BAYWIDE ENVIRONMENTAL MONITORING REPORT 2002-2005

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Cover Photograph Sandwich Tern: Courtesy of Gerold Morrison.

BAYWIDE ENVIRONMENTAL MONITORING REPORT, 2002-2005

TAMPA BAY, FLORIDA

Tampa Bay Estuary Program, December 2006
Technical Publication # 06-06

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Anthony J. Janicki	2. Progress Towards Goals of the Tampa Bay CCMP 2002-2005	H. Greening
Holly Greening	3. Monitoring Programs in Tampa Bay	A .P. Squires and A. Poe
	4. Bay Characteristics	R. Pribble
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	Special Topic- Redesigned Water Quality Monitoring	K. Hammer-Levy
	Special Topic- Bridge Construction for Habitat Management	E. Fehrmann
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	Special Topic- Wastewater Spills	A. P. Squires and K. Hackett
	8. Seagrass Monitoring: Aerial Photography	K. Kaufman
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	Special Topic- Oyster Reefs	C. Sutton, P. Clark, and K. Sanderson
	Special Topic- Dredged Hole Habitat Study	L. M. Cross
	11. Sediment Contaminants and Benthic Assemblages in the Lower Hillsborough, Palm, Alafia and Little Manatee Rivers	S. Grabe and D. J. Karlen
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Holly Greening, (Tampa Bay Estuary Program)

Effective monitoring is essential for a successful bay restoration effort. Communities must have a way to measure return on investment, assess progress towards restoration and protection goals and fine-tune priorities as needed. The Tampa Bay Baywide Environmental Monitoring Program is implemented by a number of the Tampa Bay Estuary Program partners and other entities, and builds upon existing monitoring data to more clearly assess progress in the bay's recovery. In addition to measuring laboratory standards for water quality, the monitoring program for Tampa Bay also seeks to measure the condition and diversity of bay habitats and the animals that inhabit them.

The baywide monitoring program is not run by one agency, but is a combined effort of Manatee and Pinellas counties, the Environmental Protection Commission of Hillsborough County (EPCHC), the City of Tampa, the Florida Department of Environmental Protection (FDEP), the Fish and Wildlife Research Institute of the Florida Fish and Wildlife Conservation Commission (FWC-FWRI), the Southwest Florida Water Management District (SWFWMD), Tampa Bay Water, the United States Geological Survey (USGS), and Audubon of Florida. Continuous coordination between the various monitoring entities participating in this combined effort is therefore essential. Coordination for the water and sediment/benthic quality element of the program is accomplished through the Regional Ambient Monitoring Program (RAMP), which was initiated by the TBNEP in 1992, but is now coordinated by the local governments who run the monitoring programs. Regional coordination of seagrass monitoring is also run by local governments.

THE TAMPA BAY BAYWIDE ENVIRONMENTAL MONITORING REPORT

The purpose of the Baywide Environmental Monitoring Report is to summarize the results of key monitoring programs that have been implemented in the Tampa Bay region. The report is intended to be updated every few years, so that each new edition will include long-term trends while emphasizing changes during the reporting period. As an essential element of the TBEP approach, well-designed monitoring programs provide information needed to assess resource status and to ascertain any trend response from implemented management actions. Therefore, technically sound monitoring programs are critical to objectively assess the effectiveness of management decisions, and to evaluate the return on investments allocated to protect and enhance bay resources.

Report Contents

This report includes a synopsis of Tampa Bay and its watershed. The background information providing in the first three chapters is followed by more specific information and data depicting temporal and geographical trends of important ecological components. These include the following:

- Salinity and freshwater inflows;
- Nutrient loadings;
- Water quality;
- Seagrass coverage and condition;
- Benthic habitats;
- Sediment quality and benthic assemblages;
- Fisheries; and
- Bird populations.

The final chapter includes the synthesis and conclusions from monitoring programs presented in this report.

The 2002-2005 Tampa Bay Baywide Environmental Monitoring Report is the fourth BEMR in the series, and follows reports covering the years from 1992-1993, 1993-1998, and 1998-2001. All reports are available in electronic format from the Tampa Bay Estuary Program (www.tbep.org).

PROGRESS TOWARDS WATER AND SEDIMENT QUALITY AND HABITAT GOALS FOR TAMPA BAY RESTORATION AND PROTECTION: 2002-2006

H. Greening (Tampa Bay Estuary Program)

In 1996, the local, state and federal partners of the Tampa Bay National Estuary Program (now the Tampa Bay Estuary Program) adopted the Tampa Bay Master Plan for the protection and restoration of the natural resources of Tampa Bay (TBNEP 1996). Recognizing that the establishment of clearly defined and measurable goals is crucial for a successful resource management effort, an Interlocal Agreement was signed by the TBEP partners in 1998, which included specific goals and targets to address priority issues (TBNEP 1998).

Evaluation of goals and targets for water and sediment quality, bay habitats, fish and wildlife, dredged material management, spill prevention and response, and a new action plan addressing invasive species generally shows progress in most cases. However, reaching goals will require the continuation of a strong scientific base, cooperation among scientists and bay managers, and dedication and commitment from all stakeholders. Progress towards specific goals water and sediment quality and habitat are summarized here, for the time period through 2006.

Seagrass, water quality, and nitrogen reduction targets: 2006 Update

In 1996, the TBNEP Management Conference adopted a minimum goal of increasing the current Tampa Bay seagrass cover to 95% of that present in 1950, to a total of 38,000 acres baywide (TBNEP 1996).

Between 1988 and 1996, seagrass acreage increased at a rate of 200-300 acres per year. El Niño rains and associated decreased water clarity and salinity in 1998 resulted in seagrass losses of about 2,000 acres baywide between 1996 and 1999. In January 2002, seagrass acreage increased by 1,237 acres baywide, a 5% increase from 1999. Between 2002 and January 2004, seagrass increased by an additional 946 acres baywide (Tomasko et al. 2005). The 2005 seagrass goal includes the protection of the existing 27,024 acres (2004 estimate) and restoration of an additional 10,976 acres (Figure 1).

The TBEP and its partners have also adopted chlorophyll *a* targets for Tampa Bay based on the light requirement of the seagrass species *Thalassia testudinum* (turtlegrass) (Janicki and Wade 1996; Greening and Janicki 2006). The average annual chlorophyll *a* targets for each major bay segment are:

Old Tampa Bay	8.5 *ug*/L
Hillsborough Bay	13.2 *ug*/L
Middle Tampa Bay	7.4 *ug*/L
Lower Tampa Bay	4.6 *ug*/L

Light attenuation goals are to maintain a minimum of 20.5% light to depths where seagrass occurred in 1950 for seagrass recovery in each bay segment (Janicki et al. 2000).

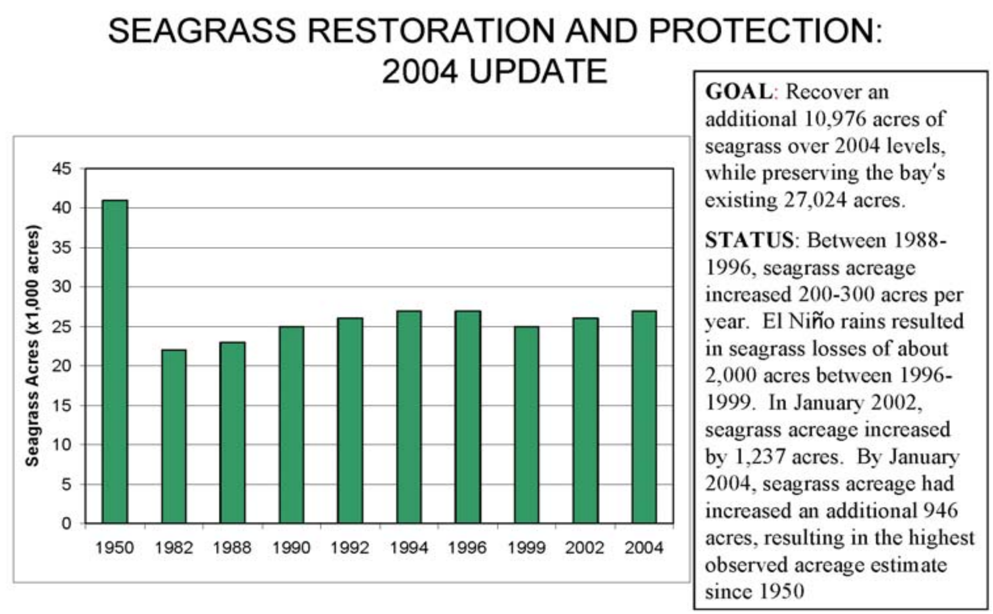

Figure 1. Seagrass cover (acres) in Tampa Bay, 1950 through 2004. (Data source: Southwest Florida Water Management District SWIM Department).

Average annual chlorophyll *a* concentrations for each bay segment show that all four major bay segments continue to show long-term improvements, and met targets in most years since 1986 (Figure 2). As expected, targets were not met in any of the segments during the heavy rainfall El Niño years in 1995 and 1998. Old Tampa Bay did not meet chlorophyll *a* or light attenuation targets in the years 2003-2004, prompting initiation of a special study investigation in this segment in 2004. Lower Tampa Bay did not meet chlorophyll *a* targets in 2005 (Figure 3), but did meet the light attenuation target (Janicki Environmental, Inc. 2006).

Based on modeling results, it appears that light and chlorophyll levels can be maintained at necessary levels by "holding the line" at average annual nitrogen loadings estimated for 1992-1994 (Janicki and Wade 1996; Greening and Janicki 2006). However, given the 20% increase in the watershed's human population and associated increases in nitrogen loading that are projected to occur over the next 10-20 years, an average annual reduction of 17 tons, starting in 1995, is needed to offset expected increases and maintain loadings at 1992-1994 levels (Janicki and Wade 1996; Greening and Janicki 2006). The annual reduction goal is 84 tons reduced from 1995 levels (TBNMC 1998).

To address the long-term management of nitrogen sources, a Nitrogen Management Consortium of local electric utilities, industries and agricultural interests, as well as local governments and regulatory agency representatives, has developed a Consortium Action Plan to address the target load reduction needed to "hold the line" at 1992-1994 levels. Implemented and planned projects collated in the 1995-1999 and 2000-2005 Consortium Action Plan met and exceeded the agreed-upon annual nitrogen loading reduction goal in 2000 of 84 tons, with an estimated annual reduction of 134 tons in 2000 (Greening and DeGrove 2001) and 108 tons in 2005 (TBEP, unpublished data).

Atmospheric Deposition: 2006 Update

Current estimates indicate that 25-30% of the total nitrogen load to Tampa Bay is contributed by atmospheric deposition (rainfall and dryfall) directly to the bay's surface (Pribble and Poor 2004). Another 10 -20% is contributed from atmospheric deposition falling in the watershed, and washed to the bay in stormwater (Pollman et al. 2004).

Sources of nitrogen in atmospheric deposition contributing to nutrient loading to Tampa Bay are split between those generated within the watershed (65%) and those outside the Tampa Bay region (Pribble and Poor 2004) . Preliminary results from NOAA's Regional Atmospheric Deposition Model (Dennis 2003) indicate that the nitrogen airshed for Tampa Bay includes all of Florida and north almost to Atlanta.

Preliminary modeling results and data also suggests that, although mobile sources (such as automobiles, trucks, and buses) contribute approximately 35% of the nitrogen emissions in the Bay area, they contribute more than 50% of the atmospheric nitrogen deposited on the bay and watershed (N. Poor, pers. comm; Pribble and Poor 2004).

Benthic Quality: 2006 Update

The Tampa Bay Sediment Quality Assessment Group (SQAG) met for a number of years to develop numerical targets for measuring the condition of Tampa Bay benthic habitats.
A Tampa Bay Benthic Index, using metrics of the benthic organism community, was developed, revised and tested, and approved by the SQAG participants in late 2003 (Malloy et al. 2007). The SQAG and TAC also endorse the development of assessment and management strategies for priority areas containing sediment contaminants in Tampa Bay.

The Tampa Bay Benthic Index scores indicate that most of Tampa Bay remains "healthy", with the exception of areas around the Port of Tampa, mouth of the Hillsborough River, near the St. Petersburg/Clearwater Airport, Bayboro Harbor/Port of St. Petersburg, and Apollo Beach/Big Bend. The SQAG and Tampa Bay Estuary Program Technical Advisory Committee participants identified those sites as priority areas for development of action plans, scheduled for development in 2007.

Habitat Restoration and Protection: 2006 Update

Significant progress has been made in restoring the historic balance of coastal habitats in Tampa Bay, a key goal of the estuary program's bay management blueprint. This strategy reflects efforts to provide a mosaic of habitats to support wildlife that rely on different habitats at various stages in their life cycles (Henningsen 2004; Lewis and Robison 1995). The concept of restoring an optimum balance of habitats continues to have important implications for Tampa Bay and other areas. Historically, habitat restoration and land acquisition have been largely opportunistic ventures, with agencies and

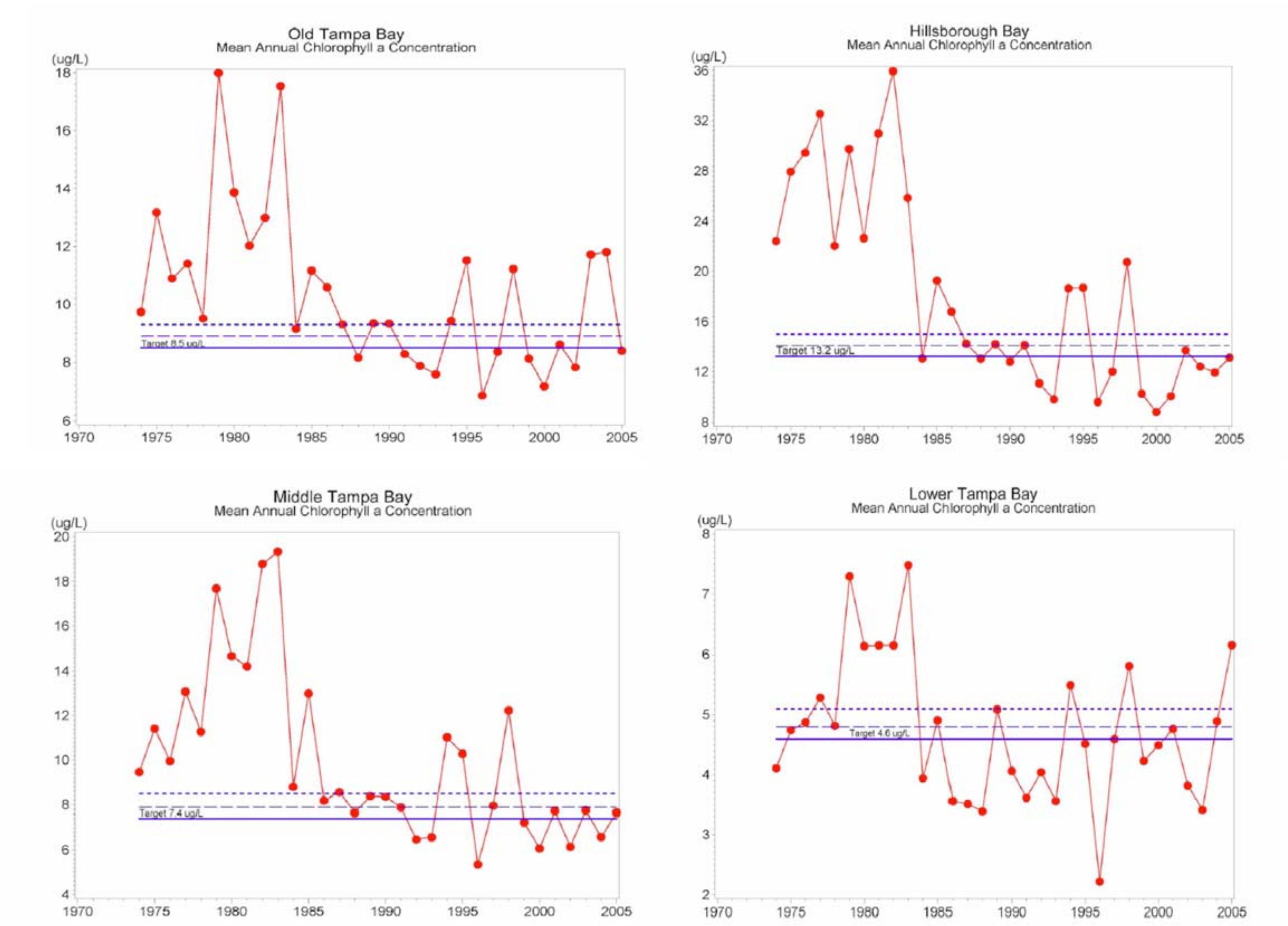

Figure 2. Average annual chlorophyll *a* concentrations (*u*g/l) for major bay segments. Solid line indicates target concentration, and dashed line indicates $\pm$ 2 S.D. (Data source: Environmental Protection Commission of Hillsborough County).

Year	Old Tampa Bay	Hillsborough Bay	Middle Tampa Bay	Lower Tampa Bay
1975	Red	Red	Red	Green
1976	Red	Red	Red	Yellow
1977	Red	Red	Red	Red
1978	Red	Red	Red	Yellow
1979	Red	Red	Red	Red
1980	Red	Red	Red	Red
1981	Red	Red	Red	Red
1982	Red	Red	Red	Red
1983	Red	Yellow	Red	Red
1984	Red	Green	Red	Yellow
1985	Red	Red	Red	Yellow
1986	Red	Yellow	Red	Green
1987	Red	Yellow	Red	Green
1988	Yellow	Green	Yellow	Green
1989	Red	Yellow	Red	Yellow
1990	Red	Green	Red	Yellow
1991	Green	Yellow	Yellow	Yellow
1992	Yellow	Green	Yellow	Yellow
1993	Yellow	Green	Yellow	Yellow
1994	Yellow	Yellow	Red	Red
1995	Red	Yellow	Red	Yellow
1996	Yellow	Green	Yellow	Green
1997	Yellow	Green	Red	Yellow
1998	Red	Red	Red	Red
1999	Yellow	Green	Yellow	Yellow
2000	Green	Green	Yellow	Yellow
2001	Yellow	Green	Yellow	Yellow
2002	Yellow	Green	Green	Green
2003	Red	Yellow	Green	Yellow
2004	Red	Green	Green	Yellow
2005	Green	Green	Yellow	Yellow

Figure 3. Results of the Decision Matrix over the period of record, 1975-2005, for the four major bay segments (Source: Janicki Environmental, Inc. 2006).

communities purchasing and restoring what was most readily available or visibly connected to the bay. That approach helped build awareness of the environmental plight and needs of the bay at a time when that was most critically needed.

In recent years, the focus shifted to providing a mosaic of habitat types within a given project to maximize the benefits to fish and wildlife. The TBEP partners took this concept a step further by developing restoration and protection goals based on the needs of key wildlife guilds or groups that share common habitat and feeding preferences. These efforts have helped drive important gains in critical habitats that might otherwise have been overlooked.

Restoration of low-salinity habitats was given highest priority in the estuary program's Master Plan for Habitat Restoration and Protection because these habitats have declined faster than others, imperiling the species that depend on them (Lewis and Robison 1995; TBNEP 1996).

As reported by TBEP partners, nearly 380 acres of oligohaline habitat was restored from 1995 to 2003, far exceeding the initial goal which was to restore 100 acres every five years. That's roughly one-fifth of the long-term restoration goal of 1,800 acres of low-salinity tidal marsh, areas that are vital to the survival of juvenile snook and mullet and numerous wading birds. TBEP partners documented a total of 2,357 acres of estuarine habitat restoration between 1996 and 2003 (Figure 4).

recent research results have indicated that water quality and restoration goals and targets for tidal rivers, streams and creeks may be different than those for open waters of the Bay. A new initiative to address tidal rivers and streams is scheduled for 2005-2007.

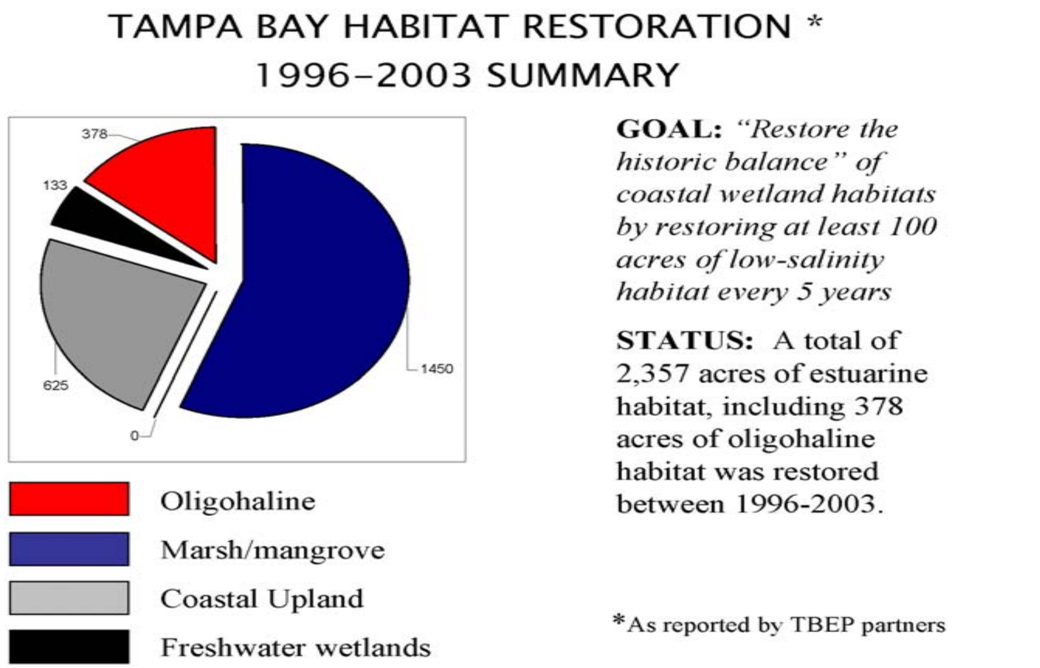

Figure 4. Estuarine habitat restoration (acres) in Tampa Bay and its watershed by type, 1995-2003. Information sources: SWFWMD, FDEP, EPCHC, counties of Hillsborough, Manatee and Pinellas, cities of St. Petersburg, Clearwater and Tampa.

More than 60% (1450 acres) of the total restored acres were marsh/mangrove, and 27% (625 acres) were coastal uplands.

Critical habitats not included in the 1995 Bay Habitat Master Plan are hard bottom habitats, both submerged and oyster bars. These important habitat types will be included in the Master Plan update, currently being finalized. In addition,

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Amy Poe (Janicki Environmental, Inc.)

WHY MONITOR?

The environmental monitoring of Tampa Bay's waters is important to a wide range of interests, from recreational boaters, fisherman, and swimmers, to commercial fisherman, government environmental managers, scientists, and politicians. Monitoring information can provide information:

- to evaluate pollution abatement actions;
- to serve as an early warning system, to obviate higher-cost solutions to environmental problems;
- to help answer simple questions, for example, about the safety of swimming or consumption of fish and shellfish;
- for support of environmental quality standards developed by environmental managers and regulators; and
- to determine compliance with permit conditions.

TBEP MONITORING PROGRAMS

In recognition of the importance of monitoring for the above listed reasons and for the successful implementation of the Comprehensive Conservation and Management Plan (CCMP), the TBEP funded two projects aimed at designing a basinwide monitoring program for Tampa Bay. The first project encompassed two reports, the *Compendium of Current Monitoring Programs in Tampa Bay and its Watershed* (TBNEP Tech. Publ. #02-92), and the *Design of a Basinwide Monitoring Program for Tampa Bay* (TBNEP Tech. Publ. #09-92). The second project, documented in a report entitled *A Monitoring Program to Assess Environmental Changes in Tampa Bay, Florida* (TBNEP Tech. Publ. #02-93), developed recommendations to local governments for specific monitoring designs.

The primary developments from the first project were the establishment of overall monitoring program goals and the definition of specific monitoring program objectives. This first project laid the groundwork for subsequent monitoring designs by:

1) identifying existing monitoring programs in Tampa Bay and its watershed,
2) defining monitoring program goals and objectives,
3) identifying indicators and a sampling design appropriate to those objectives, and
4) identifying how existing Tampa Bay monitoring programs can be incorporated and modified to meet the agreed upon monitoring objectives.

The program was not intended to replace any existing monitoring programs, but instead provided a framework upon which existing monitoring programs could be built and identified important gaps in the existing monitoring network.

Existing Monitoring Programs

In the report on the compendium of monitoring programs, programs were grouped into three components: water quality, habitat, and living resources. Two more water quality and living resources monitoring programs were implemented recently (2000 and after) in association with the planned surface water withdrawal projects and the construction of the Tampa Bay desalination facility at Big Bend. In addition to these programs, an atmospheric deposition monitoring program began gathering data in 1996. Many of the existing water quality programs are municipal or county programs implemented to comply with point source permit requirements. Habitat and living resource components are primarily addressed through state and regional monitoring programs.

The most noteworthy water quality programs are the continuous ongoing surface water monitoring programs conducted by the Environmental Protection Commission (EPC) of Hillsborough County, Pinellas County, Manatee County, and the City of Tampa. Ambient water quality monitoring by EPC has been conducted since 1972 at 52 stations covering the Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay, and Lower Tampa Bay segments. Pinellas County and Manatee County have implemented surface water quality monitoring programs in Boca Ciega Bay and the Manatee River/Terra Ceia Bay region, respectively. In addition to these county programs, the City of Tampa has been conducting long-term surface water quality monitoring primarily in Hillsborough Bay and Middle Tampa Bay since 1976. Monitoring programs associated with the Tampa Bay desalination facility are conducted by Tampa Bay Water and the EPC. As a condition of the water use permits the Tampa Bay Water developed the Hydrobiological Monitoring Program (HBMP) which includes montoring of hydrology, water quality, biota and habitat. The Hillsborough Independent Monitoring Program (HIMP) includes synoptic surveys, moveable datasonde deployments and fixed continuous monitoring. Finally, some water quality sampling programs were conducted by the USGS associated with special projects.

The Tampa Bay Atmospheric Deposition Study (TBADS), after approval by the EPA Great Waters Program, was begun in the spring of 1995, and resulted in data collection beginning in August 1996. Data collection is continuing at this time. These data have yielded estimates of wet nitrogen and phosphorus deposition and dry nitrogen deposition to the surface of the bay, and have been utilized in a study of rainfall nutrient contributions to stormwater runoff nutrient loads. Bulk atmospheric deposition of nutrients to the bay has been estimated.

Habitat programs are conducted by federal, state, regional, and local government agencies. Habitat programs include monitoring of shoreline vegetative habitats via satellite imagery by the Florida Marine Research Institute (FMRI) of the Florida Fish and Wildlife Conservation Commission (FWC) and the National Oceanic and Atmospheric Administration (NOAA), seagrass mapping by the Southwest Florida Water Management District Surface Water Improvement and Management (SWFWMD SWIM) Program using aerial photo-interpretation, sediment toxicity studies by NOAA, and watershed characterization studies by Pinellas County. Sediment chemistry, grain size, and benthos have been monitored annually by EPC and Manatee and Pinellas counties. In addition, the HBMP and HIMP programs include habitat monitoring components.

Living resources are monitored by the FWC FMRI, NOAA, and the local chapter of the National Audubon Society. The FMRI conducts numerous programs that assess marine mammals, fisheries, and sea turtle nesting activity. NOAA has conducted special projects under their Mussel Watch and Oyster projects. Finally, Audubon's Coastal Island Sanctuaries program counts bird populations in the Tampa Bay area.

Monitoring Goals and Objectives

In the report documenting the basinwide monitoring program for Tampa Bay, two monitoring goals were selected for the TBEP:

- to measure the effectiveness of management actions and programs implemented under the CCMP, and
- to provide information that can be used to redirect and refocus the management plan over time.

Four monitoring objectives were developed after considerable discussion among members of the TBEP Technical Advisory Committee, and include:

- estimation of the areal extent and temporal trend in areal extent of habitat and water quality conditions in Tampa Bay that do not meet living resource requirements;
- assessment of the relative abundance and condition of fish populations of Tampa Bay over time;
- estimation of the areal extent and quality of seagrass, mangroves, and coastal marshes in Tampa Bay over time; and
- estimation of the areal extent and trends in areal extent of oligohaline habitat in Tampa Bay and its tributaries.

Monitoring Programs for Tampa Bay

In the second TBEP monitoring project, monitoring designs were developed to address benthic quality, scallop abundance, water quality, seagrass coverage and quality, and fish abundance. Recommended designs were developed to be consistent with the goals and objectives previously agreed upon for Tampa Bay. An important aspect incorporated into these monitoring programs was the use of a probability-based sampling design. This type of sampling design allows for unbiased estimates of abundance and areal extent of key indicator components.

The benthic quality and scallop abundance monitoring designs represented two new programs. The benthic quality program was the most important design since it filled a gap in the existing monitoring network. No long-term comprehensive program to assess the status and trends in benthic quality existed or had been undertaken in Tampa Bay. The scallop monitoring design filled the need to assess adult scallop abundance in a scientifically acceptable manner, and provided a mechanism for citizen volunteers to see Tampa Bay first-hand by assisting in evaluating population levels.

The remaining three program elements were ongoing and include water quality monitoring by local county and municipal governments, seagrass monitoring by the SWFWMD and the City of Tampa, and fisheries monitoring by the FWC

FMRI. Recommendations were made to modify and/or augment these programs in order to address the TBEP monitoring objectives.

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Report Contents

This report includes a synopsis of Tampa Bay and its watershed. The background information provided in the opening three chapters, including progress toward goals of the Tampa Bay CCMP, will be followed by more specific material depicting temporal and geographical trends of important ecological components. Components addressed include:

- Salinity and freshwater inflows;
- Nutrient loadings;
- Water quality;
- Seagrass coverage and health;
- Benthic habitats;
- Sediment quality and benthic assemblages;
- Fisheries; and
- Bird populations.

The final chapter includes the synthesis and conclusions of monitoring information previously presented.

R. Pribble (Janicki Environmental, Inc.)

INTRODUCTION

This chapter discusses the various influences on the ecological health of the Tampa Bay estuarine system. The status of the ecosystem is determined by physical and chemical factors. Meteorological conditions in the area influence the amount of water draining to the bay from its watershed, and the distribution and flow patterns of water masses in the bay. Characteristics of the watershed are in part responsible for both the quality and quantity of freshwater entering the estuary, and the physical characteristics of the bay determine the movement of water in the bay.

Associated with the water masses in Tampa Bay are physical and chemical characteristics that impact the range and health, both in time and space, of habitats within the ecosystem. Drainage from the watershed carries nutrient, suspended sediment, and toxic loads, as determined by various characteristics of the watershed. Saltwater from the Gulf of Mexico also contains chemicals and sediments, and the combination of the loads carried by the saltwater and freshwater masses determines the types of biological communities in the ecosystem. Circulation patterns, flushing and exchange rates, temperature, nutrient, and salinity distributions, and sedimentation are all related to the physical structure of Tampa Bay, and the locations of biological communities are influenced by some or all of these.

Water column communities are adapted to certain ranges of nutrients, salinity, temperature, dissolved oxygen, and light conditions. The health of submerged aquatic vegetation depends on the light environment and conditions on the bottom of the bay. The health of benthic ecosystems depends on sediment conditions, food supply, and oxygen availability. All of these are determined by the interactions of the physical/chemical properties in water masses and the movement of these water masses, which are ultimately determined by the characteristics of the watershed and the bay's physical structure.

PHYSICAL SETTING

Tampa Bay is on the west central coast of Florida between 27.5^{o} and 28^{o}N latitude (Figure 4-1). The land surrounding the bay is relatively flat, and the subtropical climate is mild. The average annual temperature is around 22^{o}C (72^{o}F). The low topography allows an unimpeded path for winds and rains to move across the area. The proximity of the Gulf of Mexico tends to moderate temperatures, with the water acting as a heat sink in the summer and a heat source in the winter.

The Tampa Bay area receives an average of 140 cm (55 inches) of precipitation each year, with approximately 30% of this falling during November through April. Approximately 60% of the annual rainfall occurs during June through September as the result of thunderstorms. These thunderstorms are often caused by differences in heating rates between the land and nearby water. Local variations in precipitation can be very high, as these thunderstorm systems are often not large. This wet-season rainfall results in higher freshwater input to the bay during the summer.

Wind characteristics are determined by the interaction of long- and short-term wind patterns. Long-term wind patterns result from large-scale atmospheric features, such as the Atlantic high-pressure system that drives winds from the south and southeast over the Tampa Bay watershed in the summer months. During the wet season, sea breeze convective winds interact with the winds from the south produced by the high-pressure system. Wind speeds associated with the sea breeze convection are normally strongest along the coast and weaker inland, with short-term wind speeds of 22-31 mph resulting from a thunderstorm. Wind speeds resulting from the sea breeze convection increase during the day, peak in late afternoon, and decrease in the evening.

During the dry season (November-April), sea breeze convection lessens as less heating occurs. Wind patterns during these months are influenced by frontal systems moving through the area, bringing colder air with them. Winter cold fronts normally affect the Tampa Bay area about once a week, with winds over the duration rotating through 360 degrees. Maximum wind speeds at the leading edge of the front are from the southwest, and may be as high as 45-58 mph, although generally these maximum wind speeds are about 18 mph.

Winds affect the general circulation of the Tampa Bay estuary, as well as the magnitude of the tides. Winds from the northeast associated with the passage of frontal systems over the fall-winter period result in a lowering of mean sea level by several inches, as well as lower water temperatures in the bay. Winds blowing into the bay along the bay's axis (from the south/southwest) result in an increase of mean sea level, and produce non-tidal currents from the middle to the bottom of the water column directed out of the bay within the deep channel, with return flow nearer the surface and along the sides. When winds blow in the opposite direction, the converse occurs.

