall Charlotte H West Wall Charlotte H	Gasparilla S/Charlotte H Gasparilla S/Charlotte H
Lower Charlotte Harbor	4	Lower Charlotte H	Gasparilla S/Charlotte H
Pine Island Sound	6	Pine Island Sound	Pine Island Sound
Matlacha Pass	3	Matlacha Pass	Matlacha Pass
San Carlos Bay	4	San Carlos Bay	
Estero Bay	6	Estero Bay	Estero Bay
Total Sites	46		

Sampling frequency and period—CHEVWQMN sampling occurred synoptically each month, within 1 hour of sunrise on the first Monday of each month at all stations simultaneously. The sampling frequency crossed tidal cycles and included the lower Secchi depth and dissolved oxygen values associated with early morning hours. A six year period of monthly dry and rainy season data was used, which included November 1998 through October 2004. The dry season included the months of November through May each year and the rainy season included June through October (Montgomery, 2005).

Field methods—Field methods are described in detail in the Comprehensive Quality Assurance Project Plan for the CHEVWQMN (FDEP, 1997). Surface water samples were collected and field measurements were made for 10 physical and chemical parameters which included wind speed and direction, wave height, tide stage, water depth, Secchi depth, temperature, pH, dissolved oxygen and salinity. Water was also collected in clean sample bottles for the following 7 laboratory parameters: chlorophyll *a*, turbidity, color, total phosphorus, total Kjeldahl nitrogen, nitrate/nitrite, and fecal coliform bacteria. The nutrient bottle was pre-acidified. Samples were stored on ice and transported to the laboratory within the maximum holding times. An additional ten percent of field samples were collected for duplicate and blank analyses. Water clarity was measured using a .20 m Secchi disc with a line calibrated at 0.10 m intervals. No depth profiles or bottom samples were collected.

Laboratory methods—Laboratory analyses, summarized in Table 2, were conducted by certified laboratories using standard methods (APHA 1992, USEPA 1979). Color was determined by visual

TABLE 2. Certified Laboratories and Analysis Methods Used for the Charlotte Harbor Estuaries Volunteer Water Quality Monitoring Network (July 1998–Current).

Analyte	FDEP South Dist Jul 98–Nov 01	Cape Coral Dec 01–Dec 02	Tri Tech Jan 03–Dec 03	FDEP South Dist Jan 04–Current
Color	SM 2120 B ⁽¹⁾	SM 2120 B ⁽¹⁾	SM 2120 B ⁽¹⁾	EPA 110.2 ⁽²⁾
Turbidity	EPA 180.1 ⁽²⁾	SM 2130 B ⁽²⁾	EPA 180.1 ⁽²⁾	EPA 180.1 ⁽²⁾
Chlorophyll <i>a</i>	SM 10200 H ⁽²⁾	(samples not analyzed)	SM 10200 H ⁽²⁾	SM 10200 H ⁽²⁾

⁽¹⁾ Standard Methods for the Examination of Water and Waste Water, 18th Edition. 1992. AMPHA.

⁽²⁾ Methods for Chemical Analysis of Water and Wastes. 1979. USEPA.

TABLE 3. Typical Water Quality Values for Florida Estuaries and Suggested Estuary Health Categories.

Reference	Secchi depth (m) ⁽¹⁾⁽²⁾	Color (PCU) ⁽¹⁾⁽³⁾	Turbidity (NTU) ⁽¹⁾⁽⁴⁾	Chl <i>a</i> (µg/l) ⁽¹⁾⁽⁵⁾	Estuary Category
Typical FL WQ Values ⁽¹⁾⁽⁶⁾	≥1.4 m	≤10 PCU	≤1.9 NTU	≤3.8 µg/l	Above Average
Typical FL WQ Values ⁽¹⁾⁽⁷⁾	0.9–1.3 m	11–25 PCU	4.1–2.0 NTU	3.9–7.8 µg/l	Average
Typical FL WQ Values ⁽¹⁾⁽⁸⁾	<0.8 m	≥26 PCU	≥4.2 NTU	>7.9 µg/l	Below Average
FL Impaired Waters Criteria ⁽⁹⁾	—	—	—	≥11 µg/l	Impaired

⁽¹⁾ Typical Water Quality Values for Florida's Lakes, Streams & Estuaries (Hand, 2004).

⁽²⁾ Based on 69,000 Secchi depth samples, 2,657 stations, 21 Florida estuaries, 1990–2003.

⁽³⁾ Based on 43,000 color samples, 1,805 stations, 21 Florida estuaries, 1990–2003.

⁽⁴⁾ Based on 237,000 turbidity samples, 3,512 stations, 21 Florida estuaries, 1990–2003.

⁽⁵⁾ Based on 62,000 chlorophyll *a* samples, 2,338 stations, 22 Florida estuaries, 1990–2003.

⁽⁶⁾ Percentile rankings (median values): 70–100% Secchi depth; 0–30% color, turbidity & chlorophyll *a*.

⁽⁷⁾ Percentile rankings (median values): 40–69% Secchi depth; 31–60% color, turbidity & chlorophyll *a*.

⁽⁸⁾ Percentile rankings (median values): ≤39% of Secchi depth; ≥61% of color, turbidity & chlorophyll *a*.

⁽⁹⁾ FL Impaired Waters Criteria. (FDEP, 2002).

comparison using the platinum cobalt method (SM 2120B, EPA 110.2). Turbidity was determined by a turbidity meter, (Hach model number 18900) (EPA 180.1, SM 2130 B). Chlorophyll *a* was determined spectrophotometrically, without pheophytin correction (SM 10200 H). Because of time and funding constraints, chlorophyll *a* analyses were not conducted from December 2001 through Dec 2002. Ten percent of the samples were run as laboratory replicates and blanks.

