HOURLY DISSOLVED OXYGEN MEASUREMENTS IN CENTRAL ESTERO BAY, LEE COUNTY, SOUTHWESTERN FLORIDA

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ABSTRACT

Dissolved oxygen is an essential component in the aquatic environment. Of all the parameters that characterize an estuary, the level of dissolved oxygen in the water is one of the best indicators of the estuary's health. An estuary with little or no oxygen in its waters cannot support healthy levels of animal or plant life. The health of an estuary can, to a large degree, be determined by observing the near-dawn dissolved oxygen concentrations. Dissolved oxygen concentrations of 5.0 mg/L or higher are able to support a well-balanced, healthy biological community. However, when concentrations fall below the current Florida Department of Environmental Protection (FDEP) value of 4.0 mg/L, some researchers consider that a complete alteration of the biotic assemblage in the estuary occurs.

In this study, dissolved oxygen (DO) concentrations and other physical water quality parameters were measured hourly, from June 1996 to August 1997, using a programmed continuous digital recorder deployed in a major *Thalassia* and *Haladule* seagrass bed in the shallow waters of central Estero Bay. Measurements recorded showed that the DO concentrations increase rapidly between the hours of 1000 and 2000 (10 AM to 8 PM) with a near-dawn low. During the surveys of June and July 1996, the near-dawn hourly-measured maximum DO concentration (mg/L) was below 5 mg/L, and the plotted data of maximum and minimum values, spanning a 24-hour time period, had the same curve shape. In August, September and October 1996, the maximum recorded DO concentration increased to over 9 mg/L. This increase in dissolved oxygen production by the seagrass appeared to be directly related to water depth and water temperature, that is, the shallower the depth, the greater the sunlight penetration, and only indirectly to salinity and other parameters. Rainfall analysis showed that heavy rainfall appeared to have only a dampening effect on dissolved oxygen production over the seagrass beds, which may be due to cloud cover and the slight lowering of water temperature during the rain storms. All recorded data showed that near-dawn DO concentrations in central Estero Bay regularly experienced values below 2.0 mg/L, far below the recommended EPA and FDEP minimum of 4.0 mg/L.

As the health and productivity of the bay and species diversity are affected by low dissolved oxygen values, the importance of near-dawn measurements cannot be underestimated. Near-dawn DO sags are probably the most important water quality variable affecting both the general health of the bay and species abundance and diversity. Daytime or one-time sampling gives both over-optimistic values and erroneous assessments of existing water quality. If continuous recording devices are not readily available, then hourly 2-hr DO curves should be constructed for each month of the year and then the daytime or one-time values can be plotted on the curves to determine by extrapolation the near-dawn DO sags for water quality evaluation.

INTRODUCTION

The health of an estuary can, to a large degree, be determined by observing dissolved oxygen concentrations. A vast array of organisms are dependent upon adequate levels of dissolved oxygen for survival. Most animals and plants can grow and reproduce unimpaired when DO levels exceed 5 milligrams per liter (mg/L). If DO levels fall under 2 mg/L, a condition known as hypoxia,

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many species will move elsewhere and non-mobile species may die. A second condition, known as anoxia, occurs when the water becomes totally depleted of oxygen (<0.5 mg/L) and results in the death or avoidance of any organism that requires oxygen for survival. Although excess nutrients from human activities are a major cause of hypoxia and anoxia, these conditions may also occur in estuaries relatively unaffected by humans, however, the severity of low DO and the length of time that low oxygen conditions persist are less extreme. The consequences of these changes frequently have both ecological and economic significance. However, it should be noted that some systems, such as swamps, can exhibit naturally low dissolved oxygen concentrations, without adverse effects on the biota.

Oxygen enters an estuary's waters from the atmosphere and through aquatic plant and phytoplankton photosynthesis. Currents and wind-generated waves boost the amount of oxygen entering the water by putting more water in contact with the atmosphere. Oxygen solubility in water is poor, however, and even well-aerated, freshwater at zero degrees centigrade can only hold 14.2 mg/L of oxygen when fully saturated. Saltwater can absorb even less oxygen than freshwater. Similarly, warm water, fresh or salt, holds less oxygen than cold (Friedemann and Hand 1989).

The breakdown of organic matter is an integral part of an estuary's ecological cycle, and, like animal and plant respiration, also consumes oxygen. Decomposition of large quantities of organic matter by bacteria can severely deplete the water of oxygen and make it uninhabitable for other species (Friedemann and Hand 1989). An overload of nutrients from wastewater treatment plants or runoff from farm fields or from residential developments also adds to the problem by fueling the overgrowth of phytoplankton. The phytoplankton ultimately die and fall to the bottom where they decompose, using up oxygen in the waters of the estuary (Friedemann and Hand 1989).

The concentration of dissolved oxygen is an important indicator of existing water quality and reflects the ability of a body of water to support a healthy and diverse biological community. Measuring oxygen can be based on the percent saturation in the water, taking into account the temperature and conductivity both of which affect its capacity to hold oxygen. Diurnal variation in dissolved oxygen levels is generally higher in estuaries than in streams due to the higher rates of primary productivity in estuaries (Friedemann and Hand 1989).

At the surface of an estuary, the water at mid-day is often close to oxygen saturation, due both to mixing with air and the production of oxygen by plant photosynthesis. As night falls, photosynthesis ceases and plants consume available oxygen, forcing DO levels to decline (Friedemann and Hand 1989). Cloudy weather may also cause surface water DO levels to vary over short time periods, since reduced sunlight slows photosynthesis. The DO levels in deeper parts of an estuary fluctuate according to the rate of oxygen diffusion from the upper layer and the amount of mixing caused by storms, wind, currents, and the circulation of water temperature differences between the layers. Stratification is quite effective in blocking the transfer of oxygen and nutrients between the upper and lower layers. In a well-stratified estuary, very little oxygen may reach the lower depths and the deep water may remain at a fairly constant lower level of DO until the stratification disintegrates with the changing of tides, seasons, or a large storm (Friedemann and Hand 1989).

