Technical Report No. 98-02

# PROCEEDINGS OF THE CHARLOTTE HARBOR PUBLIC CONFERENCE AND TECHNICAL SYMPOSIUM

March 1997

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Editor

Published by the South Florida Water Management District and
the Charlotte Harbor National Estuary Program
1998

# NUTRIENT, CHLOROPHYLL AND DISSOLVED OXYGEN CONCENTRATIONS IN CHARLOTTE HARBOR: EXISTING CONDITIONS AND LONG-TERM TRENDS

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## ABSTRACT

Color levels and concentrations of nitrogen, phosphorus and chlorophyll *a* in Charlotte Harbor exhibit pronounced salinity-related gradients which extend from the head of the estuary to its mouth. In addition to this underlying longitudinal pattern, inputs of nutrient-rich and highly colored fresh water, which enter the Harbor primarily from the north via the Peace and Myakka River basins, provide considerable temporal variability and contribute to the seasonal formation of lateral and vertical concentration gradients. During a recent (1993–1996) monitoring period, seasonal phytoplankton blooms produced maximum chlorophyll *a* concentrations in the range of 60-120 $\mu$g/l, primarily in the tidal reaches of the Peace and Myakka Rivers and the northern Harbor. Seasonally predictable chlorophyll concentrations of this magnitude are considered evidence of hypereutrophy in some estuarine classification systems. Hypoxia (dissolved oxygen concentrations less than 2 mg/l) also occurred seasonally during 1993–1996, primarily (but not exclusively) in the tidal river reaches and northern Harbor during periods of elevated freshwater inflow. Average concentrations of dissolved inorganic phosphorus (DIP) exceeded the requirements of typical estuarine phytoplankton at all monitoring stations during the years 1993–1996. Average concentrations of dissolved inorganic nitrogen (DIN) also exceeded typical phytoplankton requirements at most stations during the high-flow (July–October) seasons of those years. During the low-flow (November–June) season in the higher-salinity portions of the estuary, however, average DIN concentrations fell to levels ($<2\mu$M) at which nitrogen limitation is likely to occur for some taxa. In addition to external loadings of "new" nitrogen from the watershed and airshed, monitoring data suggest that DIN concentrations during the high-flow season may have been augmented by internal fluxes of "recycled" ammonia-N, presumably generated through bacterial remineralization of organic N and benthic ammonia releases. Available long-term data indicate that concentrations of DIP and TP, although remaining quite elevated, have declined significantly in the Harbor over the period 1976–1996, a pattern reported in previous studies. Dissolved oxygen and salinity levels also showed evidence of statistically significant declining trends over the 1976–1996 period, although these latter trends may represent artifacts arising from methodological differences between the 1976–1990 and 1993–1996 monitoring projects used to construct the long-term data set.

## INTRODUCTION

Cultural eutrophication—an increase in a water body's trophic state caused by anthropogenic nutrient loads—has been identified as a priority problem affecting estuarine water quality on a national and worldwide basis (Day et al. 1989). In order to protect water quality during the period of continuing

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population growth that is projected for many coastal watersheds in coming decades, estuary management programs are working to quantify existing water quality conditions, estimate the relative magnitudes of anthropogenic and non-anthropogenic nutrient loads, and develop strategies for managing future loadings. These management efforts are typically "resource-based," seeking to achieve and maintain adequate water quality to ensure the continued survival of target organisms—such as seagrasses and economically important finfish and shellfish species—at desired levels (e.g., Chesapeake Bay Program 1992, Tampa Bay National Estuary Program 1997).

The Southwest Florida Water Management District's (SWFWMD) Surface Water Improvement and Management (SWIM) program is working in conjunction with the Charlotte Harbor National Estuary Program and others to develop resource-based water quality goals and nutrient loading targets for the portion of the Charlotte Harbor estuarine system that falls within SWFWMD's jurisdiction. As one component of that effort, SWFWMD and two cooperators—the Florida Department of Environmental Protection (FDEP) and the Environmental Quality Laboratory, Inc. (EQL)—have performed synoptic monthly monitoring at 12 fixed stations located in Charlotte Harbor proper and two stations located in Boca Grande Pass (Fig. 1) throughout the period 1993–1996. Other projects conducted by the SWFWMD SWIM program have sought to estimate annual loadings of nutrients and total suspended solids discharged to the Harbor from its watershed and airshed (Coastal Environmental, Inc. 1995) and develop nutrient loading targets for the tidal reaches of the Peace and Myakka Rivers, important pathways for external nutrient loadings entering upper Charlotte Harbor (SWFWMD 1997).

In this paper we provide a summary of the monitoring data collected by SWFWMD, FDEP and EQL during 1993–1996, emphasizing nutrient, chlorophyll, and dissolved oxygen concentrations as indicators of trophic state conditions. We also describe water quality trends observed in Charlotte Harbor over the period 1976–1996, based on parametric and nonparametric trend analyses performed using data collected by EQL during 1976–1990 and the SWFWMD/FDEP/EQL data collected during 1993–1996.

## METHODS

### 1993–1995 Monitoring

Between January 1993 and December 1996, SWFWMD, FDEP, and EQL staff conducted monthly monitoring at 12 stations located in Charlotte Harbor and two stations located in Boca Grande Pass (Fig. 1). Sampling was conducted synoptically (within a single tidal cycle), with each station occupied within one hour of predicted (astronomical) low tide.

Stations P-1 through P-4, and MY-1 through MY-4, were located in the tidal reaches of the Peace and Myakka Rivers, respectively (Fig. 1). Stations UH-E, UH-C, and UH-W were located in the upper (northern) Harbor, immediately down-estuary of the river mouths. These sites were chosen to provide information on spatial and temporal water quality patterns in a portion of the estuary where three-dimensional variability (involving longitudinal, lateral, and vertical salinity gradients) appears to be pronounced, particularly during periods of elevated freshwater inflow. Stations MH and LH were located in the Middle and Lower Harbor, respectively, and station BGP was located within Boca Grande Pass. Station GM was located about 4.5 nautical miles offshore, near the seaward end of Boca Grande Pass, representing the saltwater end-member of the sampling effort. Due to its location, sampling was not performed at station GM during several periods of inclement weather,