Data manipulation and analysis methods—Data were entered into an Access© data base and reviewed for transcription errors and outliers (greater than 2 standard deviations from mean). Descriptive statistics (medians, means, ranges and standard errors) for each of the eight estuary regions, parameters and seasons were calculated using Excel©. Comparisons of mean values between estuaries, seasons and years for each parameter were made using analysis of variance (ANOVA) with Excel©. Correlations (Pearson's) of chlorophyll *a* to total nitrogen and color to salinity were calculated, with pair wise deletion of missing data points, using SPSS©. Correlations (Pearson's, Spearman's) and regressions between the 4 parameters for each of the estuaries were conducted using Excel© for multiple regressions and using SPSS© for forward stepwise regressions, with list wise deletion of data points. Three dimensional graphs of relationships between color, chlorophyll *a* and turbidity for each estuary were produced using S© software.

Data interpretation—As a guide for interpreting water quality values relative to estuary health, median values for each estuary region were compared to typical water quality values for Florida estuaries (Hand, *In Press*; Friedemann et al., 1989). A summary of the ranges of typical values is shown in Table 3. These typical water quality values were based on median values found between 1990 and 2003 in 22 estuaries throughout Florida from more than 1,800 ambient stations and 43,000 samples. For each parameter, median values for each site were used to create a percentile distribution of values found throughout the estuaries and time period sampled. The CHEVWQMN median values for each estuary, as shown in Table 4, were compared to the typical water quality value percentiles. It is recognized that the statewide median values do not take into consideration important geographic and morphological differences in estuaries around the state. However, the values do provide a good overview of the variation of water quality conditions throughout Florida. They also provide information about important parameters, such as turbidity and color, which are not used in other state, regional or national estuary trophic state classification systems such as the Florida Trophic State Index (Friedemann et al., 1989) and NOAA's estuarine eutrophication survey (NOAA, 1996).

TABLE 4. Median and Mean Values for Secchi Depth, Color, Turbidity, and Chlorophyll *a* (November 1998–October 2004).

Estuary	Secchi depth (m) ⁽¹⁾				Color (PCUs) ⁽²⁾				Turbidity (NTUs) ⁽³⁾				Chl <i>a</i> (µg/l) ⁽⁴⁾			
	Median	Mean	SE	n	Median	Mean	SE	n	Median	Mean	SE	n	Median	Mean	SE	n
Lemon Bay	1.1*	1.1	0.02	310	20*	25	1	407	2.7*	3.2	0.18	408	5.2*	7.4	0.45	333
Gasparilla																
S/Cape H	1.4	1.5	0.07	58	15*	20	1.3	122	3*	3.5	0.28	122	3.7	4.7	0.37	103
Upper																
Charlotte H	0.9*	1	0.02	262	45*	66	3.2	379	2.8*	3.3	0.13	378	6.4*	9.5	0.57	310
Lower																
Charlotte H	1.5	1.8	0.09	82	20*	27	1.7	180	2.3*	2.7	0.18	180	4.4*	5.7	0.41	148
Pine Island																
Sound	1.3*	1.5	0.05	130	15*	21	1.1	289	2.8*	3.9	0.21	297	5.2*	6.6	0.36	226
Matlacha Pass	1.7	1.7	0.04	221	25*	31	1.5	244	2.3*	2.6	0.1	244	3.6	5.3	0.46	196
San Carlos																
Bay	1.4	1.5	0.04	187	15*	21	1.3	179	3.5*	4.9	0.68	179	4.0*	5.2	0.39	146
Estero Bay	1.1*	1.2	0.04	133	21*	28	1.4	255	4.2*	5.6	0.34	255	4.2*	5.7	0.35	201
All Estuaries	1.2*	1.3	0.02	1383	20*	33	0.1	2064	2.8*	3.7	0.09	2063	4.9*	6.7	0.18	1854

⁽¹⁾ * values are < 1.4 m Secchi depth found in the most transparent 30% of FL estuaries (Hand, 2004).

⁽²⁾ * values are > 10 PCU Color found in the least colored 30% of FL estuaries (Hand, 2004).

⁽³⁾ * values are > 1.9 NTU found in the least turbid 30% of FL estuaries (Hand, 2004).

⁽⁴⁾ * values are > 3.8 µg/l Chl *a* found in the healthiest 30% of FL estuaries (Hand, 2004).

RESULTS—Chlorophyll *a*-nitrogen and color-salinity relationships—For the region as a whole, chlorophyll *a* and nitrogen were significantly ($p = .01$) positively correlated. In addition color and salinity were significantly ($p = .01$) negatively correlated for each estuary, as well as for the region as a whole. As salinity decreased, color increased.

Secchi depth—Secchi depth values varied widely throughout the sampling region and period. ANOVA results for the region as a whole indicated that Secchi depth varied significantly between the 8 estuaries ($p < .0001$), between the 2 seasons ($p < .0001$) and between the 6 years ($p < .0001$). Median and mean Secchi depth values for each estuary are shown in Table 4 and seasonal ranges are shown in Figure 2. Secchi depth values ranged from 0.2 m in Gasparilla Sound/Cape Haze to 3.9 m in San Carlos Bay. The widest range of Secchi depth values occurred in Matlacha Pass in the rainy season, and the narrowest range occurred in Estero Bay during the rainy season. Mean Secchi depth values for each estuary ranged from 1.0 m in Upper Charlotte Harbor to 1.8 m in Lower Charlotte Harbor. Seasonal mean values were significantly different in two of the estuaries: Upper Charlotte Harbor and Matlacha Pass. According to Hand (*In Press*), 30% of Florida estuaries have median Secchi depth values ≥ 1.4 m. Four of the Charlotte Harbor estuaries had median Secchi depth values ≥ 1.4 m, suggesting above average Secchi depth conditions: Gasparilla Sound/Cape Haze, Lower Charlotte Harbor, Matlacha Pass and San Carlos Bay. Forty percent of Florida estuaries have median Secchi depth values < 0.8 m (Hand, *In Press*), but none of the Secchi depth medians in the Charlotte Harbor estuaries were less than 0.8 m.