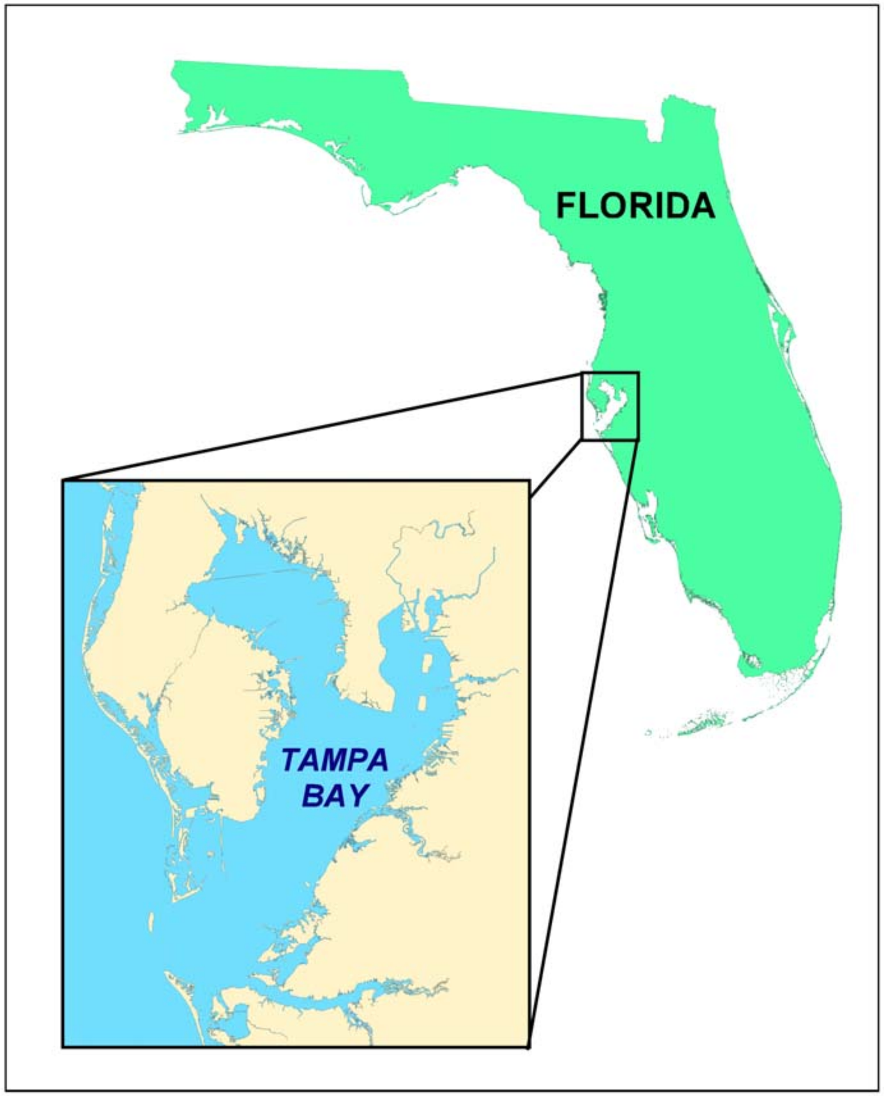

Figure 4-1. Location of the Tampa Bay estuarine system.

Severe freezes occur about once every 20 years, and relatively non-destructive freezes occur about once or twice a year. Severe freezes are more likely inland, where the distance from the waters of the gulf and bay results in less protection than for coastal areas.

During the summertime (wet season), air temperatures rise to 35-37°C (mid- to upper-90°s F) in the area of developing thunderstorms, then drop rapidly by 5-17°C (9-31°F) just prior to a downpour. In the Tampa Bay region, especially inland, temperatures of 32°C (90°F) or greater occur an average of 100 days each year.

Tropical storms and hurricanes introduce unique climatic characteristics and conditions affecting local ecosystems. The Tampa Bay watershed is most likely to be hit by a tropical storm/hurricane in September and October. Associated with these systems is a storm surge, the result of high winds and low barometric pressure. The highest storm tide recorded in Tampa Bay was 4.5 m (15 feet) in 1848. Rainfall from these systems is normally 12-25 cm (5-10 inches) over the period of storm passage, with more than 30 cm (12 inches) of rain in 24 hours in 1960 as Hurricane Brenda struck the bay area.

WATERSHED DESCRIPTION

The Tampa Bay watershed, or drainage basin, covers approximately 5,950 km^2 (2,300 mi^2) (Figure 4-2). The watershed includes all or parts of Pasco, Pinellas, Hillsborough, Polk, Manatee, and Sarasota counties. Approximately five percent of the watershed is internally drained, and does not contribute to runoff except in rare instances. For the purposes of better delineating runoff sources, the watershed is divided into ten major basins. These major basins correspond to the drainage areas of the four major rivers (Hillsborough, Alafia, Little Manatee, and Manatee) and the six ungaged drainage basins (Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay, Lower Tampa Bay, Boca Ciega Bay, and Terra Ceia Bay).

The ten major drainage basins provide freshwater inflow to seven Tampa Bay segments. Two of these seven major segments' watersheds are made up of more than one drainage basin. The watershed of the Hillsborough Bay segment is composed of the Coastal Hillsborough Bay basin (7% of the entire Tampa Bay drainage basin), the Hillsborough River basin (26% of the entire watershed), and the Alafia River basin (14% of the entire watershed). Similarly, the Middle Tampa Bay segment watershed is made up of the Coastal Middle Tampa Bay basin (7% of the entire watershed) and the Little Manatee River basin (9% of the entire watershed). Even further subdivision of the watershed into 435 subbasins has been made by the TBEP, building on earlier work by the USGS.

The watershed contains various sources of runoff which deliver freshwater and the associated nutrients and pollutants to the Tampa Bay estuarine system. These sources are divided into nonpoint sources, atmospheric deposition (directly to the open water of the estuary), point sources (domestic, industrial, and springs), groundwater, and septic tank leachate and wastewater residual solids.

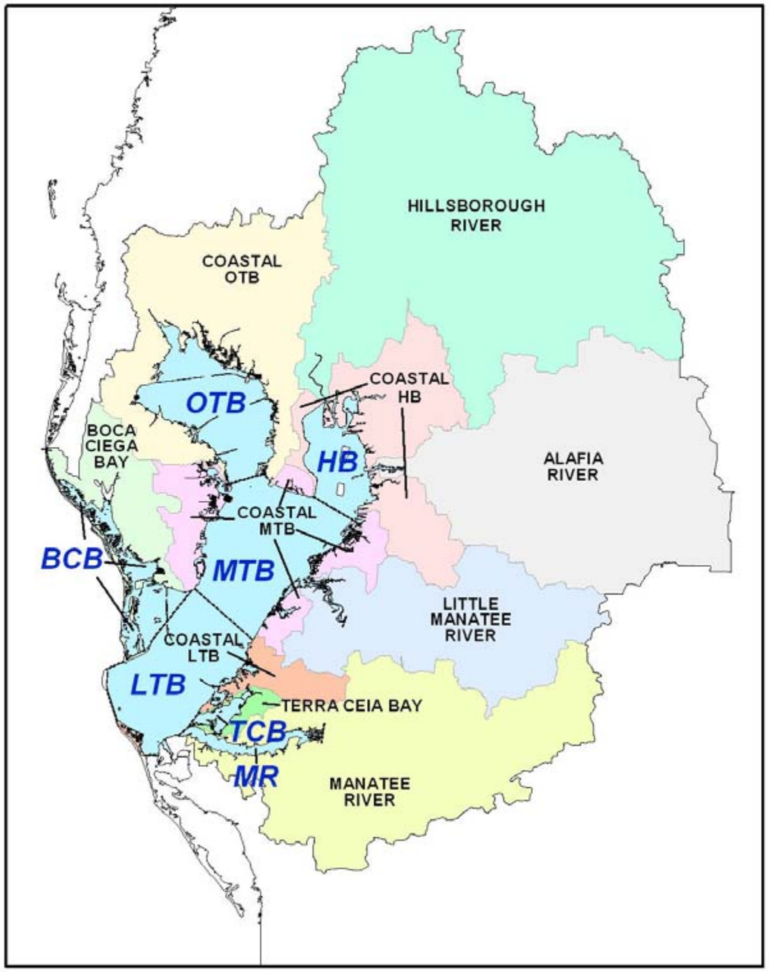

Figure 4-2. The Tampa Bay estuary with the ten major drainage basins of the watershedand the seven bay segments of Tampa Bay (OTB-Old Tampa Bay; HB-Hillsborough Bay; MTB-Middle Tampa Bay; LTB-Lower Tampa Bay; BCB-Boca Ciega Bay; TCB-Terra Ceia Bay; MR-Manatee River).

Nonpoint sources include stormwater runoff, base flow, and direct overland flow. The Little Manatee, Hillsborough, Alafia, and Manatee rivers, as well as the Lake Tarpon Outfall and the Tampa Bypass Canal, are all nonpoint sources of freshwater inflow. Wetlands may also contribute, depending on the season.

Also contributing as a source of freshwater, nutrients, and pollutants is rainfall directly on the various bay segments. Dry deposition of nutrients and pollutants may occur in the absence of rainfall. Atmospheric nutrients are mainly supplied by industries and automobiles, with natural sources of atmospheric nutrients believed to be less significant.

Point sources are comprised of domestic, industrial, and spring discharges. Point sources contribute discharge through either direct surface discharge, to surface water bodies such as streams, creeks, rivers, or bay waters, or through application to land, as in discharge to a settling pond or to an irrigation system. Important springs in the Tampa Bay watershed are Crystal Springs, Sulphur Springs, Buckhorn Springs, and Lithia Springs.

Groundwater inflows occur from the water table, intermediate, and Floridan aquifers, and may enter the bay from the shoreline or bay bottom. Septic tank leachate and wastewater residual solids are of special concern as nutrient and pollutant sources in areas with high concentrations of septic tank systems near bay waters.

The Tampa Bay watershed's four major tributaries, in conjunction with more than 40 creeks and coastal streams, strongly influence the Tampa Bay estuary, providing freshwater to mix with the saline waters of the bay. This mixing of freshwater and saltwater influences both physical and biological aspects of the Tampa Bay estuarine system.

Runoff from the Tampa Bay watershed is affected by various factors, including topography, soils distribution, hydrogeology, land use, and rainfall. The main factor impacting runoff patterns is land use. As urbanization increases, activities that affect surface hydrology occur: canals are dug, tributaries are straightened, reservoirs are built, and land surface is paved over.

For estimating nonpoint source flows and pollutant loads, land use in the Tampa Bay watershed was divided into four major categories: urban, agricultural, wetlands, and other undeveloped lands. In 1995, urban lands accounted for approximately 33% of the watershed area, with agricultural, wetlands, and other undeveloped lands making up approximately 39%, 18%, and 10%, respectively, of the drainage basin lands. Each land use category has different drainage and retention characteristics.

BAY DESCRIPTION

Physical Structure

Tampa Bay covers an area of about 1,030 km^2, or 398 mi^2 (Table 4-1). It extends approximately 35 miles (56 km) inland from the Gulf of Mexico, and is 5 to 10 miles (8-16 km) wide along the majority of its length. It is crossed by four major causeways, and has 42 nautical miles of dredged channels with designed mean low water depths of 6 to 13 m (20 to 43 feet). The major shipping channel has been dredged from the mouth of the bay to the upper reaches of the Middle Tampa Bay segment, where it splits to the north into the Old Tampa Bay segment and to the northeast into the Hillsborough Bay segment. The average depth of the bay is approximately 4 m (13 feet), with the maximum natural depth of 27 m (89 feet) found in a small area at the mouth of the bay in the Egmont Channel.

Tampa Bay is subdivided into seven segments (Figure 3-2). The Lower Tampa Bay segment connects the mouth of the bay to the Gulf of Mexico. The Lower Tampa Bay segment is joined on the southeast by the Manatee River and Terra Ceia Bay segments, with the Boca Ciega Bay segment adjacent to the north.

The next segment up the bay is Middle Tampa Bay, with the Hillsborough Bay segment connecting to the northeast and the Old Tampa Bay segment adjoining to the north. The southern boundary of the Hillsborough Bay segment crosses from the southernmost point of the Interbay Peninsula southeast to Hillsborough County. For the Old Tampa Bay segment, the southern boundary links the closest points of the Pinellas and Interbay Peninsulas.

Water Movement

Water movements in Tampa Bay are controlled by tidal processes, winds, the physical structure of the bay, and freshwater inflow. Tidal forcing is primarily mixed lunar semi-diurnal and solar diurnal, resulting in two unequal high and two unequal low tides daily, with an average tidal range of about 0.7 m (2.3 ft). The physical structure of the bay, including human-made changes, defines the location of some circulation gyres, as well as the path of water exchange between bay segments and the Gulf of Mexico.

Table 4-1. Parameters for four main Tampa Bay segments and Tampa Bay as a whole.

Bay Segment	Surface Area km^2 (mi^2)	Volume million m^3 (million ft^3)	Average Depth m (ft)	Watershed Drainage Area km^2 (mi^2)
Tampa Bay	1030 (398)	3,300 (116,000)	4 (13)	5,950 (2,300)
Lower Tampa Bay	247 (95)	1,200 (42,100)	4 (13)	298 (115)
Middle Tampa Bay	310 (120)	1,166 (40,900)	4 (13)	952 (368)
Hillsborough Bay	105 (41)	306 (10,700)	3 (10)	2,797 (1,081)
Old Tampa Bay	200 (77)	548 (19,200)	3 (10)	774 (299)
Manatee River	55 (21)	-	-	833 (322)
Boca Ciega Bay	93 (36)	-	-	238 (92)
Terra Ceia Bay	21 (8)	-	-	35.7 (13.8)

Freshwater inflow to the bay, and especially Hillsborough Bay, is essential to maintain flushing.

Tidal action results in currents of approximately 1.8 m/s (5.9 ft/s) on ebb tides and approximately 1.2 m/s (3.9 ft/s) on flood tide at the mouth of Tampa Bay. The flood tide follows the main navigational channel as it propagates into the bay, and splits into Old Tampa Bay and Hillsborough Bay where the channel diverges. Current speeds are decreased by about 90% by the time the tidal influence reaches Hillsborough Bay. It takes the flood tide 3.5 hours to propagate from the mouth to the upper reaches of the bay, with shorter duration for the ebb cycle.

Tidal forcing leads to water exchange between segments and with the Gulf of Mexico. Lower Tampa Bay interacts with the Gulf of Mexico, Boca Ciega Bay, Terra Ceia Bay, and Middle Tampa Bay, and tidally exchanges approximately 6.5% of its total volume each day. Middle Tampa Bay has a daily tidal exchange of approximately 4.6% of its total volume, and interacts with Old Tampa Bay, Hillsborough Bay, and Lower Tampa Bay. Old Tampa Bay also has a daily tidal exchange rate of approximately 4.6% of its volume, and interacts on its southern boundary with Middle Tampa Bay. Hillsborough Bay has the least tidal exchange of any of the major segments, with only approximately 1.4% of its volume exchanged daily.

The physical structure of the bay also affects circulation and flushing. Besides the previously mentioned tidal flow following the dredged main channel of the bay, other circulation features are associated with human-made causeways of the four main bridges spanning the bay. A series of tidal gyres is present in the bay, and it has been hypothesized that the creation of these circular tide-induced features is aided by the causeway structures. The gyres can be from one to six miles in diameter, and may decrease the exchange of water, as well as the nutrient and pollutant loads associated with it, in the northern portions of the bay.

Freshwater inflow to Tampa Bay is about 63 m^3/s, or about 2 billion m^3 (525 billion gallons) on an annual basis, with the four major rivers contributing about 70%-85% of this. The Hillsborough and Alafia rivers, contributing approximately 44% of the total freshwater inflow to Tampa Bay, discharge to the Hillsborough Bay segment. The Little Manatee River discharges to Middle Tampa Bay on the eastern shore, and Lower Tampa Bay receives freshwater input from the Manatee River in the southeast.

Even though Tampa Bay is considered to be a vertically well-mixed estuary (little vertical change in salinity/density), the freshwater inflow results in horizontal salinity gradients important in the circulation and flushing of Tampa Bay, especially along the eastern shore where most of the freshwater inflow occurs. Despite the fact that freshwater inflow is only 63 m^3/s, compared to the average tidal flow at halftide of 25,500 m^3/s, these horizontal salinity gradients may dominate the residual (not tidal-induced) circulation of Tampa Bay. Observational data to support this hypothesis are lacking, although model results indicate that fresher water exits the bay along its banks and near the surface, while saltier water enters the bay along its axis and nearer the bottom.

Salinity and Temperature Patterns

Salinity patterns in Tampa Bay are as expected, with higher salinities in areas which interact strongly with the Gulf of Mexico, and lower salinities in regions affected by freshwater inflow and regions farthest away from the Gulf. Surface salinities are normally 1-2 ppt (parts per thousand) less than those near the bottom. Minimum salinities occur in September of each year, with maximum salinities in June. Variability between years of 6-10 ppt at the surface and 5-6 ppt near the bottom occurs, with a pronounced salinity gradient along the axis of the bay in both wet and dry years. This horizontal salinity gradient between Hillsborough Bay and the mouth of Tampa Bay is about 10 ppt throughout the year. Physical alterations to the bay, especially the shipping channel network, strongly influence bay salinities, with a tongue of high salinity extending up the center of the bay along the main channel.

Salinity values are affected by precipitation, evaporation, freshwater input, and interaction with the Gulf of Mexico. The highest salinities are found in late spring and early summer, following the low rainfall and runoff of the dry season. The lowest salinities, in September, are related to high rainfall and runoff. Local effects of riverine inputs are obvious during the wet season.

Salinity in Lower Tampa Bay, nearest the mouth of the bay, generally ranges over 25-38 ppt, with salinity in the north portion of Lower Tampa Bay rarely below 30 ppt. Middle Tampa Bay, serving as a transitional area between the northern and southern regions of the bay, has salinities of 25-35 ppt, and the southern portion of this segment, like the northern portion of Lower Tampa Bay which joins it, very seldom has salinities less than 30 ppt. Old Tampa Bay, in the northern part of Tampa Bay, receives runoff from urban areas within its watershed, and has a higher range of salinities than do the more southern regions of the bay, with salinities normally varying over 18-32 ppt. Hillsborough Bay, by virtue of the relatively large volume of freshwater discharge it receives from rivers and the surrounding urban area, has the lowest salinities in the bay, with a salinity range of 15-30 ppt.

Temperature patterns in the waters of Tampa Bay, like salinity patterns, show little vertical variation. Variations in annual average water temperature between the surface and the bottom are only up to 1°C (1.8°F). Maximum water temperatures of 28-30°C (82-86°F) are found in June through August, with minimum temperatures of 15-18°C (59-64°F) in December through February. As expected, temperatures follow a smooth seasonal pattern, with similar seasonal temperature patterns throughout the bay.

Sedimentology

Tampa Bay has its geologic origins in a drowned river valley system that was flooded over a period beginning 6000-8000 years ago and ending between 3000 and 5000 years ago. Prior to this flooding, with sea level 100 m lower than present and land extending 160 km farther west, streams carried quartz sand that had eroded from the Tertiary terrace deposits in central Florida, which were formed during a period of high sea level. This quartz sand was deposited directly into Tampa Bay after the most recent sea level rise, and joined other deposits of muds, peats, and oyster bars to make up the sediment within the bay. There are up to 20 m of unconsolidated sediments in Tampa Bay, with surface sediments consisting of a mixture of quartz sands, shell material, and muds high in organic matter.

Sediments are classified as being land-derived or marine-derived. Land-derived sediments are predominantly quartz sands and silt, with some fine-grained organic materials and clay minerals mixed in. Quartz sand-sized sediments originated during the early period of bay flooding, and are found throughout the bay. Marine-derived sediments are coarse-grained calcium carbonate from marine shells. Various factors play a role in the distributions of the different types of sediments, including grain size and depositional environment.

The distribution of old quartz sands within Tampa Bay is controlled by physical processes, with limited input of new quartz sands via exchange with the Gulf of Mexico. High energy events, such as storms and strong tides, serve to redistribute these quartz sands, which predominate in open portions of the central and lower bay, mainly because of the lack of modern sediment deposition.

Most current additions of land-derived sediments are fine-grained muds with high quartz and organic matter components, with which contaminants are associated. Mud-sized (fine-grained) sediments tend to collect in depressions in the floor of the bay and in dead-end canals, where low-energy zones exist. Fine-grained sediments high in organic matter (muck) occupy 15-20% of the Hillsborough Bay bottom, normally where the bay floor is more than 4 m (13 feet) deep, and have been accumulating in these areas for about the last 5000 years. In less developed areas and near the mouth of the bay, where higher-energy zones (high rates of flushing and disturbance) are prevalent, mud-sized sediments are more scarce.

Controlling factors affecting the distribution of these fine-grained land-derived sediments are bathymetry (as described above), physical processes, and sediment origin. The physical processes in some areas of the bay are not highly energetic, and these are the areas nearest the source of the fine-grained land-derived sediments, so that these regions are most likely to accumulate fine-grained land-derived sediments.

The sediments with a marine source are almost entirely calcium carbonate from marine shells, and are larger, coarser-grained sediments. Muds are also created from the breakdown of algae within the bay. The larger-grained sediments may be produced within the bay or imported from the Gulf of Mexico via tidal currents. Calcium carbonate sediments generally increase as a proportion of total sediments with increasing nearness to the bay mouth, and within open portions of the bay. In some peripheral areas, these sediments may be layered within fine-grained, land-derived sediments, which may represent either local calcium carbonate production and sedimentation, or may be the result of storm events.

The distribution of these coarse-grained, marine-derived sediments is controlled by physical processes and the origin of the sediment. A combination of these factors explains the increase in these sediments as the mouth of the bay is approached, where stronger tidal action and more marine conditions prevail. Even when tidal energy is too low to move the coarse-grained sediments, it can still provide a means for removing fine-grained sediments and leaving deposits of predominantly coarse-grained sediments.

CONCLUSION

The Tampa Bay ecosystem is strongly influenced by the local meteorological conditions occurring over the watershed and bay, affecting freshwater inputs to the bay. The characteristics of the Tampa Bay watershed determine the quality and quantity of the fresh water inflow to the bay. This fresh water inflow, in combination with the physical structure of the bay and the associated water movements, is an important factor in producing patterns of salinity, temperature, and sedimentation that define the limits of biological communities.

R. Pribble and A. Poe (Janicki Environmental, Inc.)

- CHAPTER HIGHLIGHTS -

- *Examination of salinity records from the 1960s through 2005 shows no long-term changes in areal extent of salinity zones.*
- *No long-term trends in surface or bottom salinity were found over the last 40 years in the four mainstem segments of Tampa Bay.*
- *The total quantity of freshwater loading to the four mainstem segments of the bay has not changed over the last 60 years. However, the seasonality of freshwater inflow has changed, most noticeably in those watersheds most subjected to land use changes.*

INTRODUCTION

The Tampa Bay region is one of the most rapidly growing areas in the U.S. Along with growth have come increasing needs for environmentally sound water resource development. Concerns have been expressed regarding the influence of urbanization and groundwater pumping on the hydrologic budget of the bay and its tributaries. Recent plans have also been approved to allow withdrawals from two of the major rivers flowing to the bay, and for a seawater desalination plant on the eastern shore of Tampa Bay.

The cumulative effects of the current and planned water resource activities on the bay and its resources are of concern to public policy makers and environmental managers in the area. Knowledge of the status and trends of salinity conditions in the bay is a critical component of the assessment of the potential changes in the bay that may result from changes in freshwater inflow. Additionally, historical changes in freshwater inflow to the bay provide a measure of the expected flow variation when the rivers are not subject to any future surface water withdrawals. This chapter presents the results of analyses of

- historical trends in salinity, and
- historical changes in freshwater inflow to Tampa Bay.

SALINITY

The Environmental Protection Commission of Hillsborough County (EPCHC) has been collecting water quality data monthly in Tampa Bay since 1972. In addition, salinity observations have been collected as part of several studies performed in the bay since the 1960s (Finucane and Dragovich, 1966; Saloman,, 1974.

The salinity data from the studies referenced above and from the EPCHC were used to develop areal estimates of salinity ranges found in Tampa Bay for each decade of the 1960-2005 period. The results of this analysis suggest that salinity has not changed over the decadal scales examined, as shown in Figure 5-1. The ranges of the salinity classes in this figure represent biologically significant salinity zones.

Further analysis of the salinity data collected by the EPCHC was performed to examine long-term trends in surface and bottom salinity in each of the four mainstem segments of the bay (as in Janicki et al., 2001). The trend test results for surface and bottom salinity are shown in Table 5-1.

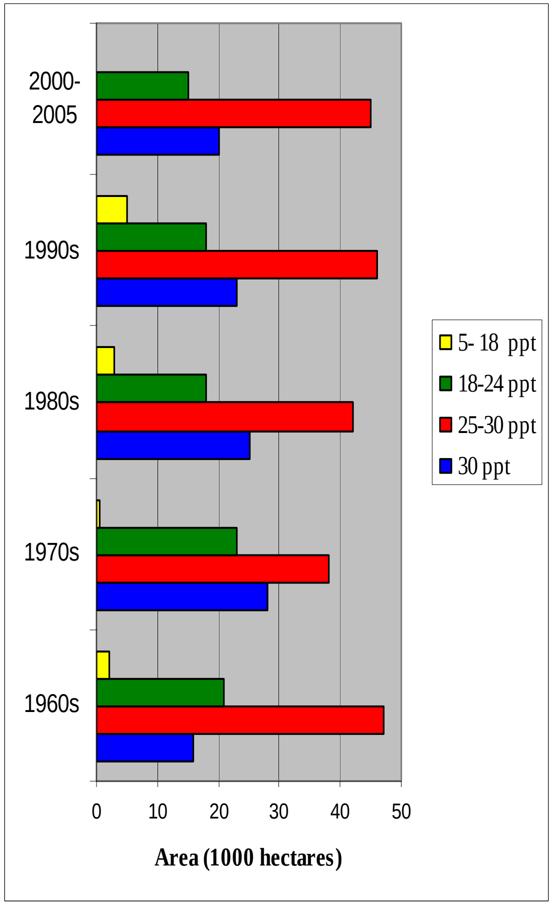

Figure 5-1. Area of salinity classes for each decade, 1960's – 2000's.

No significant trends were found for surface or bottom salinity in Hillsborough Bay, Old Tampa Bay, and Middle Tampa Bay. In Lower Tampa Bay, a statistically significant but small reduction was found in surface and bottom salinity. Figure 5-2 shows box and whisker plots of the salinity

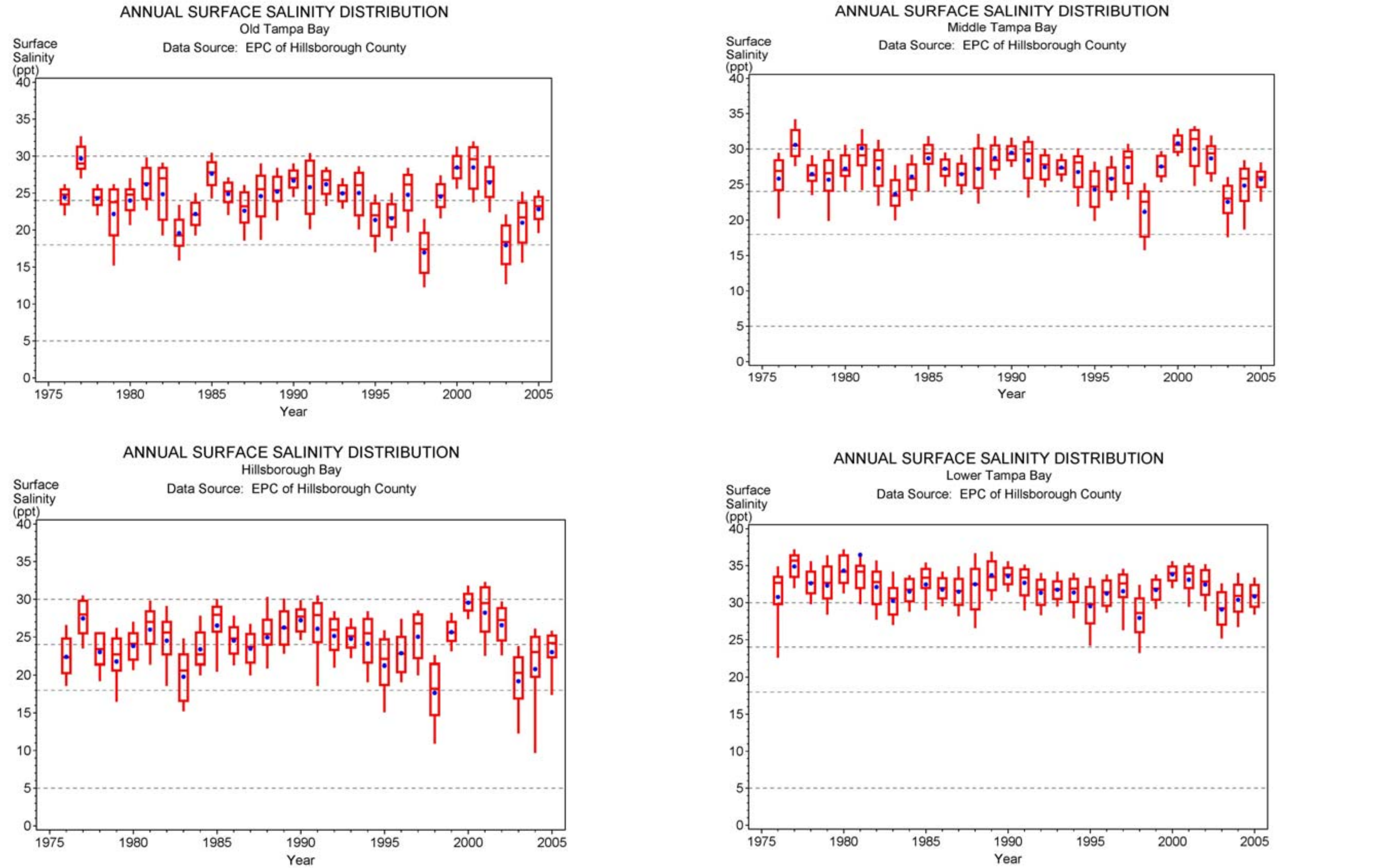

Figure 5-2. Box and whisker plots of mean annual salinity in the four mainstem segments of Tampa Bay.

data, with lines at the salinity values defining the ranges of the classes shown in Figure 5-1. Generally, it can be concluded that the long-term salinity trends in the mainstem of Tampa Bay have not been significant.

Table 5-1. Long-term nonparametric trend test results for surface and bottom salinity in the mainstem segments of the bay.

BAY SEGMENT	SALINITY	
	Surface	Bottom
Old Tampa Bay	0	0
Hillsborough Bay	0	0
Middle Tampa Bay	0	0
Lower Tampa Bay	-	-

The typical distribution of mean annual surface salinity for the 1976-2005 period is shown in Figure 5-3. As shown in this figure, and the box and whisker plots, the lowest salinities are normally found in Hillsborough Bay and Old Tampa Bay.

FLOW

Estimates of hydrologic loadings to Tampa Bay have been compiled for the 1938-1940 period and for the recent period utilizing the same rainfall record (Zarbock et al., 1994). Comparisons of the average monthly inflows for the historical and recent periods for each of the four mainstem bay segments are shown in Figure 5-4. This analysis suggests that although there does appear to have been a change in the seasonal distribution of freshwater inflow, there has been no change in the total annual inflow. A likely cause of the observed change in seasonal runoff is land use change, with the more developed land uses in the watershed during the recent period resulting in more rapid transport of stormwater runoff to

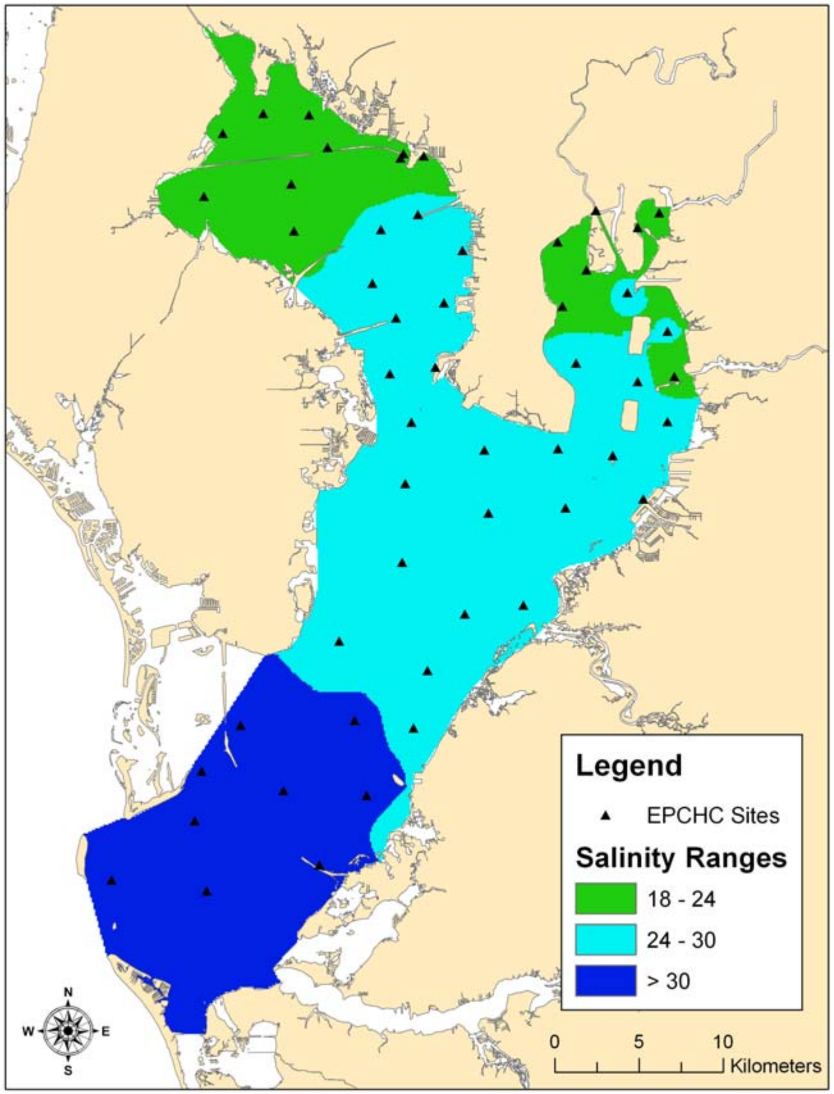

Figure 5-3. Typical distribution of mean annual surface salinity for the 1976-2005 period.