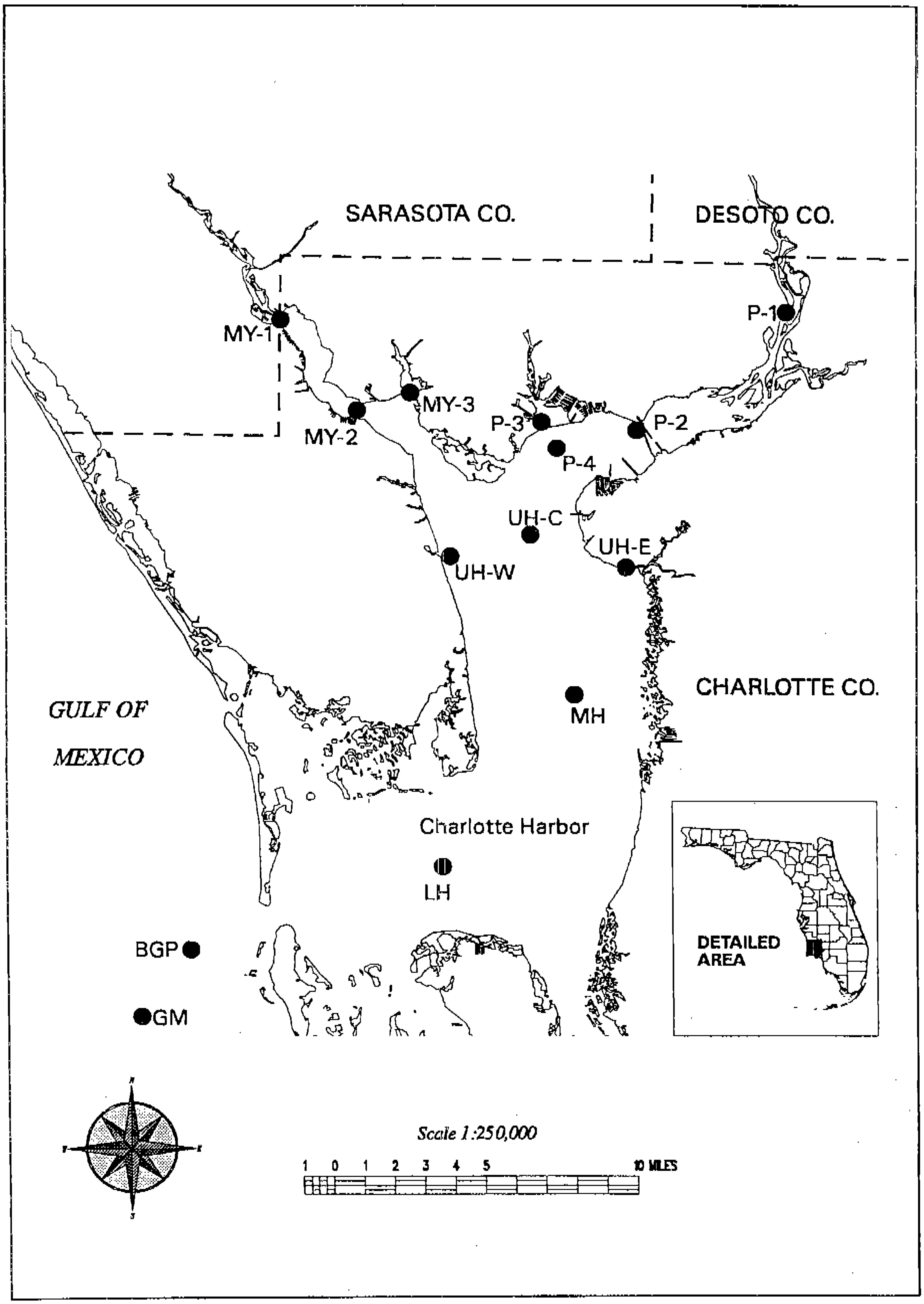

**Figure 1**. Locations of SWFWMD/FDEP/EQL monitoring stations in Charlotte Harbor, 1993–1996.

producing data gaps which occurred most frequently during winter months rather than being randomly distributed over time. To avoid potential analytical biases produced by these gaps, data from station GM were omitted from the analyses reported here.

Vertical hydrographic profiles of temperature, pH, conductivity, salinity and dissolved oxygen (DO) concentration were recorded using multi-probe (Hydrolab Corp.) instruments which were calibrated immediately before and after each sampling event. Hydrographic data were recorded at 1 m intervals at the deeper stations located in the southern portion of the estuary (MH, LH, BGP, and GM) and at 0.5 m intervals at the shallower stations located in the northern portion (P-1 through P-4, MY-1 through MY-3, UH-W, UH-C, and UH-E). Water clarity was measured using a 20-cm Secchi disk. Near-surface water samples for analyses of nutrient, chlorophyll, and other chemical constituents were collected from the upper 1 m of the water column at all stations, using 2.2 l acrylic (Wildco alpha) bottles. At stations where water depth was typically greater than 3 m (stations P-4, UH-C, MY-2, MH, LH, BGP, and GM), an additional near-bottom sample was also collected, within the lower 1 m of the water column, during each sampling event.

Color levels and concentrations of nutrients and chlorophyll *a* were determined using standard methods (summarized in Table 1). These analyses were performed by the SWFWMD Environmental Chemistry Laboratory from January 1993 through March 1996, and by EQL from April 1996 through December 1996. Concentrations of dissolved nitrogen and phosphorus forms were measured using samples which were filtered immediately following collection through MFS 0.45 um cellulose acetate membrane filters and stored on ice until analysis. Glass fiber filters for chlorophyll analyses (Gellman A/E, 1 um) were stored frozen prior to extraction.

### Long-Term Trend Analyses

Nonparametric (seasonal Kendall) tests for trend were applied by one of us (R. Montgomery, unpublished) to a long-term data set collected by EQL in Charlotte Harbor between 1976 and 1990. These data were collected pursuant to compliance monitoring requirements of a water use permit issued to the Peace River/Manasota Regional Water Supply Authority by the SWFWMD (EQL 1995). Sampling locations are shown in Fig. 2. Sampling and analytical methods were summarized by EQL (1995).

Parametric (SAS GLM) trend analyses were performed for SWFWMD by Coastal Environmental, Inc. (1996), using a combined data set which was produced by merging the 1976-1990 EQL monitoring data with the 1993-1996 SWFWMD/FDEP/EQL data summarized in this report. Methods used to construct and analyze the combined data set were summarized by Coastal Environmental, Inc. (1996).

## RESULTS AND DISCUSSION

### Existing Conditions: Nutrients and Chlorophyll *a*

Over the 1993–1996 sampling period, average near-surface salinity, color, dissolved inorganic phosphorus (DIP), dissolved inorganic nitrogen (DIN), and chlorophyll *a* concentrations exhibited pronounced longitudinal gradients (Figs. 3a-d) which extended from the head of the estuary, in the tidal reaches of the Peace and Myakka Rivers, to its mouth at Boca Grande Pass. Lateral and vertical gradients of salinity and other water quality constituents were also observed, appearing to be most pronounced during seasonal periods of elevated freshwater inflow. Lateral gradients in near-surface salinity were apparent in the northern Harbor (e.g., compare the average annual