Although one may think of water as homogeneous and non-changing, its

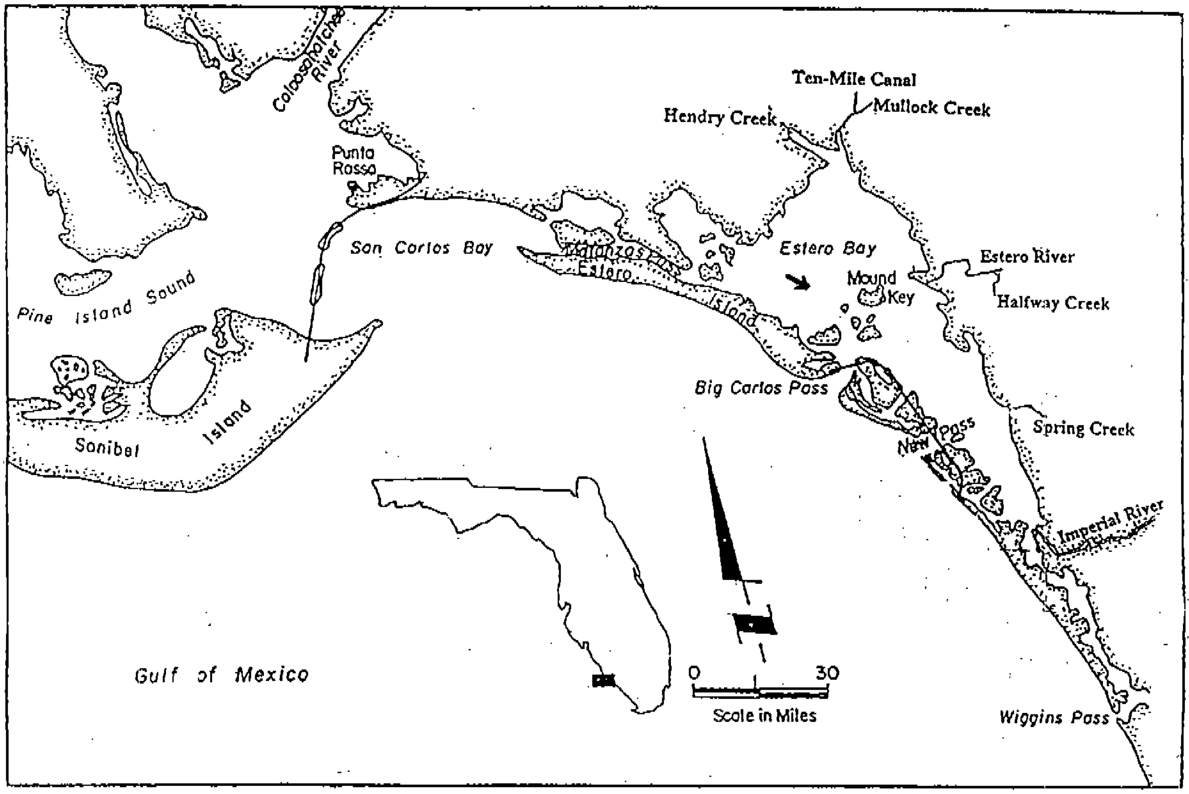

Figure 1. Location of Estero Bay in Lee County, southwestern Florida and the outline of the boundaries of the Estero Bay Aquatic Preserve in Lee County, Florida. The sampling site, marked by an arrow, is located in a seagrass meadow at Starvation Flats in the central part of Estero Bay.

chemical constitution does, in fact, vary over time. Oxygen levels, in particular, may change sharply in a matter of hours, making it difficult to assess the significance of any single DO value. Daytime and mean measurements of dissolved oxygen may have limited significance, since nocturnal respiration and other episodic instances of low dissolved oxygen have a significant impact on aquatic biota. Diurnal dissolved oxygen studies are a necessity for gaining a full understanding of the oxygen cycle in a particular body of water (Friedemann and Hand 1989). The consequences of a rapid decline in DO (less than 2.0 mg/L) sets in quickly and animals must move to areas with higher levels of oxygen or perish. This immediate impact makes measuring the level of DO an important means of assessing the status of water quality. This study investigated the hourly changes in DO mg/L for monthly periods at different times of the year to determine the validity of the hypothesis that near-dawn DO measurements better reflect stresses within the bay than one-time site-specific data-point measurement.

The study area is located in the central seagrass area of Estero Bay (Fig. 1) in the tidal circulation area of Big Carlos Pass within the Estero Bay Aquatic Preserve, Lee County, Florida. This preserve was the first aquatic preserve to be established in Florida in 1966, and was brought under standard management by the Florida Aquatic Preserve Act in 1975. The preserve covers an area of about 4,525 hectares (11,200 acres) with a drainage basin encompassing 758.5 km^2 (293 mi^2), located approximately 24 km (15 mi) south of Fort Myers and about 26 km (16 mi) north of Naples, along the western coastline of, and entirely within, Lee County. Lee

County has a total land area of 263,865 hectares (652,000 acres) with 950 km (590) miles of shoreline, and more than 100 islands (Godschalk & Associates 1988). In 1995, Lee County had a population of 324,520 residents with about 1.5 million seasonal visitors. The average air temperature is 23.3°C (73.9°F) and water temperature is 25.28°C (77.5°F). The climate is subtropical, with a long-term average annual rainfall of 1,430 mm (56.3 inches). Generally, the majority of this rainfall is concentrated between June and September during the wet season, that is, May through October (Godschalk & Associates 1988). The surface water of Estero Bay is more than 38 km^2 (15 mi^2). The estuary complex began to form approximately 5,000 years ago when a rise in sea level drowned the Preserve area. This flooding caused marine sediments to be deposited at the mouths of the Caloosahatchee River and the bay area. The clastic sediments from rivers, streams, and from offshore were transported by the longshore currents south to be deposited as barrier islands bounding the present Estero Bay and also filled the bay to its present shallow depth. The strong tidal and storm influences formed a large tidal delta inside of Big Carlos Pass. Within the bay area, there are hundreds of low-lying islands and oyster bars, many covered with mangroves. These back-bay islands have no upland areas, except on Mound and Dog keys. Mangrove trees are by far the most dominant vegetation in the estuarine complex. Extensive marine grassbeds are found in certain protected shallow areas of the bay (Mitchell-Tapping et al. 1996).