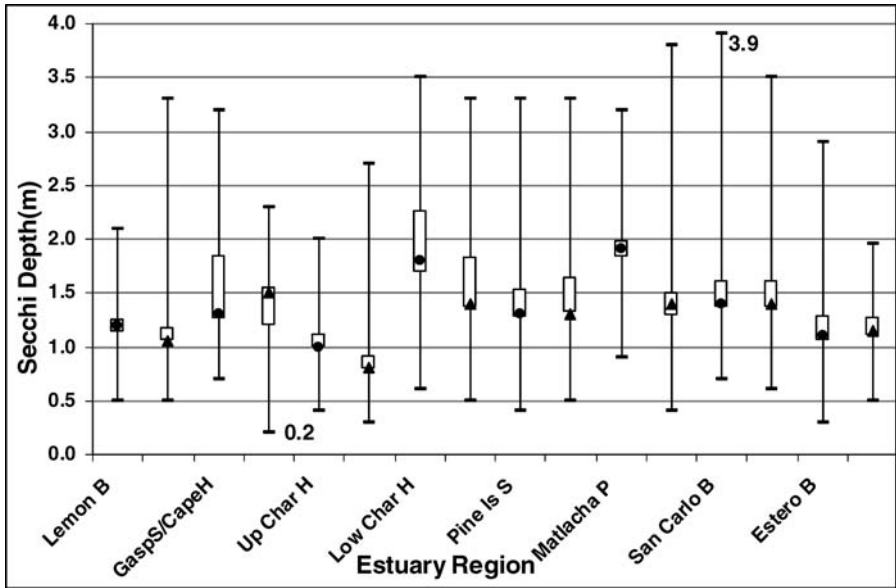


FIG. 2. Seasonal Secchi depth Ranges for Each Estuary Region (November 1998–October 2004). Vertical Bar represents data range. Box represents 95% confidence interval of mean. Symbols represent seasonal medians: ● = Dry Season ▲ = Rainy Season.

Color—Color also varied widely throughout the sampling region and period. ANOVA results for the region as a whole indicated that color varied significantly between the 8 estuaries ($p < .0001$), between the 2 seasons ($p < .0001$) and between the 6 years ($p < .0001$). Median and mean color values for each of the estuaries are given in Table 4 and seasonal color ranges are shown in Figure 3. Color values ranged from 3 PCU–400 PCU throughout the sampling area and period. The highest color values were found in Upper and Lower Charlotte Harbor. Mean color values for the estuaries ranged from 20 PCU for Gasparilla Sound/Cape Haze to 66 PCU for Upper Charlotte Harbor. The widest color range was found in Upper Charlotte Harbor for both seasons. Seasonal mean color values were significantly different in all 8 estuaries. According to Hand (*In Press*), 30% of FL estuaries have median color values ≤ 10 PCU, and 40% have color medians ≥ 26 PCU. Seven of the Charlotte Harbor estuaries fell within the intermediate color range of 10–25 PCU. Only Upper Charlotte Harbor had color values greater than 26 PCU, associated with Florida’s most highly colored estuaries.

Turbidity—Turbidity values varied widely throughout the sampling region and period. ANOVA results for the region as a whole indicated that turbidity varied significantly between the 8 estuaries ($p < .0001$), between the 2 seasons ($p = .03966$) and between the 6 years ($< .0001$). Median and mean estuary turbidity values are given in Table 4 and seasonal ranges are shown in Figure 4. Turbidity values ranged from 1 NTU to 120 NTU, being highest in San Carlos Bay, Lemon

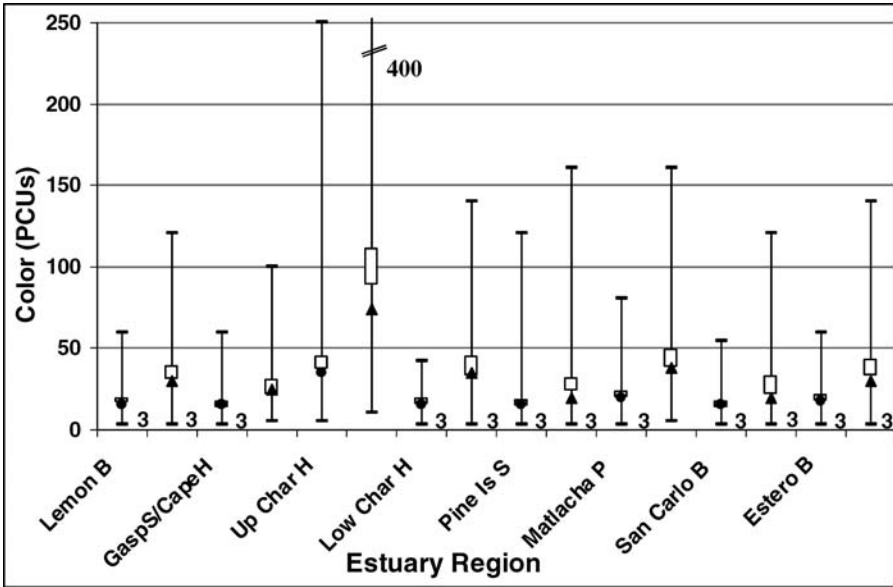


FIG. 3. Seasonal Color Ranges for Each Estuary Region (November 1998–October 2004). Vertical Bar represents data range. Box represents 95% confidence interval of mean. Symbols represent seasonal medians: ● = Dry Season ▲ = Rainy Season.