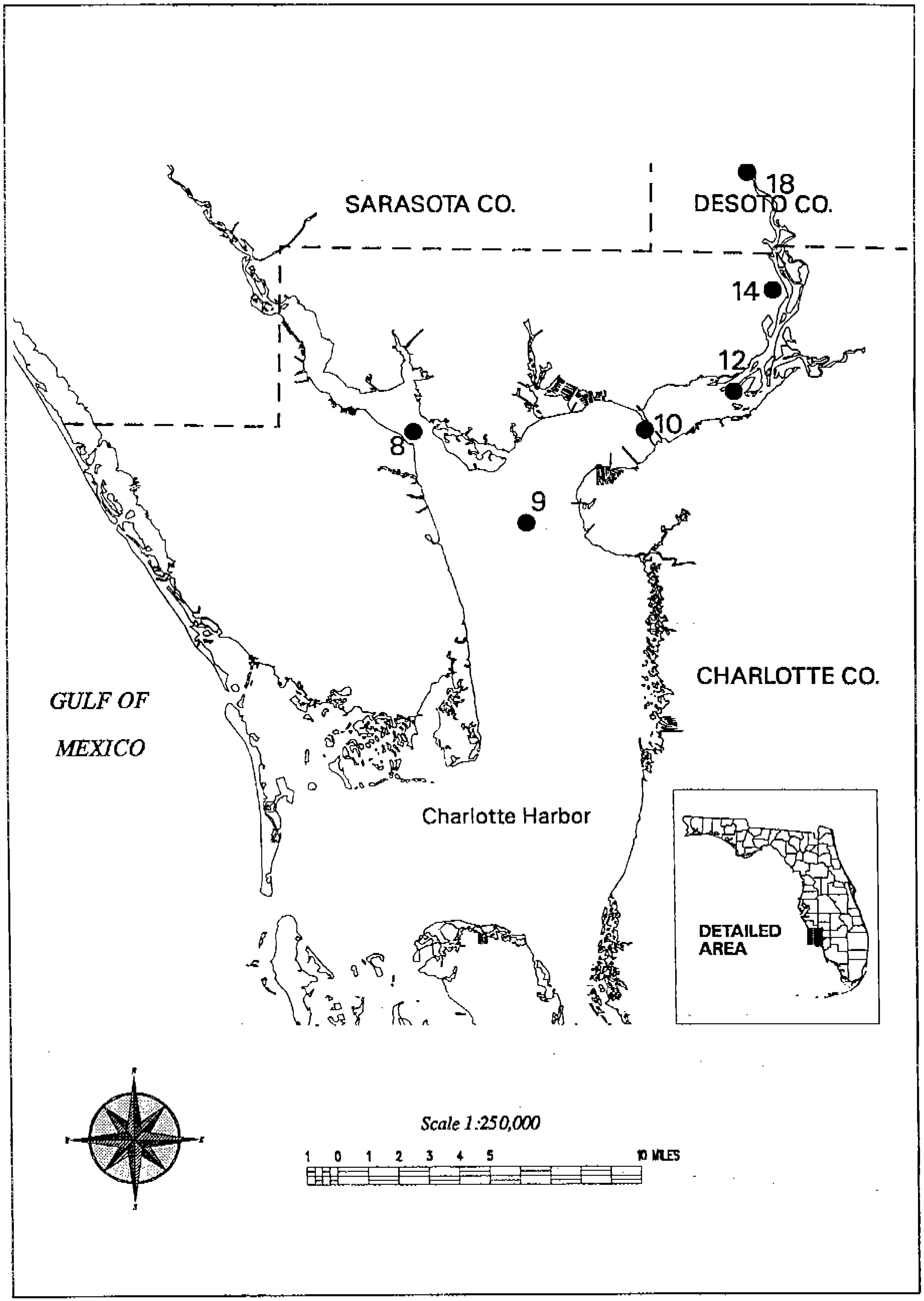

**Figure 2**. Locations of EQL monitoring stations, 1976–1990.

**Table 1.** Analytical methods.

| ANALYTE | SWFWMD | EQL |
|---|---|---|
| Chlorophyll (a, b, c and phaeophytin) | Standard Methods (18th ed.) 10200 H | Standard Methods (18th ed.) 10200 H |
| $NO_2 + NO_3$ (dissolved) | EPA 353.2 | EPA 353.2 |
| $NH_3$ (dissolved) | Standard Methods (18th ed.) 4500-$NH_3$ H | EPA 350.1/350.3 |
| Total Kjeldahl Nitrogen | EPA 351.2 | EPA 351.2/351.4 |
| Phosphorus (total) | EPA 365.1 | EPA 365.3 |
| $PO_4$ (dissolved) | Standard Methods (18th ed.) 4500-P-F | EPA 365.2 |
| Color | Standard Methods (18th ed.) 2120 B | EPA 110.2 |

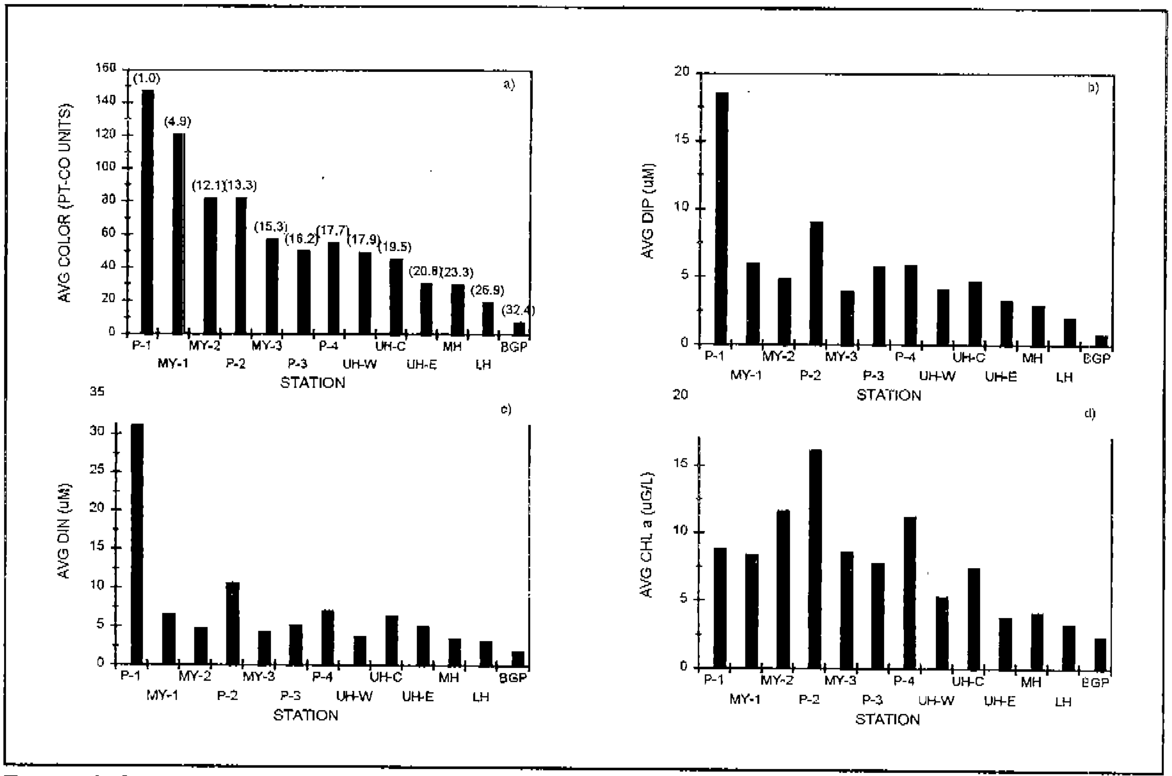

**Figure 3.** Longitudinal gradients in average near-surface concentrations of: a) color; b) dissolved inorganic phosphorus (DIP); c) dissolved inorganic nitrogen (DIN); and d) chlorophyll *a* at SWFWMD/FDEP/EQL monitoring stations during 1993–1996. Stations are ranked on the basis of average near-surface salinity (salinity values [ppt] are shown in parentheses in Fig. 3a).