The water characteristics of the bay vary in response to the daily, seasonal and long term forces, and the many and varied conditions found in each of the minor streams from 10 watersheds flowing into the estuary. In the northern portion of the bay, Cow Creek, sometimes called Cow Slough, and No Name Slough both flow into small bays, while Hendry Creek, Mullock Creek and Ten-Mile Canal input waters from the southern and eastern portions of the city of Fort Myers. In the central area, Halfway Creek, a former Pleistocene swale between dunes, flows into the Estero River and Spring Creek, also a Pleistocene swale area. flows into the bay and is affected by nearby residential development. In the southern part of the bay, the Imperial River drains the largest watershed in Lee County. This river basin near Bonita Springs has experienced large developments, such as Bonita Bay, that have affected the watershed in the southern part of Lee County. During a period of rainstorms (444.75 mm: 17.51 inches) in October 1995, the Imperial Watershed measured a record runoff of 243×10^6 m^3 (197,400 acre-ft) of water that flooded the low-lying areas of Bonita Springs (Mitchell-Tapping et al. 1996). The long-term runoff (1940–1995) for this watershed averaged 87.2×10^6 m^3 (70,940 acre-ft) which includes past hurricane stormwater (Mitchell-Tapping et al. 1996).

Estero Bay is classified as a D-lagoonal type estuary, as it lacks significant fresh water input, is unstratified, and has a strong tidal exchange due to the restricted size of its inlets. The bay is very shallow, less than 1 m in most areas, and is dominated by marine tidal forces with an occasional influence of stormwater discharges from a number of small rivers and creeks. The modification of upland drainage by agriculture, urban development, the Ten-Mile canal draining from the City of Fort Myers into Mullock Creek, the Kehl canal into the Imperial River, and numerous finger canals and channels in residential developments surrounding the preserve, have had a very significant impact on the water quality and heavy metal concentrations on the bottom sediments of the bay during the wet season (Mitchell-Tapping et al. 1997).

An experiment to determine changes in physical water-quality parameters was started in June 1996 and continued through December 1997. An autonomous, remote, continuous-recording device was used to measure pH, specific conductance, dissolved oxygen (mg/L), temperature (°C), depth (m), and salinity (‰). It was calibrated according to the manufacturers specifications before and after each deployment. The continuous recording device has the capacity to measure DO in both mg/L and percentage, but as the DO percentage readings are affected by local changes in barometric pressure, it is very hard to calibrate, especially during a long-term deployment. Therefore, although both were recorded, only the DO in mg/L, which is not affected by changes in barometric pressure, was used in the analysis. The depth was calibrated in meters below NAVD (North American Vertical Datum of 1988) using an onshore survey marker at a known NAVD elevation. The instrument was programmed to measure the physical water quality parameters every hour for at least a month, and was recalibrated and reprogrammed before each deployment. The instrument deployment site was located in a major seagrass meadow, with abundant *Thalassia* and *Halodule*, in a shallow (<1m) area in the central part of the bay. Seagrasses are not true grasses, but flowering plants with stems, leaves, roots and flowers, and are more closely related to lilies (Fonseca 1994). The area was chosen because seagrasses serve as a good indicator of water quality because they are very sensitive to change (Virstein and Morris 1996). Light penetration into estuarine waters is one of many critical factors to seagrasses. Algal growth (due to high nutrient levels in the water), turbidity, and stormwater runoff all lessen the amount of light that reaches the grasses and therefore impact their growth. In the Indian River Lagoon National Estuary Program (Virstein and Morris 1996), seagrasses are the only indicator used to measure water quality changes, and in the Tampa Bay National Estuary Program and the Chesapeake Bay restoration effort they are the primary indicator of water quality. Estero Bay Preserve has experienced significant urban growth surrounding the Preserve and also receives sudden natural flood amounts of freshwater input in the northern, central, and southern portions of the Bay related to stormwater runoff. Some of the activities responsible for decreased water quality include dredge and fill projects, nonpoint source pollution from road runoff, septic systems, and agricultural practices, and turbidity from boat propellers. Along with these developments has come a decline in seagrasses in the Bay as noted in surveys performed in 1972 by McNulty et al. (Estevez et al. 1981), in 1974 by Tabb et al. (1974), in 1991 by Lee County Environmental Laboratory (unpublished, but GIS maps available from Lee County Tax Office in Fort Myers), and in 1996 by Mitchell-Tapping et al. (1996). In addition to serving as a good indicator of water quality, seagrasses are also important for their functions in the marine environment. Seagrasses provide critical habitat for many estuarine species, including fish, crabs, and shrimp. Small fish use the grasses as a nursery and adults feed in them, while crabs, shrimp, mollusks, and other marine creatures attach themselves to the grasses to feed or hide (Fonseca and Fisher 1986; Fonseca 1995).

METHODS

At the seagrass meadow site, the instrument was suspended, about 5 cm above the seafloor, inside a protective perforated PVC pipe supported within a tripod. The site was marked with two mooring posts either side of the tripod. At the end of each deployment, the instrument was recovered and the recordings downloaded into a computer spreadsheet program. The data was then plotted and charted for each deployment in 24-hour time periods. Some records, however, showed that during a low-low tide the probes of the instrument had been exposed to air for about two hours, thereby giving false readings for that period. In the analysis of the data, these records were excluded. Due to an error in programming, DO readings were recorded every 2 hours during deployment in late August, September, and October 1996. November 1996 data was not recovered due to damage of the instrument in the field requiring factory repairs.

OBSERVATIONS AND DISCUSSION

The results of the study, presented monthly in a 24-hour graphic chart form, shows curves of the concentration of dissolved oxygen in Estero Bay that increase rapidly between the hours of 1000 and 2000 (10 AM to 8 PM) and decrease to a near-dawn sag. Near-dawn sags and daytime high DO concentrations are considered the most important indicators in the assessment of the health of the bay.