Bay and Estero Bay. Widest turbidity ranges were found in the San Carlos Bay rainy season, Lemon Bay dry season and Estero Bay dry season. Mean turbidity values for the estuary regions ranged from 2.6 NTU in Matlacha Pass to 5.6 NTU in Estero Bay. Seasonal turbidity means were statistically different in Matlacha Pass and Estero Bay. According to Hand (*In Press*), 30% of Florida estuaries have median turbidity values ≤ 1.9 NTU and 40% have turbidity values > 4.2 NTU. Seven of the Charlotte Harbor estuaries had turbidity median values in the intermediate range of 2.0–4.1 NTU, suggesting average conditions relative to Florida estuaries. Only Estero Bay had values exceeding the 4.2 NTU associated with the most turbid 40% of Florida estuaries, suggesting below average conditions.

Chlorophyll a—ANOVA results for the region as a whole indicated that chlorophyll *a* varied significantly between the 8 estuaries ($p < .0001$), between the 2 seasons ($p = .00013$), and between the 6 years ($p < .0001$). Chlorophyll *a* median and mean estuary values are given in Table 4 and seasonal chlorophyll *a* ranges are shown in Figure 5. Chlorophyll *a* values ranged from 1.0 $\mu\text{g/l}$ to 79.5 $\mu\text{g/l}$ throughout the sampling area and period. Highest values and ranges were found in Lemon Bay, Upper Charlotte Harbor and Matlacha Pass. Mean chlorophyll *a* values ranged from 4.7 $\mu\text{g/l}$ in Gasparilla Sound/Cape Haze to 9.5 $\mu\text{g/l}$ in Upper Charlotte Harbor. Seasonal mean chlorophyll *a* values were significantly different in only one estuary: Pine Island Sound. According to Hand (*In Press*), 30% of Florida estuaries have chlorophyll *a* values ≤ 3.8 $\mu\text{g/l}$ and 40% have chlorophyll *a* values ≥ 7.9 $\mu\text{g/l}$.

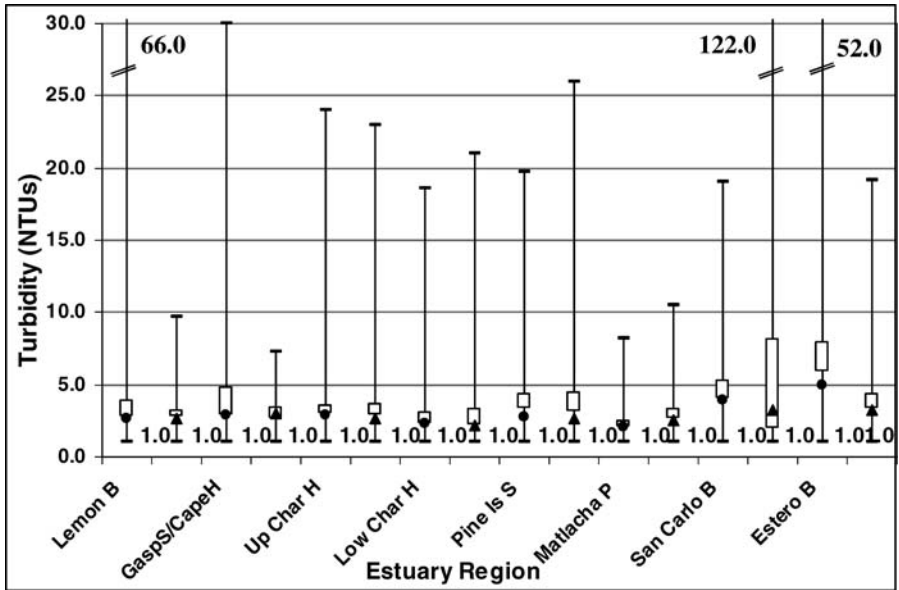


FIG. 4. Seasonal Turbidity Ranges for Each Estuary Region (November 1998–October 2004). Vertical Bar represents data range. Box represents 95% confidence interval of mean. Symbols represent seasonal medians: ● = Dry Season ▲ = Rainy Season.

The Florida Impaired Waters criterion for chlorophyll *a* is $\geq 11 \mu\text{g/l}$ (FDEP, 2002) and the NOAA estuarine eutrophication survey considers values $\geq 20 \mu\text{g/l}$ as “high” (NOAA, 1996). In the Charlotte Harbor region, two estuaries (Gasparilla Sound and Matlacha Pass) had median chlorophyll *a* values associated with the lowest 30% of Florida estuaries, suggesting above average chlorophyll *a* conditions. Chlorophyll *a* median values for the other six estuaries fell within the intermediate range associated with 31–60% of Florida estuaries, suggesting average chlorophyll *a* conditions. While none of the estuaries had median or mean values that exceeded the $11 \mu\text{g/l}$ Impaired Waters criterion (FDEP 2002), individual values exceeded that criteria at least once in all estuaries and in all seasons.

Color, turbidity and chlorophyll a relationships—Spearman’s correlations between turbidity, color and chlorophyll *a* for each estuary were calculated (Table 5). For all estuaries combined, chlorophyll *a* was significantly correlated to both turbidity ($p < .05$) and to color ($p < .05$). However, turbidity and color were not significantly correlated for the region as a whole. For the individual estuary regions, significant relationships ($p < .05$) between all pairs of the three variables were shown in 3 estuaries: Lemon Bay, Pine Island and Upper Charlotte Harbor. No significant correlations between any pair of the three variables were found in two estuaries: Gasparilla Sound/Cape Haze and Estero Bay. In Lower Charlotte Harbor, chlorophyll *a* was significantly ($p < .05$) related to both turbidity and color, but