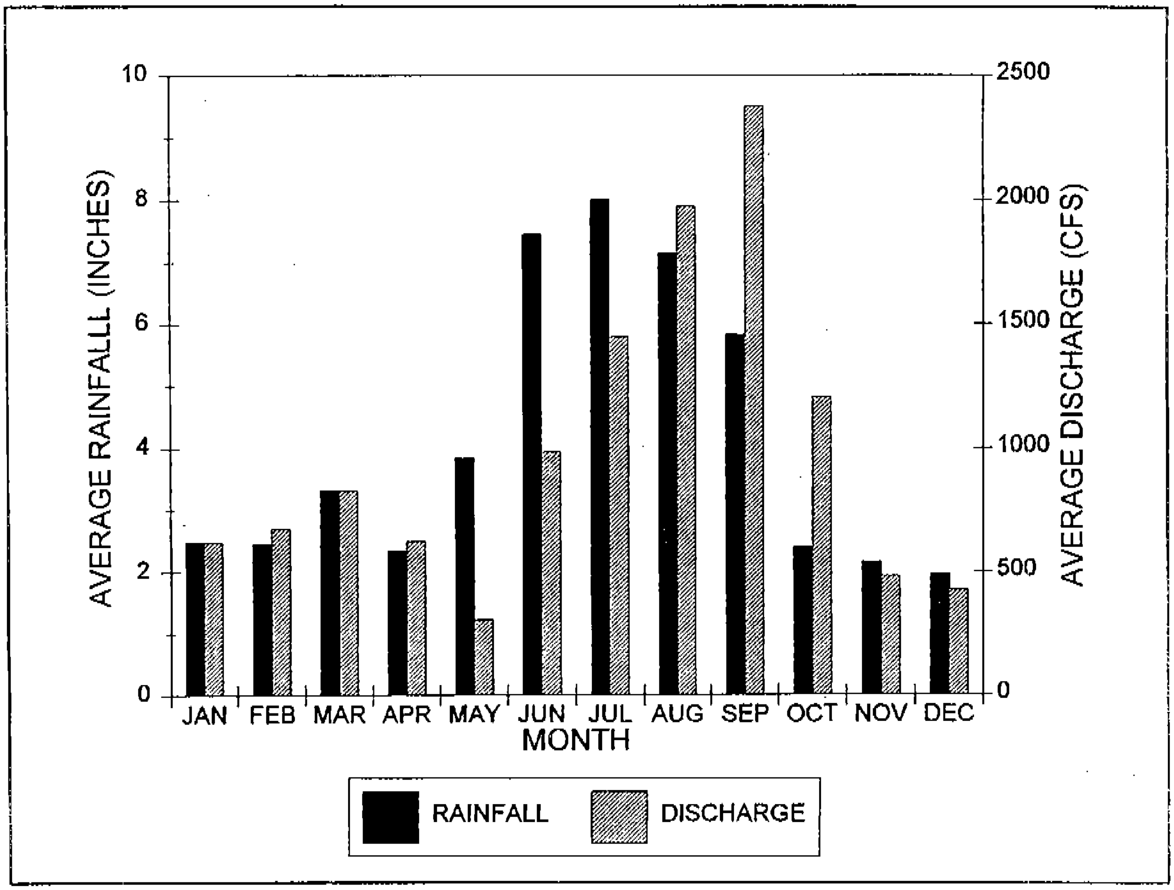

**Figure 4**. Average monthly rainfall at three long-term National Weather Service monitoring sites (Winter Haven, Bartow and Wauchula) and average monthly stream discharge at two long-term USGS monitoring stations (Peace River at Arcadia, Horse Creek near Arcadia) in the Charlotte Harbor watershed, 1976–1996.

near-surface salinities at stations UH-E, UH-C, and UH-W shown in Fig. 3a), presumably caused by preferential near-surface flow along the western shoreline of the low-salinity water discharged from the Peace and Myakka River systems (e.g. Stoker 1986, 1992). Vertical gradients in salinity and dissolved oxygen concentrations were observed most frequently in the tidal rivers and northern Harbor, and are discussed in greater detail below.

As a result of seasonal variations in precipitation and stream discharge within the Peace and Myakka River basins (Fig. 4), Charlotte Harbor receives seasonally-variable loadings of fresh water, nutrients and other water quality constituents (e.g., Coastal Environmental, Inc. 1995). Precipitation can also vary considerably from year to year, producing large inter-annual variability in freshwater inflows, estuarine salinity (Fig. 5) and constituent loadings (Squires, this volume). As a result, water quality conditions observed at a given time and place within the Harbor tend to reflect both large-scale patterns, such as longitudinal gradients brought about by advective and dispersive mixing of riverine and marine water masses within the estuary, and more localized spatio-temporal variability driven by the timing, magnitude and location of fresh water and nutrient inputs from the watershed (e.g., McPherson and Miller 1990, McPherson et al. 1990, Montgomery et al. 1991) .

Chlorophyll *a* concentrations observed in near-surface samples during 1993–1996 are

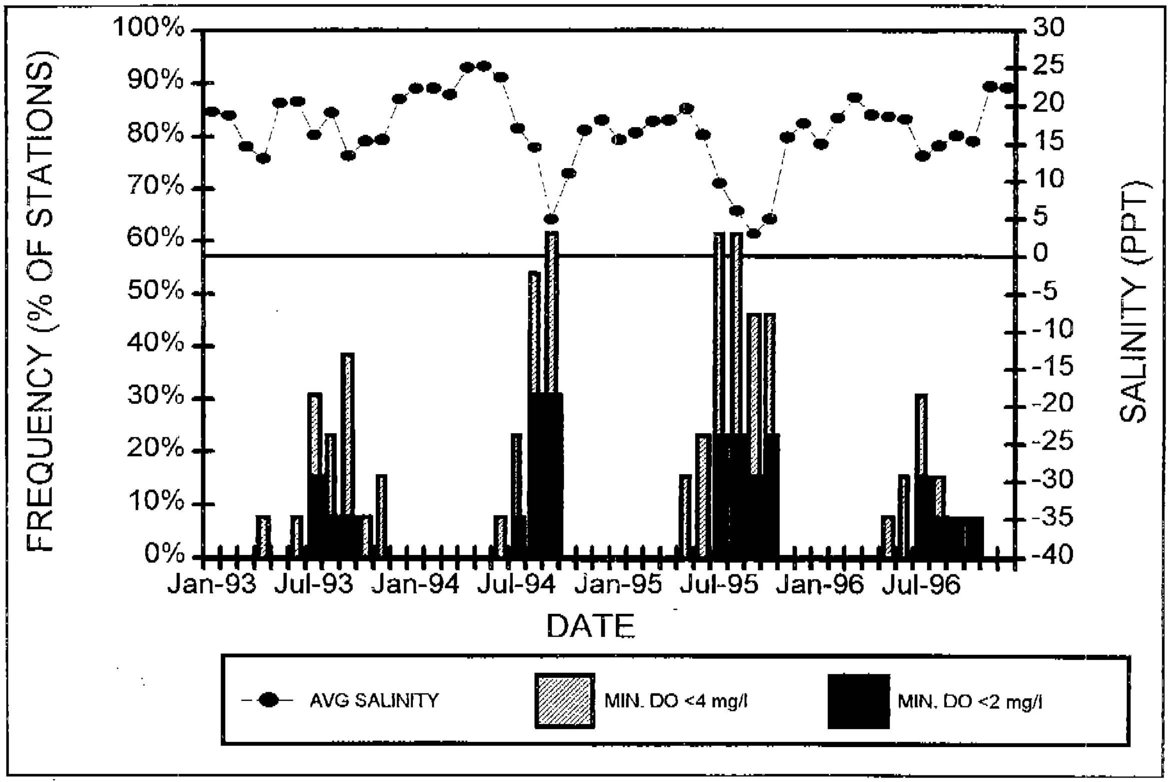

**Figure 5.** Frequency (% of SWFWMD/FDEP/EQL stations) at which minimum DO concentrations <4 mg/l and <2 mg/l were observed during 1993–1996. Average near-surface salinity (averaged across stations) is plotted to indicate temporal variability in freshwater inflows.