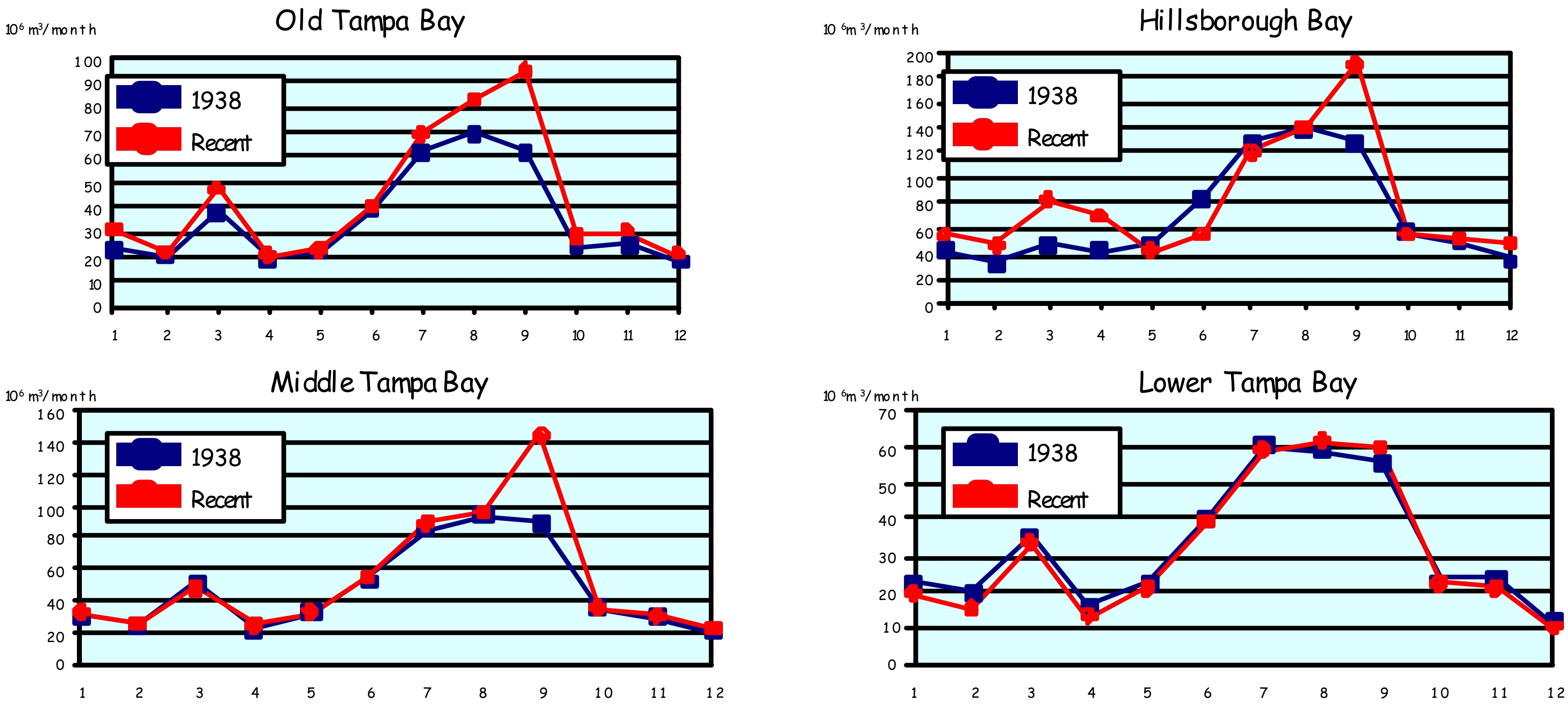

Figure 5-4. Comparison of historical and recent monthly freshwater inflows to the four mainstem segments of Tampa Bay.

Tampa Bay than in the historical period. It is notable that the most obvious changes in seasonality of discharge are found in those watersheds most subjected to development (Old Tampa Bay and Hillsborough Bay).

CONCLUSIONS

- No trends in salinity were found in Tampa Bay over the period of record.
- No trends in the areas of mean annual surface salinity zones were found in Tampa Bay over the period of record.
- The volume of freshwater inflow to Tampa Bay has not changed appreciably over time. However, the timing of freshwater inflows has changed, primarily due to land use changes associated with development in the watershed.

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Tampa Bay Water System: Groundwater, Surface Water, and Reservoir

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BACKGROUND

Tampa Bay Water is a regional water supply authority created in 1998 by inter-local agreement among six member governments: Hillsborough County, Pasco County, Pinellas County, New Port Richey, St. Petersburg and Tampa. Chapter 373 F.S. enabled the creation of the regional authority for the purpose of developing, recovering, storing, and supplying water for county or municipal purposes while reducing unacceptable adverse environmental effects and maximizing economical development of water resources. Tampa Bay Water is obligated to meet the current and future water needs of its Member Governments. In order to meet these needs, Tampa Bay Water owns and operates water supply facilities including wellfields, surface water withdrawals, a seawater desalination facility, treatment facilities, storage facilities such as the off-stream reservoir, pumping stations, and transmission mains.

In 1989, the Southwest Florida Water Management District's Governing Board declared an area encompassing parts of Hillsborough and Pasco counties and all of Pinellas County to be included in the Northern Tampa Bay Water Use Caution Area (NTBWUCA). The Governing Board took this action based on growing concerns about hydrologic impacts to wetlands, lakes, and rivers, resulting from ground-water withdrawals. Because the majority of ground-water use in the area is for public supply, most of the water resource impacts were located in areas surrounding the major public supply wellfields. The Northern Tampa Bay Water Resource Assessment Project (NTBWRAP) was initiated as part of a long-term goal to assess water resource impacts and determine water availability for the area. The NTBWRAP area was delineated to include areas of significant groundwater withdrawals and water resource impacts (SWFWMD 2006).

The NTBWRAP area encompasses approximately 1,500 square miles, including parts of Hernando, Pasco, Hillsborough, Polk counties, and all of Pinellas County. Ground-water withdrawals in the area have increased from less than 50 million gallons-per-day (mgd) in 1960 to more than 200 mgd in the 1990s. Prior to the 1950s, many of the wells used for water supply in coastal communities experienced saltwater intrusion. Because of this and in order to meet the increasing demands of the area, the production of groundwater for public supply moved to inland areas. In 1996, the District completed the NTBWRAP and concluded that the major public supply well fields were responsible for the majority of observed impacts to lakes in the area. Though it was also concluded that regional saltwater intrusion was not a major concern in the area, it is possible that saltwater intrusion could occur on a local scale (SWFWMD 2006).

In an effort to help resolve the resource impacts in the NTBWUCA, the District entered into an agreement with Tampa Bay Water and its member governments. An overall strategy to reduce reliance on ground water, implement alternative sources and allow recovery of natural systems was put in place in May 1998 with the approval of the Northern Tampa Bay New Water Supply and Ground-Water Withdrawal Reduction Agreement (Partnership Agreement). The key objectives identified in the Agreement were the development of at least 85 mgd of new water supply, the phased reduction of withdrawals to no more than 90 mgd by December 31, 2007 from the existing 11 wellfields that comprise the central system, the ending of litigation, and up to $183 million in financial assistance from the District for new water supply development and conservation (SWFWMD 2006).

Tampa Bay Water has spent the last eight years designing, permitting and constructing a nearly billion dollar water supply system to achieve diversification and reduced reliance on groundwater supply. As part of the recovery strategy for the NTBWUCA, Tampa Bay Water developed the Enhanced Surface Water System (ESWS) that is designed to manage and optimize withdrawals, conveyance, and storage of surface water supply. This system includes intake and pumping stations on the Alafia River and Tampa Bypass Canal (TBC), a 66-mgd surface water treatment plant, and the C.W. Bill Young Regional Reservoir (Regional Reservoir). Figure 1 shows the locations of the new ESWS facilities, as well as existing groundwater wellfields.

Tampa Bay Water's phased reductions in groundwater pumping from the eleven consolidated permit wellfields in the northern Tampa Bay area required a decrease from the original permitted capacity of 191 mgd to no more than 121 mgd annual average beginning in 2003, and no more than 90 mgd annual average beginning in 2008. As a result of the development of the new water supplies and favorable hydrologic conditions, groundwater pumping reduction goals have been met ahead of schedule (SWFWMD 2006).

The Partnership Agreement also called for Tampa Bay Water's member governments to achieve 17 mgd of water savings through demand management measures by 2005. Tampa Bay Water's member governments were successful in achieving and exceeding this goal well in advance of the deadline and anticipate saving 31 mgd by the end of 2010.

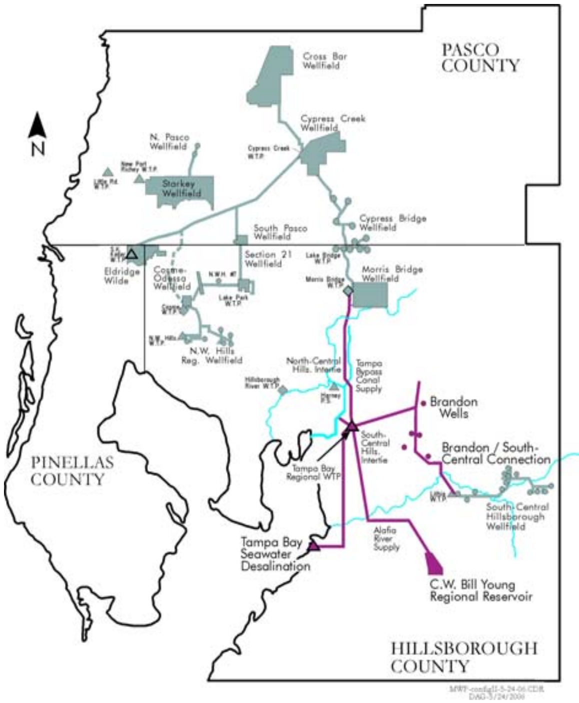

Figure 1. Tampa Bay Water's Existing Water Supply Facilities.

SYSTEM OVERVIEW

Tampa Bay Water's current system includes three sources of supply: groundwater, surface water including an off-stream reservoir and desalinated seawater, making system operation much more complex than the previous operation of groundwater wellfields. Other new components include a 66 mgd surface water treatment facility, multiple pumping facilities, 12 miles of 84-inch diameter finished water pipeline, and 23 miles of 72 and 84-inch diameter raw water pipelines.
As the new facilities have become operational, the focus has shifted to operation of a complex integrated regional system (see Figure 2). While there are some other potable water supply systems in the country that have more than one supply source, the combination of supply sources and high water quality delivery requirements make the Tampa Bay Water system one of the most complex water supply systems in North America (Black and Veatch 2005).

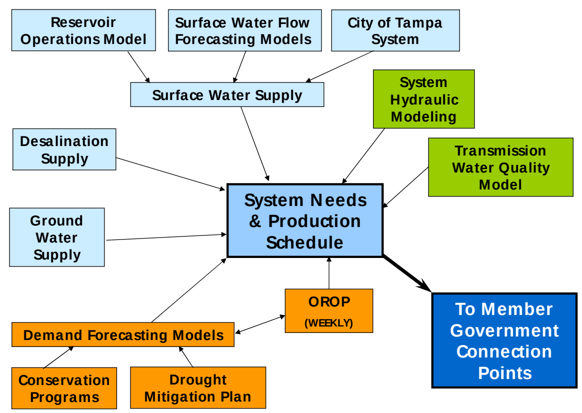

Figure 2. Schematic of Tampa Bay Water Operations

The system has been developed to receive raw water from 189 groundwater production wells, three surface water supply sources, one reservoir, and the Tampa Bay Seawater Desalination facility (see Figure 1). Raw groundwater is treated at one of six groundwater treatment facilities. For the Enhanced Surface Water System, raw surface water is provided from the Tampa Bypass Canal/Hillsborough River System (about 75%) and the Alafia River (about 25%). Depending on available quantities and regional demand, surface water is sent to the Regional Treatment Facility for immediate use or is diverted to the Regional Reservoir for storage. Treated desalinated seawater from Hillsborough Bay will be blended with the other treated water supplies prior to distribution.

Finished water is pumped by one of two high service/blending facilities into more than 100 miles of pipeline and delivered to member governments through 20 points of connection.

There are many variables and constraints that must be considered in making operations and supply decisions. Making operations decisions for such a unique system is complex, and Tampa Bay Water uses advanced science and technology to make day to day operating and supply decisions. Tampa Bay Water collects more than a million pieces of data annually to use in the decision making process. This information is used along with numerous models in a decision support system (DSS) to determine system needs and production schedules; a general schematic is provided in Figure 3.

With the new surface water sources, water quality becomes an independent variable unlike that experienced in the traditional groundwater system. The surface water sources are subject to uncontrollable events such as floods, phosphorous releases or high fluoride levels in the Alafia River, unexpected agricultural practices in the drainage basin for the Hillsborough River and Alafia River, or extremes in flow rates that lead to chemical changes in source water. These events impact treatment processes, and in some cases may result in an impact so severe that the water source is unusable for days or potentially weeks. If such an event occurs, the system must be flexible enough to adjust from dependency on a particular quantity from a particular source to a different mix of raw water sources. The system was designed to meet water quality parameters through blending and must have the flexibility to operate at varying blend levels while meeting a required set of water quality characteristics (Black and Veatch 2005).

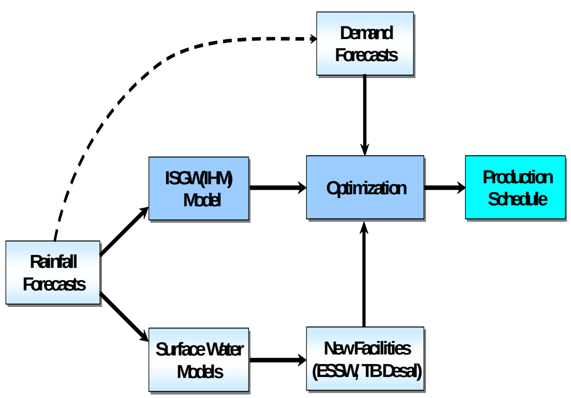

Figure 3. Schematic of Tampa Bay Water DSS

Tampa Bypass Canal/Hillsborough River

The Hillsborough River basin covers approximately 650 square-miles and is supplied by several major tributaries including Cypress Creek, Trout Creek, Blackwater Creek, and Crystal Springs. The basin chiefly consists of large, flat wetland areas that drain to the Hillsborough River during times of high water. Before reaching Tampa Bay, the Hillsborough River enters the Hillsborough Reservoir which has served as a water supply source for the City of Tampa since the 1920's.

This drainage basin is complex (Figure 4) in its lower reaches, and includes a number of flow control structures and canals, including the Tampa Bypass Canal (TBC) that was constructed by the U.S. Army Corp Engineers between the late 1960s and 1980s to provide flood control for the densely developed portion of the Hillsborough River watershed near Tampa.

Construction activities for the TBC were authorized and funded under the Four Rivers Basin Project which was authorized by the Flood Control Act of 1962. The TBC system is owned and operated by the Southwest Florida Water Management District and has been used very effectively as a flood control system since its completion.

During periods of exceptional flooding, water from the Hillsborough River can be retained in the Lower Hillsborough Flood Detention Area (LHFDA) and diverted into the TBC. The LHFDA is a 26 square-mile area delineated by a levee with a crest elevation at 48 feet, NGVD. When extreme flooding occurs and S-155 is closed, water is retained in the LHFDA and released when flooding conditions subside. Flow from the Hillsborough River can also be diverted into the TBC at Structure 161. TBC flow is discharged into the Palm River at structure S-160; this water is ultimately discharged into McKay Bay.

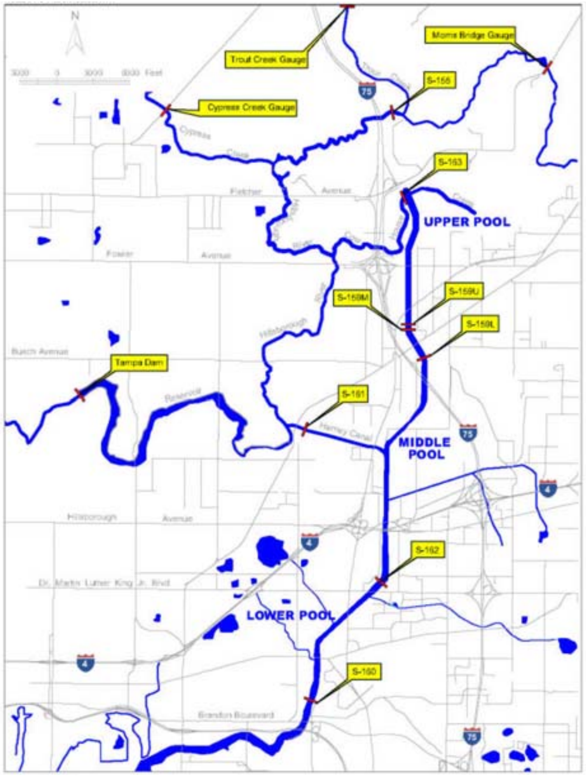

Figure 4. Tampa Bypass Canal/Hillsborough River System

The TBC is approximately 14 miles long and was constructed along the general flow path of Six-mile Creek. Six-mile Creek was a small natural creek bed with an average discharge of approximately 60 cubic feet per second (cfs) during the 10-year period from 1956 to 1965. Much of the base flow of Six-mile Creek came from springs in the areas. The TBC was designed to convey a discharge of 12,000 cfs from the LHFDA, 4,000 cfs from the Hillsborough River by way of the Harney Canal (S-161), and 9,000 cfs for runoff from the 33 square-mile area adjacent to the TBC. The TBC was constructed with trapezoidal channels having bottom widths ranging between 200 and 300 feet. Between 1975 and 2004, the average discharge of the TBC at structure S-160 was about 172 cfs and the maximum daily discharge was 10,800 cfs.

The TBC also serves as a critical source of drinking water for the Tampa Bay region. Excavation during construction of the TBC system breached the top of the Upper Floridan Aquifer at numerous locations. The result was a relatively stable base-flow of groundwater into this system, with most of the base-flow originating in the TBC Middle Pool. Studies conducted by Geraghty and Miller (1981 and 1986) indicate that even under drought conditions, the TBC Middle Pool is capable of yielding a potable water supply of approximately 20 mgd.

In January 1985, the West Coast Regional Water Supply Authority (now Tampa Bay Water) installed temporary pumping facilities on the Harney Canal portion of the TBC Middle Pool to augment the City of Tampa's municipal supply in the Hillsborough River Reservoir. Augmentation of the Hillsborough River Reservoir using temporary facilities was conducted periodically during the mid 1980's and early 1990's.

In 1992, the West Coast Regional Water Supply Authority completed permanent augmentation facilities, known as the Harney Pump Station, near TBC Structure S-161 (Figure 5). These facilities are permitted for an average annual quantity of 20 mgd and a peak monthly quantity of 40 mgd. Since 1985 they have averaged 7.4 mgd for augmentation of the Hillsborough River Reservoir.

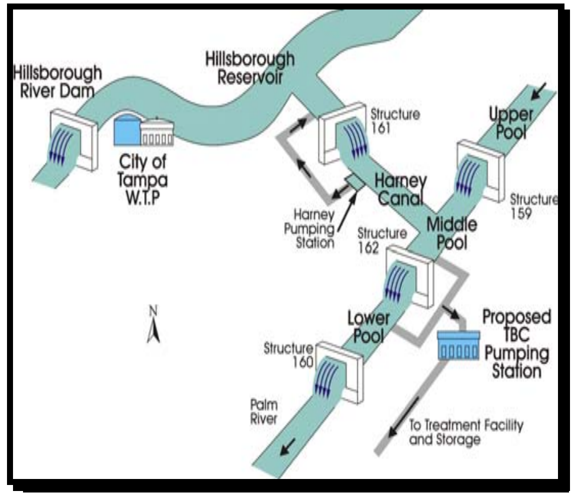

Figure 5. TBC and Harney Pump Stations

In 1999, Tampa Bay Water received a Water Use Permit (WUP) to harvest flow from the Hillsborough River and the TBC for this component of Tampa Bay Water's Enhanced Surface Water System. Regional withdrawal facilities are located adjacent to TBC Structure S-162 (Figure 5) and were completed in the summer of 2002.

The TBC Pump Station includes intakes installed on both sides of Structure S-162 so that water can be withdrawn from the Middle Pool or the Lower Pool, or both concurrently. The Middle Pool intake is meant to harvest water that has been diverted from the Hillsborough River through Structure S-161. The Lower Pool intake is meant to harvest groundwater inflow and local surface water runoff at the TBC.

Permitted withdrawals from the Lower Pool allow up to 80% of flows over S-160 above 11 cfs, to a maximum of 100 cfs. The WUP also allows diversions from the Hillsborough River (through Harney Canal) for withdrawal from the Middle Pool when discharge at Tampa Dam above 100 cfs; subsequent withdrawals from the Middle Pool range from 10-30% (sliding scale), up to 300 cfs maximum. As a general operational rule, Middle Pool withdrawals are confined to water diverted through S-161.

The current pumping capacity of the TBC pump station is approximately 137 mgd, with an expansion capability to 259 mgd.
The TBC Pump Station went on-line in September 2002 and has averaged 34.2 mgd through September 2005 (17.9 mgd from the Hillsborough River and 16.3 from the TBC source).

Although permit conditions would have allowed significantly higher withdrawals from these sources, storage was unavailable until February 2005 when the C.W. Bill Young Regional Reservoir was completed.

Alafia River

The Alafia River watershed encompasses approximately 460 square miles. While most of the watershed is located in Hillsborough County, the headwaters are located in Polk County, where the land has been mined extensively for phosphate ore. The river extends 23 miles from its mouth at Hillsborough Bay near Gibsonton, eastward to the confluence of its two major tributaries: the North and South Prongs. Below the confluence of the North and South Prongs, the river has three major tributaries: Turkey, Fishhawk, and Bell Creeks.

In 1999, Tampa Bay Water received a Water Use Permit to withdraw from the Alafia River as part of the Enhanced Surface Water System. The intake and pumping station located near Bell Shoals Road, went on-line in February 2003.

The withdrawal schedule for the Alafia River project was developed to minimize impacts to the riverine system by maintaining natural variability and not withdrawing water during low flow periods. Permitted withdrawals include up to 10% of flow above 124 cfs at Bell Shoals Road (corresponds to the 80th percentile), up to a maximum of 80 cfs.

Regional Reservoir

The C.W. Bill Young Regional Reservoir (Regional Reservoir) in southeastern Hillsborough County is part of Tampa Bay Water's Enhanced Surface Water System that includes withdrawals from three sources (Alafia River, Tampa Bypass Canal, and Hillsborough River) and a surface water treatment plant, and was built to operate as part of an integrated withdrawal, conveyance and treatment system. Reservoir construction was completed and filling began in February 2005, and the facility went on-line to the regional system in January 2006.

The Regional Reservoir provides raw water storage for withdrawals during high river flows for later use during low river flow periods when no withdrawals can occur. The Regional Reservoir's storage capacity is approximately 15 billion gallons (48,000 acre-feet). Structurally, it is an earthen embankment with an average height of 45 feet and an average water depth of 40 feet. The Reservoir is deeper than natural systems in Florida and the interior is free of vegetation, with 16 inches of soil cement lining the interior walls.

The Regional Reservoir does not contain a spillway, and its design allows it to operate as a closed system, with water conveyed to and removed from the facility through a closed pipeline. The design and permitted operating scenario do not include an outfall to adjacent water bodies.

The Environmental Resource Permit issued by FDEP for the Regional Reservoir, requires water quality sampling and analysis of the water column and sediments within the reservoir, and groundwater wells located outside the reservoir. The FDEP determined this monitoring would provide reasonable assurance that water quality impacts are not occurring to the groundwater system through seepage.

The Reservoir is a key part of the Enhanced Surface Water System and is critical for public supply during the dry season. During the dry months of April to June 2006, the Reservoir supplied all of surface water for the regional system- nearly six billion gallons.

Tampa Bay Seawater Desalination

Tampa Bay Water's Seawater Desalination facility located adjacent to Tampa Electric's Big Bend Power Station on Hillsborough Bay is a key component of the Master Water Plan. The Seawater Desalination facility is designed to produce up to 25 mgd of potable water, and is the largest desalinated seawater facility in North America. The facility initially went on-line in 2003, but was taken off-line for remediation in 2005 and is expected to be producing water again in late 2006. See Chapter 6 of this report for more information.

Water Year 2005 Production

In Water Year 2005 (WY05), surface water contributed an average of approximately 48 mgd to the regional demand of 169 mgd. During WY05, combined withdrawals from the TBC and Hillsborough River sources averaged 61.2 mgd. Withdrawals from the Lower and Middle Pools averaged 35.3 mgd and 25.9 mgd respectively. Monthly averages of the combined production ranged from a low of 21.8 mgd during February to 135.8 mgd in July. Pumped quantities were conveyed through an 84-inch diameter pipeline to the Regional Facilities Site, then either sent to the Regional Reservoir or mixed with water (when available) from the Alafia River, treated and distributed to Tampa Bay Water member governments.

During WY05, Tampa Bay Water production from the Alafia River averaged 22.2 mgd or approximately 73% of the permitted allowable quantity. Monthly average production ranged from a low of 0.2 mgd during October 2004, to 47.6 mgd in July 2005. Pumped quantities were conveyed either to the Regional Reservoir or to the Regional Facilities Site where it was mixed with water (when available) from the TBC and Hillsborough River, treated and distributed to Tampa Bay Water member governments.

During WY05, Tampa Bay Water's use of available surface water resulted in 12.9 billion gallons of raw surface water being delivered to the Regional Reservoir for storage of which approximately 4.3 billion gallons came from the Alafia River and 8.6 billion gallons came from the TBC.

ENVIRONMENTAL MONITORING

When planning and studying new projects, detailed environmental assessments are conducted to determine if the potential project is environmentally sustainable as well as technically feasible. Typical environmental protection activities for wetlands and surface water bodies include: impact assessment and permitting, evaluations of minimum flows and levels, development of environmental monitoring programs, and mitigation/ restoration design and implementation.

The Consolidated Water Use Permit for the 11 Central System Wellfields required the development of a comprehensive Environmental Management Plan (EMP). The EMP monitors the status of adjacent wetlands, lakes and other natural systems for any changes associated with groundwater withdrawals including recovery in areas of reduced pumping. A standardized monitoring methodology was developed to ensure consistent evaluations of wetlands and lakes associated with each facility. If long-term monitoring identifies changes or systems that are not responding as expected to reduction in groundwater withdrawals, the EMP also provides for timely action to improve environmental conditions at those sites.

Additional major sources of groundwater supply include the South-Central Hillsborough Regional Wellfield and the Brandon Urban Dispersed Wells. For these areas, wetlands, lakes, and other natural systems are monitored under separate EMPs. All wellfield areas are included in analysis of digital satellite imagery for land use and vegetative changes. Tampa Bay Water currently spends approximately $2 million per year monitoring environmental conditions for groundwater wellfields.

The Consolidated Permit also requires the development of a comprehensive mitigation plan for addressing historical environmental impacts in the vicinity of these wellfields. Phase I of the Environmental Restoration Program included an evaluation of candidate sites for augmentation and the identification of sources and quantities of water needed to restore affected wetlands and lakes. All sites appropriate for mitigation were identified and ranked in a preliminary priority list and an in-depth cost and feasibility evaluation was conducted with implementation at priority sites currently underway.

Treated surface water has been part of the regional system since late 2002. Environmental concerns related to surface water sources reflect the natural areas and recreational/aesthetic values provided by these waterbodies, as well as their contribution to the Tampa Bay ecosystem.

In addition to withdrawal schedules intended to minimize impacts to the systems by maintaining variability and low flows, Water Use Permits issued by the Southwest Florida Water Management District for the TBC Water Supply Project (including the Hillsborough River High Water Source) and the Alafia River Project required the development of a comprehensive Hydrobiological Monitoring Program (HBMP). The HBMP monitors hydrological and biological conditions in the lower Alafia and Hillsborough Rivers, the Palm River/Tampa Bypass Canal, and McKay Bay, as well as areas of Tampa Bay where these systems discharge. This comprehensive monitoring program, which costs nearly $1 million annually, was developed with input from numerous stakeholders including local environmental agencies, university experts and consultants (see TBEP 2003, PBSJ 2006).

The HBMP includes triggers and associated management actions to be taken if this early warning system shows any unforeseen impacts related to the withdrawals. Based on the most recent assessment comparing pre- and post-operational conditions, no significant impacts have been identified (PBS&J 2006).

Tampa Bay Water's Optimized Regional Operations Plan (OROP) ensures water demand for the tri-county region can be met with minimal adverse environmental impacts by using sophisticated computer models to analyze and forecast groundwater and surface water conditions at water supply facilities. Based on continual field monitoring and condition forecasts, water production can be rotated or adjusted to avoid ecological harm.

LONG-TERM SUPPLY PLANNING

The purpose of Tampa Bay Water's Long-Term Water Supply Planning program is to ensure that regional water supplies are sufficient to meet current and future demands. Tampa Bay Water is required by an Inter-local Agreement with its member governments to update its Long-Term Plan of the Master Water Plan every five years to meet the water needs of the Member Governments for the next 20 years. The original Master Water Plan was developed in 1998. The first Long-Term Water Supply Plan update for the Master Water Plan was prepared in 2003. The next update of the plan will be completed in 2008. The updates include analyses of current and future water supplies and demands in order to determine when new supplies need to be developed.

The group of water supply projects recently completed will meet regional water demands through 2012 and helped to meet the agreed upon cutbacks in groundwater production. It takes up to 10 years to plan, permit, design and build drinking water facilities. Planning for the future ensures the region's supply can meet demand in an environmentally sound and cost effective manner. In September 2003, Tampa Bay Water's Board of Directors finalized the Demand Forecasting System and completed a detailed Probabilistic Need Forecast. This work is updated annually. The results of the most recent Probabilistic Need Forecast indicate that an additional 12 mgd of new supplies will be needed by 2012. As a result, a second configuration of project(s) must be considered in order to meet the region's needs in the 2012 timeframe. These long-term planning efforts ensure adequate supplies to our member governments over the twenty-year planning horizon.

Development of the Long-term Plan incorporated input from a technical advisory committee that included representatives from each member government, a planning advisory committee, and public input at public workshops and meetings. After further investigation of the short-listed projects, several projects were selected for more investigation. Tampa Bay Water's Board of Directors approved the incorporation of several of these water supply projects into the Master Water Plan.

The current Tampa Bay Water Master Water Plan consists of projects that have been approved by Tampa Bay Water's Board of Directors for further implementation. From the Master Water Plan, the Board then chooses projects for system configurations. Projects selected for a system configuration typically undergo stages of development, with Board approval occurring at each stage prior to a project moving forward:

- preliminary design and major permitting
- final design, permitting, and property acquisition
- construction.

Projects from System Configuration I including the Brandon Urban Dispersed Wells, Enhanced Surface Water System, and Tampa Bay Seawater Desalination, were completed by 2005, although remediation of the Desalination plant will not be completed until December 2006.

In October 2006, Tampa Bay Water's Board of Directors considered four potential water supply projects for further development for System Configuration II. These included: the Downstream Augmentation Project, the Downstream Enhancements Project, the Mid-Pinellas Brackish Water Project, and the Crystals International Water Supply Project. At the October 2006 meeting, additional activities were approved for the Downstream Augmentation and Enhancements projects, and the two other projects were moved from Configuration II to the long-term planning list.

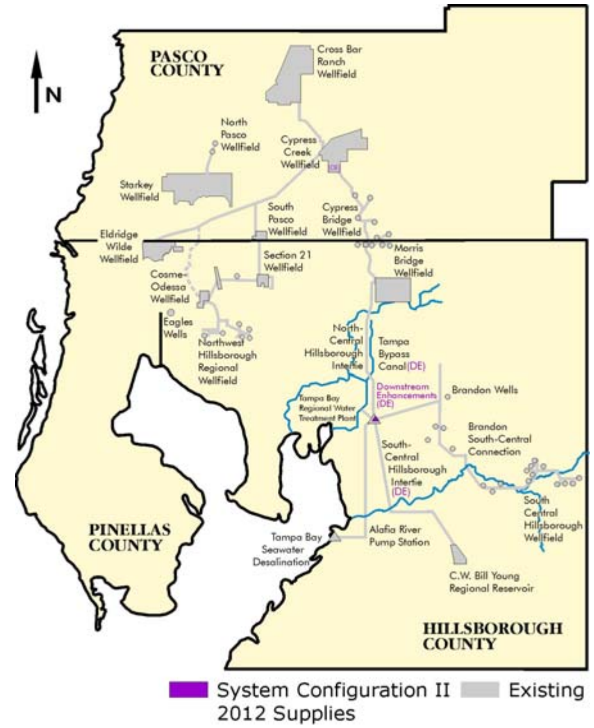

Figure 6. Existing and Future Water Supply Projects

The Downstream Enhancements project would build on Tampa Bay Water's existing Enhanced Surface Water System. Initial studies for the project examined how potential surface water withdrawals under mid-range (higher) flow conditions could be more fully utilized, while protecting important low and high flows. These studies followed a recommendation by the Tampa Bay Estuary Program and the Agency on Bay Management staff to consider this concept to help meet future regional supply needs.

The first two phases of the Downstream Enhancements project were approved for System

Configuration II by Tampa Bay Water's Board of Directors at its October 2006 meeting. This included modifying existing water use permits at the Hillsborough River and Tampa Bypass Canal and expanding the Surface Water Treatment Plant. These modifications would allow the use of additional mid-range (higher) flows, but would continue to protect low and high flows in these systems.

Two potential later phases of the project were approved by the Board of Directors for further study as alternatives to meet the region's water supply needs between 2017 and 2025. These alternatives include: building a second reservoir, using additional mid-range (higher) flows from the Alafia River, and downstream augmentation for the Hillsborough River. Further study of these alternatives is expected to occur over the next few years. Tampa Bay Water's Board of Directors also approved initiation of the next long-term planning process to update the Master Water Plan. This will begin in 2007 and be completed in 2008.

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Gerold Morrison and Edward Sherwood (Environmental Protection Commission of Hillsborough County)
Keli Hammer-Levy (Pinellas County Department of Environmental Management)
Rob Brown and Greg Blanchard (Manatee County Environmental Management)

-CHAPTER HIGHLIGHTS-

- *The dramatic water quality improvements that occurred in Tampa Bay during the mid-1980s – which involved water clarity, concentrations of nutrients and chlorophyll-a, dissolved oxygen levels and several other indicators – have been maintained through 2005.*

- *Old Tampa Bay, Hillsborough Bay and Middle Tampa Bay have shown significant increases in water clarity during the period 1980 through 2005.*

- *Old Tampa Bay, Hillsborough Bay and Middle Tampa Bay have also shown significant reductions in chlorophyll-a concentrations during from 1980–2005.*

- *Dissolved oxygen concentrations have maintained their improved levels through 2005.*

- *Hillsborough Bay continues to have the highest percentage of samples not meeting State water quality standards for dissolved oxygen.*

- *Many differences in water quality that occur within and among the four main-stem segments (Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay and Lower Tampa Bay) follow the bay's horizontal salinity gradients. Locations near the head of the bay, which are more heavily influenced by inputs of nutrients and other constituents from the watershed, have generally lower salinities, higher nutrient and chlorophyll-a concentrations, more stressful DO regimes, and lower levels of water clarity. Locations closer to the bay mouth, which are more strongly influenced by water masses from the Gulf of Mexico, show generally higher salinities, lower nutrient and chlorophyll-a concentrations, less stressful DO regimes, and greater water clarity.*

INTRODUCTION

The water quality of Tampa Bay is an important issue for the west-central Florida region, both ecologically and economically. Water quality influences which animals and plants can live and reproduce in the bay, their abundance, and where and when they can be found. Many commercially and recreationally important fish and shellfish species are dependent on the bay, and the quality of its water, during some portion of their life cycle. The region's economically vital recreation and tourism industries also benefit from good water quality, which provides residents and visitors the environmental and aesthetic conditions needed for the enjoyment of recreational activities such as swimming, boating and fishing. Periods when bay water quality was visibly degraded, such as the late 1970s and early 1980s, have demonstrated the negative regional impacts that such degradation can cause.

Periodic assessments of water quality are helpful for tracking conditions and trends, for documenting the outcomes of water quality management programs, and for providing an early warning if conditions begin to decline in some portions of the bay. Since no single measurement can adequately summarize water quality conditions, they are assessed here using a suite of indicators that have been chosen because of their ecological relevance, or because they are currently being used by bay managers to track progress toward key water quality management goals.

BACKGROUND

As noted elsewhere in this report (Chapter 2), water quality in Tampa Bay is much better today than it was several decades ago. The improvement is due to a number of factors, including:

- advances that have been made at many of the region's wastewater treatment plants and industrial facilities;
- improvements in stormwater management and permitting activities;
- more stringent regulation of dredge and fill activities;
- reduced pollutant discharges from port facilities during cargo-handling and dry-dock operations; and
- increasing implementation of best management practices (BMPs) to reduce pollutant discharges from agricultural operations.