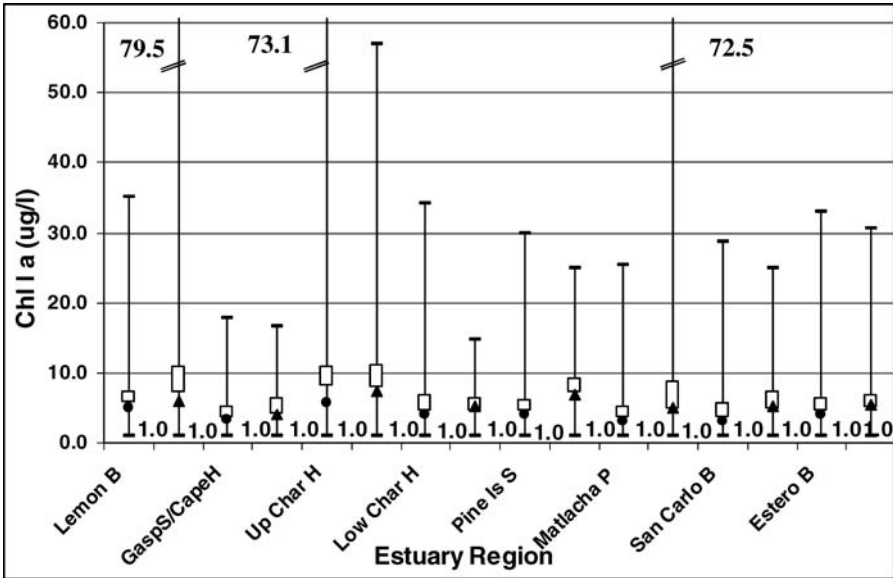


FIG. 5. Seasonal Chlorophyll *a* Ranges for Each Estuary Region (November 1998–October 2004). Vertical Bar represents data range. Box represents 95% confidence interval of mean. Symbols represent seasonal medians: ● = Dry Season ▲ = Rainy Season.

color and turbidity were not related. And, in Matlacha Pass color was significantly ($p < .05$) related to both turbidity and chlorophyll *a* but turbidity and chlorophyll *a* were not significantly related. For visual reference, relationships between color, turbidity and chlorophyll *a* for each estuary are shown in the three dimensional scatter plots given in Figure 6.

Secchi depth relationships to color, turbidity and chlorophyll a—Results of multiple regression analyses for Secchi depth compared to color, turbidity and

TABLE 5. Correlations between Turbidity, Color and Chlorophyll *a* for Each Estuary Region (November 1998–October 2004).

Estuary	Turbidity: Color R ²	Turbidity: Chlorophyll <i>a</i> R ²	Color: Chlorophyll <i>a</i> R ²
Lemon Bay	0.121*	0.144*	0.292*
Gasparilla S/Cape Haze	0.053	0.155	0.194
Upper Charlotte Harbor	0.121*	0.308*	0.137*
Lower Charlotte Harbor	0.095	0.258*	0.262*
Pine Island Sound	-0.044*	0.152*	0.282*
Matlacha Pass	0.271*	0.107	0.221*
San Carlos Bay	0.024	-0.073	0.276*
Estero Bay	-0.099	0.058	-0.013
All Estuaries Combined	0.04	0.134*	0.246*

* Values are significant at the 0.01 level.

chlorophyll *a* for each estuary are shown in Table 6. Six of the 8 estuaries showed a significant correlation of Secchi depth to color + turbidity + chlorophyll *a*. Only Gasparilla Sound/Cape Haze and San Carlos Bay showed no significant relationship between Secchi and the other 3 parameters collectively. The percent of Secchi depth change explained by the combination of these three variables ranged from 53% for Lower Charlotte Harbor to 26% in Lemon Bay. A stepwise regression was conducted to select the best variable or set of variables that explained the most variation in Secchi depth. Results of the stepwise regression analysis for Secchi depth compared to color, chlorophyll *a* and turbidity for each estuary are shown in Table 7. Only the variables that maximize the explained variability in Secchi depth and have at least a .05 significance level are displayed. For the Charlotte Harbor estuarine complex as a whole, color explained the most variation in Secchi depth (R squared = 0.173), followed by a combination of color and turbidity (R squared = 0.202). For six of the individual estuary regions (excluding Pine Island Sound and Estero Bay) color also explained the most variation in Secchi depth, ranging from 39% in Lower Charlotte Harbor to 4% in San Carlos Bay. In both Pine Island Sound and Estero Bay, turbidity explained the most variation in Secchi depth, with turbidity and color combined explaining all the estimated variation. Chlorophyll *a* was a significant contributor to Secchi depth prediction only in Lower Charlotte Harbor.

DISCUSSION—General considerations—The findings of this study were consistent with previous water quality studies in the Charlotte Harbor region (Miller and McPherson 1994; Tomasko et al., 2001; Morrison et al., 2002; Janicki Environmental Inc., 2003), and answered the three initial questions posed. 1) Water clarity, as measured by Secchi depth, varied widely throughout the region and seasons. The lowest Secchi depth mean values, associated with the highest light attenuation, were found in Upper Charlotte Harbor (1.0 m), Lemon Bay (1.1 m) and Estero Bay (1.2 m). Compared to other Florida estuaries, four of the estuary regions had above average Secchi depth conditions associated with the clearest 30% of Florida estuaries (Gasparilla Sound/Cape Haze, Lower Charlotte Harbor and Matlacha Pass). Four of the estuaries studied, as well as the region as a whole, had average water clarity associated with the intermediate 31–60% of Florida estuaries. 2) Color, turbidity and chlorophyll *a* together contributed to light attenuation to varying degrees in the different estuaries within the region. The strongest relationships between water clarity and the combination of color, turbidity and chlorophyll *a* were found in Lower Charlotte Harbor (53%), Matlacha Pass (41%) and Estero Bay (35%). 3) The strongest predictor of water clarity was color in all estuaries except Estero Bay.

Additionally, turbidity was a strong predictor of water clarity in all six estuaries, and in the region as a whole, and was the primary predictor in Estero Bay. Chlorophyll *a* was a significant contributor to Secchi depth prediction only in Lower Charlotte Harbor. Also, both turbidity and chlorophyll *a* showed elevated mean and peak values in some estuaries and seasons. The highest turbidity values occurred in San Carlos Bay, at the mouth of the Caloosahatchee River, during the rainy season.