summarized in Figs. 3d and 6. Mean concentrations (Fig. 3d) were highest near the mouths of the Peace and Myakka Rivers and lowest in the lower Harbor and Boca Grande Pass, a pattern also observed in previous studies (e.g., McPherson et al. 1990, Montgomery et al. 1991). Near-surface chlorophyll *a* concentrations exceeding 60 μg/l, reflecting episodic phytoplankton blooms, were observed seasonally near the river mouths and the central portion of the upper Harbor (Fig. 6). Chlorophyll *a* concentrations greater than 60 μg/l were observed at one or more of the SWFWMD/FDEP/EQL stations during each of the years 1993–1996. These levels were restricted to the latter part (June–November) of each year, occurring most frequently during the month of July. Seasonally predictable chlorophyll *a* maxima of thismagnitude are considered indicative of hypereutrophic conditions in some estuarine water quality classification systems (e.g., NOAA 1996). Chlorophyll *a* concentrations exceeding 20 μg/l, which would be categorized as "high" in the NOAA (1996) classification system, were observed consistently in the tidal rivers and upper Harbor in the months of July-September during the 1993–1996 monitoring effort.

As noted above, concentrations of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) showed pronounced longitudinal, salinity-related gradients during 1993–1996 (Fig. 3b, c). The observed gradients suggest that large inputs of these constituents occurred in the fresh water discharged from the watershed to the tidal reaches of the Peace and Myakka Rivers, with subsequent dilution by lower-nutrient seawater entering the estuary from the Gulf of Mexico. Although quantitative estimates of annual external DIN and DIP

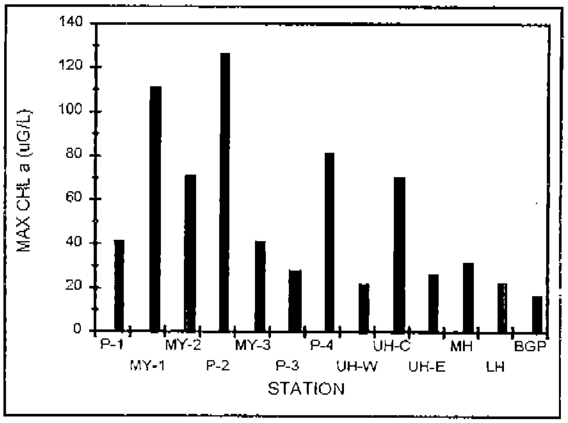

**Figure 6**. Maximum chlorophyll *a* concentrations observed at SWFWMD/FDEP/EQL monitoring stations in Charlotte Harbor, 1993–1996.

loadings are not yet available, estimates of annual external total nitrogen (TN) and total phosphorus (TP) loadings have been summarized by Coastal Environmental, Inc. (1995) and by Squires et al., this volume). Those estimates indicate that the largest annual external TN and TP loadings are discharged to Charlotte Harbor from the Peace River watershed and enter the estuary via the river's tidal reach.

In addition to dilution by lower-nutrient seawater, concentrations of DIN and DIP in estuaries are often affected by biological processes, such as uptake by phytoplankton, which typically provide the bulk of the primary production occurring in these systems, and microbially-mediated regeneration and recycling (Day et al. 1989). During the 1993–1996 sampling period, average concentrations of dissolved inorganic phosphorus were consistently >0.3 uM (Fig. 3), a level at which the DIP uptake capacity of most estuarine phytoplankton taxa becomes saturated (Day et al. 1989, Ambrose et al. 1991). P-limitation of phytoplankton-based primary production thus appears unlikely in the portions of the Harbor considered here. Average concentrations of dissolved inorganic nitrogen also exceeded typical saturation levels (~5 uM) of estuarine phytoplankton over much of the Harbor during the months of July–October (Fig. 7a), suggesting that N-limitation was unlikely in this portion of the year. During the months of January-June, however, in which rainfall and river discharge typically reach their lowest annual levels, average DIN concentrations at stations in the middle and lower Harbor (Fig. 7b) fell at times to levels (<2 $\mu$M) that would be limiting for some phytoplankton taxa (Day et al. 1989, Mackas and Harrison 1997). These observations suggest that if external nitrogen loadings to the Harbor were to increase in future years, detectable water quality responses (e.g., increases in phytoplankton productivity, standing stock chlorophyll *a* concentrations or overall trophic state conditions) would most likely be found in the higher-salinity portions of the estuary during the January–June time period, the

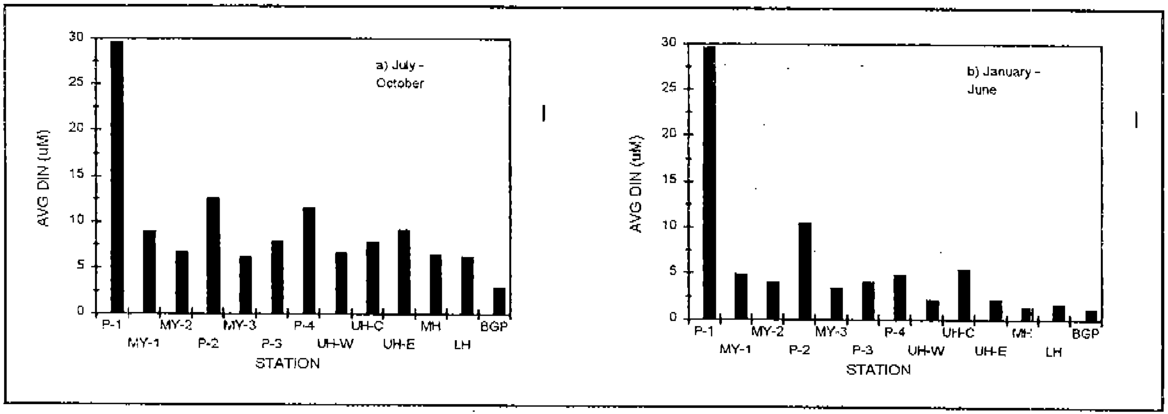

**Figure 7**. Longitudinal gradients in average near-surface DIN concentrations at SWFWMD/FDEP/EAL monitoring stations during a) "high-flow" (July–October) and b) "low-flow" (January–June) seasons, 1993–1996.

areas and season in which N-limitation appears to be occurring under existing loading conditions.