Between the 1960s and the early 1980s, large quantities of nitrogen and phosphorus – contributed by sources such as sewage effluent, stormwater runoff, leaks and spills from industrial and shipping facilities, and exhaust gases from cars, trucks and power plants – were discharged to the bay each year from its watershed and airshed. Nitrogen and phosphorus are essential nutrients that are required for the healthy growth of plants and animals. In surface water bodies like the bay, however, excessive nutrient inputs can be damaging if they lead to harmful levels of eutrophication. Symptoms of excessive eutrophication include undesirably high levels of algae growth. High concentrations of algae reduce the clarity of water and contribute to large fluctuations in dissolved oxygen levels. Reduced water clarity limits photosynthesis in submerged plants, including seagrasses. Low levels of dissolved oxygen are stressful fro many species of fish, shellfish and other invertebrates (Santos and Simon 1980, NRC 2000, Cloern 2001, TBEP 2006).

These sorts of water quality problems were obvious in the bay during the early 1970s, when local monitoring programs were first initiated (Johansson 1991). At that time eutrophication was particularly severe in Hillsborough Bay, the portion of Tampa Bay that was receiving the largest inputs of treated sewage effluent and industrial leaks and spills from facililties located along its highly-urbanized shoreline (Johansson 1991), as well as large freshwater inflows and pollutant loadings from the Hillsborough, Palm and Alafia River watersheds (Dooris and Dooris 1982).

At the watershed scale, management of eutrophication must focus on the control of both nitrogen and phosphorus inputs (Cloern 2001, Paerl et al. 2004). Phosphorus is usually the nutrient of greatest concern in the freshwater tributaries and tidal fresh portions of an estuary, because excessive phosphorus loads to these areas can stimulate blooms of undesirable phytoplankton, particularly nitrogen-fixing cyanobacteria. Such blooms are detrimental in several ways:

- Blooms are aesthetically unattractive, and nitrogen fixing species can persist long periods of time;
- many species of cyanobacteria are not preferred food items for the small fish and invertebrates that feed on other phytoplankton, and thus are not desirable components of the aquatic food web; and
- a number of species of cyanobacteria produce toxins (neurotoxins and hepatoxins) that can have undesirable health effects in wildlife and in humans (Sellner 1997).

In contrast to the situation in freshwater and tidal freshwater areas, in the brackish and marine portions of estuaries (areas where salinities are typically >0.5 psu) nitrogen is usually the nutrient of greater concern, because it is the nutrient that more frequently limits phytoplankton productivity in those locations (NRC 2000, Cloern 2001, Paerl et al. 2004).

Tampa Bay is somewhat unusual with respect to the nitrogen and phosphorus loadings it receives, because of the geological characteristics of its watershed. Each of the four rivers that discharge to the bay – the Hillsborough, Alafia, Little Manatee and Manatee rivers – drains portions of the “central Florida phosphate district”, which makes up large a portion of the Tampa Bay watershed. This area contains large underground deposits of a phosphatic matrix (a mix of clay, quartz sand, dolomite and phosphate ore) that is strip-mined and processed to produce commercial fertilizer and livestock feed-supplement products (McClellan and Eades 1997). The central Florida phosphate district, along with a second mining area located in northern Florida, produces the largest annual tonnage of phosphate ore (>30 million tons in 1990) of any U.S. state, and about 30% of total world production (McClellan and Eades 1997). The rivers and streams that drain the phosphate district contain unusually high concentrations of phosphate, in comparison to surface waters in other parts of Florida and the U.S., due to a combination of natural leaching and discharges from phosphate mining and processing operations (Odum 1953).

As a result of of the very large loads of phosphorus that Tampa Bay receives from its watershed, concentrations of soluble reactive phosphorus (SRP) usually exceed phytoplankton requirements in most portions of the bay and the tidal reaches of its major tributaries (Johansson 1991, Vargo et al 1991, Wang et al. 1999). Recent research suggests that in some years the phosphorus and colored dissolved organic matter (CDOM) discharged from Tampa Bay and Charlotte Harbor may contribute to the development of blooms of nitrogen-fixing cyanobacteria (*Trichodesmium* spp.) in nearshore waters of the Gulf of Mexico (Walsh et al. 2003).

Under certain conditions the *Trichodesmium* blooms may, in turn, provide nutrients that help support blooms of red tide (*Karenia brevis*) in the nearshore area located between the mouths of Tampa Bay (Walsh et al. 2003).

Within Tampa Bay itself, phytoplankton productivity rates appear to be influenced by a number of environmental factors. Bioassay experiments conducted by the City of Tampa's Bay Study Group (Johansson 1991, 2005) indicate that phosphorus has not been a limiting nutrient in their Hillsborough Bay study areas, and that the availability of nitrogen (rather than phosphorus) is more likely to limit phytoplankton productivity in those areas. Short-term bioassays measuring carbon-14 uptake rates, conducted by Vargo et al. (1991) in the Little Manatee and Alafia rivers and nearby portions of Tampa Bay, produced varying responses to N and P additions and suggested that, at times, inorganic N and P were both present at elevated (non-limiting) concentrations in those areas. Vargo et al. (1991) concluded that "phytoplankton populations in… Tampa Bay can be considered nutrient sufficient to borderline nitrogen limited for short-term photosynthesis requirements." Using a water quality model (the U.S. EPA-supported 'Water Analysis Simulation Program' [WASP]), Wang et al. (1999) concluded that phytoplankton productivity in the bay during the years 1985 through 1994 was limited primarily by the availability of sunlight (due to light attenuation by phytoplankton, turbidity and water color) and secondarily by the availability of inorganic nitrogen.

Among the many factors that affect phytoplankton productivity in the open waters of the bay, anthropogenic nitrogen loading appears to be the primary one that can be most effectively controlled by management activities carried out in the watershed (Johansson 1991, TBEP 2006; Greening and Janicki 2006). As a result, the principal focus of the Tampa Bay eutrophication management effort, as explained in Chapter 2, has been to cap the nitrogen loadings entering the bay at levels necessary to achieve bay-wide water clarity targets and seagrass restoration goals.

Reflecting this concern, a number of steps have been taken by the local community to reduce the anthropogenic nitrogen loads that enter the bay each year from the watershed and airshed. Since 1980, all municipal wastewater treatment plants that discharge to the bay and its tributaries have been required by state law (the Grizzle-Figg Act, Sect. 403.086 Florida Statutes) to meet advanced wastewater treatment standards. This step dramatically reduced annual loads of nitrogen, phosphorus and biochemical oxygen demand from these sources. Since the mid-1980s, newly-constructed commercial and residential developments have been required to provide detention and treatment of a portion of the stormwater. At port facilities located on the shoreline of Hillsborough Bay, several commercial shipping companies that handle large quantities of nitrogen and phosphorus-rich fertilizer products, have taken steps to reduce spillage of those materials as they are transferred to and from ships. In addition, several power plants located on the bay have reduced the amount of nitrogen they release to the atmosphere each year, by changing from coal to cleaner-burning fuels or by increasing the level of treatment given to combustion gases before they are discharged from the plant stacks.

As noted by Greening and Janicki (2006), these actions have had several important results: reducing the overall tonnage of nitrogen that enters the bay each year; reducing the relative importance of "point source" discharges such as municipal sewage treatment plants; and increasing the relative importance of stormwater runoff, atmospheric deposition and other "non-point" sources.

Because many of the actions taken to reduce nitrogen loads have also reduced phosphorus inputs, additional results have included reductions in phosphorus loads and SRP concentrations in the bay, and changes in N:P ratios in the bay water column. These changes are discussed in greater detail below.

The water quality improvements brought about by reduced nutrient loads have also been accompanied by changes in the relative abundance of different taxonomic groups within the bay's phytoplankton community. During the late 1970s and early 1980s, for example, dense blooms of the cyanobacteria *Schizothrix calcicola* (*sensu* Drouet) were a common annual event in Hillsborough Bay and Old Tampa Bay (Johansson and Lewis 1992, Johansson 2005). (*Schizothrix* is a genus of non-heterocystous filamentous cyanobacteria that includes several species that are suspected or known to be nitrogen fixers [Paerl 1990, Belnap 2002].) By the latter 1980s and early 1990s – following the large reductions in anthropogenic N and P loads – the *Schizothrix* blooms were no longer evident, and estuarine diatoms and dinoflagellates had become the dominant phytoplankton taxa (Johansson 2005). Macroalgal abundance also declined during the late 1980s and early-to-mid 1990s, and in the mid-1980s a seagrass species (*Halodule wrightii*) began to re-colonize shallow areas of the bay bottom (Johansson 2005).

DATA SOURCES USED IN THIS REPORT

Water quality in the seven segments of Tampa Bay is routinely monitored by four local government agencies: the Environmental Protection Commission of Hillsborough County (EPC), Pinellas County Department of Environmental Management (PCDEM), the Manatee County Environmental Management Department (EMD), and the City of Tampa (COT).

EPC has been monitoring water quality on a monthly basis since the early 1970s, sampling more than 50 stations at fixed locations in the four segments – Old Tampa Bay (OTB), Hillsborough Bay (HB), Middle Tampa Bay (MTB), and Lower Tampa Bay (LTB).

From 1991-2002, PCDEM monitored a series of fixed and random sites within Boca Ciega Bay (BCB). From 2003 to present the County monitored randomly selected sites within the defined TBEP boundaries of OTB, MTB, and BCB.

Manatee County EMD changed its sampling program from sampling a set of fixed stations monthly during 1992-1995, to sampling a set of 24 randomly selected stations each year beginning in 1996. The program now samples one-third (8) of all stations each month, thus allowing all 24 stations to be sampled once in each three month period. Chlorophyll and water clarity targets have not yet been developed for either bay segment. EMD uses Secchi disk depths to estimate water clarity.

The geographical boundaries sampled by EMD also changed in 1996. Fixed stations (1992-95) were located within the boundaries of Terra Ceia Bay (TCB) and the Manatee River (MR), with water quality results grouped by each bay segment. In the existing program, randomly selected stations (1996-2001) were grouped into a single North Manatee County (NMC) segment, were located within the boundaries of TCB and the MR, and included lower Tampa Bay waters extending one nautical mile from shore between TCB and the MR.

COT has been monitoring water quality at several stations in HB and one station in MTB since the late 1970s.

With the exception of data collected in NMC, which were collected quarterly, most data included in this report were collected on a monthly basis. The four monitoring programs are coordinated through a “regional ambient monitoring program” (RAMP). RAMP participants from each agency meet on a roughly quarterly basis to coordinate field and laboratory methods, maximize the between-program comparability of sampling methods and analytical results, and minimize overlap and duplication of effort among the agencies. The Tampa Bay RAMP group works as a subset of the larger Southwest Florida RAMP, which was initiated by the Tampa Bay Estuary Program and is coordinated by the three National Estuary Program offices (Tampa Bay, Sarasota Bay and Charlotte Harbor) present in the region. The Southwest Florida RAMP includes all local and state government monitoring programs that are currently active in the coastal area that extends along the Gulf Coast from the Big Bend area to Pine Island Sound.

WATER QUALITY INDICATORS

For the purposes of this summary, water quality indicators have been grouped into four broad categories, based on the primary water quality management issues to which they relate. These categories are:

- Water clarity and its components (important factors in seagrass management)
- Nutrient levels (important for their primary effects on phytoplankton and macroalgae growth, and their secondary effects on water clarity and dissolved oxygen availability)
- Dissolved oxygen levels (an important determinant of habitat quality for most multicellular plants and animals)
- Physical indicators such as salinity and temperature (important determinants of habitat suitability for many plants and animals)

These groups of indicators are described in more detail in the following sections. Because of the substantial water quality improvements that have occurred in the bay since 1980, the summaries of each indicator focus on two distinct time periods: the pre-1980 period when water quality was much poorer than it is today, and the post-1980 period (1980 – 2005) when generally improving trends have been evident.

For some of the water quality indicators discussed here, changes have occurred over time in either sample collection or laboratory analytical methods. For indicators, including certain inorganic nitrogen and inorganic phosphorus forms, these changes make it impossible to construct a methodologically-consistent time series of data that extends back to the pre-1980 period. Such situations are noted in the text, and discussions of trends in the affected indicators are restricted to the time periods for which methodologically-consistent data are available.

This chapter does not address indicators related to fecal contamination of water, possible pathogenicity, or other issues related to human health and the safety of bay waters for swimming and other types of contact recreation. Readers interested in these topics are encouraged to visit websites maintained by the Florida Department of Health, including the Healthy Beaches Program site (http://esetappsdoh.doh.state.fl.us/irm00beachwater/default.aspx) and the Environmental Health Program site (http://www.doh.state.fl.us/Environment/water/index.html).

WATER CLARITY AND ITS COMPONENTS

Water clarity is affected by several biotic and abiotic factors, such as the abundance of microscopic algae (phytoplankton), concentrations of suspended sediments and other inorganic particles, and levels of water "color" (colored dissolved organic matter, or CDOM).

As noted by the TBEP (2006), water clarity is one of the most important factors affecting the survival, growth and distribution of seagrass beds in Tampa Bay. Seagrasses are flowering plants that live submerged in the bay and other coastal waters. Because the plants require sunlight to flourish, the densest and most luxuriant beds are usually found in shallow, clear waters near the shoreline. The distribution and abundance of seagrasses in the bay are inextricably linked to water clarity: the clearer the water, the deeper seagrass beds can grow. Events that impact water clarity — such as dense algae blooms, dredging projects that generate turbidity blooms, or extreme rainfall events that cause discharges of highly colored water to the bay — can affect the size, density, and habitat value provided by seagrass beds.

Seagrass beds provide important habitat for a number of important fish and invertebrates, including red drum, spotted seatrout, spot, silver perch, sheepshead, snook, and several species of crabs and shrimp. They are also important feeding areas for the endangered Florida manatee. Because of their pivotal role in the Tampa Bay ecosystem, seagrasses have been chosen as the primary biological and environmental indicator of the bay's "health" by the region's resource managers (Chapter 2).

Secchi Disk Depth

The simplest method for determining water clarity the amount of light penetration in the water column is with a Secchi disk, which is a black and white disk typically measuring 20 to 30 centimeters in diameter. A line is fastened at the center and the disk is lowered into the water until it disappears from sight. This depth of disappearance is called the Secchi disk depth.

Secchi disk data collected by the EPC since the early 1970s provide the longest-term record of changes in water column transparency in the four bay segments – OTB, HB, MTB, LTB – that make up the main-stem of Tampa Bay. As shown in Fig. 6-1, annual mean Secchi depths became progressively shallower (water transparency was reduced, and light attenuation increased) in each of these segments during the years 1974 through 1979. Between 1980 and 2005, Secchi depths showed a generally increasing trend, indicating that water column transparency was increasing (improving) and light attenuation levels were falling during this period (Fig. 6-1). With the exception of Lower Tampa Bay, which does not show a significant increasing trend in Secchi depth during the 1980 through 2005 period, each of these trends is statistically significant (Table 6-1). The horizontal red lines that are included in several panels of Fig. 6-1 indicate Secchi depth targets adopted by the TBEP and its partners to support bay-wide seagrass restoration goals. The methods used to develop those targets and goals have been summarized by Greening and Janicki (2006). Recent progress in meeting these water quality targets is summarized in Chapter 2.

Chlorophyll-*a*

Chlorophyll-*a* is a green pigment found in plants that allows absorption of photons from sunlight,

Table 6-1. Temporal trends (Kendall tau-b values and significance levels) in annual mean Secchi disk depth in the four main-stem segments of Tampa Bay during the pre-1980 and 1980 – 2005 time periods. (Data source: EPCHC)

	Time Period	
Bay Segment	**1974 – 1979**	**1980 – 2005**
Hillsborough Bay	-0.60 (0.09) [1]	0.50 (<0.001)
Old Tampa Bay	-0.87 (0.01)	0.37 (<0.01)
Middle Tampa Bay	-0.87 (0.01)	0.38 (<0.01)
Lower Tampa Bay	-0.87 (0.01)	0.18 (0.19)[1]

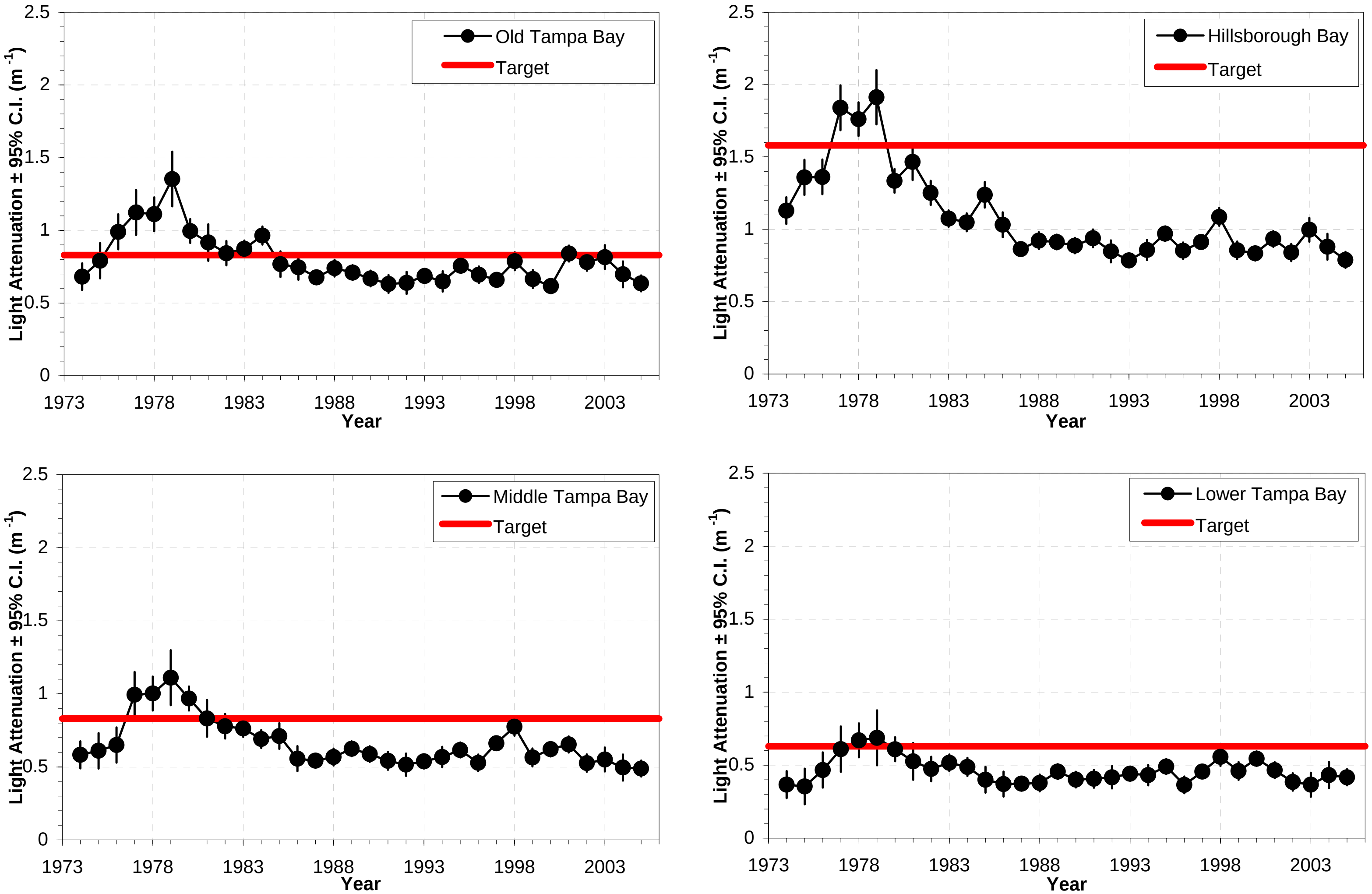
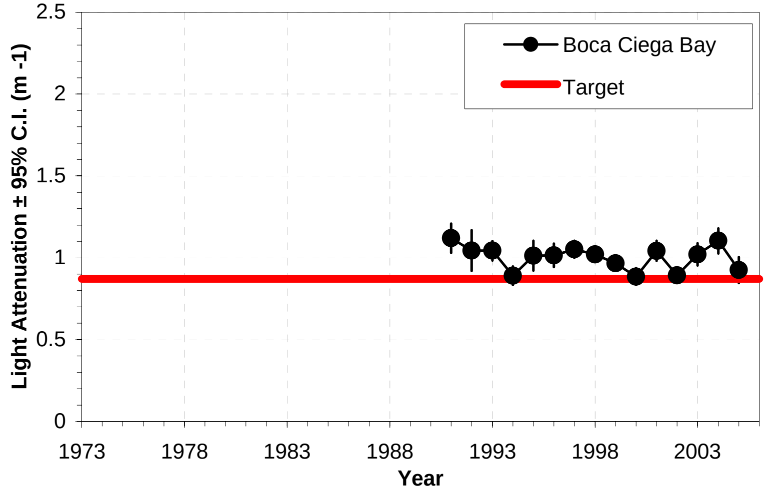
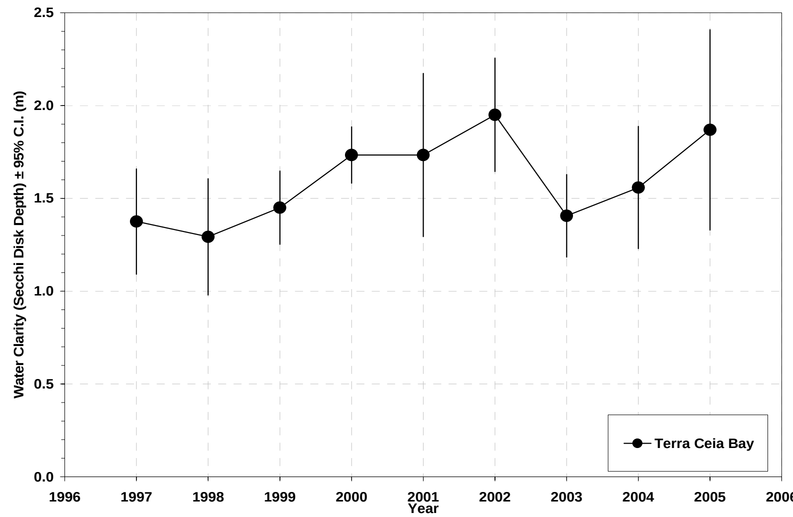


Figure 6-1. Mean annual light attenuation (m $^{-1}$) based on secchi depth and TBEP bay-segment specific targets in the major bay segments of Tampa Bay. Data source: EPCHC water quality monitoring program.





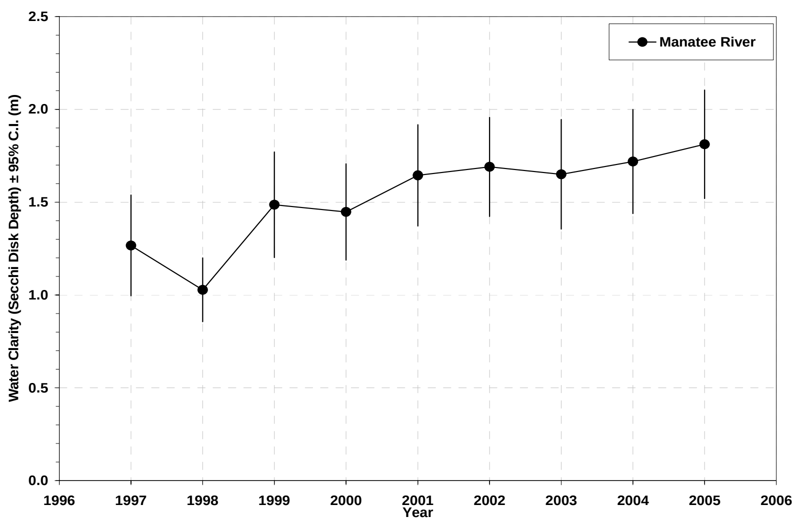


Figure 6-1 (cont'd). Mean annual light attenuation (m^{-1}) based on secchi depth in Boca Ciega and Terra Ceia Bays and the Manatee River with the proposed TBEP proposed targets for Boca Ciega Bay. Data sources: PCDEM & MCEMD water quality monitoring program.

providing the energy necessary to convert CO_2 and water molecules to carbohydrates during the process of photosynthesis. Chlorophyll-*a* concentrations are widely used to estimate phytoplankton abundance and biomass, and overall trophic state conditions, in surface water bodies. High levels of chlorophyll-*a* usually indicate highly eutrophic water quality, while low levels indicate less productive (oligotrophic or mesotrophic) conditions. Increasing concentrations of chlorophyll-*a* usually reflect increases in nutrient loads and increasing eutrophication of aquatic ecosystems.

Occasionally elevated chlorophyll-*a* concentrations are not necessarily problematic, however. Instead, it is the long-term persistence of elevated levels that raise water quality concerns. Therefore resource managers typically monitor annual mean chlorophyll-*a* concentrations at the bay-segment scale.

Chlorophyll-*a* levels in all waterbodies fluctuate over time, in response to a number of environmental factors. Concentrations are often higher following rain events, because of nutrients in the rainfall itself and in stormwater runoff. Higher chlorophyll-*a* levels are also common during summer months, when light levels and water temperatures are high, because these conditions also stimulate phytoplankton growth.

Tidal effects can also cause changes in chlorophyll-*a* concentrations. Tidal mixing tends to reduce chlorophyll-*a* concentrations by decreasing the residence time of phytoplankton in the photic zone. Tidal currents can also cause re-suspension of fine sediments from the bay bottom, and the resulting turbidity can reduce the amount of sunlight that is available in the water column to support photosynthesis. Similarly, changes to the bay that decrease tidal circulation (*e.g.*, construction of causeways and dead-end residential canals), and changes that increase circulation (*e.g.*, dredging of deep navigation channels) can also influence chlorophyll-*a* concentrations in local areas affected by these changes, because tidal circulation tends to reduce phytoplankton residence times and dilute nutrients from land-based sources, making them less available to support phytoplankton growth. Reducing circulation increases residence time therefore making nutrients more available for phytoplankton growth. The opposite is true in areas where circulation has been increased.

Long-term trends in annual mean chlorophyll-*a* concentrations in the four main-stem segments of the bay are shown in Fig. 6-2, and their statistical significance is summarized in Table 6-2. Statistical associations (Kendall tau-b) between annual mean Secchi disk depth and annual mean chlorophyll-*a* concentrations in the four main-stem segments, for the period 1980 through 2005, are summarized in Table 6- 3. The long-term improvements in water column transparency that occurred in HB, OTB and MTB between 1980 and 2005 (shown in Fig. 6-1) were clearly associated with reductions in phytoplankton biomass that occurred during the same periods (Table 6- 3). The horizontal red lines that are included in several panels of Fig. 6-1 indicate chlorophyll-*a* targets adopted by the TBEP and its partners to support bay-wide seagrass restoration goals. The methods used to develop those targets and goals have been summarized by Greening and Janicki (2006). Recent progress in meeting these water quality targets is summarized in Chapter 2.

Mean annual mean Secchi disk depths and chlorophyll-*a* concentrations from Boca Ciega (BCB) and Terra Ceia Bays (TCB) are shown in Figures 6-1 and 6-2. Annual mean chlorophyll- *a* concentrations varied from 5.3 ug/L to 8.9 ug/L and 4.9 µg/L to 16.2 µg/L during the reporting periods for BCB and TCB respectively. The mean annual chlorophyll-a data for BCB is fairly consistent year to year. The dramatic swings in the annual average chlorophyll- *a* concentrations within TCB coincide with changes in annual rainfall. Wetter years support a larger phytoplankton bloom. The long term average chlorophyll-a concentration in BCB is 7.0 ug/L. The proposed chlorophyll-a target for BCB is 7.41 ug/L (TBEP 2006b). The long term average chlorophyll- *a* concentration in Terra Ceia Bay was 8.9 µg/L. By way of comparison, this is twice the 4.4 µg/L reported for the same 10-year period in lower Tampa Bay. BCB light attenuation averaged 1.0 m^{-1} over the reporting period. The proposed light attenuation target for BCB is 0.87 m^{-1} (TBEP 2006b). Terra Ceia Bay water clarity, represented by mean annual Secchi disk depths, ranged from about 1.25 m to 1.95 m. Larger depths indicate better water clarity. Secchi disk depths in Terra Ceia Bay have averaged greater than 1.4 m since 1999, a positive trend.

Mean annual Secchi disk depths and chlorophyll-*a* concentrations from the Manatee River are also shown in Figures 6-1 and 6-2. Annual average chlorophyll- *a* concentrations ranged from about 5.6 µg/L to 10.6 µg/L during the 10-year period shown in the figure. The long term average chlorophyll-*a* concentration in the Manatee River was 7.8 µg/L, slightly lower than the value reported from Terra Ceia Bay. Dramatic swings in annual average chlorophyll- *a* concentration are apparent in the Manatee River. As in Terra Ceia Bay, this behavior is also coincident with changes

Table 6- 2. Temporal trends (Kendall tau-b values and significance levels) in annual mean chlorophyll-*a* concentrations in the four main-stem segments of Tampa Bay during the pre-1980 and 1980 – 2005 time periods. (Data source: EPCHC)

	Time Period	
Bay Segment	**1974 – 1979**	**1980 – 2005**
Hillsborough Bay	0.47 (0.19)[1]	-0.46 (<0.001)
Old Tampa Bay	0.33 (0.35)[1]	-0.35 (0.01)
Middle Tampa Bay	0.60 (0.09)[1]	-0.48 (<0.001)
Lower Tampa Bay	0.60 (0.09)[1]	-0.10 (0.47)[1]

[1]Trend not significant at the p<0.05 level.

Table 6- 3. Association (Kendall tau-b values and significance levels) between annual mean Secchi disk depth and annual mean chlorophyll-*a* concentrations in the four main-stem segments of Tampa Bay during the 1980 – 2005 time period. (Data source: EPCHC)

Bay Segment	**Association (Tau b value and significance level)**
Hillsborough Bay	-0.50 (<0.001)
Old Tampa Bay	-0.48 (<0.001)
Middle Tampa Bay	-0.54 (<0.0001)
Lower Tampa Bay	-0.44 (<0.01)

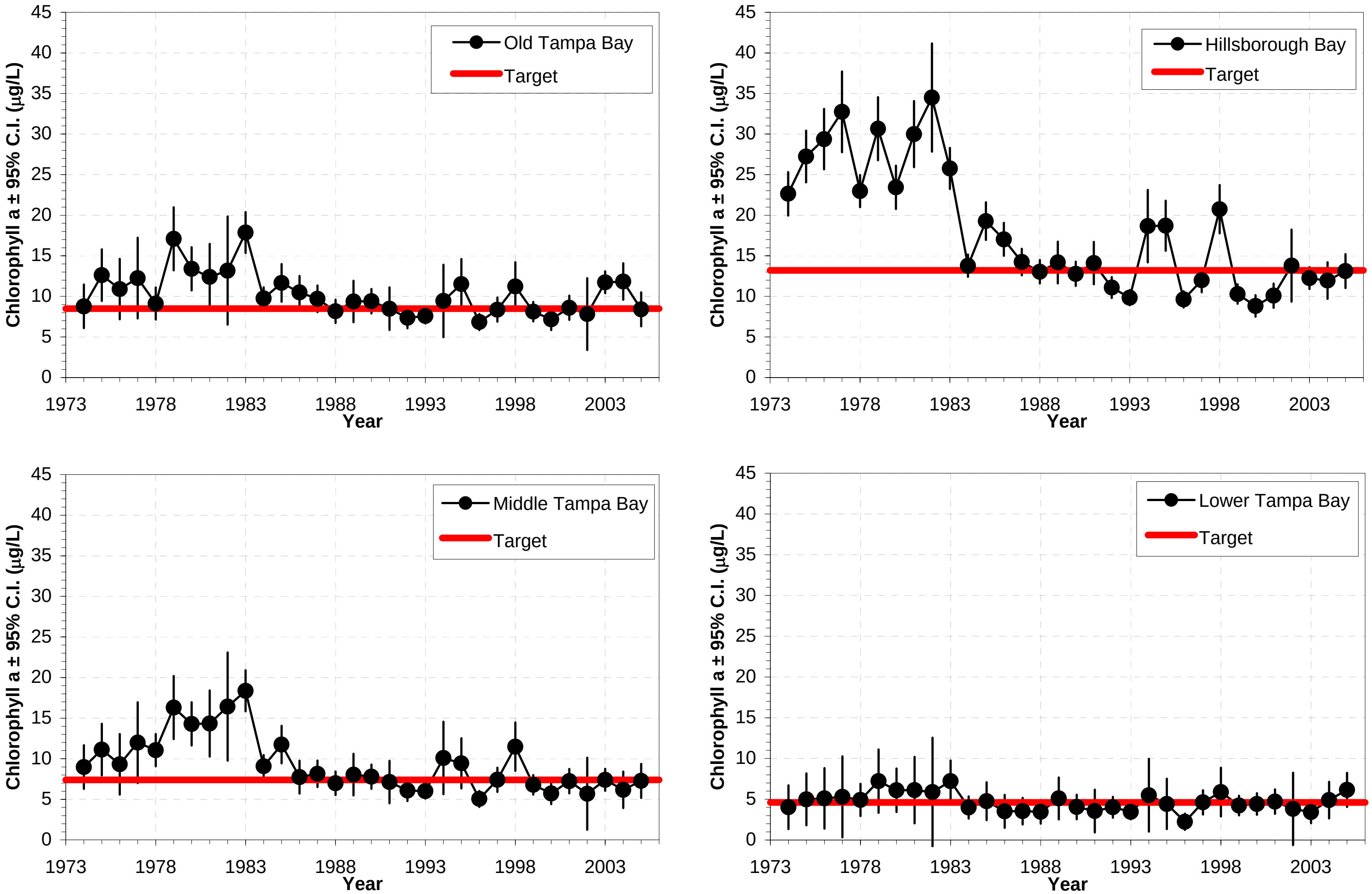


Figure 6-2. Mean annual chlorophyll-a (µg/L) concentrations and TBEP bay-segment specific targets in the major bay segments of Tampa Bay. Data source: EPCHC water quality monitoring program.