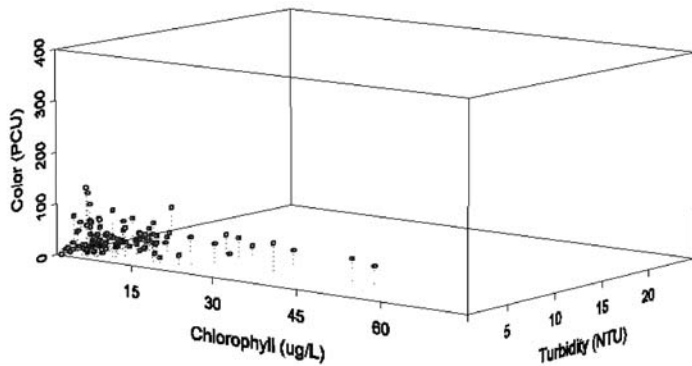
High turbidity values occurred in Lemon Bay and Estero Bay during the dry season; these are the shallower estuaries and windiest months of the study. While none of the mean chlorophyll *a* values for the estuaries exceeded the 11 µg/l Impaired Waters criterion for chlorophyll *a*, significant chlorophyll *a* peaks (≥ 73 µg/l) occurred in the rainy season in Lemon Bay, Upper Charlotte Harbor and Matlacha Pass and individual monthly values exceeded the 11 µg/l in each season of each estuary.

Resource management considerations—Throughout the Charlotte Harbor region, water clarity targets need to be fully developed for each aquatic preserve which will allow long term sustainability and restoration of existing seagrass habitats. Optical models, such as those proposed by Corbett and Hale (2006), can be used to quantify relationships between seagrass light requirements and partial light attenuation associated with color, turbidity and chlorophyll *a* for each specific estuary. Once water clarity targets have been established, efforts are needed to identify and quantify both natural and anthropogenic sources of turbidity and nutrients within the watersheds of each aquatic preserve. Possible sources of elevated turbidity levels in estuaries include freshwater in-flows and resuspension of bottom sediments due to changes in hydrologic regimes (CHNEP, 2005), dredging and filling (Duarte, 2002), and wave and storm action (Preen et al., 1995). For example, high dry season turbidity levels in Lemon Bay, Estero Bay and Gasparilla Sound/Cape Haze may be strongly related to sediment resuspension. Restoration efforts designed to reduce turbidity would be directed most effectively toward restoring natural hydrology and minimizing anthropogenic sources of sediment resuspension.

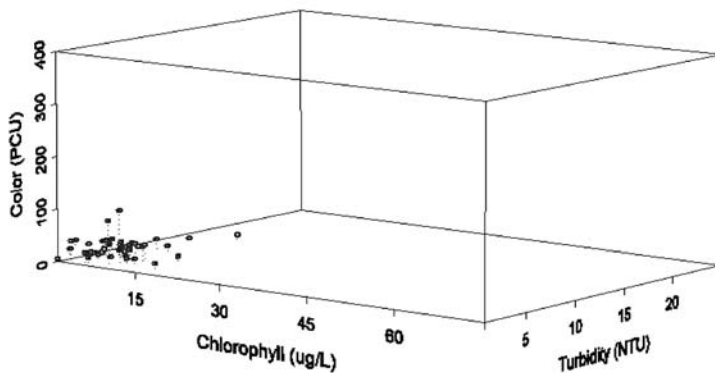
High rainy season turbidity in San Carlos Bay, Matlacha Pass and Pine Island Sound may be more strongly related to freshwater in-flows. Possible sources need to be identified and quantified, but restoration may focus on reestablishing natural hydrologic flow regimes in the tributaries, especially in the Caloosahatchee River. Additional turbidity reductions could be accomplished by reducing storm water velocity and volume through installation of a variety of appropriate retention systems for existing and future impervious areas (Peluso and Marshall, 2002). Water clarity could also be enhanced by reducing chlorophyll *a* values. Elevated chlorophyll *a* values in estuaries are associated with excess nitrogen and phosphorus inputs from anthropogenic sources and resuspension of nutrient rich sediments (Kennish, 2000). Possible nitrogen sources include stormwater runoff, septic tank systems, rainfall and groundwater base flow (Tomasko et al., 2001). Sources of nutrients supporting high rainy season chlorophyll *a* values in Lemon Bay, Upper Charlotte Harbor and Matlacha Pass need to be identified, quantified and remediated through a variety of non-regulatory and regulatory best management practices and approaches.

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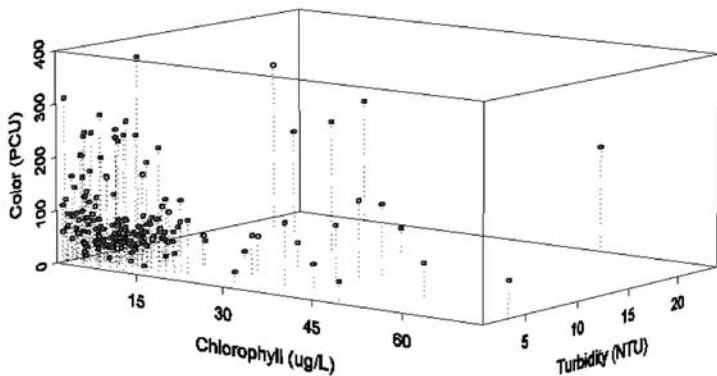
FIG. 6. Color, Turbidity and Chlorophyll *a* Regressions for Each Estuary Region (November 1998–October 2004).