In addition to external loadings from the watershed and airshed, circumstantial evidence suggests that internal cycling may also play an important role in Charlotte Harbor's annual nitrogen budget. In the case of Tampa Bay, an estuary whose watershed adjoins Charlotte Harbor's to the north and west, a recent water quality modeling study (Martin et al. 1996) estimated that more than 90% of the annual DIN input to the water column was associated with internal cycling processes, such as benthic ammonia releases and bacterial remineralization of organic N within the water column and sediments. Although external loadings represent the ultimate source of "new" nitrogen for the estuary, and drive long-term changes in the trophic state, only a small proportion (less than 10%) of the estimated annual DIN input to the water column of Tampa Bay was attributed to external sources (Martin et al. 1996, Morrison et al. 1997). These estimates were consistent with empirical results obtained in nutrient-addition phytoplankton bioassays (Rodriguez 1991). Although comparable modeling and empirical studies have not yet been performed in Charlotte Harbor, the similarities that exist between the two estuaries (e.g., trophic state conditions, watershed physiography and climate) suggest that similarities may also occur in the relative importance of internal and external DIN sources in the nitrogen budgets of the two systems.

Circumstantial evidence that internal cycling may play an important role in Charlotte Harbor's annual nitrogen budget is apparent in the 1993–1996 monitoring data. Mean monthly concentrations of dissolved ammonia-N in near-surface and near-bottom samples (averaged across all stations) are summarized in Fig. 8. Average near-bottom concentrations showed pronounced peaks during the months of August, September and October, a period when near-surface and near-bottom waters in deeper portions of the northern Harbor were typically separated by a pronounced salinity-based density gradient associated with seasonally-elevated fresh water inflows. Average near-bottom ammonia-N concentrations exceeded near-surface concentrations in September samples (Fig. 8), implying the existence of an internal source of ammonia-N in the sediments or near-bottom waters during this portion of the year.

## Existing Conditions: Trophic State Index

The Florida Trophic State Index (TSI), which was developed by FDEP (Hand et al. 1994) to summarize water quality conditions on a statewide basis, provides a convenient method for comparing the trophic state of Charlotte Harbor with other Florida estuaries. We calculated TSI values on a station-by-station basis using data from the 1993–1996 SWFWMD/FDEP/EQL monitoring program and the following equations (from Hand et al. 1994):

$$\mathrm{TSI}_{\mathrm{TN}} = 56.0 + 19.8(\log_e [\mathrm{TN}])$$

and

$$\mathrm{TSI}_{\mathrm{Chla}} = 16.8 + 14.4(\log_e [\mathrm{Chl}\ a])$$

where [TN] and [Chl *a*] represent mean near-surface TN (mg/l) and chlorophyll *a* ($\mu$g/l) concentrations observed at a given station over the 4-year sampling period. Average TSI values were calculated for each station by averaging the $\mathrm{TSI}_{\mathrm{TN}}$ and $\mathrm{TSI}_{\mathrm{Chla}}$ values obtained for that station.

The results of these calculations are shown in Figure 9. Average TSI values for stations located in the tidal reaches of the Peace and Myakka Rivers and the central portion of the upper Harbor ranged between 50 and 60 during the 1993–1996 sampling period. In the FDEP classification system, these values

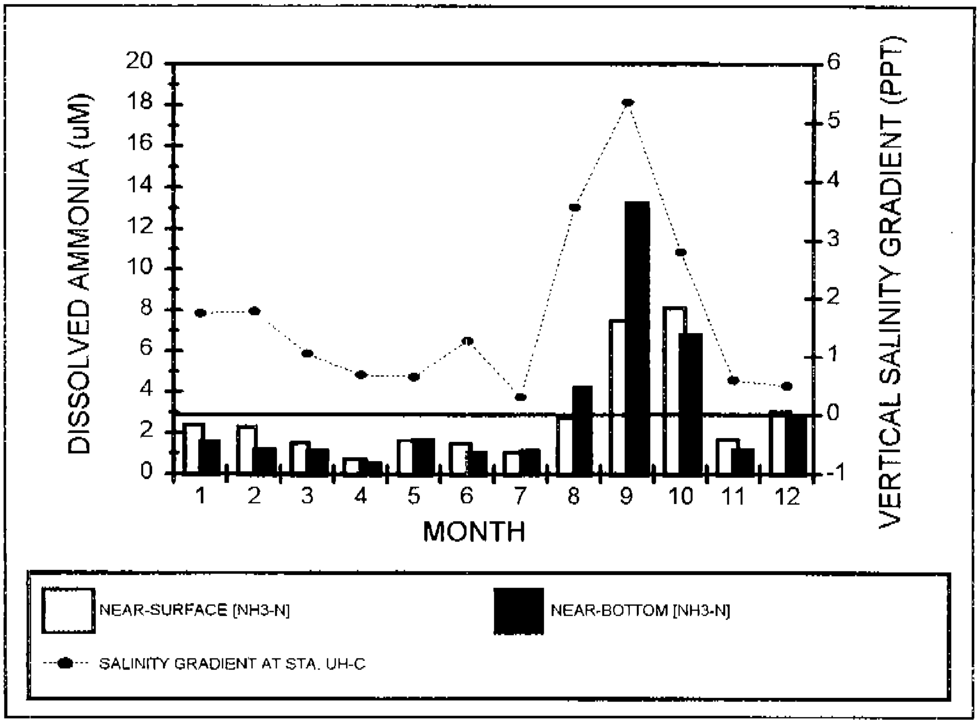

**Figure 8.** Average monthly dissolved $NH_3$-N concentrations observed in near-surface and near-bottom samples (all stations), and average magnitude of the vertical salinity gradient at station UH-C (located in the central upper harbor), during 1993–1996.

would be characterized as representing "fair" water quality conditions (Hand et al. 1994). In general, stations within the Peace River exhibited higher TSI values than stations in comparable salinity zones within the tidal Myakka River. TSI values decline, and water quality conditions improve from "fair" to "good" in the FDEP classification system (Hand et al. 1994), as one moves down-estuary from the river mouths to Boca Grande Pass (Fig. 9), reflecting the longitudinal gradients in nutrient and chlorophyll *a* concentrations noted earlier (e.g., Fig. 3).

## Existing Conditions: Dissolved Oxygen

Eutrophication often leads to reduced dissolved oxygen (DO) availability in near-bottom waters, through a chain of events in which increased primary production in the water column brings about increased biochemical oxygen demand (BOD) in the water column and sediments, driven by increased rates of cellular respiration, decomposition of organic material, and microbial oxidation of reduced nitrogen forms.

In the case of Charlotte Harbor, however, depressed DO concentrations in near-bottom waters may also occur for purely physical reasons during periods of elevated freshwater inflow. During such periods the water column can become vertically stratified, with a near-surface layer of less dense (lower salinity) riverine water lying above a denser (higher salinity) layer of estuarine or gulf water. Inputs of atmospheric oxygen to the lower portion of the water column are thus reduced, and DO concentrations fall as oxygen is consumed to support respiration and other biochemical processes. The fact that elevated freshwater inputs and vertical water column stratification tend to occur in Charlotte Harbor during the months of

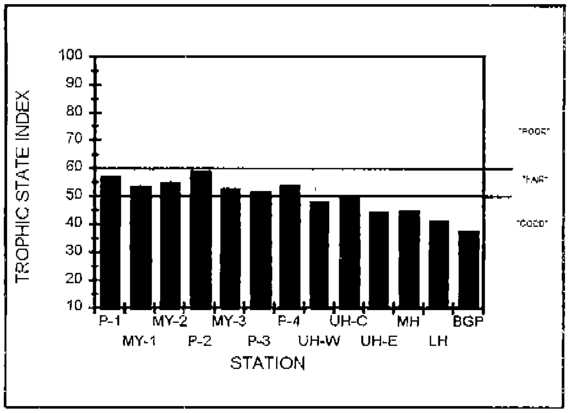

**Figure 9**. Florida Trophic State Index (TSI) values for SWFWMD/FDEP/EQL monitoring stations, 1993–1996. Plotted values are arithmetic means of $TSI_{TN}$ and $TSI_{CHLA}$ values.