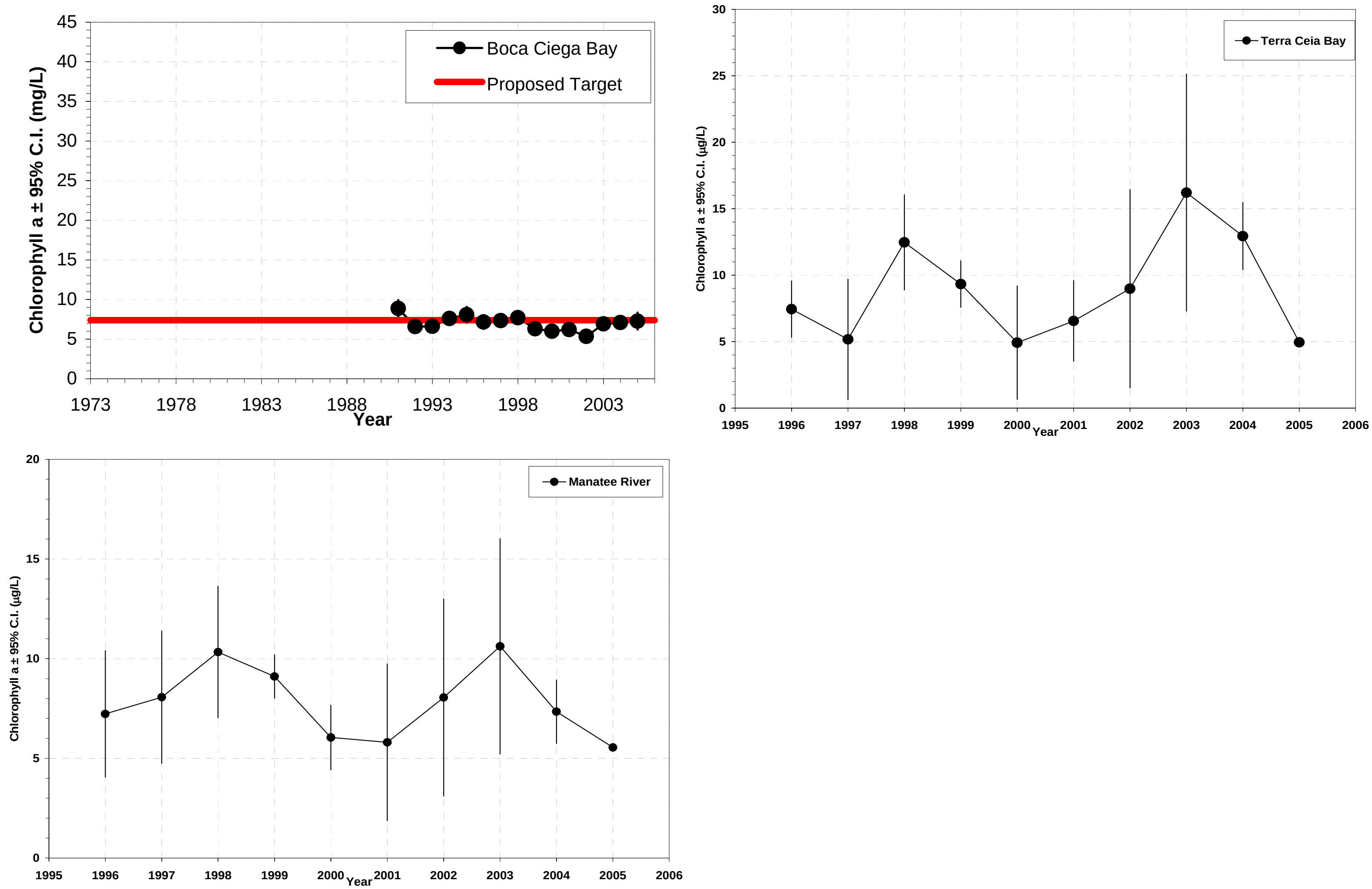


Figure 6-2 (cont'd). Mean annual chlorophyll-a (mg/L) concentrations in Boca Ciega and Terra Ceia Bays and the Manatee River with the proposed TBEP proposed targets for Boca Ciega Bay. Data sources: PCDEM & MCEMD water quality monitoring program.

in seasonal rainfall. Manatee River water clarity, represented by mean annual Secchi disk depths, ranged from about 1.05 m to 1.80 m. Larger Secchi depths indicate better water clarity. Secchi disk depths in the Manatee River have been improving since 1998. Recent annual Secchi disk means have approached those observed in Terra Ceia Bay, a shallower waterbody with less highly colored water.

Color

Colored dissolved organic matter (CDOM), which leaches naturally from decaying vegetation in the watershed, enters Tampa Bay in the fresh water that is discharged from wetlands, lakes, streams and rivers. It is also generated in portions of the bay, in areas such as mangrove forests and seagrass beds, whose discharges of CDOM may affect color levels in shallow-water areas (R. Johansson, pers. comm..)

CDOM absorbs light primarily in the blue and green portions of the spectrum, and can be an important source of light attenuation in areas of the bay that receive large freshwater inflows. Color levels in the bay fluctuate a great deal seasonally and from year to year (Fig. 6-3), but have shown no long-term trends in the main-stem bay segments during the years 1974 through 2005. Not surprisingly, year-to-year variations in color in the four main-stem segments are highly correlated with variations in annual rainfall (Morrison et al. *in press*).

Statistical associations (Kendall tau-b) between annual mean Secchi disk depth and annual mean color levels in the four main-stem segments, for the period 1980 through 2005, are summarized in Table 6- 4. Statistically significant negative associations between the two indicators occurred in OTB and HB during the period. Associations between Secchi depth and color in the other two segments were non-significant.

Table 6- 4. Association (Kendall tau-b values and significance levels) between annual mean Secchi depth and annual mean color in the four main-stem segments of Tampa Bay during the 1980 – 2005 time period. (Data source: EPCHC)

Bay Segment	**Association (Tau b value and significance level)**
Hillsborough Bay	-0.29 (0.04)
Old Tampa Bay	-0.45 (0.001)
Middle Tampa Bay	-0.21 (0.13) [1]
Lower Tampa Bay	-0.003 (0.98) [1]

[1]Association not significant at the $p<0.05$ level.

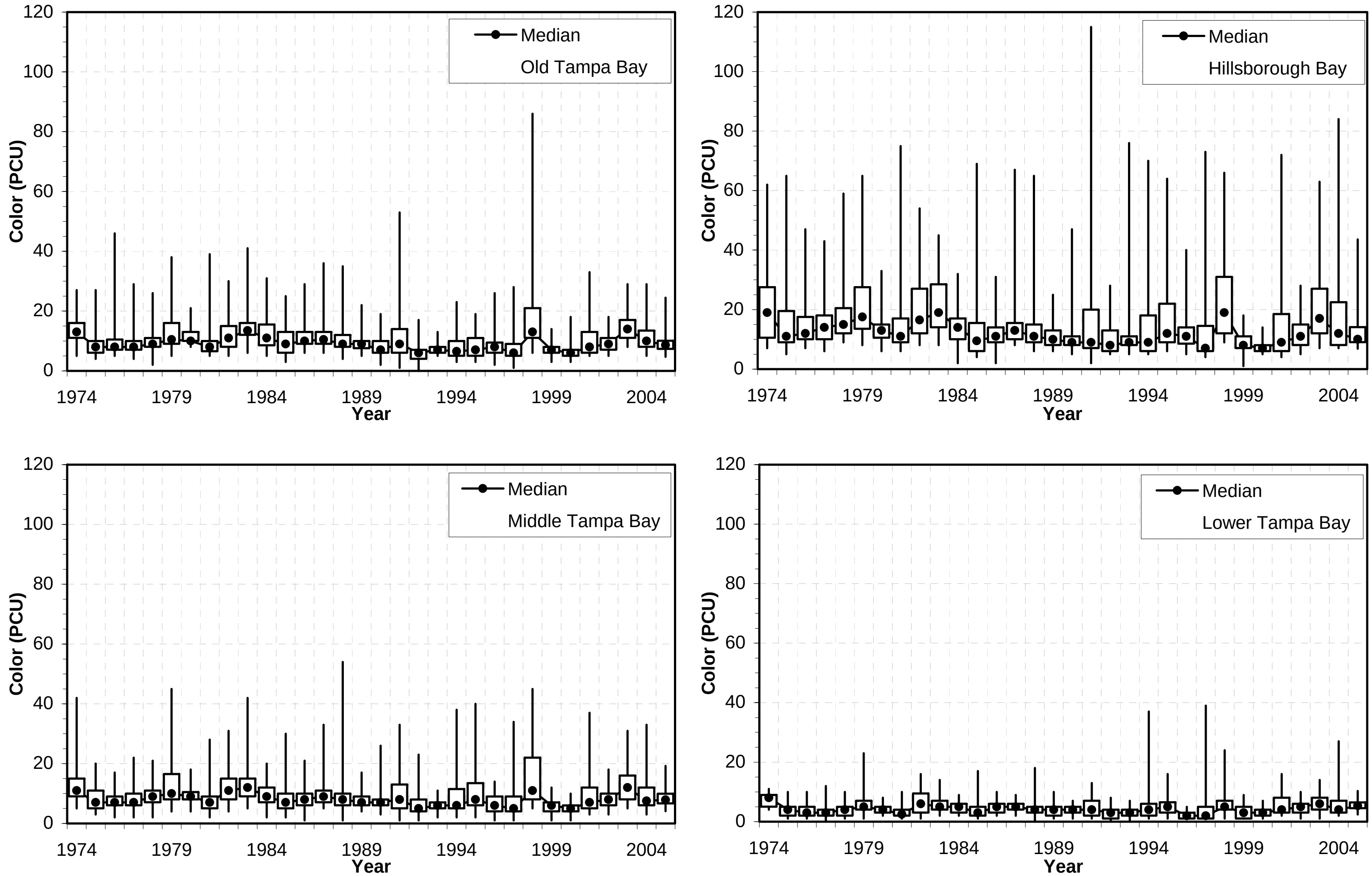


Figure 6-3. Box and whisker plots of annual color (PCU) distribution in the major bay segments of Tampa Bay. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year. Data source: EPCHC water quality monitoring program.

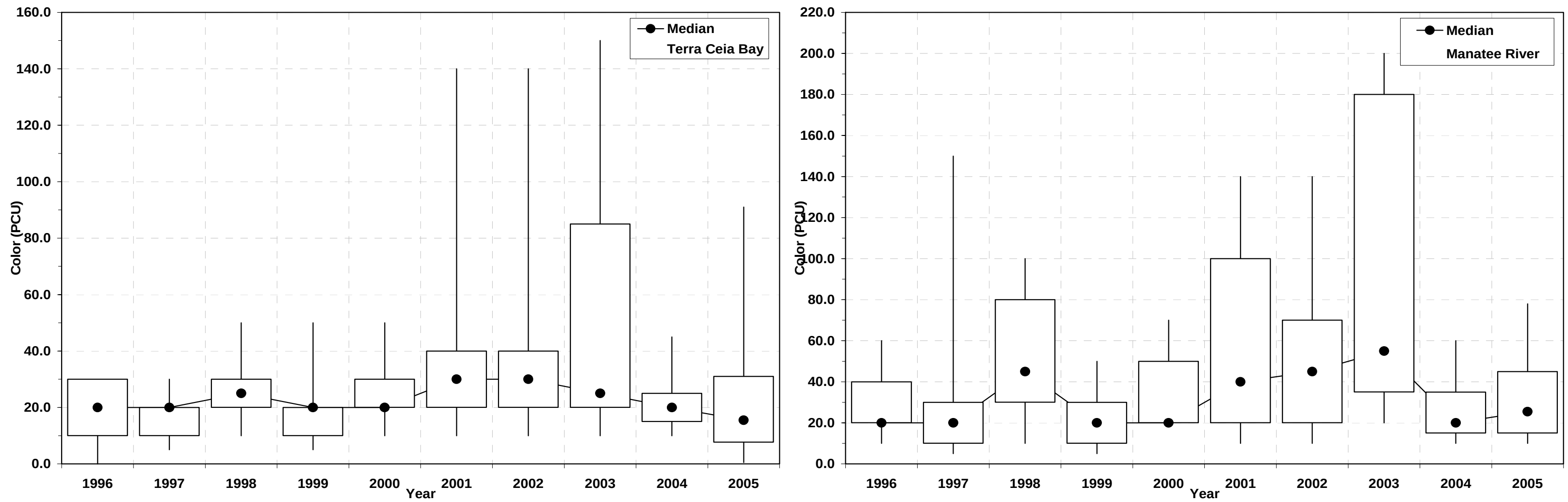


Figure 6-3 (cont'd). Box and whisker plots of annual color (PCU) distribution in Terra Ceia Bay and the Manatee River. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year. Data source: MCEMD water quality monitoring program.

Turbidity

Turbidity can be defined as a decrease in the transparency of water due to the presence of suspended material (such as plankton, organic debris, silts, and clays) – and some dissolved substances – which cause incident light to be scattered, reflected and attenuated rather than transmitted in straight lines.

Long-term trends in annual mean turbidity levels in the four main-stem segments of the bay are shown in Fig. 6-4, and their statistical significance is summarized in Table 6- 5. Downward (improving) trends in turbidity levels occurred in two of the four segments (HB and MTB) during the 1980 – 2005 period. Statistical associations (Kendall tau-b) between annual mean Secchi disk depth and annual mean turbidity levels in the four main-stem segments, for the period 1980 through 2005, are summarized in Table 6- 6. A highly significant ($p<0.05$) association occurred in only one segment (LTB) during the period. A marginally-significant ($p<0.10$) association occurred in MTB.

Turbidity variation in BCB and Terra Ceia Bay is summarized in Figure 6-4. The annual median turbidity within BCB and Terra Ceia Bay varied between 1.8 NTU to 5.4 NTU and 2.0 NTU to 3.8 NTU during the reporting periods.. The highest maximum value observed in Terra Ceia Bay during the reporting period was 12.0 NTU. Water with this value would appear virtually clear. The light environment of Terra Ceia Bay is not significantly affected by water column turbidity.

The annual median turbidity within the Manatee River varied between 1.7 NTU to 4.1 NTU during the 10-year period covered in Fig. 6-4. The highest maximum value observed during the reporting period was 16.8 NTU. Water with this turbidity value would appear virtually clear. The Manatee River is generally recognized as having highly colored water, but with low suspended sediment loads. This appears typical of most Florida 'black water' rivers.

Table 6-5. Temporal trends (Kendall tau-b values and significance levels) in annual mean turbidity (NTU) in the four main-stem segments of Tampa Bay during the pre-1980 and 1980 – 2005 time periods. (Data source: EPCHC)

	Time Period	
Bay Segment	**1974 – 1979**	**1980 – 2005**
Hillsborough Bay	0.73 (0.04)	-0.39 (<0.01)
Old Tampa Bay	0.20 (0.57) [1]	-0.18 (0.20) [1]
Middle Tampa Bay	0.33 (0.35) [1]	-0.43 (0.002)
Lower Tampa Bay	0.60 (0.09) [1]	-0.16 (0.24) [1]

[1]Trend not significant at the $p<0.05$ level.

Table 6-6. Association (Kendall tau-b values and significance levels) between annual mean Secchi disk depth and annual mean turbidity in the four main-stem segments of Tampa Bay during the 1980 – 2005 time period. (Data source: EPCHC)

Bay Segment	**Association (Tau b value and significance level)**
Hillsborough Bay	-0.15 (0.28) [1]
Old Tampa Bay	-0.04 (0.79)[1]
Middle Tampa Bay	-0.26 (0.06) [1]
Lower Tampa Bay	-0.40 (<0.01)

[1]Association not significant at the $p<0.05$ level

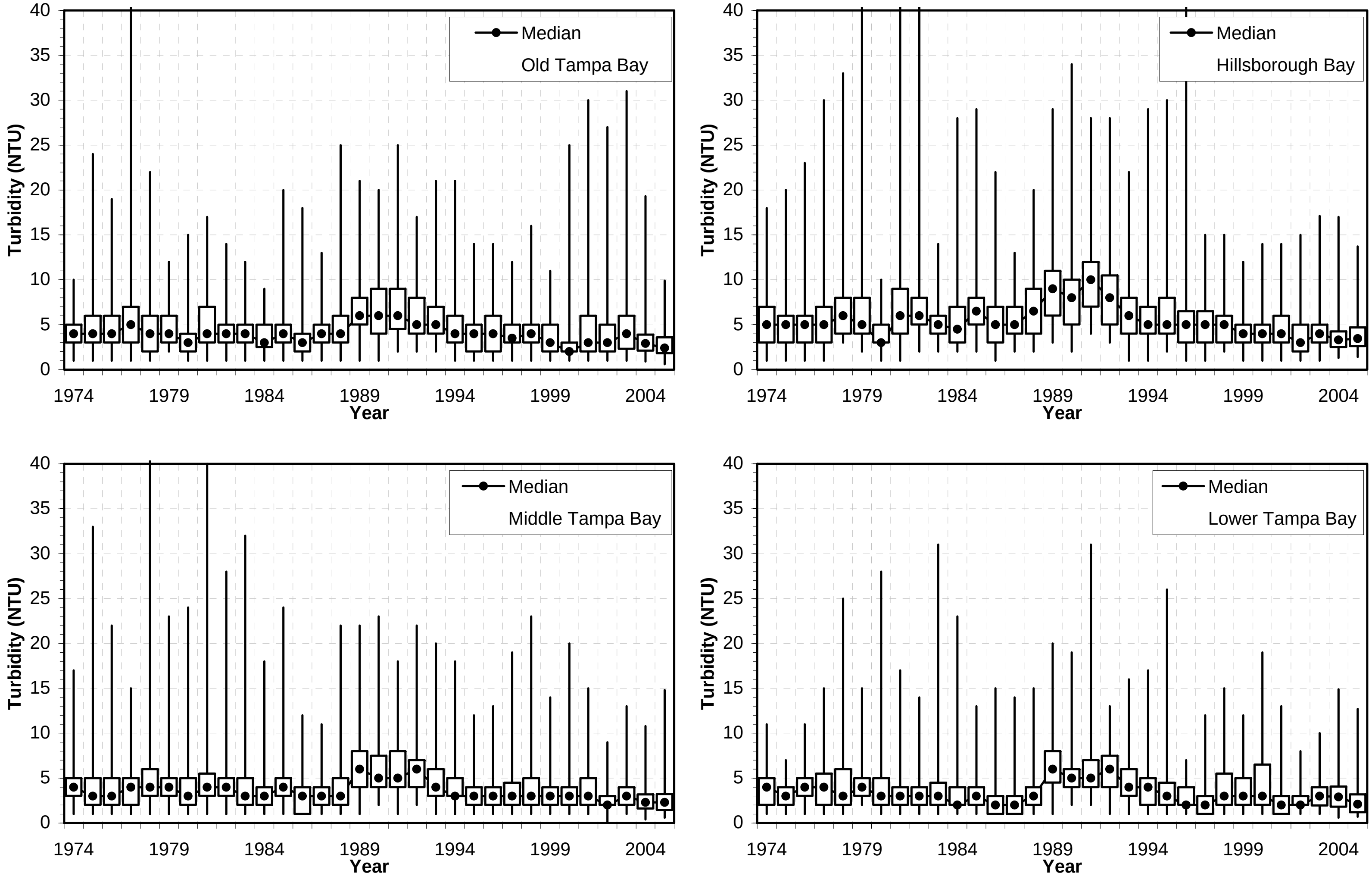


Figure 6-4. Box and whisker plots of annual turbidity (NTU) distribution in the major bay segments of Tampa Bay. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year.
Data source: EPCHC water quality monitoring program.

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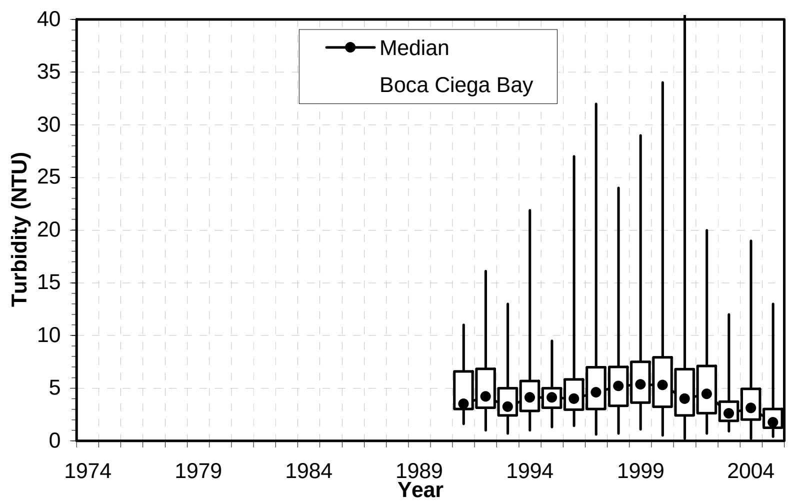
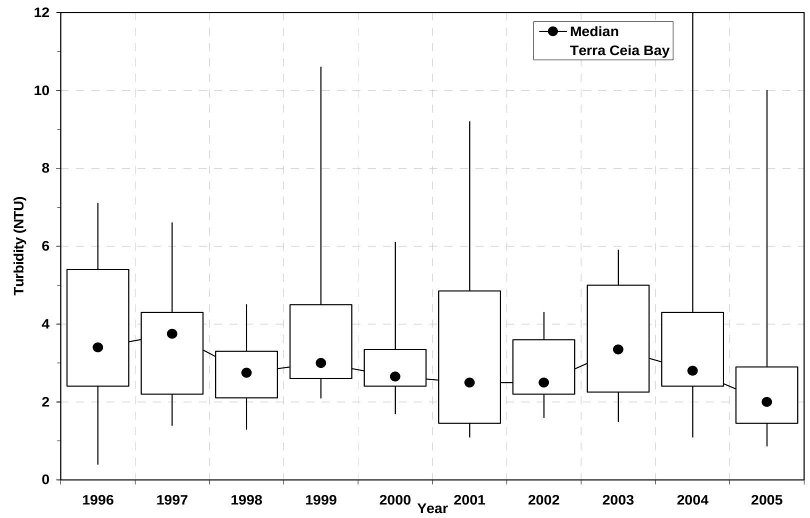




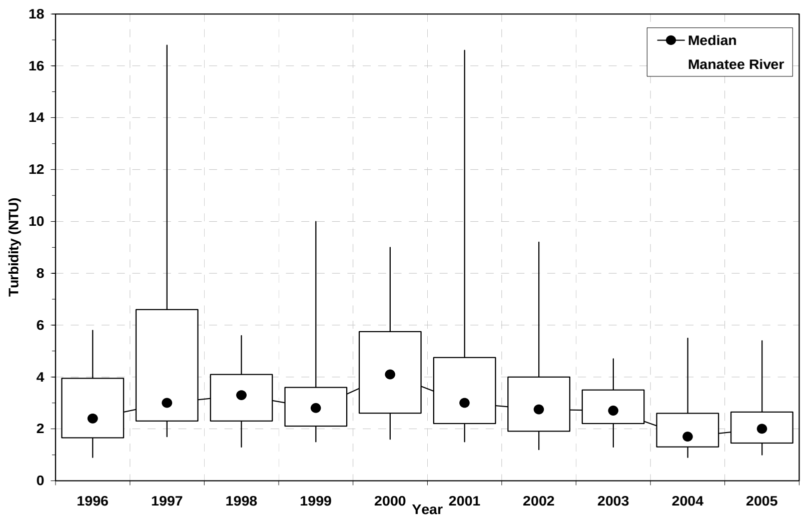


Figure 6-4 (cont'd). Box and whisker plots of annual turbidity (NTU) distribution in Boca Ciega and Terra Ceia Bays and the Manatee River. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year. Data source: PCDEM & MCEMD water quality monitoring program

NITROGEN AND PHOSPHORUS CONCENTRATIONS

The nutrients nitrogen (N) and phosphorus (P) are chemical elements that are essential for the survival, growth and reproduction of plants and animals. Nitrogen is a key component of amino acids, proteins, DNA and RNA. Phosphorus is found in nucleic acids, certain fats (phospholipids), and in adenosine di-phosphate and tri-phosphate (ADP and ATP), which are key molecules for the storage and use of chemical energy in living cells.

Biogeochemical processes transfer different forms of nitrogen and phosphorus through the atmosphere, hydrosphere and biosphere, in what are known as nitrogen and phosphorus cycles. The major non-anthropogenic sources of biologically-available N are nitrogen-fixing bacteria – including several aquatic species that are abundant in lakes, rivers and streams in the Tampa Bay watershed – which convert N_2 gas from the atmosphere and water column into forms that can be taken up by higher plants and animals. The major non-anthropogenic source of biologically-available phosphorus is the weathering of phosphate-rich geological deposits. In addition to these non-anthropogenic sources, human activities – particularly the combustion of fossil fuels and the large-scale industrial use of chemical nitrogen fixation (for N), and the processing of phosphate ore to produce N and P-enriched fertilizer products (for both N and P) – became large sources of bio-available N and P during the 20th century (NRC 2000). Atmospheric deposition, stormwater runoff, freshwater inputs from rivers and streams, and discharges of wastewater from sewage treatment plants and fertilizer manufacturing facilities are important routes through which bio-available N and P are discharged to Tampa Bay (TBEP 2006a).

Excessive inputs of nutrients can contribute to undesirable levels of eutrophication in coastal waters (NRC 2000, Cloern 2001). The general pattern of change involves a shift from large macrophytes (including seagrasses) towards faster-growing macroalgae and phytoplankton that capture and use light more efficiently. High loadings of organic matter to the sediment, from wastewater discharges or following the collapse of algal blooms, promotes oxygen consumption through decomposition, and can potentially lead to hypoxic or anoxic events. Low dissolved oxygen concentrations can harm benthic invertebrates, fish, and other organisms. Nitrification and denitrification rates can also be inhibited when the availability of dissolved oxygen is reduced. Reductions in denitrification efficiencies can help to initiate or maintain algal blooms by increasing fluxes of nutrients from sediments to the overlying water column. Overall, eutrophication can cause excessive primary production, a reduction in secondary production, changes in trophic structure, energy flow and nutrient dynamics, and an overall reduction of species diversity (NRC 2000, Cloern 2001). Many of these effects have been observed in Tampa Bay, particularly during the 1970s and 1980s (e.g., Johansson 1991, 2005; Greening and Janicki 2006)

As noted by Greening and Janicki (2006), Tampa Bay currently receives much smaller annual loadings of nitrogen and phosphorus than it did several decades ago, thanks to regional improvements in wastewater and stormwater treatment practices and other watershed management activities that have occurred since the early 1980s.

Trends in TN and TP concentrations

Main-stem segments

Long-term trends in annual concentrations of total nitrogen (TN) and total phosphorus (TP) in the four main-stem segments of the bay are shown in Figs. 6-5 and 6-6, and their statistical significance is summarized in Table 6- 7. The time period analyzed in this case begins in 1981, the first year for which reliable TN data are available. Significant downward trends in TP concentrations occurred in each of the four segments during the 1981 – 2005 period. Significant downward trends in TN during that period occurred only in Hillsborough Bay (Table 6- 7)

Boca Ciega Bay and Terra Ceia Bay

Median annual total nitrogen concentrations in BCB and Terra Ceia Bay varied between 0.35 mg/L and 0.62 mg/L and 0.51 mg/L and 0.93 mg/L respectively (Figure 6-5) There is no discernable pattern in the variation of this nutrient. The long-term median annual total nitrogen is 0.53 mg/L in BCB and 0.69 mg/L in TCB, the same value observed during the same period from the Manatee River. Median annual total phosphorus concentrations (Figure 6-6) appear to show a slight downward trend in TCB and is relatively unchanged in BCB over the reporting period. On several occasions, minima in total phosphorous concentrations approached laboratory detection limits, thus the absence of ‘whiskers’ extending below the markers.

Table 6-7. Temporal trends (Kendall tau-b values and significance levels) in annual mean TN and TP concentrations in the four main-stem segments of Tampa Bay during the period 1981 through 2005. (Data source: EPCHC)

	Nutrient Form	
Bay Segment	**TP**	**TN**
Hillsborough Bay	-0.69 (<0.0001)	-0.37 (<0.01)
Old Tampa Bay	-0.73 (<0.0001)	-0.06 (0.67)[1]
Middle Tampa Bay	-0.71 (<0.0001)	-0.15 (0.28)[1]
Lower Tampa Bay	-0.57 (<0.0001)	-0.02 (0.89)[1]

[1]Trend not significant at the p<0.05 level.

Manatee River

Median annual total nitrogen concentrations in the Manatee River varied between 0.43 mg/L and 1.00 mg/L during the 10-year period shown in Figure 6-5. There is no discernable pattern in the variation of this nutrient. The long-term median annual total nitrogen in Manatee River is 0.69 mg/L, the same value that was observed during the same period from Terra Ceia Bay. During our 10-year reporting period, median annual total phosphorus concentrations in the Manatee River (Figure 6-6) ranged between 0.06 mg/L to 0.31 mg/L. There appears to be a slight downward trend in total phosphorous concentrations in the graph. However, there has been little change in the annual maxima of total phosphorous concentration during this period. This suggests that events that may transport large amounts of phosphorous to the estuary are still occurring, although at reduced frequency and/or severity.

Trends in DIN and SRP Concentrations

Dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus (SRP) are forms of N and P that are readily available to support phytoplankton and macroalgal growth. Long-term trends in annual concentrations of these N and P forms in the four main-stem segments of the bay are summarized in Table 6- 8. The time period analyzed in this case begins in 1991, the first year for which sufficiently frequent SRP data are available to support trend analysis at the bay-segment scale. Significant (p<0.05) downward trends in SRP concentrations occurred in OTB and MTB during the 1991 – 2005 period. A marginally-significant (p=0.10) downward trend in SRP was observed in HB. No significant downward trends in DIN were detected during the period (Table 6- 8).

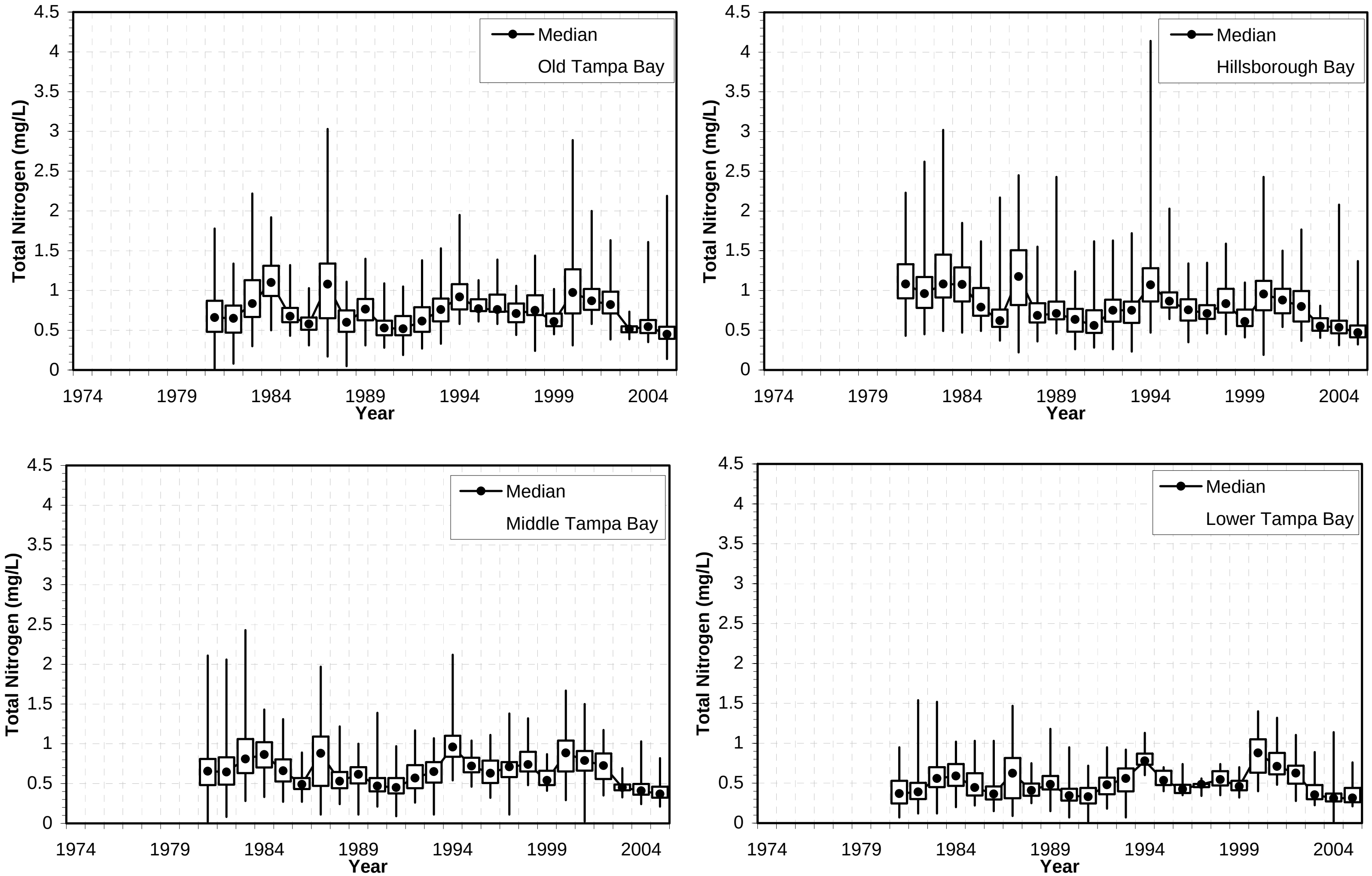
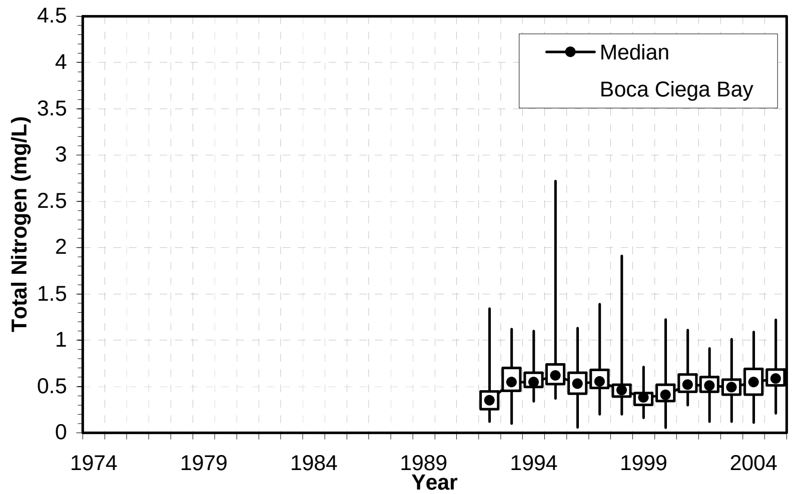
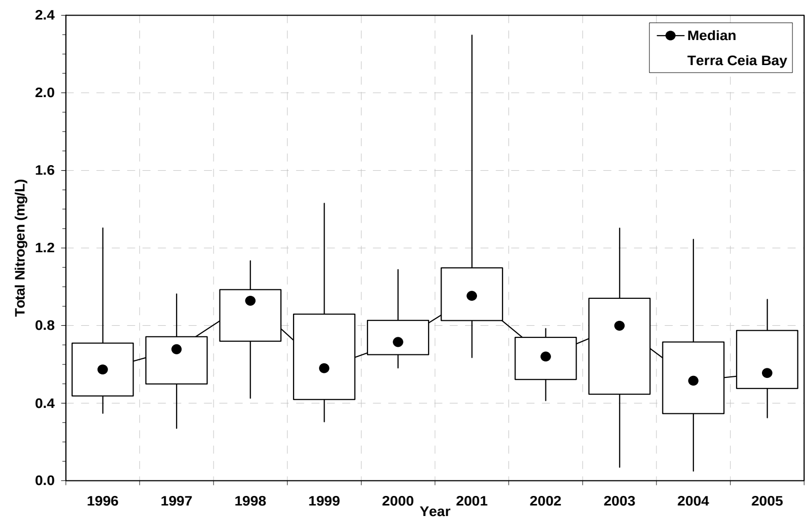


Figure 6-5. Box and whisker plots of annual total nitrogen (mg/L) distribution in the major bay segments of Tampa Bay. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year.
Data source: EPCHC water quality monitoring program





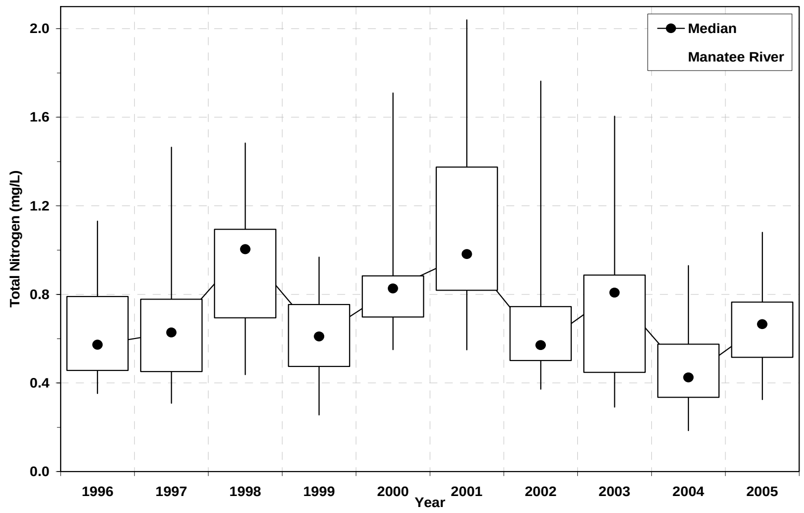


Figure 6-5 (cont'd). Box and whisker plots of annual total nitrogen (mg/L) distribution in Boca Ciega and Terra Ceia Bays and the Manatee River. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year.
Data source: PCDEM & MCEMD water quality monitoring program.