Hourly charts of DO (mg/L) during June and the first week of July 1996 show that the daylight maximum DO is less than 1.8 mg/L. The near-dawn sag is well below 0.5 mg/L during both June and July 1996 (Fig. 2). The DO (mg/L) during July 27–31, compared to July 1-6, and August 1996 shows the daytime maximum DO is now increasing to greater than 8.0 mg/L (Fig. 3). The rapid increase of DO to above the FDEP minimum of 4.0 mg/L has probably occurred about the 20th July, unfortunately during the recovery and recalibration time of the instrument. The near-dawn sag, although increasing from previous months, is well below 2.0 mg/L, but rises above this value in late August 1996. It was initially thought that this was instrument failure or calibration problems, but a similar low values were obtained during the first week of July in 1997. Reyes and Merino (1991) also experienced a similar low in February 1986 during a study in Bojorquez Lagoon, Cancun, Mexico, which they attributed to intense north winds.

The DO (mg/L) during September 1996 and during some days in October and December 1996 recorded a daytime maximum DO that is now increasing to greater than 10.0 mg/L in September, but is starting to decrease in October and December 1996 (Fig. 4). The near-dawn sag is increasing to about 2.0 mg/L in October, but increasing in late December to over the FDEP minimum. During January, February, and March 1997 (Fig. 5), the daytime maximum DO is now decreasing to less than 8.0 mg/L. The near-dawn sag is, for a few days in January and February, above 4.0 mg/L, but decreases below 4.0 mg/L in late February and March 1997. In the surveys of June and July 1996, the measured maximum DO (mg/L) was below 4 mg/L, possibly due to water clarity and plankton blooms. In late August 1996, the DO (mg/L) increased to over 9 mg/L. This rise in DO appears to be directly related to water depth when charted, and therefore greater sunlight penetration, and water temperature. A DO high was observed from September 1996 through early February 1997. The hourly graphs of DO (mg/L) during January, February, March, and April 1997 (Fig. 5) show the daytime maximum DO is now decreasing to less than 8.0 mg/L. The near-dawn sag is for a few days above 4.0 mg/L in January and February, but decreasing below 4.0 mg/L by April 1997. The hourly graphs of DO (mg/L) during May, June, July, and August 1997 (Fig. 6) show a daytime maximum DO is now increasing to greater than 12.0 mg/L. The near-dawn sag, however, is decreasing to below 2.0 mg/L by the end of August 1997. Lewis and Estevez (1988) have reported a maximum DO low in June to August, but had a maximum high during January in a study of Hillsborough Bay. Lewis and Estevez (1988) also reported ranges of DO (mg/L) for other Florida west-coast bays (Table 1).

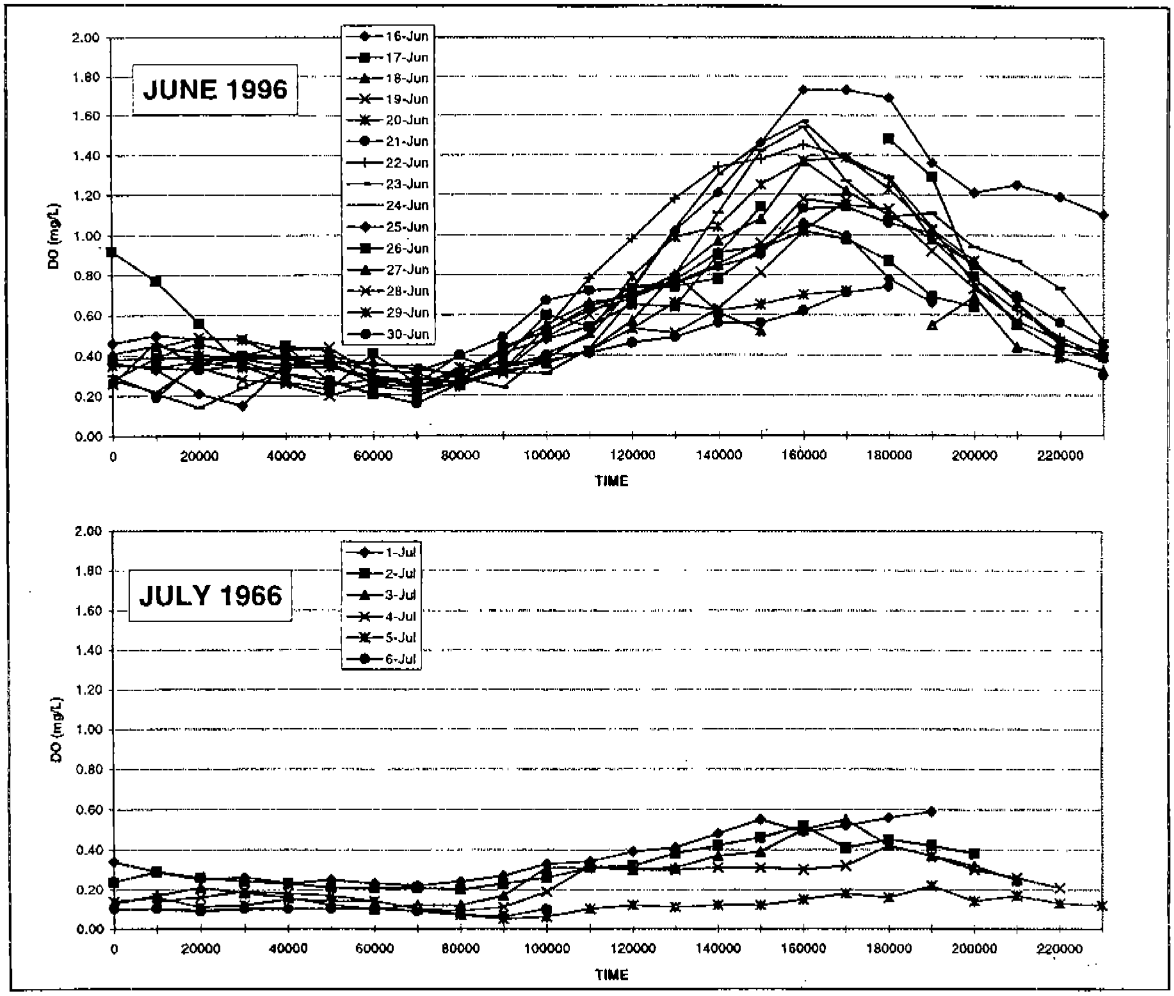

Figure 2. Hourly graphs of DO (mg/L) during June and the first week of July 1996. Note that the daylight maximum DO is less than 1.8 mg/L. The near-dawn sag is well below 0.5 mg/L during both June and July 1996.