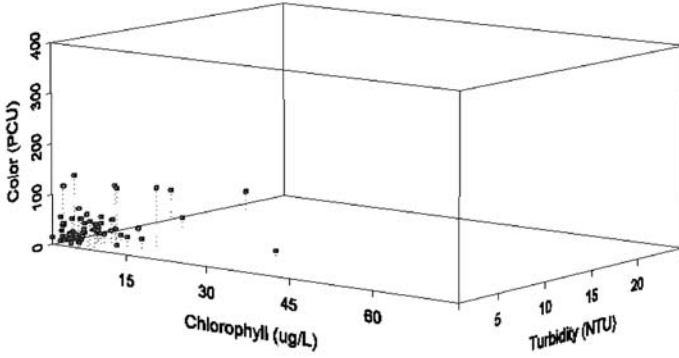
Lemon Bay



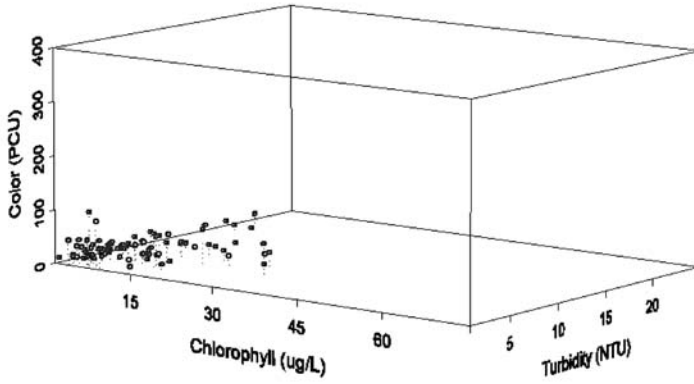
Gasparilla Sound/Cape Haze



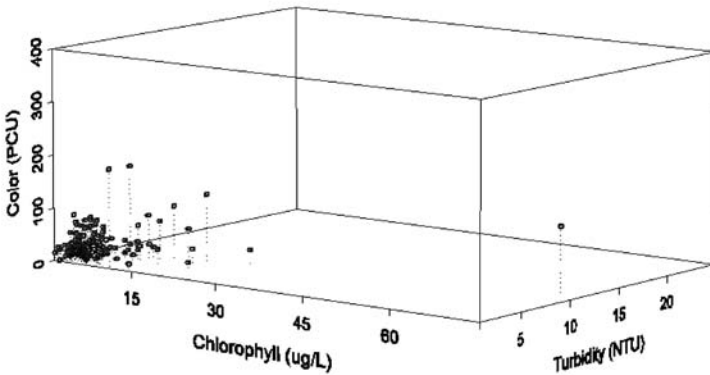
Upper Charlotte Harbor



Lower Charlotte Harbor



Pine Island Sound



Matlacha Pass

FIG. 6. Continued.

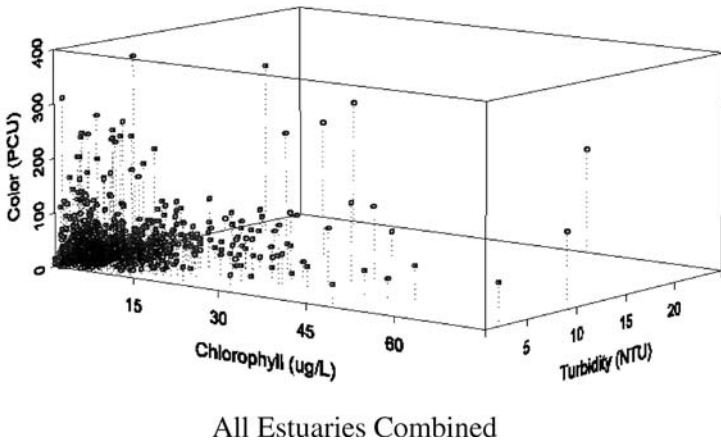
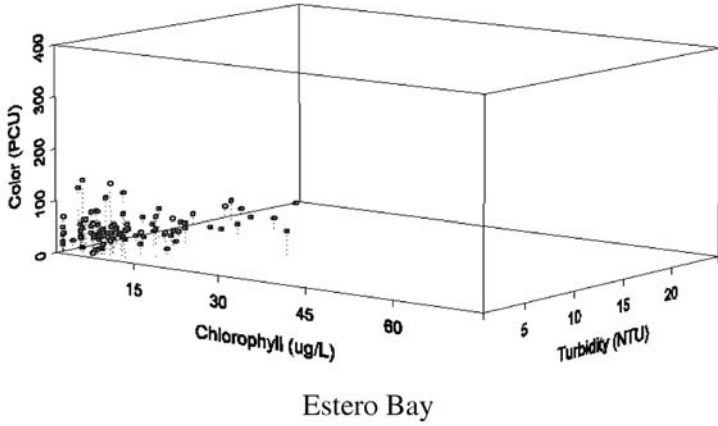
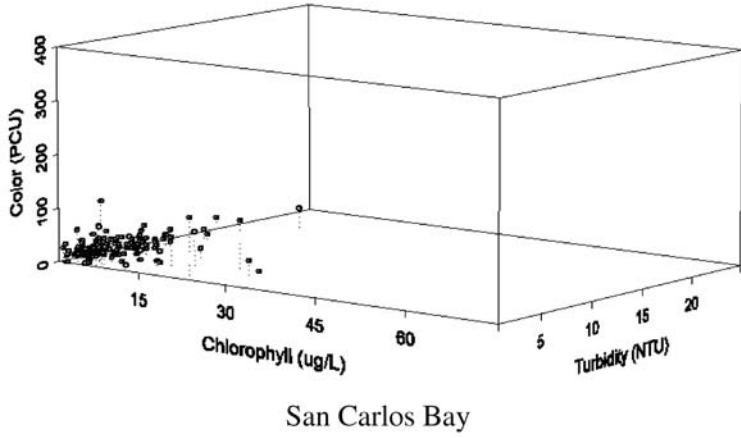


FIG. 6. Continued.

TABLE 6. Multiple Regression Analysis between Secchi Depth and Color, Turbidity and Chlorophyll *a* for Each Estuary Region (November 1998–October 2004).