July–October, when water temperatures are elevated and oxygen solubility therefore reduced, may also contribute to the development of reduced DO concentrations in the lower portion of the water column during the high-flow season.

Minimum (near-bottom) DO concentrations observed at stations sampled during the 1993–1996 monitoring effort are summarized in Fig. 10. Minimum concentrations which fell below the State criterion for estuarine waters (4 mg/l) were observed at most stations during the 1993–1996 monitoring period. Hypoxic conditions (DO concentrations <2 mg/l), whose effects on estuarine organisms can range from stressful to fatal, were observed at several stations in the tidal Peace River and upper Harbor (Fig. 10). As noted above, minimum DO concentrations followed seasonal cycles, with lowest levels observed during the months of July through October when freshwater inflows and water temperature were at or near their annual peaks. The relationship between freshwater inflow (expressed as average near-surface salinity) and frequency of depressed DO concentrations (percentage of stations at which DO concentrations <4 mg/l or <2 mg/l were recorded) is summarized in Fig. 11.

Although reduced DO availability appears generally associated with periods of elevated freshwater inflow to Charlotte Harbor (Fig. 11), water column stratification does not appear to explain all instances in which DO concentrations <4 mg/l and <2 mg/l were observed during the 1993-1996 monitoring period. Minimum (near-bottom) DO concentrations are plotted as a function of vertical salinity gradients (surface-to-bottom salinity differences) in Fig. 11. DO concentrations <4 mg/l and <2 mg/l were observed across the full range of vertical salinity gradients, including some instances in which vertical gradients were small or nonexistent.

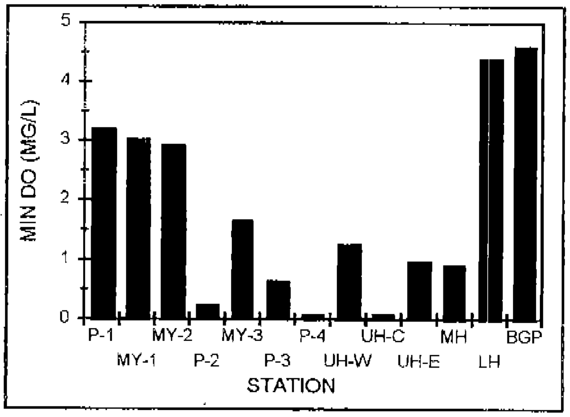

**Figure 10**. Minimum (near-bottom) dissolved oxygen concentrations observed at SWFWMD/FDEP/EQL monitoring stations, 1993–1996.

Given the apparent complexity of DO dynamics in Charlotte Harbor, and the fact that depressed DO concentrations may occur in near-bottom waters as a result of both natural and anthropogenic factors, the most pressing management issue appears to be the degree to which anthropogenic loadings of nutrients and BOD may act synergistically with natural factors to exacerbate hypoxic conditions, causing them to extend over larger areas or persist for longer periods than would occur in the absence of anthropogenic inputs.

**Table 2.** Results of nonparametric trend analyses performed by EQL (1995) using data from near-surface and near-bottom samples collected during 1976-1990. Significance levels: ns=p>0.10; *=p<0.10; **=p<0.05; ***=p<0.01. Station locations shown in Fig. 2.

| ANALYTE | EQL Station 8 | EQL Station 9 | EQL Station 10 | EQL Station 12 | EQL Station 14 | EQL Station 18 |
|---|---|---|---|---|---|---|
| Near-Surface: | | | | | | |
| Chloride | ns | ns | ns | ns | ns | ns |
| Color | ns | ns | ns | ns | ns | ns |
| Nitrate+Nitrite | ns | ns | ns | ns | ns | ns |
| Ammonia | increasing** | ns | increasing* | ns | ns | ns |
| $PO_4$ | ns | ns | declining** | declining*** | declining*** | declining*** |
| Chl *a* | ns | ns | ns | declining** | ns | ns |
| Near-Bottom: | | | | | | |
| Chloride | ns | ns | ns | ns | ns | increasing* |
| Color | ns | ns | ns | ns | ns | ns |
| Nitrate+Nitrite | ns | ns | declining** | ns | increasing* | ns |
| Ammonia | ns | ns | ns | ns | ns | ns |
| $PO_4$ | declining* | declining** | declining** | declining*** | declining*** | declining*** |

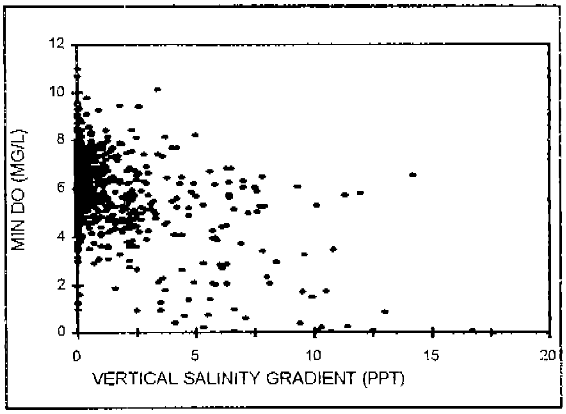

**Figure 11.** Minimum (near-bottom) DO concentrations observed at SWFWMD/FDEP/EQL monitoring sites during 1993–1996, plotted as a function of observed vertical (near-bottom vs. near-surface) salinity gradients.

## Long-Term (1976–1996) Water Quality Trends

As noted earlier, nonparametric (seasonal Kendall) analyses of long-term water quality trends were performed using data from six fixed stations, located in the tidal reaches of the Peace and Myakka Rivers and upper Charlotte Harbor (Fig. 2), which were sampled by EQL from 1976 through 1990 (EQL 1995). Near-surface and near-bottom samples were analyzed for potential temporal trends in chloride, color, nitrate+nitrite, ammonia+ammonium, and orthophosphate. Trends in chlorophyll *a* concentration were assessed for near-surface samples only.

Results of these analyses are summarized in Table 2. The most consistent trend detected was a decline in orthophosphate concentration, which was observed in near-bottom samples at all stations and in near-surface samples from the tidal Peace River and upper Charlotte Harbor. This trend, which was apparently caused by long-term reductions in anthropogenic phosphate loadings from the Peace River watershed, has also been noted by others (e.g., Fraser 1986). Despite the long-term declining trend, however, phosphate concentrations within Charlotte Harbor remain quite elevated relative to phytoplankton requirements (Fig. 3) and to other Florida estuaries (Hand et al. 1994). Other potential temporal trends (e.g., increasing ammonium+ammonia concentrations at EQL station 8) were restricted to a small subset of stations, and their environmental importance and relevance to broader resource-management issues is not yet clear.