None of the DO ranges of the bays listed in Table 1 are as great as that experienced in Estero Bay. The DO measurements show a range from 0.05 to 12.10 mg/L during the wet and dry seasons of 1996–1997. Lewis and Estevez (1988) state that Hillsborough Bay has the most oxygen stress of all the bays and that the DO levels violate existing state standards 60-90 days a year. Based on these conclusions, as Estero Bay DO levels exhibit a greater range and have more than 120 days a year violating state standards (>4.0 mg/L), one could conclude, based on this dissolved oxygen data, that Estero Bay may be more stressed than Hillsborough Bay, which may also account for the loss of seagrasses within the bay (Mitchell-Tapping et al. 1996).

Daytime or one-time DO sampling gives both over-optimistic values and erroneous assessments of existing water quality. Ranges based on studies of Estero Bay in 1995 and 1996 (Mitchell-Tapping et al. 1996), taking one-time weekly samples at certain locations in the bay and offshore Lovers Key in the Gulf of Mexico, are shown in Table 2. However, using a continuous recording device, programmed for hourly sampling over the seagrass meadow in the central portion of the bay, measurements show DO ranges from 0.05 to 11.91 mg/L during the 1996 wet

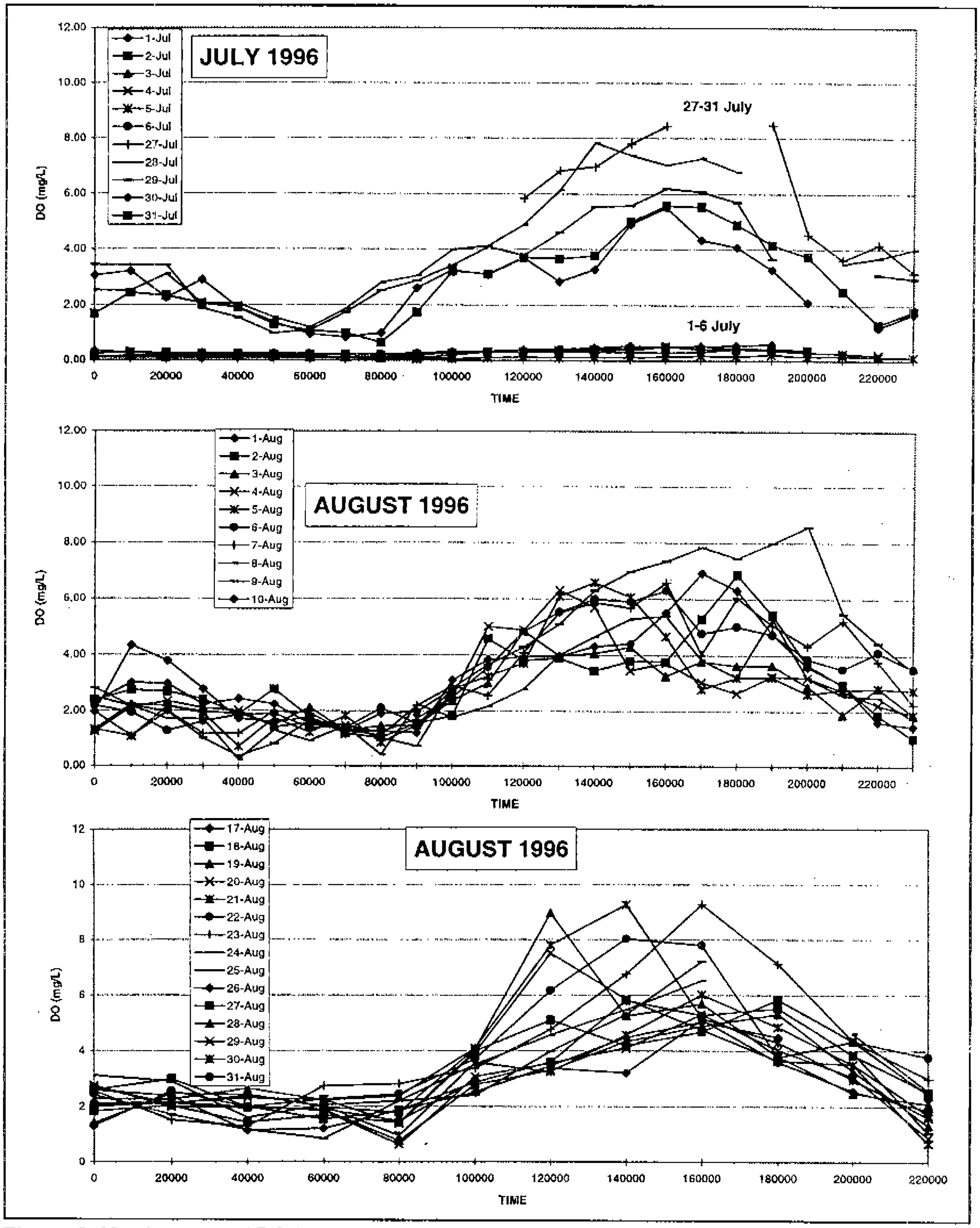

Figure 3. Hourly graphs of DO (mg/L) during July 27–31, compared to July 1–6, and August 1996. Note the daytime maximum DO is now increasing to greater than 8.0 mg/L. The rapid increase of DO to above the FDEP minimum of 4.0 mg/L has probably occurred about the 20th July, during the recovery and recalibration time of the instrument. The near-dawn sag, although increasing from previous months, is well below 2.0 mg/L, but rises above this value in late August.