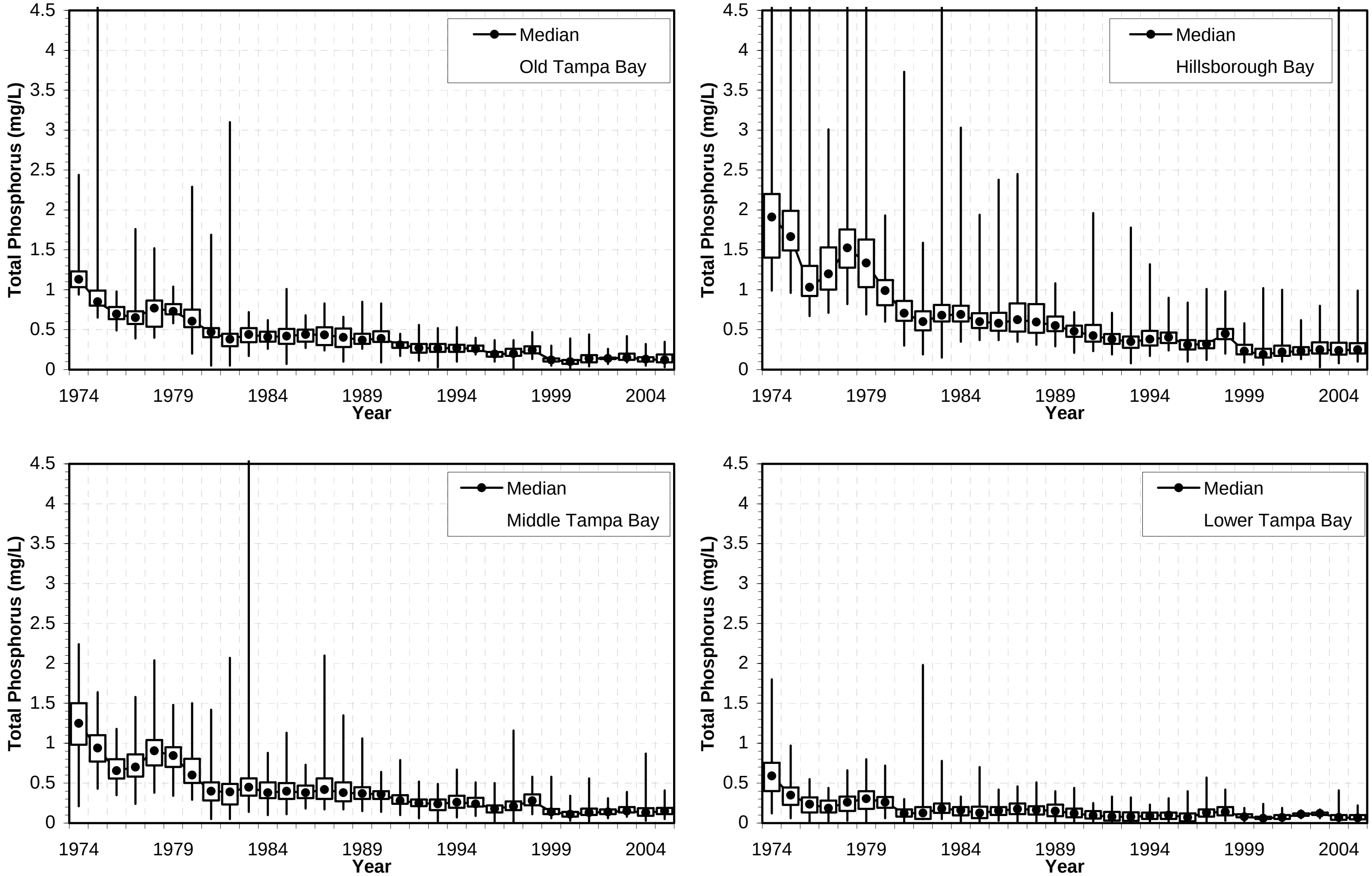


Figure 6-6. Box and whisker plots of annual total phosphorus (mg/L) distribution in the major bay segments of Tampa Bay. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year. Data source: EPCHC water quality monitoring program.

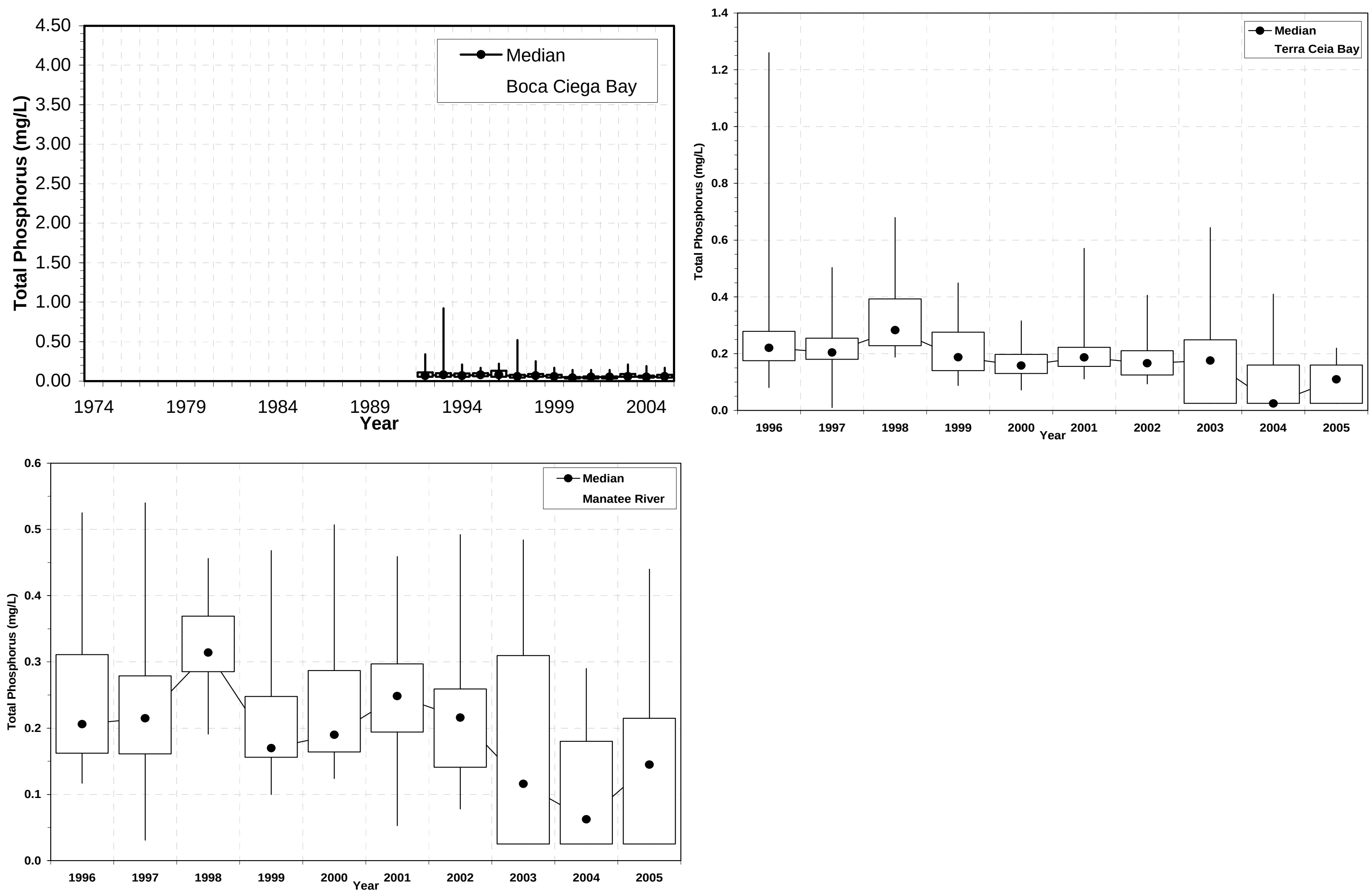


Figure 6-6 (cont'd). Box and whisker plots of annual total phosphorus (mg/L) distribution in Boca Ciega and Terra Ceia Bays and the Manatee River. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year. Data source: PCDEM and MCEMD water quality monitoring program.

Table 6-8. Temporal trends (Kendall tau-b values and significance levels) in annual mean SRP and DIN concentrations in the four main-stem segments of Tampa Bay during the period 1991 through 2005. (Data source: EPCHC)

Bay Segment	Nutrient Form: SRP	Nutrient Form: DIN
Hillsborough Bay	-0.31 (0.10) [1]	0.28 (0.15) [1]
Old Tampa Bay	-0.58 (0.002)	0.22 (0.26) [1]
Middle Tampa Bay	-0.45 (0.02)	0.20 (0.30) [1]
Lower Tampa Bay	-0.10 (0.59) [1]	0.10 (0.59) [1]

[1]Trend not significant at the p<0.05 level.

Trends in DIN and SRP ratios

In addition to the available concentrations of N and P in the water column, the ratios of TN:TP (or DIN:SRP) can also be important water quality indicators because of their potential influence on phytoplankton community structure (Sellner 1997, Cloern 2001, Rydin et al. 2002, Boesch et al. 2006).

Long-term trends in annual concentrations of these N and P forms in the four main-stem segments of the bay are summarized in Table 6- 9. The time periods analyzed begin in 1981 for TN and TP, and in 1991 for DIN and SRP, because of the data availability issues discussed earlier. Significant increasing trends in TN:TP and DIN:SRP ratios occurred in HB, OTB and MTB during these periods (Table 6- 9). A marginally-significant ($p<0.10$) increasing trend in the TN:TP ratio occurred in LTB during the 1991-2005 period, but was not reflected in the DIN:SRP ratio.

Within the phytoplankton community, different taxonomic groups show preferences for different nutrient ratios. Undesirable blooms of marine cyanobacteria, for example, commonly occur under conditions of low DIN concentrations, high SRP concentrations, and low DIN:SRP ratios (Sellner 1997, Cloern 2001, Rydin et al. 2002, Boesch et al. 2006). The cyanobacterial blooms that occurred in Hillsborough Bay during the late 1970s and early 1980s (Johansson 2005) took place at a time when N and P loads were substantially higher, and TN:TP (and perhaps DIN:SRP) ratios were significantly lower, than they are today. The greater reductions in P loads than N loads that have evidently been achieved in Hillsborough Bay, and the increases in N:P ratios that have occurred there as a result, may thus have played a role in the dramatic decline in cyanobacteria blooms, and the increased relative abundance of diatoms and dinoflagellates, that have occurred in that bay segment. This question has not received a great deal of attention from bay managers in the past, but may warrant scrutiny in the future, particularly given the additional changes in the ratios of DIN, SRP and bio-available silica (Si) that may occur in the future as the watershed becomes more developed and the nutrient content of freshwater inflows changes in response to changing patterns of water use and re-use.

Table 6-9. Temporal trends (Kendall tau-b values and significance levels) in annual mean TN:TP and DIN:SRP ratios in the four main-stem segments of Tampa Bay during the periods 1981-2005 and 1991-2005, respectively. (Data source: EPCHC)

Bay Segment	**TN:TP trend (1981 – 2005)**	**DIN:SRP trend (1991 – 2005)**
Hillsborough Bay	0.49 (<0.001)	0.58 (<0.01)
Old Tampa Bay	0.55 (0.0001)	0.58 (<0.01)
Middle Tampa Bay	0.44 (<0.01)	0.49 (0.01)
Lower Tampa Bay	0.24 (0.09) [1]	-0.24 (0.22) [1]

[1]Trend not significant at the $p<0.05$ level

DISSOLVED OXYGEN

With the exception of some specialized anaerobic organisms, dissolved oxygen (DO) is necessary for the survival of all plant and animal species. As a result, the DO concentration in water strongly influences the distribution of aquatic life. Oxygen has limited solubility in water, usually ranging from 6 to 14 mg/L. Within a waterbody, DO concentrations reflect an equilibrium between oxygen-producing processes (such as photosynthesis), oxygen-consuming processes (such as aerobic respiration, nitrification, and chemical oxidation), and the rates at which DO is added to and removed from the water column by atmospheric exchange (aeration and degassing) and hydrodynamic processes such as addition from rivers discharges and tidal exchanges, and export to the ocean. The solubility of oxygen gas in water declines with increasing temperature and salinity. Dissolved oxygen consumption and production are influenced by plant (macrophyte and phytoplankton) biomass, light intensity and water temperature – because these factors influence photosynthesis rates – and are also subject to daily and seasonal variation.

DO concentrations in coastal waterbodies naturally vary throughout the day, due to tidal exchange and because oxygen is being produced by seagrasses, phytoplankton and other algae during daylight hours when photosynthesis occurs. During the night, however, photosynthesis stops and aquatic plants and animals continue to respire, a process that consumes oxygen. Therefore productive waterbodies tend to exhibit highly variable DO concentrations over a 24-hour cycle. Nutrient enrichment and eutrophication stimulate phytoplankton and macroalgal growth, and are often accompanied by a mass influx of particulate organic matter to the sediments of coastal waterbodies. The decomposition of this organic matter by microorganisms leads to higher rates of oxygen consumption, and potential depletion of DO in bottom waters. Stratification of the water column, due to steep salinity or temperature gradients, can isolate bottom waters from oxygen-replenishing processes, giving rise to hypoxic or anoxic events.

Most aquatic organisms require oxygen in specific concentration ranges for respiration and efficient metabolism, and DO concentration changes above or below this range can have adverse physiological or behavioral effects. Even short-duration hypoxic events can cause major "kills" of aquatic organisms. Exposure to low oxygen concentrations can have an immune suppression effect on fish which can elevate their susceptibility to diseases. In addition, the adverse effects of many toxic materials (lead, zinc, copper, cyanide, ammonia, hydrogen sulfide and pentachlorophenol) can double when DO is reduced from 10 to 5 mg/L (http://www.ga.gov.au/ozestuaries/). For estuaries in the "Virginian Province" of the northeastern U.S., the U.S. EPA has concluded that DO concentrations chronically lower than 4.8 mg/L impact the growth of the immature stages of sensitive organisms, and concentrations that fall below 2.3 mg/L for even brief periods are harmful or fatal for many species (U.S. EPA 2000).

The death of immobile organisms and avoidance of low-oxygen conditions by mobile organisms can also cause changes in the structure and diversity of aquatic communities. In addition, if dissolved oxygen becomes depleted in bottom waters (or sediments), nitrification, and therefore denitrification, may be terminated, and bioavailable SRP and ammonium may be released from the sediment to the water column. These recycled nutrients can stimulate or reinforce algal blooms. Hydrogen sulfide gas, also the result of anaerobic respiration, can be toxic to benthic organisms and fishes when present in high concentrations in the water column or sediments.

Time-series box-and-whisker plots of DO concentrations in the four main-stem segments of Tampa Bay, for the years 1974 through 2005, are shown in Figs. 6-7 through 6-9. Elevated DO concentrations (>10 mg/L) in near-surface waters, are usually indicative of dense phytoplankton blooms. This occurred more frequently in Hillsborough Bay, reflecting its higher degree of eutrophication. The magnitudes of these elevated DO values, and the overall variability in annual DO concentrations (the difference between the observed maximum and minimum values) appear to be declining over time, particularly in the near-surface and mid-depth monitoring data. These patterns are presumably occurring in response to the reductions in nutrient loadings and algal biomass that have occurred during the past quarter century. Cumulative distribution function (cdf) plots of DO concentrations, for the years 2002 through 2005, are shown in Fig.6-10. DO concentrations <4 mg/L were observed in approximately 40% of the near-bottom observations made at the EPC's Hillsborough Bay monitoring stations during that period. About 10% of the near-bottom samples from Hillsborough Bay showed concentrations <2 mg/L. DO concentrations <4 mg/L and <2 mg/L were observed less frequently in the other bay segments (Fig. 6-10).

Figures 6-7, 6-8, and 6-9 also show the median annual dissolved oxygen data through the water column in BCB. Over the reporting period the graphs show no trend in the median annual values; however, the graphs do show increasing variability in the extreme high and low values not characteristic in the early years of the monitoring program. The CDF plot (Figure 6-10) of surface, mid, and bottom dissolved oxygen trends in BCB show that approximately 5-10 percent of the area does not meet the state water quality standard of 4 mg/L dissolved oxygen.

The median annual dissolved oxygen concentrations in Terra Ceia Bay varied between 6.4 mg/L to 7.7 mg/L (Figure 6-9) for the time period shown in the figure. Dissolved oxygen concentrations vary with water temperature, salinity, and the time of day the measurement was taken. Short-term changes in these other parameters are probably responsible for most of the variation in dissolved oxygen concentrations away from the median values shown in the graph. The minimum dissolved oxygen value reported in Figure 6-9, an observation of 4.6 mg/L during 2005, is well above levels that may be harmful to aquatic life

Median annual dissolved oxygen concentrations from the Manatee River varied between 6.5 mg/L to 7.2 mg/L (Figure 6-9) for the period 1996 – 2005. Dissolved oxygen levels in the Manatee River were always greater than 3.8 mg/L during the period shown in Figure 6-9.

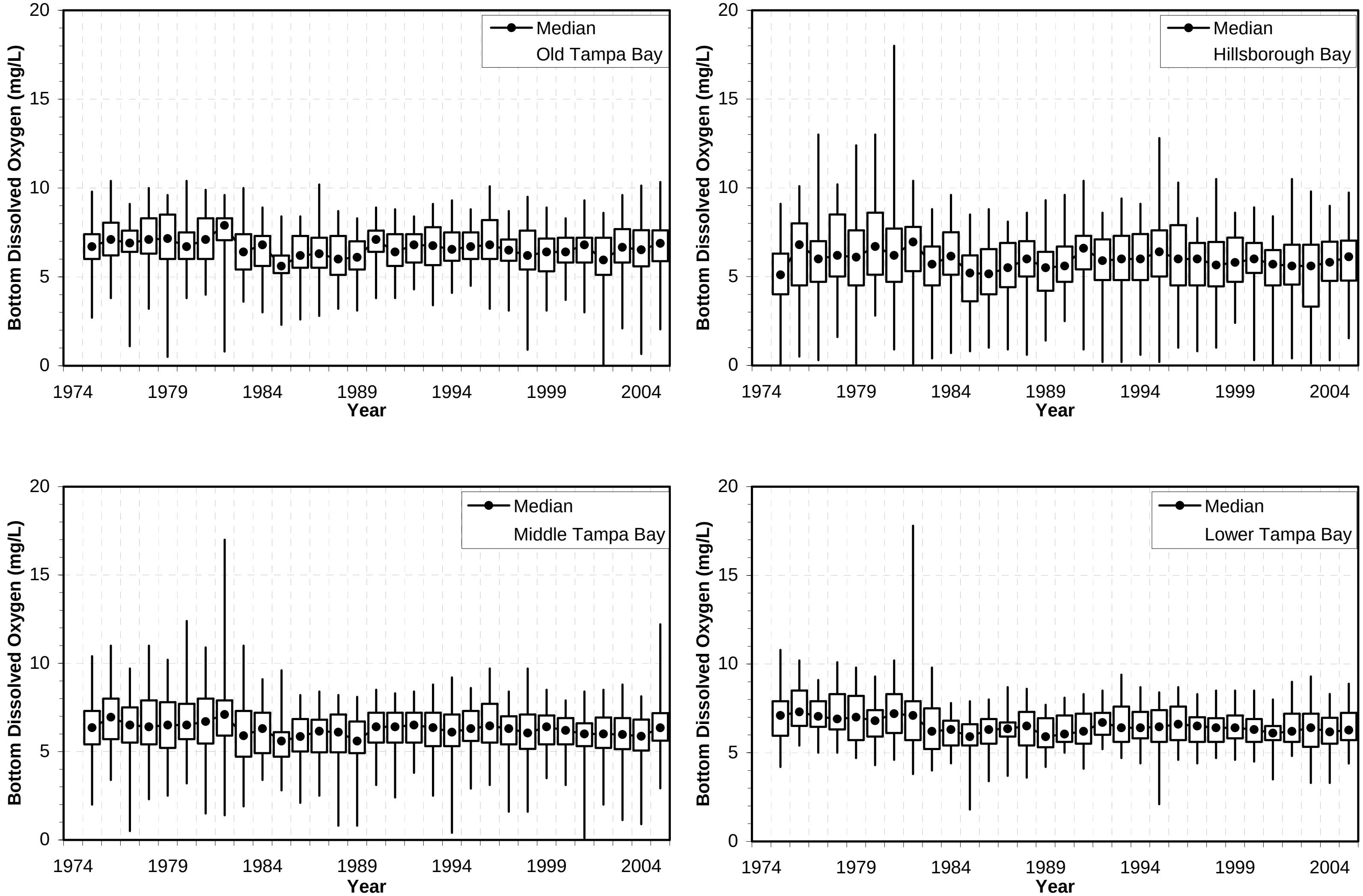


Figure 6-7. Box and whisker plots of annual bottom dissolved oxygen (mg/L) distribution in the major bay segments of Tampa Bay. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year.

Data source: EPCHC water quality monitoring program.

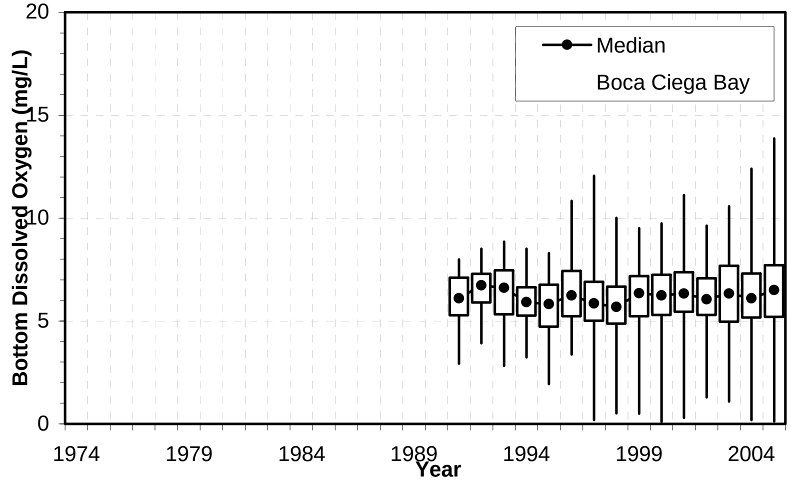


Figure 6-7 (cont'd). Box and whisker plots of annual bottom dissolved oxygen (mg/L) distribution in Boca Ciega Bay. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year.
Data source: PCDEM water quality monitoring program.

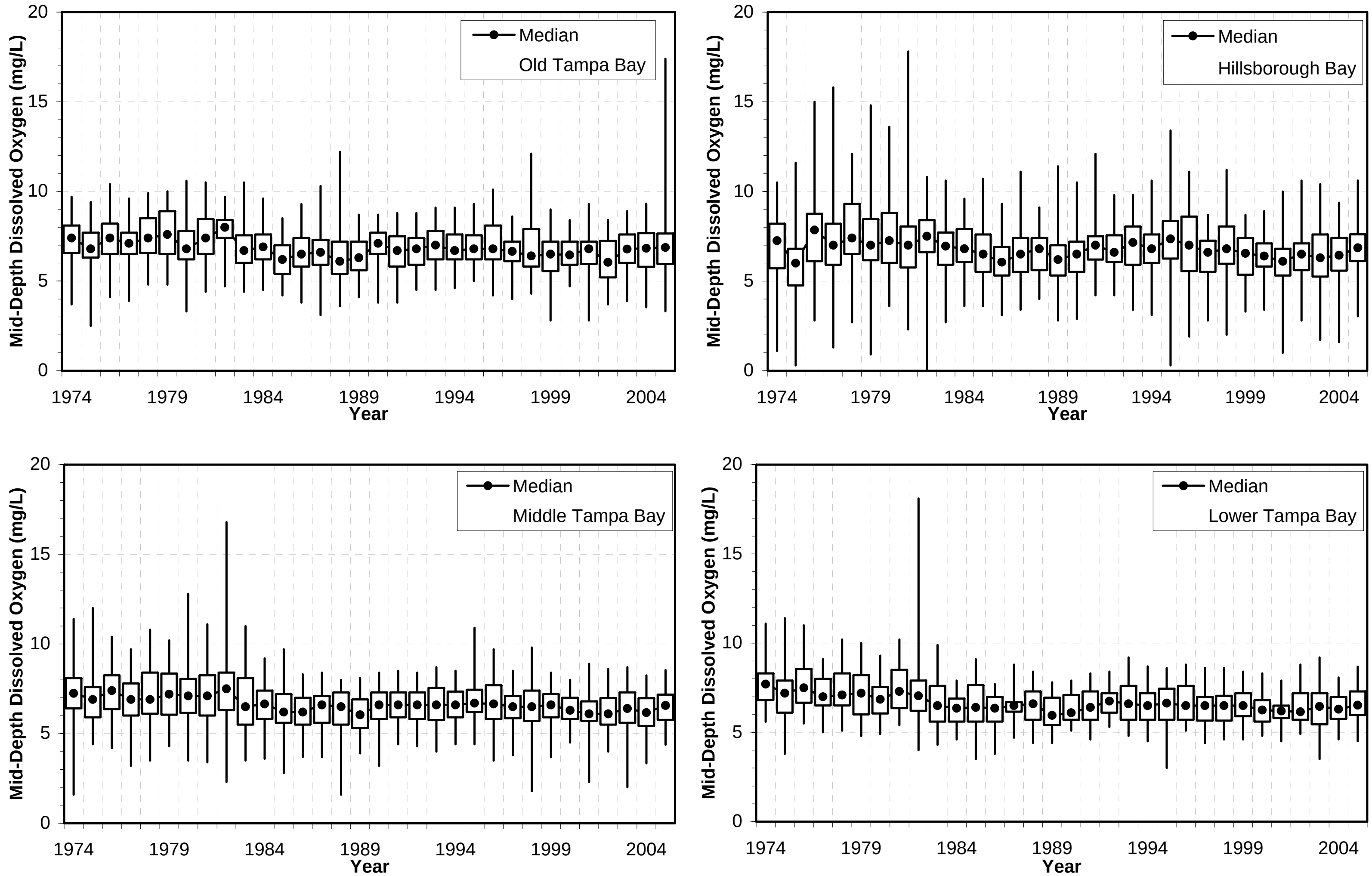


Figure 6-8. Box and whisker plots of annual mid-depth dissolved oxygen (mg/L) distribution in the major bay segments of Tampa Bay. Boxes encompass the 25^{th} and 75^{th} percentile, while whiskers span the minimum and maximum values of a particular year. Data source: EPCHC water quality monitoring program.

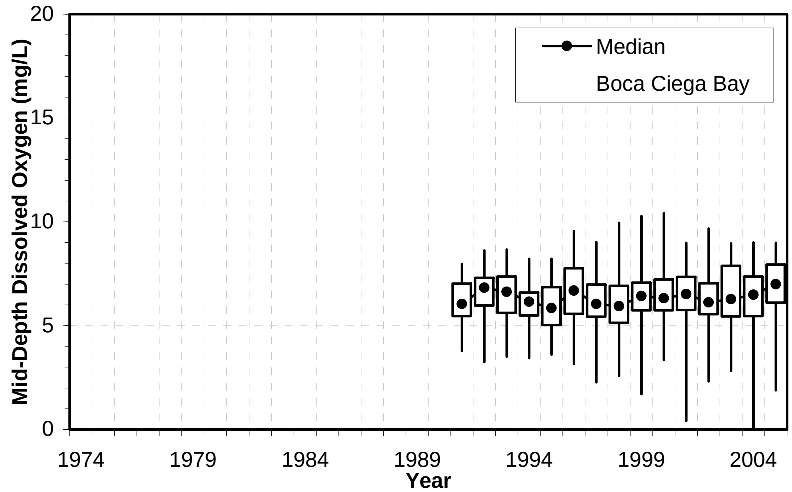


Figure 6-8 (cont'd). Box and whisker plots of annual mid-depth dissolved oxygen (mg/L) distribution in Boca Ciega Bay. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year.
Data source: PCDEM water quality monitoring program.

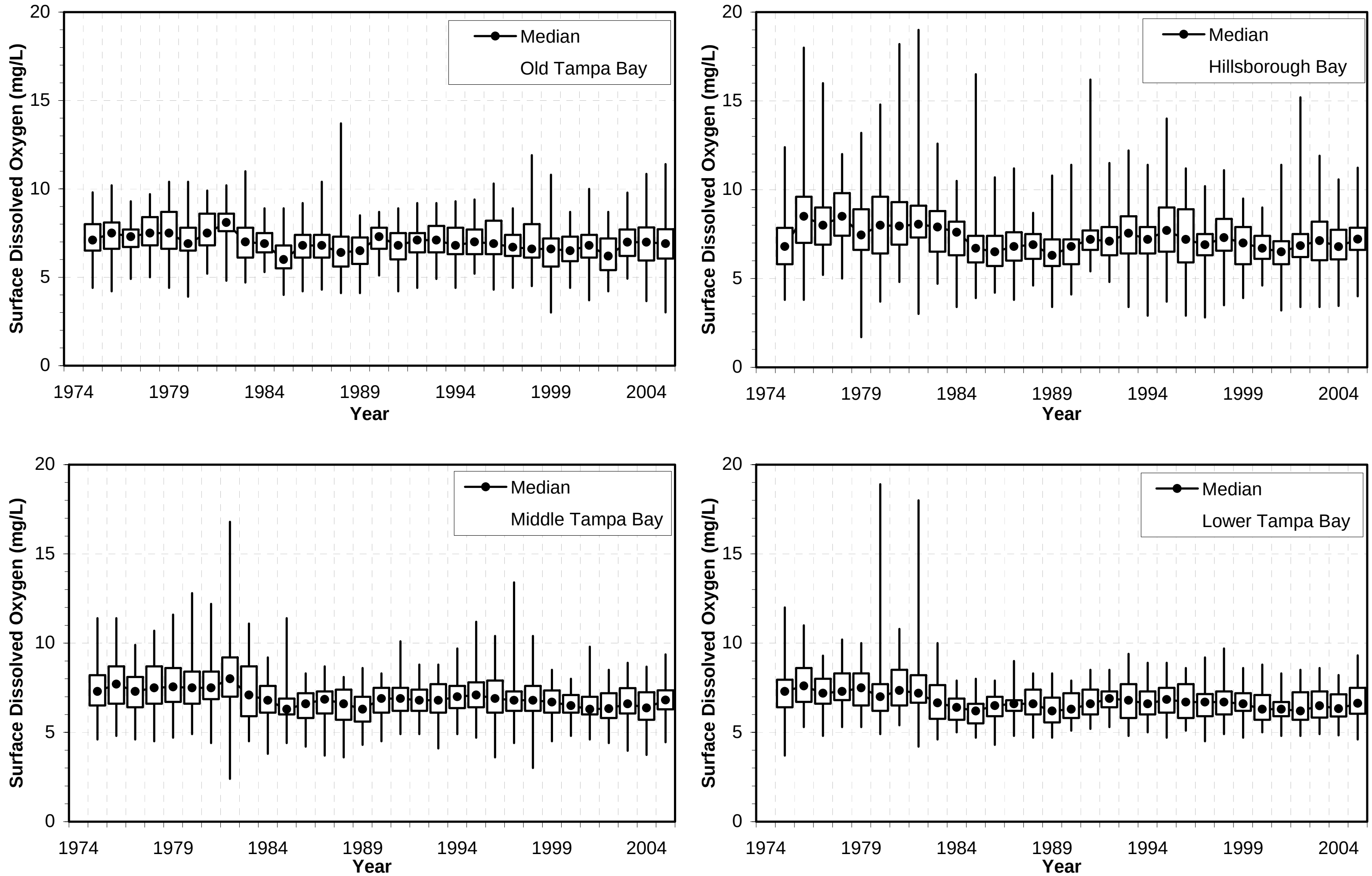


Figure 6-9. Box and whisker plots of annual surface dissolved oxygen (mg/L) distribution in the major bay segments of Tampa Bay. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year.
Data source: EPCHC water quality monitoring program.