Estuary	R Squared	Color Coefficient ²	Turbidity Coefficient ²	Chl <i>a</i> Coefficient ²	Intercept	Residual SE
Lemon Bay	0.26*	-0.01*	-0.05*	-0.01	1.62	0.34
Gasparilla S/Cape Haze	0.17	-0.01*	-0.05	-0.02	2.02	0.48
Upper Charlotte Harbor	0.30*	0.00*	-0.02*	0.00	1.27	0.31
Lower Charlotte Harbor	0.53*	-0.01*	-0.07*	-0.04*	2.81	0.57
Pine Island Sound	0.32*	-0.01*	-0.07*	-0.01	2.06	0.51
Matlacha Pass	0.41*	-0.01*	-0.13*	+0.01	2.38	0.42
San Carlos Bay	0.05	0.00	0.00	-0.01	1.67	0.56
Estero Bay	0.35*	0.00*	-0.06*	0.00	1.68	0.36
All Estuaries Combined	0.22*	-0.01*	-0.02*	-0.01*	1.74	0.52

* Values are significant at 0.05 level.

Program value—The CHEVWQMN data have been useful in evaluating water clarity relationships throughout the Charlotte Harbor estuaries based on a uniform, system wide data set. One of the primary values of the monitoring program is the use of consistent field and laboratory procedures throughout the estuary complex which facilitates data analysis. Also, the monthly, synoptic sample collection and long term sampling period allow the data to be used for spatial/temporal comparisons and trend analyses. Additional parameters from the CHEVWQMN, such as salinity, nutrients, dissolved oxygen and fecal coliform bacteria, can further our understanding of relationships between freshwater inflows and water clarity, nutrients, chlorophyll *a* and dissolved oxygen throughout the region. As watershed land use changes occur

TABLE 7. Stepwise Regressions of Secchi Predicted by Color, Turbidity and Chlorophyll *a* (November 1998–October 2004). Predictors that maximize Secchi depth variation shown.

	Strong to Weak	Predictor	Adjusted R ²	R ² Change	T	Sig Level
Lemon Bay	1	Color	0.161	0.161	-4.9	<0.01
	2	Turbidity	0.245	0.084	-3.71	<0.01
Gasparilla S/Cape H	1	Color	0.099	0.099	-2.15	<.05
	2	Turbidity	0.27	0.27	-8.06	<0.01
Upper Charlotte H	1	Color	0.298	0.028	-2.66	<0.01
	2	Turbidity	0.298	0.028	-2.66	<0.01
	3	Chlorophyll <i>a</i>	0.474	0.08	-2.9	<0.01
Lower Charlotte H	1	Color	0.394	0.394	-6.04	<0.01
	2	Chlorophyll <i>a</i>	0.474	0.08	-2.9	<0.01
	3	Turbidity	0.533	0.059	-2.62	<.05
Pine Island Sound	1	Turbidity	0.271	0.271	-5.56	<0.01
	2	Color	0.308	0.037	-2.09	<.05
Matlacha Pass	1	Color	0.315	0.315	-8.23	<0.01
	2	Turbidity	0.403	0.088	-4.64	<0.01
San Carlos Bay	1	Color	0.042	0.042	-2.39	<.05
Estero Bay	1	Turbidity	0.309	0.309	-6.38	<0.01
	2	Color	0.348	0.04	-2.34	<.05
All Estuaries	1	Color	0.173	0.174	-13.5	<0.01
	2	Turbidity	0.202	0.174	-5.64	<0.01
	3	Chlorophyll <i>a</i>	0.222	0.021	-4.86	<0.01

or resource management practices are implemented, specific, near shore fixed station sampling results can be utilized to measure habitat responses to changes. The CHEVWQMN is a cost effective method of collecting technically sound water quality data. The quality assurance and training activities included in the program design and project management, together with agency laboratory and administrative support, allow for scientifically reliable data to be collected by citizen monitors. The continuity and contributions of the citizen monitors have allowed for a longer term sampling period than would have otherwise been possible. The CHEVWQMN partnership of citizens and agency staff fosters community involvement in aquatic preserve management, and provides the agency with a better understanding of community needs.

Further investigations—Pending analyses of the CHEVWQMN data include: 1) quantifying the relationship between water clarity and maximum seagrass depth for each estuary, 2) comparing water clarity measured by Secchi depth to photosynthetically active radiation, 3) conducting trend analyses of key water quality conditions throughout the region, 4) identifying and quantifying natural and anthropogenic sources of turbidity and nutrients throughout the region, 5) determining the relationships between freshwater inflows, total nitrogen, and chlorophyll *a* throughout the region, and 6) identifying non-regulatory best management practices and regulatory actions needed to address the anthropogenic sources of turbidity and nitrogen for each aquatic preserve.

CONCLUSIONS—Seagrasses are an essential submerged habitat within the six Aquatic Preserves in the Charlotte Harbor estuary complex. Sustainability of seagrass habitat depends on maintaining and restoring water clarity, specifically related to color, turbidity and chlorophyll *a*. The 6 year results of the CHEVWQMN water quality data for these four parameters highlighted the wide range of conditions found throughout the region. Based on the analysis results, priority parameters included turbidity and chlorophyll *a* and critical locations included Upper Charlotte Harbor, Lemon Bay and Estero Bay. The study results emphasized the need for further analysis of the CHEVWQMN data to link water clarity to potential contaminant sources, watershed land uses and habitat preservation and restoration activities. The analyses also showed the strong need for development of more effective estuary health condition indices and tools. Immediate needs for the CHEVWQMN include entering the complete database into STORET and answering specific water quality trend and source questions for each aquatic preserve. With assistance from citizen and agency partners, both the CHEVWQMN and CHAP/EBAP long term seagrass monitoring efforts will continue to provide sound science for wise resource management activities.

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