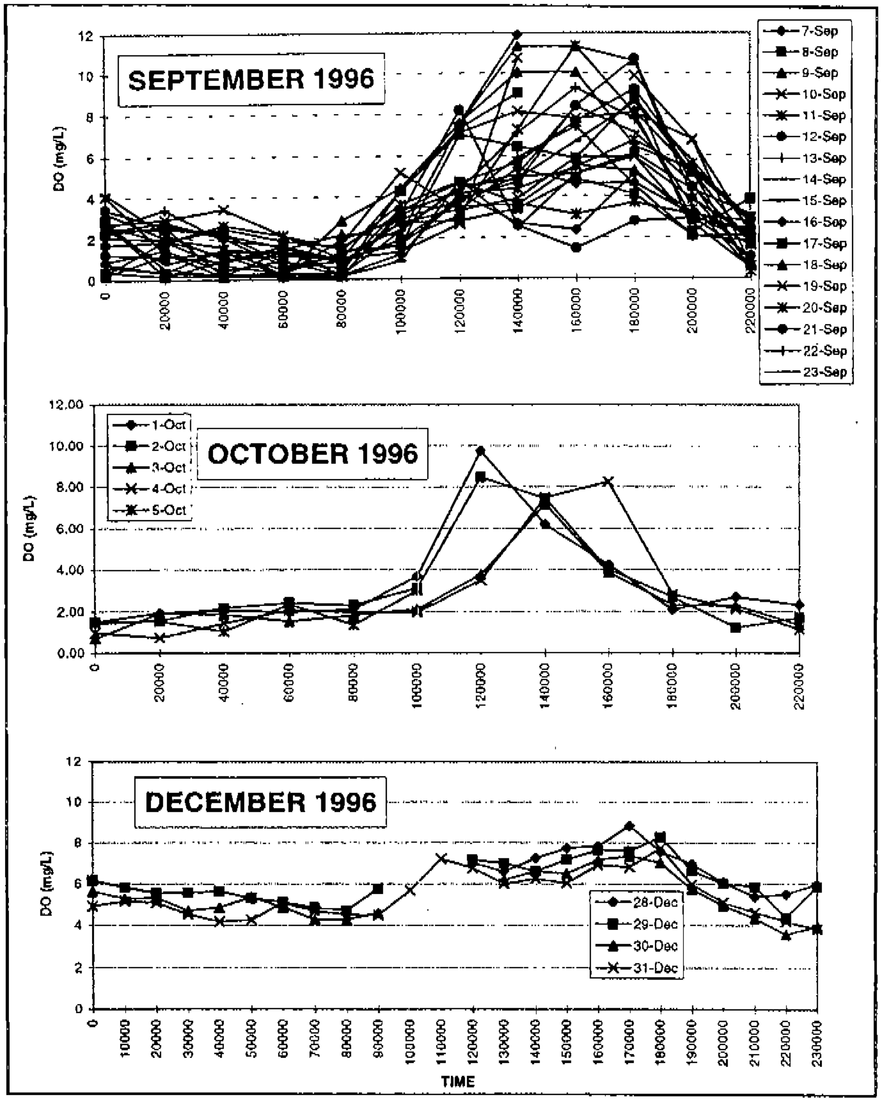

Figure 4. Hourly graphs of DO (mg/L) during September and some days in October and December 1996. Note the daytime maximum DO is now increasing to greater than 10.0 mg/L in September, but is starting to decrease in October and December. The near-dawn sag is increasing to about 2.0 mg/L in October, but increasing in late December to over the FDEP minimum.

season, and 2.07 to 12.10 mg/L during the 1996–67 dry season. From these measurements, it can be seen that the one-time daytime sampling cannot take into account near-dawn sags or daytime high DO concentrations which are the most important indicator of the health of the bay. However, it is possible to extrapolate, by using the developed hourly curves and the time of the sampling, to obtain the correct minimums and maximum DO concentrations.

Charts were also constructed to show the effect of rainfall precipitation on DO (mg/L) during the 1996 wet season. An analysis shows that heavy rainfall appears to have only a dampening effect on dissolved oxygen production (Fig. 7) over the seagrass beds and this may be due to a lowering of temperature and increase of cloud cover during rain storms.