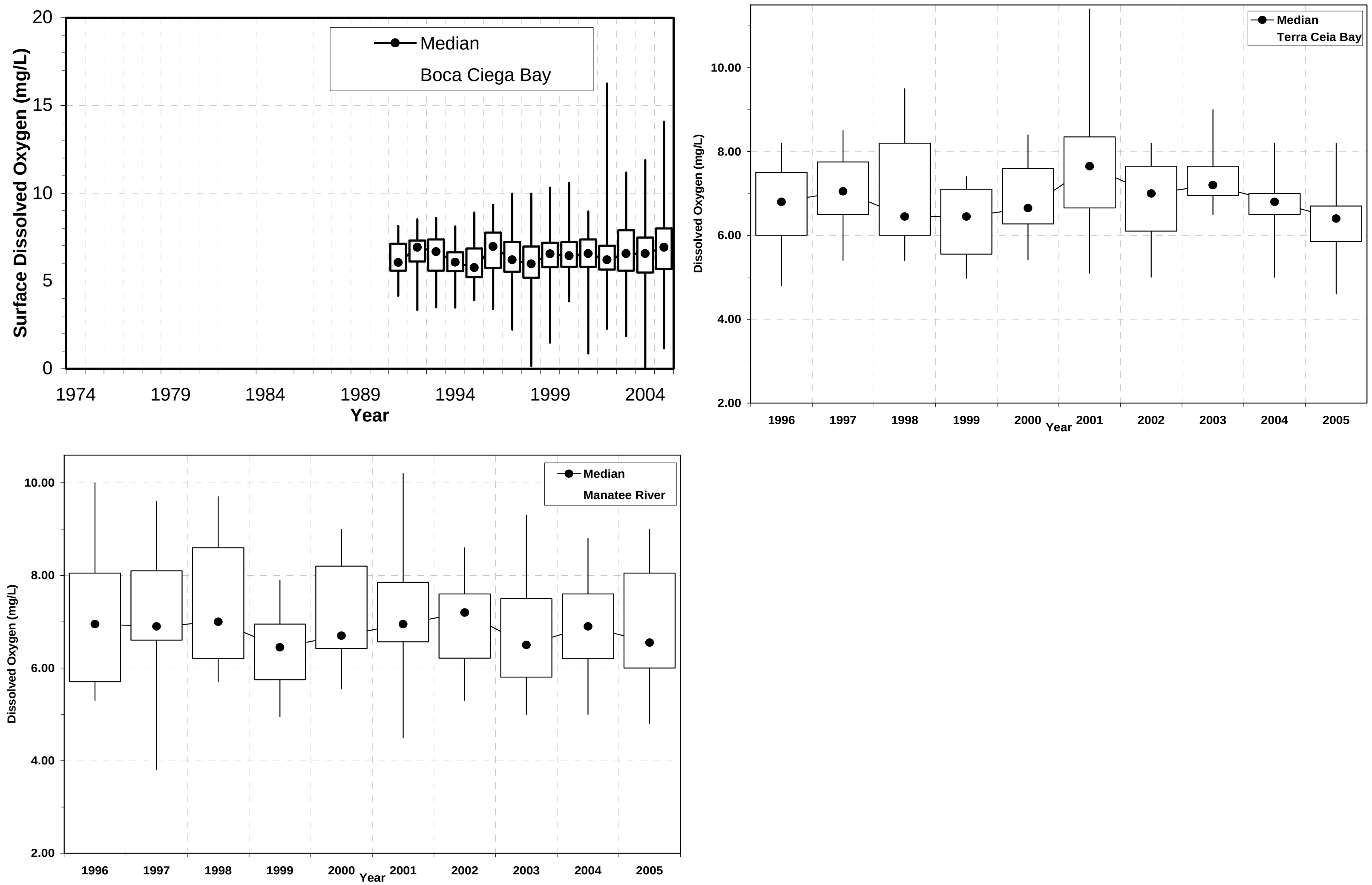


Figure 6-9 (cont'd). Box and whisker plots of annual surface dissolved oxygen (mg/L) distribution in Boca Ciega and Terra Ceia Bays and the Manatee River. Boxes encompass the 25th and 75th percentile, while whiskers span the minimum and maximum values of a particular year. Data source: PCDEM and MCEMD water quality monitoring program.

SALINITY

Bay Salinity Patterns

Salinity is a measure of the salt content of water, with seawater having a global average salinity of about 35 parts per thousand (ppt) or practical salinity units (psu). In Tampa Bay salinity levels vary spatially and temporally, ranging from fresh (< 0.05 psu) in some areas to essentially marine (30-35 psu) in others, as freshwater entering from rivers and streams mixes with seawater entering from the Gulf of Mexico. Average surface and bottom salinities in the four main-stem segments of the bay, based on monthly data from the EPC monitoring stations over the years 1980 through 2005, are shown in Figs. 6-11 and 6-12.

Salinity levels fluctuate daily with the tides, and as a result of mixing by winds and currents. Freshwater discharges are controlled by conditions in the watershed, including rainfall patterns, vegetation type, and level of development. Rainfall patterns vary seasonally and between years, in response to the frequency of frontal passages, tropical cyclones and El Niño events. Decreased freshwater inflows, due to the diversion of rivers and streams into impoundments, can potentially lead to the reduction of salinity gradients and more extended periods of elevated salinity in the landward sections of the estuary. Conversely, large discharges of stormwater runoff can depress salinity levels in inshore areas.

Hydrodynamic modeling studies indicate that, in general, the water column of the bay is partially to well-mixed, exhibiting a longitudinal salinity gradient that extends from the head of the bay to the mouth (Goodwin 1989) and a gravitationally-driven two-layered estuarine circulation pattern that is focused on the dredged shipping channels (Galperin et al. 1991, Weisberg and Zheng 2006). Since the 1800s the excavation an ongoing maintenance of the dredged shipping channels, and the extensive placements of fill to create causeways, spoil disposal islands, and for shoreline development, have caused complex changes in the bay's circulation and salinity patterns (Goodwin 1989, Weisberg and Zheng 2006).

As in many estuaries, the broad water quality patterns seen among the four main-stem segments of Tampa Bay tend to follow the longitudinal salinity gradient. Over the past several decades, Old Tampa Bay and Hillsborough Bay, the main-stem segments with lowest annual average salinities, have shown the highest concentrations of total nitrogen (Fig. 6-5), total phosphorus (Fig. 6-6) and chlorophyll-*a* (Fig. 6-2), the highest light attenuation levels (Fig. 6-1), and the most stressful DO regimes (Fig. 6-8). Middle Tampa Bay has intermediate in most of these categories, while Lower Tampa Bay has shown the highest salinity levels, lowest nutrient and chlorophyll concentrations, lowest light attenuation levels, and least stressful DO regimes. The correlation is not perfect – Hillsborough Bay and Old Tampa Bay have similar salinity levels but different chlorophyll-*a* and light attenuation characteristics in most years.

The median annual salinity trends in Boca Ciega Bay (BCB) are very similar to those in Lower Tampa Bay (Figures 6-9, 6-10 and 6-11); however, due to large freshwater discharges to the area from storm events, salinities can become very depressed in BCB surface waters. Overall, the mid depth and bottom waters appear very well mixed when comparing salinity profiles.

Water Temperature

Temperature is an important water quality component because it affects both the biology and chemistry of the bay. The metabolic rates of aquatic plants, and of most species of fish and other aquatic animals, are positively correlated with water temperature. The rates of biochemical reactions usually double when temperature is increased by 10°C within the tolerance range of an organism. This is called the *Q_{10} rule*, and it applies to biochemical reactions that affect processes such as photosynthesis, respiration, feeding, growth, and reproduction. It also applies to microbial processes such as nitrogen fixation, nitrification and denitrification. If temperature goes too far above or below the tolerance range for a given organism, its ability to survive may be compromised.

The solubility of oxygen (and other gases) in water decreases with increasing water temperature. As a result, elevated water temperatures can be particularly stressful for fish and shellfish in the bay, because of the combined effects of higher metabolic rates (which increase DO consumption) and reduced availability of DO due to its reduced solubility.

Water temperature is a particularly important indicator to track in a subtropical estuary such as Tampa Bay, whose flora and fauna can be thought of as "living on the edge" (Biber 2002). Optimal growth conditions for subtropical and tropical plants and animals are often close to their upper thermal tolerance limits, which are often within a few degrees of the mean ambient summer temperatures. This thermal stress effect is thought to make tropical organisms more susceptible to additional stressors, compared to their temperate

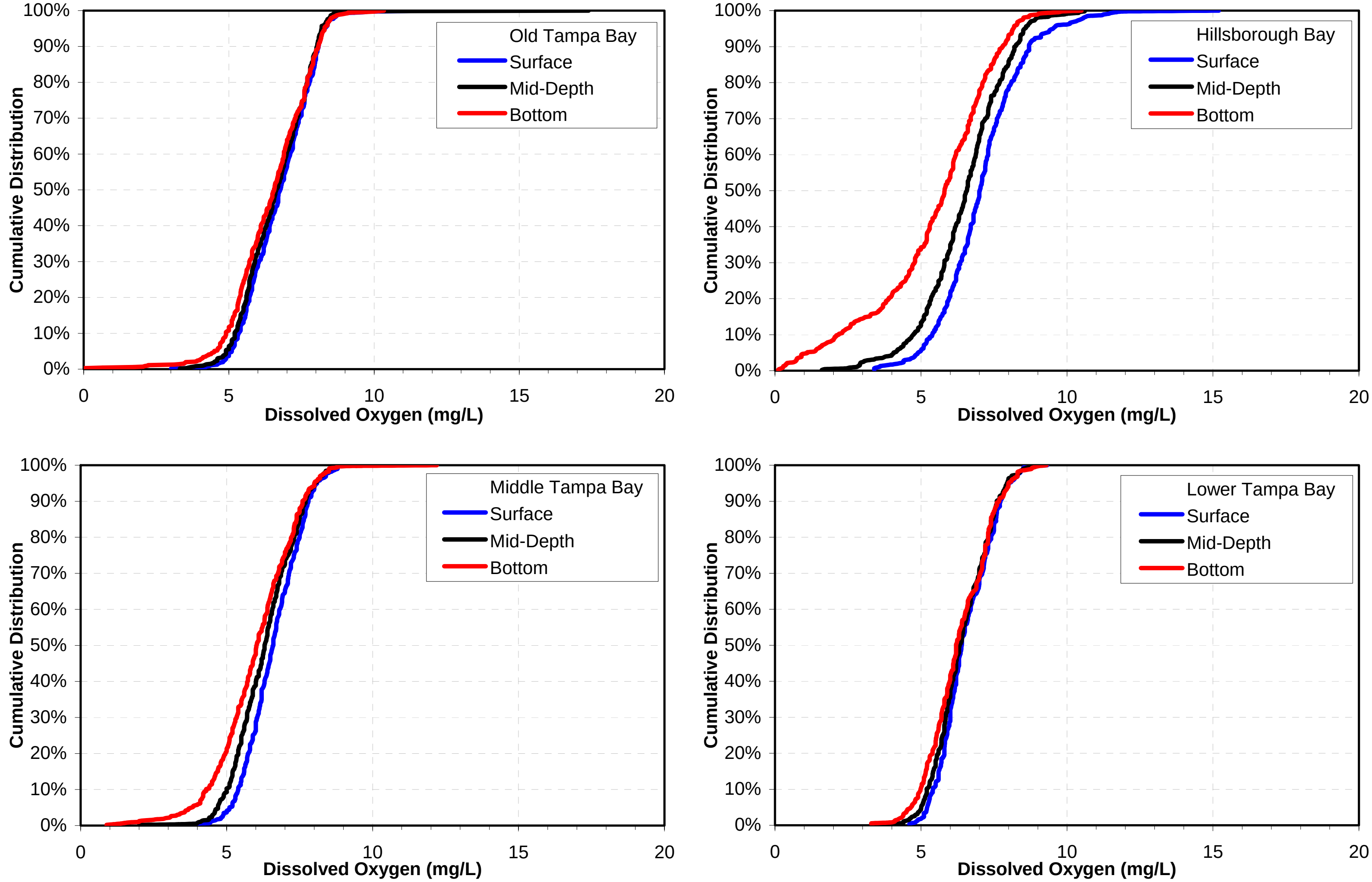


Figure 6-10. Cumulative distribution function plots of surface, mid-depth, and bottom dissolved oxygen observations in the major bay segments of Tampa Bay from 2002 – 2005.
Data source: EPCHC water quality monitoring program.

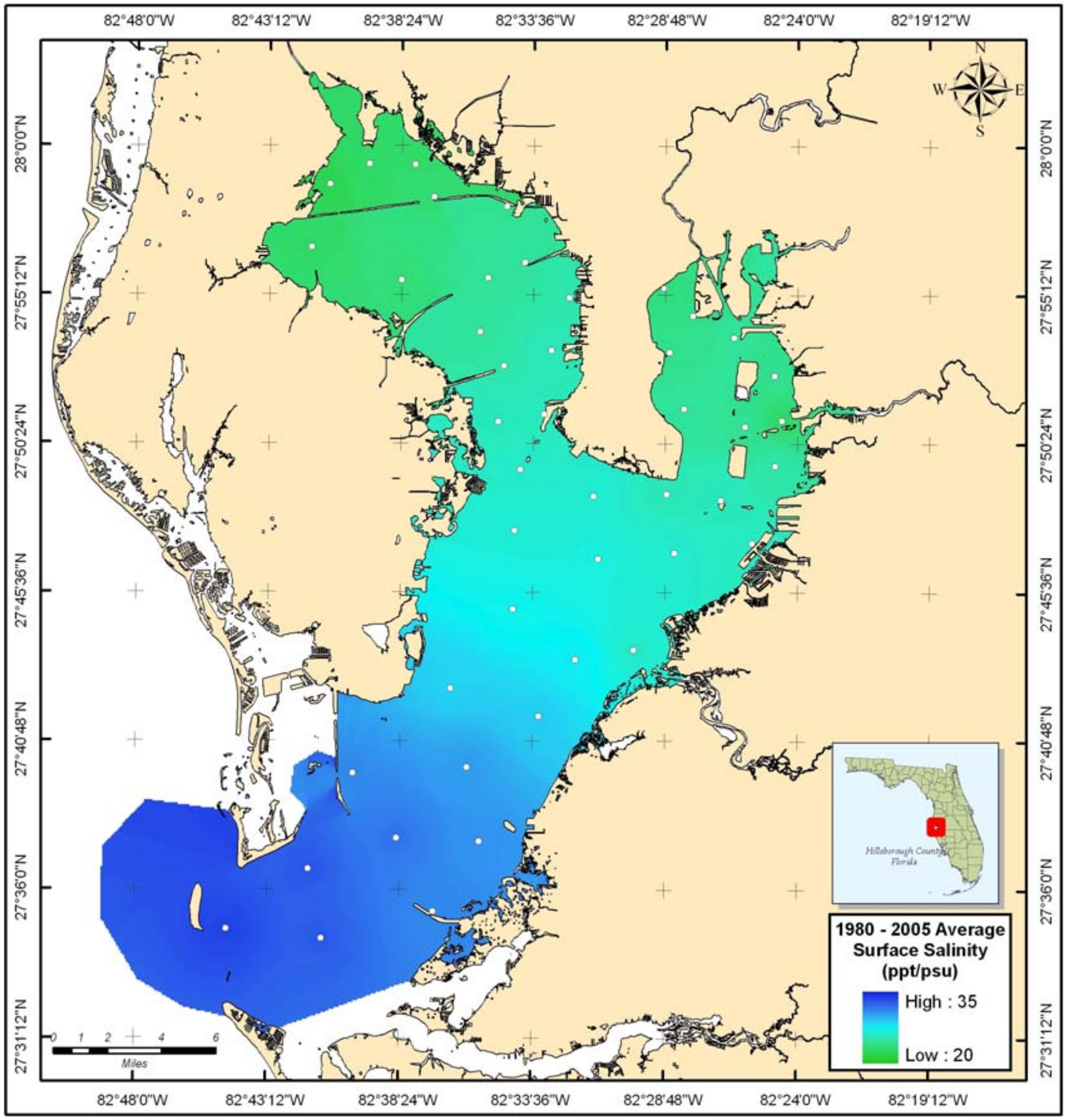


Figure 6-11. Average surface salinity from 1980 – 2005 for EPCHC stations sampled in Tampa Bay. Contour map was produced through inverse-distance weighting.

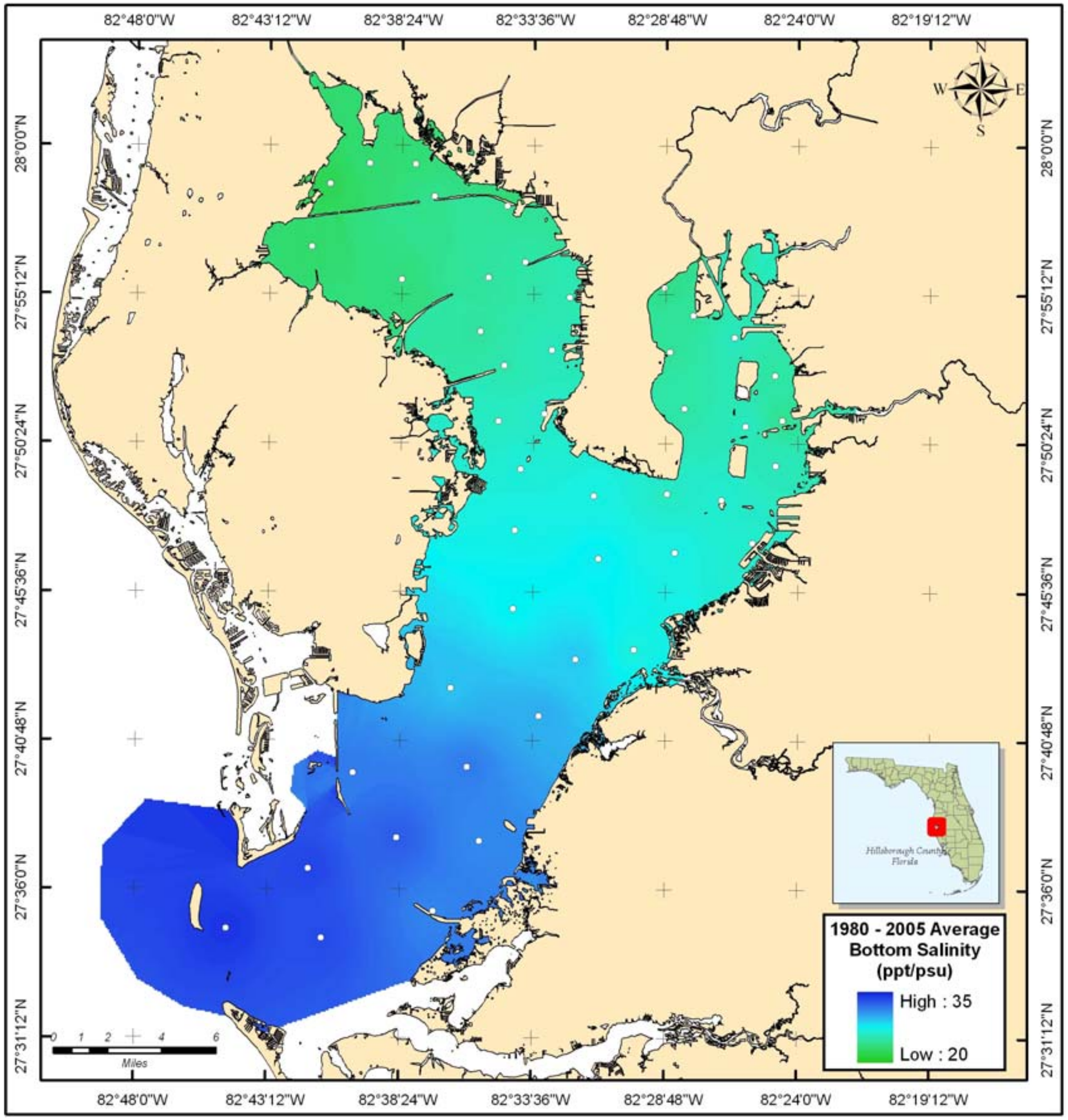


Figure 6-12. Average bottom salinity from 1980 – 2005 for EPCHC stations sampled in Tampa Bay. Contour map was produced through inverse-distance weighting.

counterparts. Time-temperature relationships appear to be important in determining the magnitude of thermal stress effects, with short periods at an elevated temperature have larger impacts than a longer time period at a slightly lower temperature (Thorhaug et al. 1973).

Conversely, periods of low water temperature can also be stressful or fatal, particularly for tropical and subtropical species that approach the northern limits of their geographic ranges in the Tampa Bay area. Examples include fish such as snook, and mammals such as the Florida manatee, which can be severely stressed or killed in some years as a result of extreme low temperature events that occur following the passage of particularly strong winter cold fronts.

Contour maps depicting mean surface temperatures in the main-stem segments of Tampa Bay during the typically warmest (July through September) and coldest (January through March) months of the year, based on monthly EPC monitoring data from the years 1980 through 2005, are shown in Figs. 6-13 and 6-14. During both seasons the areas mapped with the highest surface temperatures were located on the eastern side of the bay, in HB and MTB, near points were steam electric generating plants discharge highly heated water ("thermal effluent") that has been withdrawn from the bay and passed through the plants' cooling systems. An additional thermal discharge is present in southwestern OTB, immediately south of the Gandy Bridge causeway, but was not detected in the EPC monitoring data, presumably because no EPC monitoring stations are located in the immediate vicinity of the discharge point.

During the winter season, when water temperature in other portions of the bay drops below about 17^o C (63^o F), the heat from these types of industrial thermal discharges provides important thermal refugia for Florida manatees (U.S. Fish and Wildlife Service 2001). In Tampa Bay the major winter refugia are associated with the TECO Big Bend power plants in eastern MTB, and the Progress Energy power plant near the Gandy Bridge causeway in southwestern OTB (TBEP 2006a).

On a statewide basis, based upon recent synoptic survey data, just under two-thirds of the Florida manatee population is thought to rely in winter on thermal refugia provided by power plants and other industrial facilities (USFWS 2001).

During the summer season, when ambient water temperatures in the bay often exceed 29^o C (84^o F), areas affected by thermal discharges can exceed 30^o C (about 88^o F) (Fig. 6-13), a level that is presumably stressful for many organisms (Zieman and Wood 1975, Day et al. 1989). However, long-term studies of benthic organisms conducted by Mote Marine Laboratory in the vicinity of the Big Bend thermal discharge have shown seasonal patterns of faunal diversity and abundance similar to other regions of Tampa Bay, suggesting "a lack of serious environmental stress" on the benthic fauna in that area (Leverone et al. 1991).

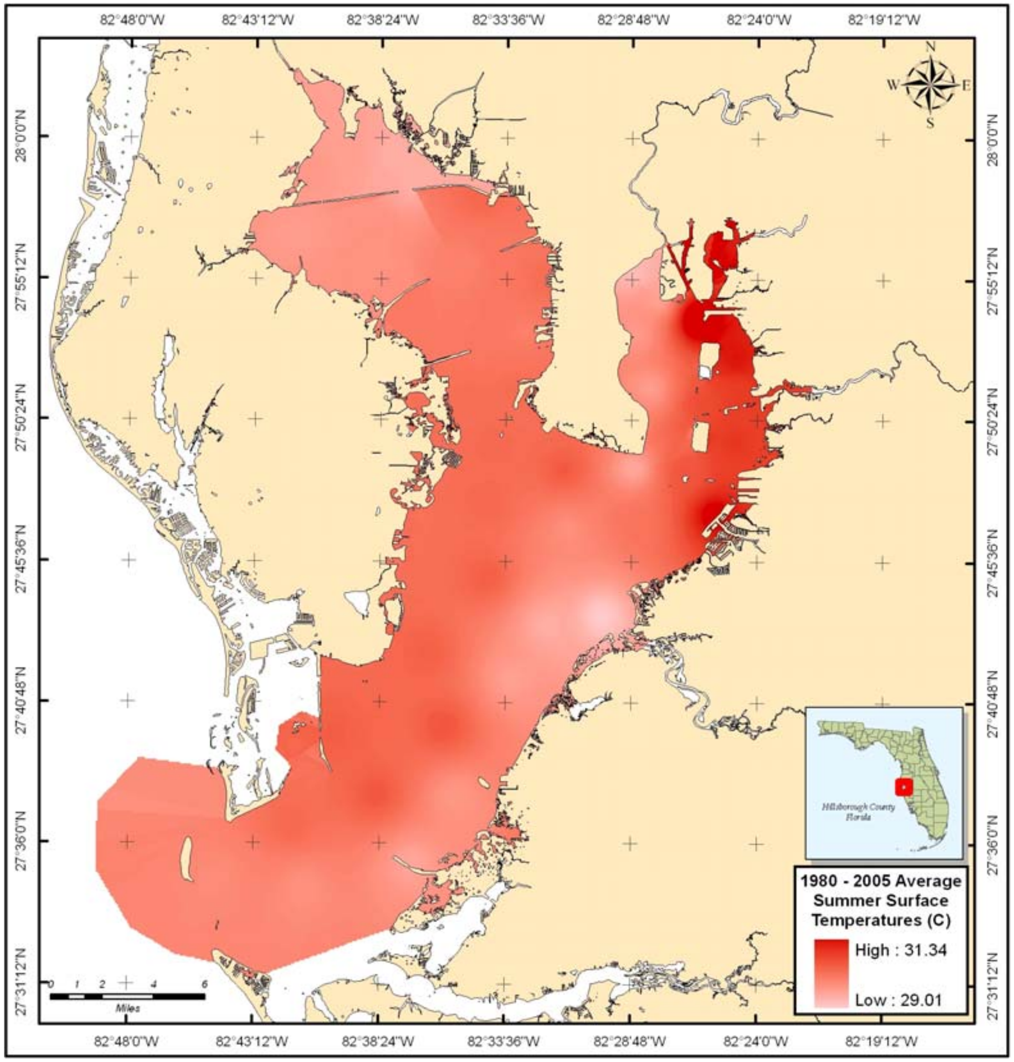


Figure 6-13. Contour map of surface temperature from 1980 – 2005 for EPCHC stations sampled in Tampa Bay during the months of July, August, and September. Contour map was produced through inverse-distance weighting of average station surface temperatures.

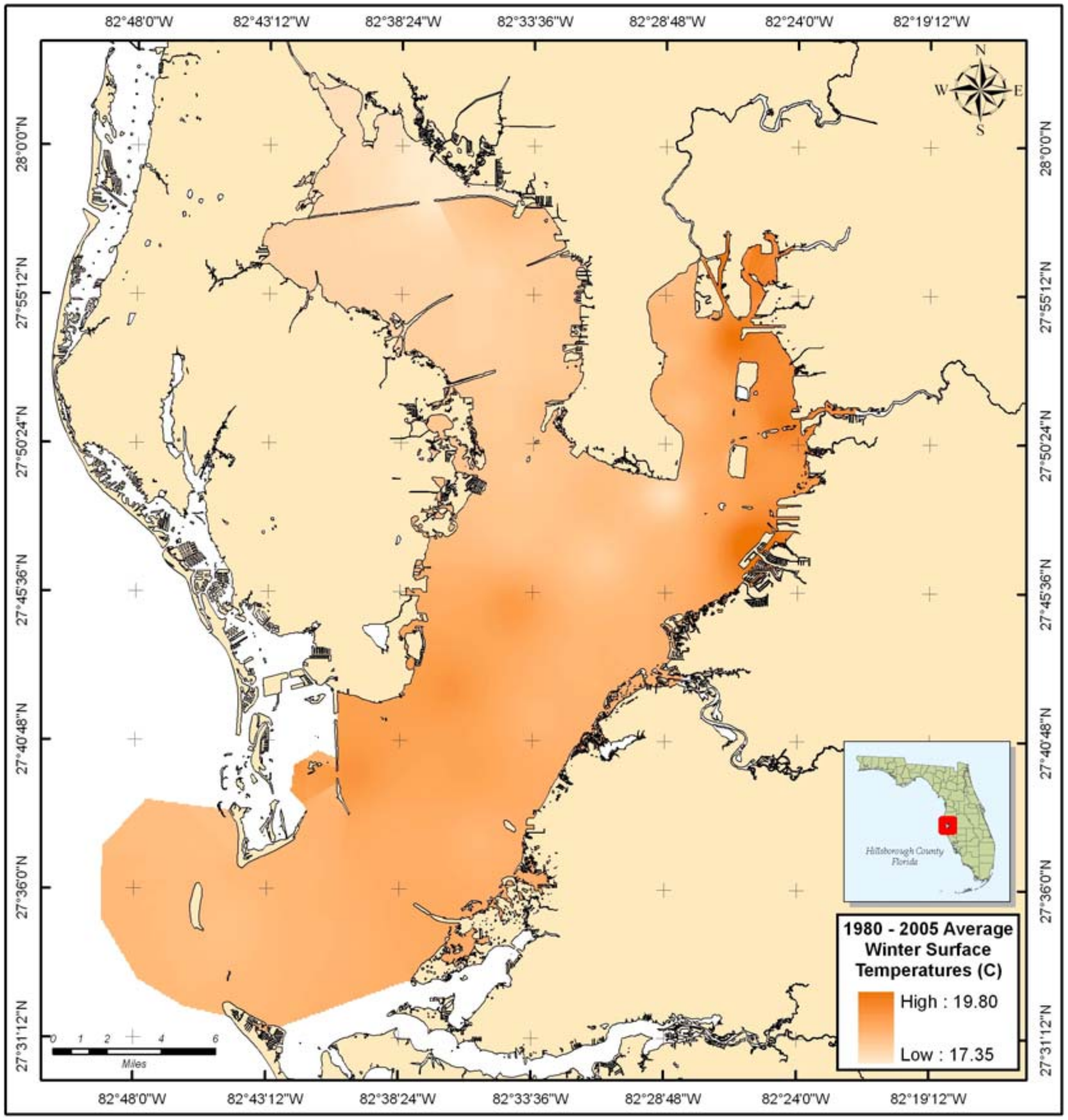


Figure 6-14. Contour map of surface temperature from 1980 – 2005 for EPCHC stations sampled in Tampa Bay during the months of January, February, and March. Contour map was produced through inverse-distance weighting of average station surface temperatures.

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Factors Affecting Poor Seagrass Recovery in Feather Sound, Tampa Bay

Lindsay M. Cross (Tampa Bay Estuary Program)

Seagrasses in many parts of Tampa Bay have expanded since the 1980s in response to clearer water from nutrient source reductions. However, the recovery rate and expansion of seagrasses in the Feather Sound region (see Figure 1) of Old Tampa Bay has been slower or declining (see Figure 2). This area has been the subject of two consecutive, two-year, multi-disciplinary projects to address the potential causes of poor seagrass recovery. Both projects have been funded by the Pinellas County Environmental Fund and involved numerous bay-area partner agencies.

Phase 1 (2002-2003)

Figure 1. Aerial view of Feather Sound and the bare "hump" feature

The first two-year study (2002-2003) focused on a broad range of possible causes of seagrass decline including: poor water quality in shallow areas, seagrass species extent and condition; changes in historical seagrass patterns; seagrass productivity and epiphyte loading; impact by waves; effects of shallow water bathymetry; and ground water influence. The study also included experimental seagrass plantings and volunteer patch monitoring. Potential causes of slower seagrass recovery identified by this study included poorer water quality, reduced circulation and slower flushing rates, increased epiphyte loads, high rates of bioturbation (by stingrays and burrowing organisms), and possibly the influence of hydrogen sulfide toxicity. Neither high wave energy nor the influence of submarine groundwater appeared to be major factors.

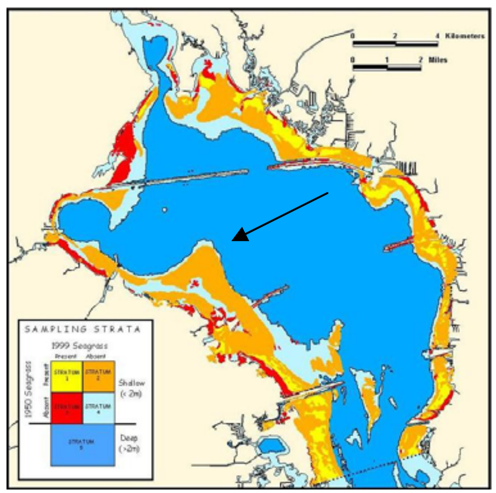

Figure 2. Change in seagrass presence and absence. Orange denotes areas that had seagrass in 1950, but not in 1999.

The Feather Sound region had poorer water quality and thus, less light available for seagrasses, than the rest of the study area during 2002-2003. Old Tampa Bay was divided into four quadrants, plus a deep area, for water quality monitoring; Feather Sound is located in the northwest quadrant (see Figure 3). This quadrant had higher chlorophyll *a*, turbidity and color; and lower transmittance during the study period than the other three. Additionally, areas where seagrasses have been lost since 1950 were significantly deeper (by an average of 0.5 meters) than the areas where seagrasses have been stable.

Seagrass-intensive monitoring examined 41 sites throughout Old Tampa Bay, including a fixed transect in each quadrant. While seagrasses were generally stable in the other three quadrants,

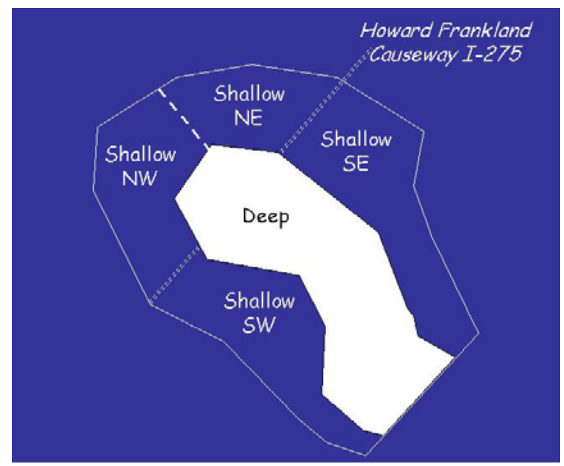

Figure 3. Depiction of the four quadrants and deep area in Old Tampa Bay. Feather Sound is located in the Northwest quadrant between Howard Frankland and Courtney Campbell causeways.

except for *Halodule wrightii* loss than occurred on the offshore face of the longshore bar in the northeast quadrant, there was significant *H. wrightii* loss in the Feather Sound quadrant between 2002 and 2003. No major changes in elevation were observed during the study period at any other sites.

Epiphytes caused about 32% light attenuation on *Thalassia testidinum* and about 25% on *H. wrightii* leaves when averaged over the entire study period and study areas, and epiphyte light attenuation was greatest for both species in the Feather Sound quadrant of the study area in 2003, but not 2002. The use of ray-exclusion devices (REDs) to eliminate effects of bioturbators, such as stingrays, was also tested in this phase. Those that stayed buried in sediment were fairly effective in deterring stingrays; however, if the mesh was exposed, it became an attachment site for algae. Additional exclusionary experiments have been tested in the current project.

Modeling showed longer water residence times in the Feather Sound quadrant than other portions of Old Tampa Bay and greater Tampa Bay, with estimates as long as 144 days. Poor flushing and high nutrient loading may have lead to decreased water quality in this region.

Experimental seagrass planting using a variety of techniques occurred at three sites throughout the bay. One year post-planting, the percent cover of seagrass was 0.9% at Feather Sound, compared to 11% at Apollo Beach and 21% at Shell Key. Since no method was significantly better among the sites, the decreased survival rate at Feather Sound may have been due to slightly poorer water quality or slightly deeper depth than at the other two transplant sites.

Phase 2 (2004-2006)

The second stage of this project is in its final stage and a final report and management recommendations for the entire project are scheduled for completion in early 2007. Since the final data analyses and results are still being generated, the following are preliminary results. The 2004-2006 Feather Sound study included seagrass transect monitoring and aerial photography, examination of causes of volunteer patch fragmentation, potential impact of wastewater treatment plant discharges and septic systems, and external land-based loadings. Development of an Optical Model to predict seagrass survival and growth throughout Old Tampa Bay was also included, along with seagrass monitoring to improve the Optical Model, and examination of circulation effects on water quality in Old Tampa Bay.