Coastal Environmental, Inc. (1996) performed parametric (SAS GLM) analyses to assess potential water quality trends occurring over the period 1976–1996, using a composite data set produced by combining the 1976–1990 EQL monitoring data with data from the 1993–1996 SWFWMD/ FDEP/EQL monitoring project. For analytical purposes, each year was divided into "high flow" (July–October) and "low flow" (November–June) seasons reflecting the seasonality of rainfall and freshwater inflows to the estuary. At the time these analyses was performed, the SWFWMD/FDEP/ EQL data set extended through May 1996.

Results of the parametric analyses are summarized in Table 3. Similar to the nonparametric analyses, the most consistent trend detected was a decline in phosphorus (TP) concentration, which was observed at both near-surface and near-bottom samples and in both the high flow and low flow seasons. As noted above, this trend appears due to reduced anthropogenic phosphorus loadings from the Peace River watershed (Fraser 1986).

Statistically significant declining trends were also observed in salinity and dissolved oxygen concentrations in the parametric analyses. However, the apparent salinity trend may be an artifact of the different monitoring designs used in the EQL (1976–1990) and SWFWMD/FDEP/EQL (1993–1996) sampling programs. The 1976–1990 data were collected during all portions of the tidal cycle, while the 1993–1996 data were collected within 1 hour of predicted (astronomical) low tide at each sampling station. This difference may have been sufficient to produce a consistent downward bias in the salinity values measured during the 1993–1996 period, relative to the 1976–1990 period. (Data interpretation difficulties of this type underscore the need to implement a consistent, long-term monitoring program throughout the Charlotte Harbor system.)

The environmental importance and resource management relevance of the possible declining DO trend (Table 3) are difficult to assess, due to the methodological differences that exist between the two monitoring programs included in the combined data set and the fact that declining DO trends have not been detected in other studies. Given the relatively high spatial and temporal frequency of hypoxia observed under existing conditions (e.g., Fig. 10), however, the possibility that average DO concentrations may be declining in some portions of the Harbor should be kept in mind during the design and implementation of future monitoring efforts.

The parametric analyses detected no significant trends in total Kjeldahl nitrogen or chlorophyll *a* concentrations within the combined data set (Table 3).

## SUMMARY

During the 1993–1996 period addressed by the SWFWMD/FDEP/EQL monitoring data, nitrogen and phosphorus concentrations were relatively elevated throughout Charlotte Harbor. Average DIP concentrations exceeded phytoplankton saturation levels at all sampling stations. Average DIN concentrations exceeded typical phytoplankton requirements at most stations during the high-flow (July-October) season, but fell to levels ($<2\ \mu$M) at which N limitation occurs for some taxa during the low-flow (November–June) season in higher-salinity portions of the estuary. If anthropogenic nitrogen loadings increase in future years, in response to increasing population growth or other factors, detectable water quality responses seem most likely to occur in the higher-salinity portions of the estuary during the January–June time period, the areas and season in which N-limitation is

**Table 3.** Results of parametric trend analyses performed by Coastal Environmental, Inc. (1996) using data from near-surface and near-bottom samples collected by EQL during 1976-1990 (station locations shown in Fig. 2) and by SWFWMD, FDEP and EQL during 1993–1996 (station locations shown in Fig. 1). Slope directions and magnitudes are listed for significant ($p<0.05$) trends. (ns = non-significant [$p>0.05$] trend.)

| PARAMETER | SEASON | YEARS | DEPTH | SLOPE |
|---|---|---|---|---|
| TP | DRY | 76–96 | bottom | -0.008 |
| | | 76–96 | surface | -0.007 |
| | wet | 76–95 | bottom | -0.011 |
| | | 76–95 | surface | -0.011 |
| TKN | dry | 79–96 | bottom | ns |
| | | 77–96 | surface | ns |
| | wet | 79–95 | bottom | ns |
| | | 76–95 | surface | ns |
| D.O. | dry | 76–96 | bottom | -0.020 |
| | | 76–96 | surface | -0.036 |
| | wet | 76–95 | bottom | ns |
| | | 76–95 | surface | -0.061 |
| SALINITY | dry | 76–96 | bottom | -0.107 |
| | | 76–96 | surface | -0.104 |
| | wet | 76–95 | bottom | -0.252 |
| | | 76–95 | surface | -0.250 |
| CHL *a* | dry | 76-96 | surface | ns |
| | wet | 76-95 | surface | ns |

most likely to occur under existing loading conditions.

As might be expected given the relatively high concentrations of dissolved inorganic N and P observed in Charlotte Harbor, chlorophyll *a* concentrations were also relatively high during the 1993–1996 sampling period. Mean concentrations were highest near the mouths of the Peace and Myakka Rivers and lowest in the lower Harbor and Boca Grande Pass, a spatial pattern observed in several previous studies (e.g., Stoker 1986, McPherson and Miller 1990, Montgomery et al. 1991).

Episodic near-surface chlorophyll *a* concentrations exceeding 60 $\mu$g/l were observed seasonally near the river mouths and in the central portion of the upper Harbor. These elevated values were observed at one or more stations during each of the years 1993–1996, occurring most frequently during the month of July. Seasonally predictable chlorophyll maxima of this magnitude are considered indicative of hypereutrophic conditions under some estuarine water quality classification systems (e.g., NOAA 1996). Chlorophyll *a* concentrations exceeding 20 $\mu$g/l, which would be categorized as "high" in the NOAA (1996) classification system, were observed consistently in the tidal rivers and upper Harbor during the months of July-September.

Trophic state index (TSI) values calculated based on average TN and chlorophyll *a* concentrations observed during 1993–1996 indicated the presence of "fair" (Hand et al. 1994) water quality conditions in the tidal Peace and Myakka Rivers and upper Harbor, and "good" (Hand et al. 1994) water quality conditions in more saline portions of the estuary, based on statewide FDEP criteria.

Conditions of reduced DO availability (DO concentrations <4 mg/l) and hypoxia (DO concentrations <2 mg/l) were observed in each of the years 1993-1996, most frequently in the tidal river reaches and upper Harbor, on a seasonal and year-to-year cycle that appeared associated with variations in freshwater inflow. Salinity-based water column stratification may explain a substantial proportion of the hypoxia observed in the estuary, although some cases of depressed DO and hypoxia were also observed at stations where vertical salinity differences within the water column were small or nonexistent. The possibility that anthropogenic nutrient loadings may act synergistically with natural factors to increase the severity, spatial extent, and/or temporal duration of hypoxic events is an issue which appears to warrant ongoing attention from resource managers.

## ACKNOWLEDGMENTS

The work reported here was funded by the Southwest Florida Water Management District (Peace River and Manasota Basin Boards) and the Florida Department of Environmental Protection. The authors thank Chris Anastasiou, Bob Brady, Kyle Champion, David Crane, Rick Crosby, Kate Davis, Rob Fenwick, Fran Flores, Jason Hood, Ray Kurz, Steve Lippson, Ed Miller, Theresa Mulroney, Nita Osterman, Mark Pike, Thomas Ries, Chris Tomlinson, Forrest Turbeville, and Wade Waltimyer for their help in the field, and the staffs of the SWFWMD and EQL laboratories for providing water chemistry data.

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