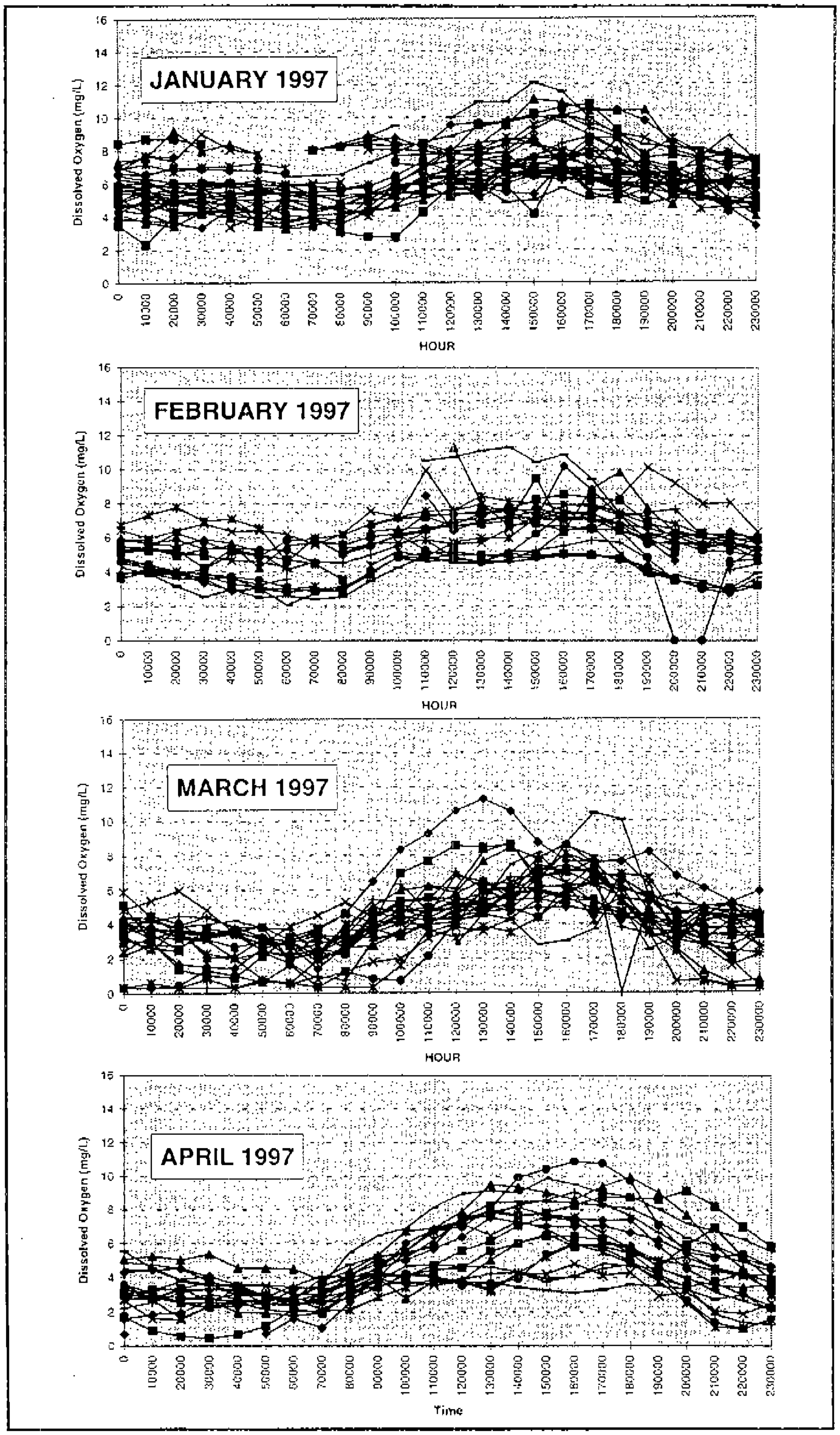

Figure 5. Hourly graphs of DO (mg/L) during January, February, March, and April 1997. Note the daytime maximum DO is now decreasing to less than 8.0 mg/L. The near-dawn sag is for a few days above 4.0 mg/L in January and February, but decreasing below 4.0 mg/L by April 1997.

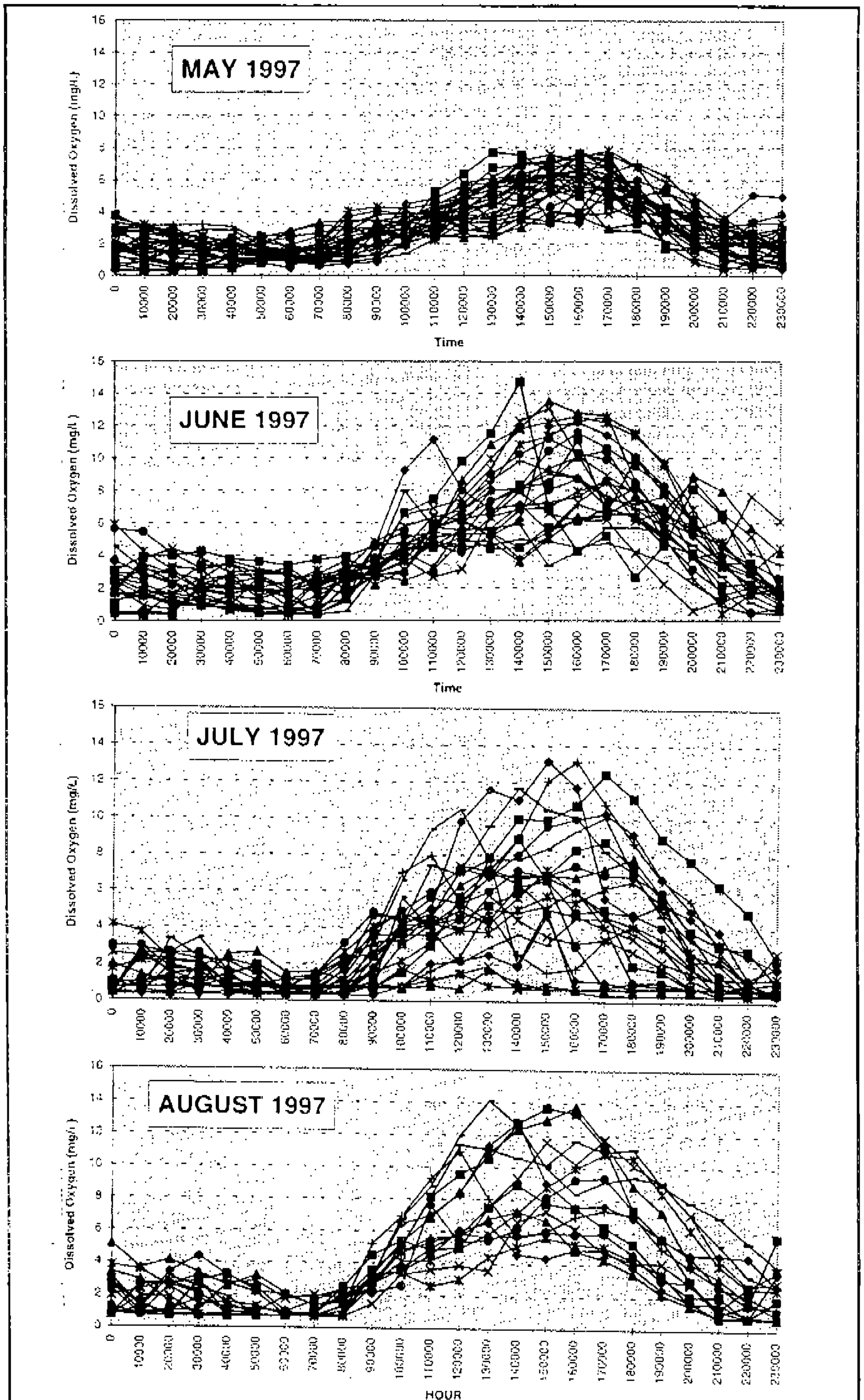

Figure 6. Hourly graphs of DO (mg/L) during May, June, July, and August 1997. Note the daytime maximum DO is now increasing to greater than 12.0 mg/L. The near-dawn sag, however, is decreasing to below 2.0 mg/L by the end of August 1997.

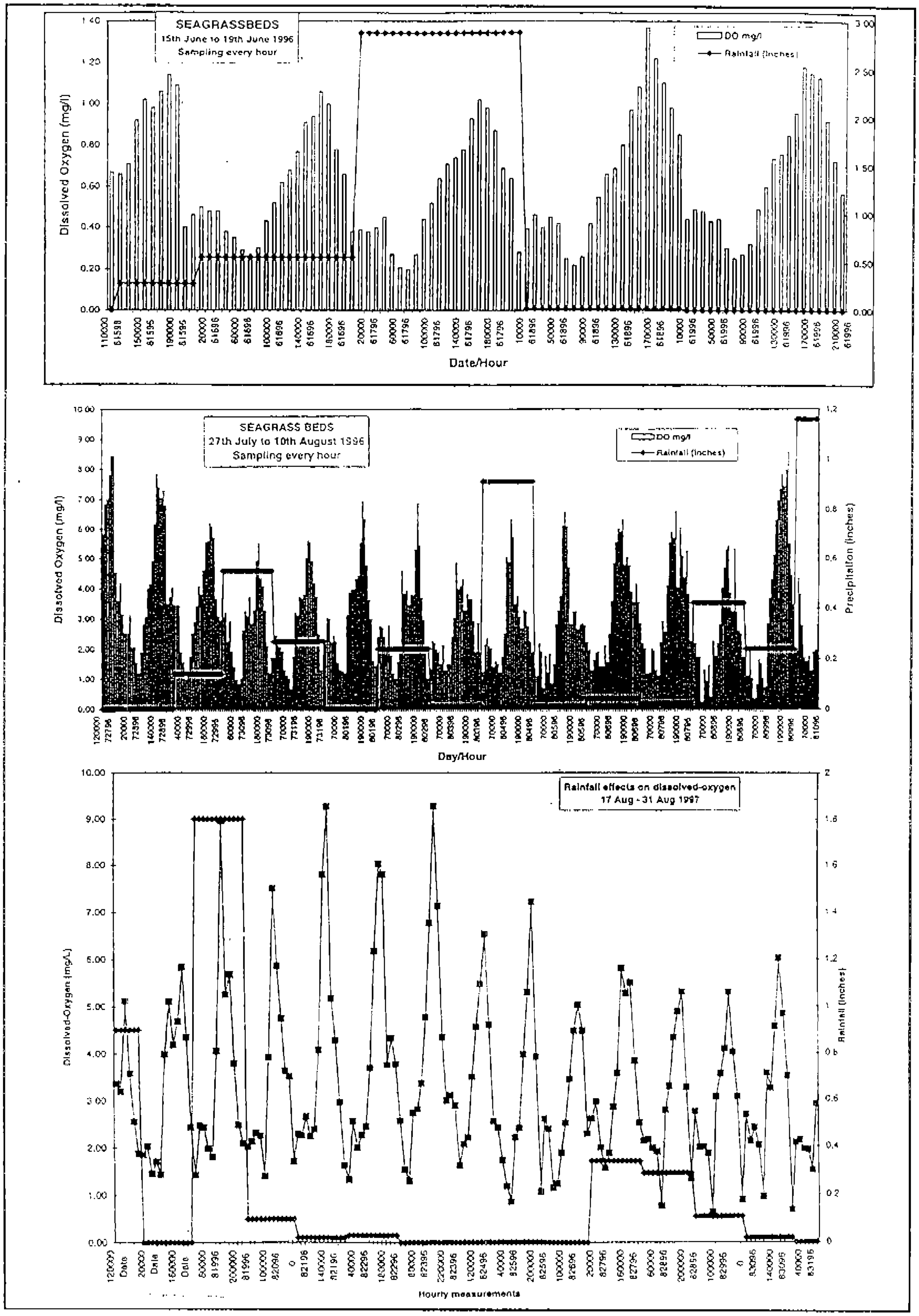

Figure 7. Charts of the effect of rainfall precipitation on DO (mg/L) during the 1996 wet season. Note the DO mg/L maximum scale value in each chart. It is interpreted that rainfall may have only a very slight dampening effect on the DO concentration.

Table 1. Florida west coast bay ranges of dissolved oxygen (mg/L).

LOCATION	RANGE (mg/L)
Hillsborough Bay	0.9–11.6
Old Tampa Bay	2.7–10.6
Upper Tampa Bay	1.1–8.1
Lower Tampa Bay	1.4–8.5
Boca Ciega Bay	1.6–10.6

Table 2. Single daytime dissolved oxygen (mg/L) measurements.

LOCATION	RANGE (mg/L)
Gulf at Lovers Key 1995–96 dry season	6.75–9.61
Gulf at Lovers Key 1995 wet season	4.13–9.08
Gulf at Lovers Key 1996–67 dry season	5.23–8.11
Gulf at Lovers Key 1997 wet season	4.37–7.61
Estero Bay 1995 wet season	2.82–8.14
Estero Bay 1995-6 dry season	5.42–9.74
Estero Bay 1996 wet season*	4.00–6.69
Estero Bay 1996–67 dry season*	4.48–8.77

*Mitchell-Tapping et al., (1997)

CONCLUSIONS

Usually waters with dissolved oxygen concentrations of 5.0 mg/L or higher can support a well-balanced, healthy biological community. However, some species cannot tolerate even slight depletion in DO, and when concentrations fall below this level the result is often a complete alteration of the biocommunity and ecosystem structure. The DO (mg/L) continuous recordings in Estero Bay show DO levels that range from 0.05 to 12.10 mg/L during the wet and dry seasons of 1996–1997, and show that more than 120 days a year violating state standards (>4.0 mg/L). From this data, it would appear that Estero Bay may be more stressed than Hillsborough Bay. This stress may account for the loss and changes in seagrass within Estero Bay over the last 24 years.

Near-dawn DO sags are probably the most important water quality variable affecting both the general health of the bay and species abundance and diversity. Daytime or one-time sampling gives both over-optimistic values and erroneous assessments of existing water quality. If continuous recording devices are not readily available, then hourly 24-hour DO curves should be constructed for each month of the year and then the daytime or one-time values can be plotted on the curves to determine by extrapolation the near-dawn DO sags for water quality evaluation.

Although this hourly diel study is still ongoing, further future investigations are considered necessary to determine the effects of sunlight and how and why naturally high productivity might affect DO patterns

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