Seagrass transect monitoring, coupled with sediment elevation measurements and bi-annual aerial photography (twice each in October and April), was conducted through fall 2006. Preliminary results suggest that there have been variations both in the percent coverage and species composition in most quadrants. These results will include a photo mosaic comparing seagrass coverage over the four-year study.

The occurrence and subsequent disappearance of *H. wrightii* patches in the Feather Sound region during the first study prompted the continued examination of various possible causes of volunteer seagrass failure. Many of these hypothesized causes, such as hydrogen sulfide toxicity, sediment nutrient depletion, and rhizome orientation, have been eliminated during the second phase as probable causes of poor seagrass recovery. The influence of bioturbators on seagrass, including large and small faunal organisms, is still being tested and may be a possible cause.

The impact of external loadings, including wastewater and septic systems, were important new components of this project and involved detecting anthropogenic forms of nitrogen using optical brighteners and isotopic analysis. Optical brighteners, used in laundry detergent to enhance color, may be used as a tracer of wastewater discharges. This experiment was performed in Phase 2; however, the technique did not produce sufficient evidence to warrant continuation. The isotopic analysis of macroalgae sentinels has been used to identify the geographic extent of waters enriched with nitrogen from wastewater treatment plants. Animal and human waste is enriched in ^{15}N (a heavier isotope than ^{14}N), while agricultural inputs are low in ^{15}N. Typically, a $d^{15}N > \sim 7.0\%$ indicates an organic source. Algae was collected from near the Skyway Bridge and deployed in the Feather Sound and Rocky Creek areas. Overall, $d^{15}N$ enrichment was highest near the wastewater treatment plant in the Feather Sound quadrant; however, there was a low signature near the “hump” feature. This may indicate that enrichment by human sources in the study area was not a factor; although, the possible influence of fertilizer (an inorganic nitrogen source) from nearby golf courses may have lowered the $d^{15}N$ ratio.

Water quality and flow measurements were taken at five stormwater locations in the watershed of Feather Sound to estimate external nutrient loads to the study area. Two sites were at a golf course which receives reclaimed water from the City of Largo, two were within the Roosevelt Basin, and the other was a salinity barrier creek. Flow and concentrations, including nitrogen, phosphorous, TSS, and turbidity, have been recorded during the wet and dry season and final analyses are ongoing. Values for all parameters appear to vary by location and time of year.

A major component of this project was the development and application of an Optical Model to predict where seagrass should be able to persist in Old Tampa Bay (see Figure 4). The model incorporates spatially intensive ambient water quality data, light attenuation, bathymetry, seagrass presence/absence, and continuous water level data into a spatially-detailed GIS grid model. The model then predicts, based on depth and light availability, the probability of seagrass occurrence. The current model uses the 2002 and 2003 water quality data from EPCHC stations and the 2001 and 2004 SWFWMD seagrass distributions. Refinements are being made to the model, including an analysis of water quality data to determine relative importance of chlorophyll *a*, color, and turbidity to light attenuation. It is expected that this model can be applied to other areas in Tampa Bay to help focus seagrass recovery and restoration efforts.

The model is being improved through targeted seagrass monitoring at 120 randomly-selected locations throughout Old Tampa Bay (30 in each of four quadrants). Comparison of the Optical Model predictions to observations from SWFWMD led to four sampling categories, including:

- regions of Old Tampa Bay that were not mapped as seagrass in the 2004 SWFWMD seagrass maps, but were predicted to have a high probability of seagrass occurrence by the Optical Model;
- regions of Old Tampa Bay that were mapped as seagrass in the 2004 SWFWMD seagrass maps, but were predicted to have a low probability of seagrass occurrence by the Optical Model;
- regions of Old Tampa Bay that were mapped as seagrass in the 2004 SWFWMD seagrass maps, but were located in areas where the reported water depth was insufficient to support seagrass (bathymetry data were reported to be less than 0 meters at mean water); and
- regions of Old Tampa Bay that were not mapped as seagrass in the 2004 SWFWMD seagrass maps, but were located in areas where the reported water depth was sufficient to support seagrass (bathymetry data were reported to be between 1.2 – 1.7 meters at mean water).

In addition to Braun Blanquet abundance of all seagrass and macroalgae at 12 evenly-distributed quadrants at each location, water quality and physical parameters have been recorded. Data collected from sites within each category will be used to modify the model inputs and results of the model compared to observations collected during recent years (2001, 2004). The overall objective is to determine why seagrass may not occur in regions where the Optical Model predicts that it should, based on depth and light availability.

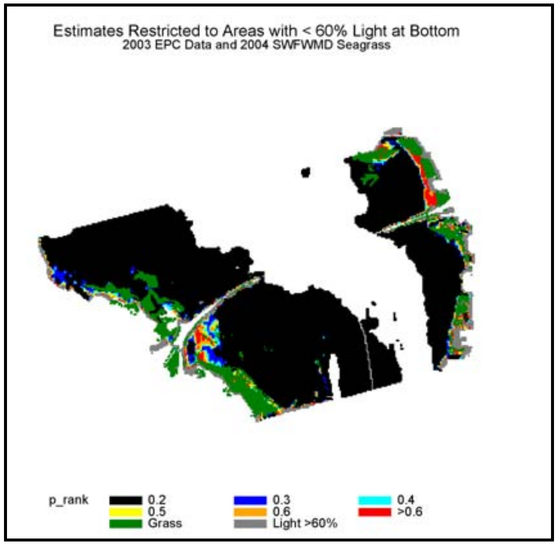

Figure 4. Example of the Optical Model results using 2003 water quality and 2004 seagrass data. Areas predicted to have a high probability of seagrass occurrence are shown in red. Areas that were mapped as seagrass by SWFWMD are shown in green.

Finally, a hydrodynamic model is being utilized to determine effects of potentially increasing residence time in particular regions on localized water quality problems that are estimated to be inhibiting restoration of seagrass in Old Tampa Bay. Preliminary results suggest that the largest variation in residence time was on the “hump;” however, additional analyses of model results are necessary.

The final products from this study will include technical reports, a report to the public, and management recommendations for how to improve seagrass recovery in this region of Tampa Bay. The project team will focus on results from both projects to determine the most likely cause(s) of poor seagrass recovery and suggest appropriate management solutions. These products will be available in early 2007.

Tampa Bay Seawater Desalination

R. McConnell (Tampa Bay Water)
R. Woithe (PBS&J)

Overview

The Tampa Bay Seawater Desalination Facility, owned by Tampa Bay Water, is located on Hillsborough Bay in the southeastern portion of Tampa Bay (Figure 1). When operating at full capacity, the Desal facility will provide the Tampa Bay region with approximately 10 percent of its drinking water supply, making it the largest reverse osmosis (RO) seawater desalination facility in North America.

The Desal facility uses reverse osmosis (RO), a mechanical process that forces seawater through semi-permeable membranes under high pressure, squeezing freshwater from saltwater and leaves salts and minerals behind in a concentrated seawater solution.

The Desal facility is designed to withdraw up to 44 mgd from TECO's Big Bend Power Station cooling water discharge conduits yielding up to 25 mgd of potable water along with approximately 19 mgd of concentrate discharged (at full capacity) into the power plant discharge canal. The withdrawal is a small fraction of the 1.4 billion gallons of cooling water used by the power plant, and the concentrate is re-diluted about 70-to-1 with cooling water before discharge so its salinity is about the same as Tampa Bay.

The Desal facility first went on-line in March 2003 and operated intermittently until June 2005, producing more than 5 billion gallons of drinking water. During this period, pretreatment and other design deficiencies were identified that limited cost-effective operation, and the facility was taken off-line for remediation in June 2005. The Desal facility is scheduled to resume operations in late 2006.

Figure 1. Tampa Bay Seawater Desalination Facility and HBMP Monitoring Areas

Monitoring Program

Monitoring for potential impacts associated with discharges from the Desal facility is based on the ambient conditions monitoring Plan of Study (POS) developed as required by special conditions of the NPDES Industrial Wastewater Permit issued by the Florida Department of Environmental Protection (FDEP). POS-required and additional supplemental sampling is performed as part of Tampa Bay Water's hydrobiological monitoring program (HBMP).

The Desal POS includes water quality and biological monitoring elements (benthic invertebrates, seagrass, and fish). The overall objectives are to monitor potential effects that may occur in Hillsborough Bay as a result of the Desal facility discharge to the Bay. Monitoring is focused in areas most likely affected by the discharge based on the hydrodynamic model developed by the University of South Florida; this includes the discharge canal, areas near the mouth of the canal, the north Apollo embayment. A control area is used for comparison.

The water quality sampling is focused on three points near the facility: the intake canal, discharge canal, and the embayment (see Figure 1), and includes four components:

- continuous specific conductance, salinity and temperature monitoring
- 72-hour continuous dissolved oxygen monitoring
- instantaneous water column profiles across tide cycle
- chloride and pH grab samples.

This element also includes water quality data collected in Hillsborough Bay by the Environmental Protection Commission of Hillsborough County (EPCHC).

The benthic invertebrate element includes sampling in monitoring strata near the facility discharge (see Figure 1). Data collection requirements specified by the permit include bimonthly water quality sampling and quarterly benthic invertebrate sampling. Data collected by other agencies are evaluated on an annual basis for seagrass and fish elements.

In addition, the discharge permit also requires monitoring of chemical constituents to ensure that water quality in Tampa Bay is protected. Monitoring and reporting activities for this requirement are performed by the facility operator.

POS monitoring began in April 2002. Bimonthly and quarterly data reports and two summary reports, the Pre-Operational Conditions Report (Janicki Environmental and PBS&J, 2005) and Hydrobiological Monitoring Summary 2002 through 2005 (PBS&J, 2006) have been submitted to FDEP. POS monitoring continues for the duration of the discharge permit, regardless of facility operational status.

Results To-Date

Monitoring data were used to evaluate potential salinity impacts from Desal facility operations during the initial operations period (March 2003 to May 2005). Intermittent operations allowed evaluation of monitoring data under a range of conditions from no production to full capacity.

As an initial evaluation of potential changes during Desal operation, salinities in the intake and discharge canals were compared during periods with and without production. Continuous surface and bottom salinity measurements were averaged and weighted to determine water column salinities and adjusted to account for travel time through the facilities to allow comparison of intake and discharge canal salinities.

This comparison showed less than 1 practical salinity unit (psu) average difference when the Desal facility was not operating (0.75 psu, Figure 2) or when the facility was operating (0.48 psu, Figure 3). Average differences between the intake and discharge canals were just above instrument detection limits (about 0.2 psu), and the greatest differences (about 2 psu) were observed during both operational and non-operational conditions.

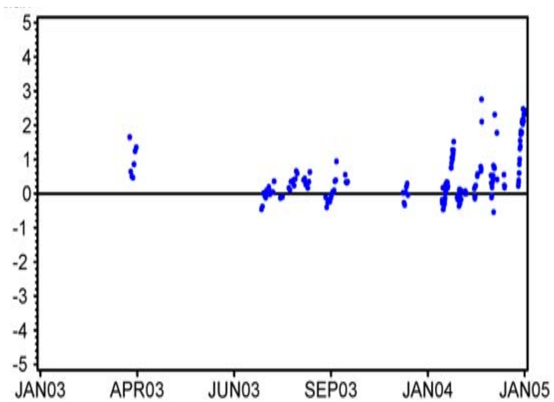

Figure 2. Difference in Intake - Discharge Canal Salinity (psu): Periods without Production

By comparison, this part of Tampa Bay typically undergoes about 8 psu salinity change (about 22 to 30 ppt) from the winter and spring dry season to the summer wet season, and during the most variable years, salinity may change as much as 14

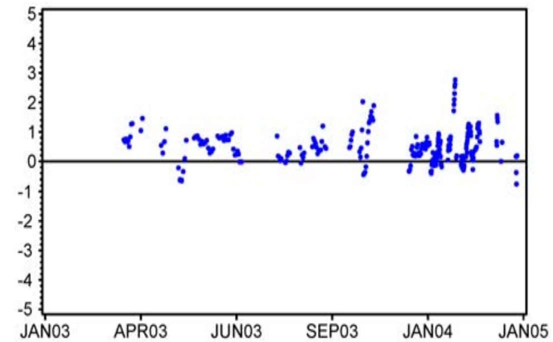

Figure 3. Difference in Intake - Discharge Canal Salinity (psu): Periods with Production

ppt. During periods of Desal facility operation, background salinities in the intake canal ranged from about 16 to 26 ppt.

The greatest potential effects from the Desal facility are expected when the ratio of concentrate discharge to TECO cooling water flow is highest (i.e., lowest cooling water flow and maximum Desal production).

A comparison of average intake and discharge salinities at increasing production rates during the initial operation period showed little difference in salinities, and no increasing trend with increased production (Figure 4).

Measured salinity changes in TECO's discharge canal resulting from Desal Plant operations were very small and could not be detected in the Bay. were not detected in adjacent areas of the Bay. In addition, if discharge from the Desal facility was elevating salinities in the adjacent Bay, a trend among the four biological monitoring areas near the mouth of the discharge canal would be expected. Salinity differences in the four biological monitoring areas during any given month were very small, did not follow a trend, and were not consistently higher or lower in any of the areas.

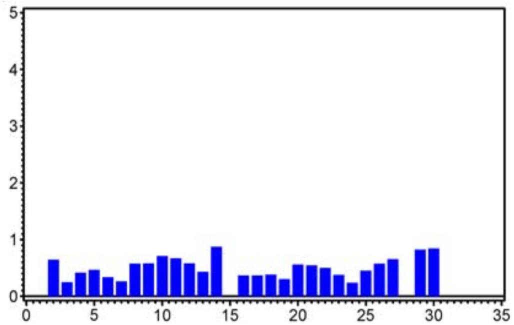

Figure 4. Difference in Intake - Discharge Canal Salinity (psu): Relative to Production Rate (mgd)

The above evaluation showed that even during periods of maximum water production, changes in salinity were within or below expected values (less than a two psu increase over background) as predicted by the USF hydrodynamic model developed during design and permitting of the facility. Consistent with these salinity observations, no adverse impacts to the abundance or diversity of biological resources near the facility discharge have been detected.

Monitoring will continue for the life of the facility, and additional evaluation will be performed as more data are collected.

Mercury Contamination in Tampa Bay

Lindsay M. Cross (Tampa Bay Estuary Program) and George Henderson (FWC FWRI)

The Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute (FWC FWRI) examines mercury levels in muscle tissue from a variety of economically and ecologically important species as part of an ongoing study to better understand mercury contamination in marine fishes (Adams *et al.*, 2003). Fisheries samples are collected from locations throughout Florida, including Tampa Bay.

Detection of mercury in commercial and recreational fish species is important for protecting human health. Mercury, a toxic metallic element, is released into the atmosphere through the burning of fossil fuels, incineration, and through the mining and refining of ores. It then falls as wet or dry deposition onto waterbodies or in the associated watersheds. It is incorporated into aquatic organisms primarily through feeding, but also through direct absorption through gills and skin (Downs *et al.*, 1998). Because it biomagnifies through trophic transfer up the food chain (Downs *et al.*, 1998), larger, longer-living predatory nekton species are more likely have higher concentrations of mercury. When consumed by humans, mercury "poisoning" can lead to nervous system disorders, particularly in children. Newer evidence also points to cardiovascular complications in older adults with high mercury levels (König *et al.*, 2005).

The FWC FWRI began an ongoing investigation of mercury levels in marine and estuarine fishes of Florida in 1989, following concerns about mercury contamination in the early 1980s (Adams *et al.*, 2003). Results have generally been presented periodically, but with mercury levels being included in the Total Maximum Daily Load decisions, a continuous reporting methodology is being considered.

The Florida Department of Health develops fish consumption advisories to alert consumers of what fish species they may safely eat and in what quantity. While mercury concentrations vary by fish species, there are certain species that typically have higher concentrations. Consumption guidelines are stricter for these apex predators and also for children and women of child bearing age. Recently, however, guidelines for the entire population have become more restrictive (Table 1).

It is anticipated that by reducing mercury inputs from the atmosphere, fish tissue mercury will ultimately decline. Some evidence exists from the south Florida Everglades studies that scrubbers on municipal incinerators have led to lower large mouth bass mercury levels. Several power plants in the Tampa Bay region have or will switch to cleaner-burning natural gas and/or improve emissions controls. However, reductions of mercury in Tampa Bay fish tissue are not expected to mirror the results in the Everglades due to the differences in waterbody characteristics. The eastern Everglades represents a relatively closed, freshwater system. Conversely, the Tampa Bay estuary is a marine environment, and, because it is an open system, it is affected by (or receives inputs from) the Gulf of Mexico and other waterbodies.

Table 1: Florida Department of Health Fish Advisory Levels

Meals	Women of Childbearing Age and Young Children	All Other Individuals
Two Per Week	< 0.1 ppm	< 0.3 ppm
One Per Week	< 0.2 ppm	< 0.6 ppm
One Per Month	< 0.85 ppm	< 1.5 ppm
Do Not Eat	>= 0.85 ppm	> 1.5 ppm

The FWC FWRI intends to sample spotted seatrout (*Cynoscion nebulosus*) as an indicator fish in Tampa Bay to detect any possible trends in mercury. To date no trends have been determined (Figure 1), however, future studies by FWC FWRI are planned for 2007 to evaluate this aspect of the mercury cycle in Tampa Bay.

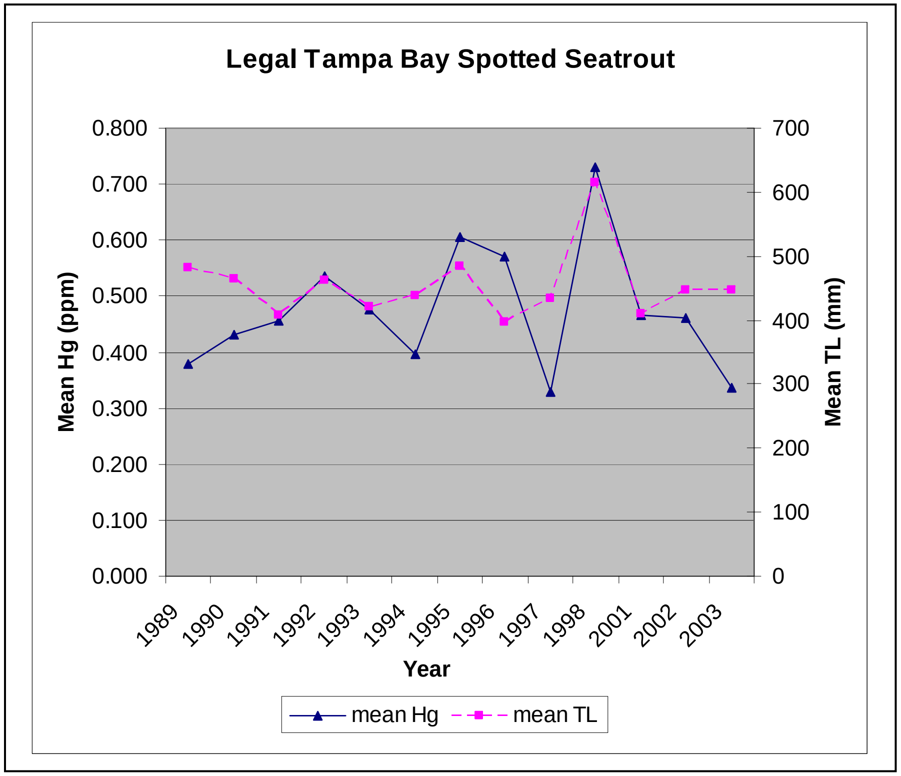

Figure 1. Mean mercury concentration and total length of spotted seatrout in Tampa Bay

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J. O. R. Johansson (Bay Study Group, City of Tampa)

-CHAPTER HIGHLIGHTS-

- *The long-term chlorophyll-a record collected by the City of Tampa's Bay Study Group was examined to determine the vertical distribution of chlorophyll-a in Tampa Bay waters. It was specifically examined to evaluate if samples collected from a single depth level in the water column provide representative estimates of average water column conditions.*

- *Weekly measurements of the vertical chlorophyll-a distribution in central HB show that the vertical variability most often is relatively small. However, elevated chlorophyll-a levels are generally found near the surface when dense phytoplankton blooms are present.*

- *Estimates of annual mean chlorophyll-a concentrations calculated from samples collected at single discrete depth levels (surface or mid-depth) in the four major Tampa Bay segments generally provide representative estimates of annual average water column concentrations.*

- *Mean annual chlorophyll-a concentrations calculated from mid-depth samples provide a more accurate, and ecologically relevant, representation of average annual water column concentrations, than similar median estimates.*

- *Determination of average water column chlorophyll-a concentrations in areas of Tampa Bay which are relatively deep and subject to frequent salinity stratification should include sampling the upper and lower portions of the water column for chlorophyll-a and detailed characterization of the salinity profile.*

INTRODUCTION

Chlorophyll-a samples are routinely collected by several Tampa Bay monitoring programs to determine bay-wide water quality conditions and the eutrophic state of the bay. The Tampa Bay Estuary Program (TBEP) uses some of this information to annually evaluate the progress of nutrient management actions aimed at achieving established bay segment specific chlorophyll-a targets (see TBEP 2000; TBEP 2006). During discussions of these evaluations, concern has been expressed that the chlorophyll-a samples used are collected from a single depth level in the water column. It is questioned if such samples provide representative estimates of average water column conditions.

To respond to this concern, the long-term chlorophyll-a record collected by the City of Tampa's Bay Study Group (COT) was examined. The COT has measured the vertical distribution of chlorophyll-a in Tampa Bay waters on a monthly, or more frequent, basis since the late 1970s. However, this record has to date not been used in the TBEP evaluations. The original purpose of the COT measurements was to complement water column determinations of phytoplankton primary production (Johansson et. al. 1985).

METHODS

Currently, four locations, two in Hillsborough Bay (HB) and one each in Old Tampa Bay (OTB) and Middle Tampa Bay (MTB), are visited on a monthly schedule by the COT for determinations of chlorophyll-a concentration at one meter intervals from near surface through most of the water column. In addition, several locations in all major bay segments, and also East Bay (EB), are sampled for surface and near bottom chlorophyll-a on a monthly, or more frequent, schedule. Further, one location in central HB, station COT4, has been sampled for chlorophyll-a at one meter intervals from surface to near the bottom on a weekly schedule since November 1988. The selected sampling locations that are included and examined in this report are shown in Figure 1.

The COT collects water at discrete depths using a vertically mounted five liter Niskin sample bottle. Chlorophyll-a concentrations are determined from a spectrophotometric method (Strickland and Parsons 1972) and also from an extracted pigment fluorometric method (modified from Phinney and Yentsch 1985; Vyhnalek 1994; Welschmeyer, 1994).

RESULTS AND DISCUSSION

Chlorophyll-a measurements collected from the selected stations during the recent decade were analyzed in detail, using both visual interpretation and simple statistics. This analysis revealed several interesting observations and considerations about the vertical distribution of chlorophyll-a.

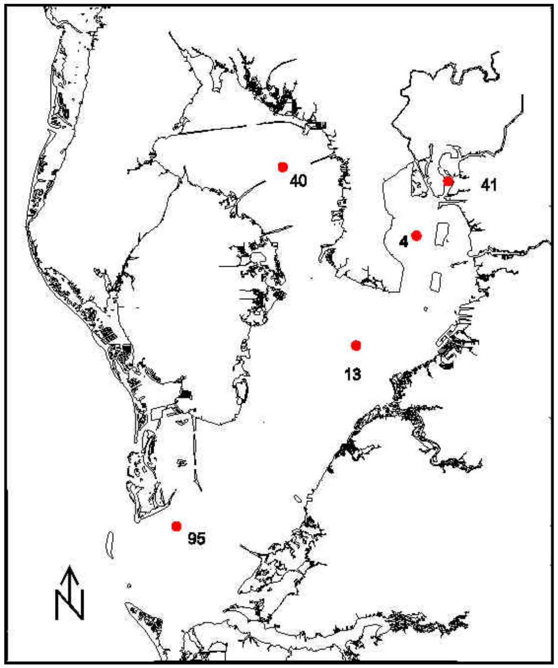


Figure 1. Map of Tampa Bay showing station COT4 in Hillsborough Bay, station COT13 in Middle Tampa Bay, station COT40 in Old Tampa Bay, station COT95 in Lower Tampa Bay, and station COT41 in East Bay.

Short-Term Variability

The weekly distribution of water column chlorophyll-a at station COT4 in central HB for the period 2000-2005 (Figure 2), clearly shows that most often during individual sampling days the vertical variability is relatively small. The uniform distribution of chlorophyll-a implies that the water column is well mixed and lacks density stratification on most sampling days. Of the 370 chlorophyll-a samplings in this record, only about 12 show a substantial vertical variation. Most of these occur during the rainy season, June through September, when phytoplankton populations usually are at maximum and blooms may be present. Excluding the 12 sampling dates with high variability, representative average water column chlorophyll-a concentrations would evidently be recorded at this location regardless of sampling depth.

Substantial variability of water column concentrations occurred during a few dates, e.g. September 2002 and September 2003, when dense phytoplankton blooms were present. The blooming organisms were most often various species of dinoflagellates. During the blooms, the highest concentrations were generally found at surface and the 1m depths and these concentrations were generally substantially higher than those measured at mid-depth, which is about 2m at station COT4.

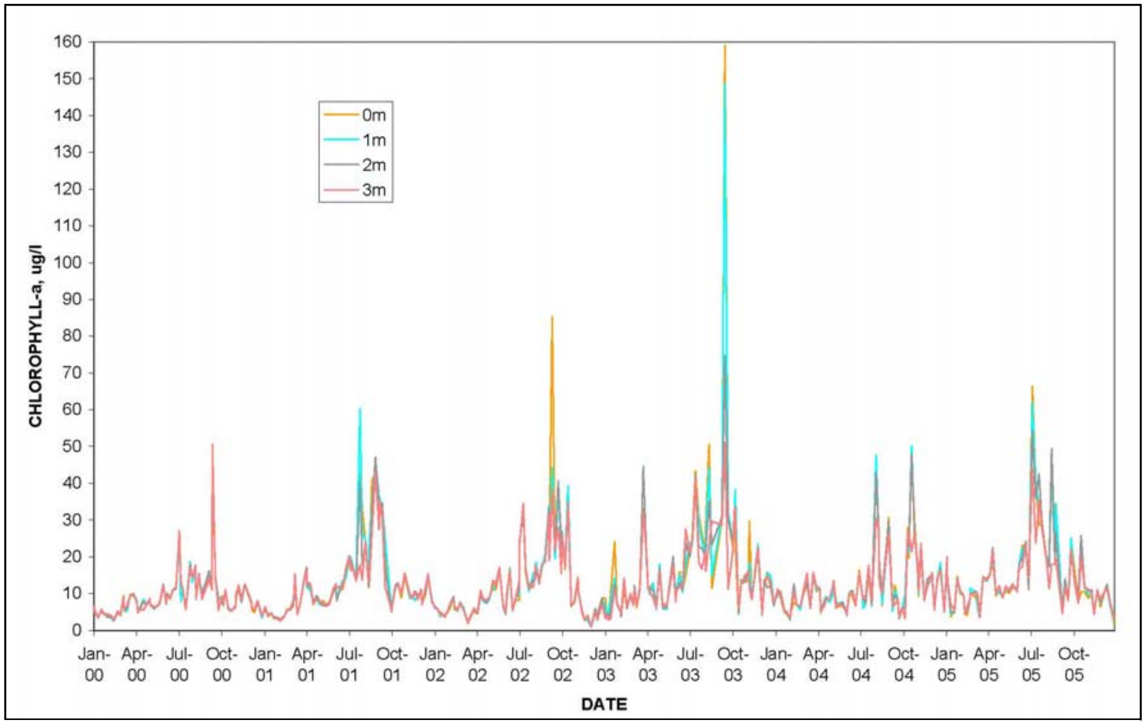


Figure 2. Weekly distribution of chlorophyll-a in the water column measured at station COT4 in central Hillsborough Bay.

The vertical distribution of chlorophyll-a seen in the weekly samples may only have occurred at the specific time of day when the samples were collected. Dinoflagellates generally migrate through the water column and their vertical distribution may be highly variable. It is unlikely that single depth level samples would represent average water column chlorophyll-a distributions when such phytoplankton populations are present in dense concentrations. In addition, salinity stratification of the water column that may follow high rainfall events may also affect the vertical distribution of phytoplankton (see below), however, substantial stratification occurs infrequently at this relatively shallow station.

Annual Means

The TBEP conducts an annual evaluation of ambient chlorophyll-a concentrations in Tampa Bay for the determination of progress towards achieving established chlorophyll-a targets (see TBEP 2000). The evaluation for each of the four major Tampa Bay segments uses annual means calculated from samples collected by the Hillsborough County Environmental Protection Commission (HCEPC) at mid-depth (Boler 2002).

The vertical chlorophyll-a data from the COT were used to examine whether the annual mean chlorophyll-a concentrations calculated from the HCEPC mid-depth samples provide an acceptable annual estimate of averaged water column concentrations. It was also examined whether samples collected at the surface would provide a better annual estimate.

The vertical chlorophyll-a distribution at COT stations located in three of the four major bay segments was used to calculate annual means based on surface samples only, approximate mid-depth samples only, and all vertical depth measurements. The weekly measurements from station COT4 were used for the HB calculations and monthly measurements from stations COT40 and COT13 were used for OTB and MTB, respectively. The period of record used for stations COT4 and COT13 was from 1995 through 2005, and for station COT40, 2000 through 2005. The results from these comparisons are shown in Table 1. The fourth major bay segment, Lower Tampa Bay (LTB), has only been sampled at surface and bottom depths at station COT95 and could not be included in this examination. The vertical chlorophyll-a distribution at this station will be discussed later in the report.

Examination of the chlorophyll-a difference between the two discrete depth samples and the water column average clearly shows that on most occasions the differences are very small. Of the 56 comparisons in the table, only ten have differences greater than 0.50ug/l. Of those ten, five have a difference larger than 1.00ug/l, with the greatest difference being 2.31ug/l.

The five differences larger than 1.00ug/l all appear to have occurred as a result of dense phytoplankton blooms. HB had extensive, but relatively short lived, dinoflagellate blooms in the fall of both 1995 and 2003. Samples collected at station COT4 during these blooms show that the densest cell concentration was generally in the upper portion of the water column. Also, OTB had a dense phytoplankton bloom in 2003, however, the organism that bloomed for an extended period (5 months) was most likely a minute chlorophyte (green alga).

Table 1. Annual mean concentrations of chlorophyll-a (ug/l) calculated from weekly measurements at station COT4 in Hillsborough Bay and from monthly measurements at stations COT40 and COT13 in Old Tampa Bay and Middle Tampa Bay, respectively. Also shown are concentration differences (ug/l) between the annual average for surface samples and water column average, and mid-depth samples and water column average.

Year	COT4					COT13					COT40				
	Surface	Mid-depth	Average all depths	Difference Surf-Avg	Difference Mid-Avg	Surface	Mid-depth	Average all depths	Difference Surf-Avg	Difference Mid-Avg	Surface	Mid-depth	Average all depths	Difference Surf-Avg	Difference Mid-Avg
1995	28.03	24.94	26.61	1.42	-1.68	10.23	9.63	9.72	0.51	-0.08					
1996	11.59	12.10	12.02	-0.43	0.08	6.15	6.49	6.27	-0.12	0.21					
1997	11.91	12.00	11.91	-0.01	0.09	5.58	5.82	5.69	-0.11	0.13					
1998	17.27	17.19	17.06	0.22	0.13	9.89	9.86	10.11	-0.23	-0.25					
1999	10.65	10.76	10.75	-0.10	0.00	4.71	4.95	5.03	-0.32	-0.09					
2000	9.01	9.34	9.24	-0.23	0.10	4.53	4.50	4.50	0.03	0.01	6.12	6.36	6.19	-0.07	0.17
2001	13.02	12.78	12.84	0.18	-0.06	6.81	6.70	6.77	0.04	-0.07	7.23	8.00	7.50	-0.27	0.50
2002	12.39	11.80	11.90	0.48	-0.11	3.69	3.84	3.79	-0.10	0.05	5.92	6.29	6.08	-0.16	0.21
2003	18.40	16.33	16.99	1.41	-0.66	7.07	7.17	7.09	-0.02	0.08	14.54	18.34	16.03	-1.49	2.31
2004	11.95	12.16	11.91	0.04	0.25	8.58	8.68	8.36	0.22	0.32	12.11	11.98	11.73	0.38	0.25
2005	14.50	14.97	14.47	0.03	0.51	5.77	6.48	6.05	-0.28	0.43	8.00	6.84	7.28	0.72	-0.44

OTB during these blooms indicate that chlorophyll-a was generally dispersed evenly throughout the water column. An even vertical dispersion of the dominating chlorophyte could be expected, because it lacked flagella and any apparent means of active vertical migration. However, in September 2003, the lower portion of the water column had by far the greatest chlorophyll-a concentrations. This specific sampling event was mainly responsible for the relatively large calculated annual difference (2.31ug/l) in 2003. September was late in the life of the alga bloom and, possibly dying and dead cells, lacking their natural buoyancy, were settling to the bottom.

It is recognized that the results presented in this report are based on the limited number of locations currently available for a detailed evaluation of the vertical distribution of chlorophyll-a in Tampa Bay. However, the results shown in Table1, suggest that on most occasions, chlorophyll-a samples collected at the discrete depths, surface or mid-depth, equally well provide acceptable estimates of annual average water column chlorophyll-a concentrations. However, for years with abundant phytoplankton populations (blooms), less representative average water column of chlorophyll-a estimates can be expected from the single depth samples.

As previously noted, LTB was not included in the evaluation shown in Table 1, because station COT95 has only been sampled at surface and bottom. COT data for the period 1996 through 2005 were used to determine if chlorophyll-a is evenly distributed throughout the water column at this location (Table 2). Also included in this table are surface and bottom chlorophyll-a measurements from station COT41 in EB. This bay segment is currently not included in the annual TBEP evaluation, however, the vertical distribution seen there provides a distinct contrast to distributions seen at station COT95 and also the locations discussed in Table 1.

The annual mean surface and bottom chlorophyll-a concentrations at station COT95 are most often very similar and it is likely that chlorophyll-a is evenly distributed throughout the water column on most occasions. However, the discrepancy between surface and bottom concentrations was large in September 2005 as a result of an unusually high surface chlorophyll-a value that concurred with a bloom of the red tide organism *Karenia brevis*. Excluding such bloom events, it can be expected, that annual mean chlorophyll-a concentrations calculated from mid-depth samples in LTB would provide an acceptable annual estimate of averaged water column concentrations.

In contrast to stations located in LTB and the other three major bay segments, station COT41 in EB shows consistently and substantially higher annual chlorophyll-a concentrations at surface than at bottom. The discrepancy is apparently the result of elevated chlorophyll-a concentrations at surface during phytoplankton blooms. Phytoplankton blooms in EB occur in the upper portion of the water column during rainy periods on a near annual basis. The blooms are often concurrent

Table 2. Annual mean concentrations of chlorophyll-a (ug/l) calculated from monthly surface and bottom measurements at station COT95 in Lower Tampa Bay and monthly or more frequent measurements at station COT41 in East Bay. Also shown are calculated concentration differences (ug/l) between annual averages for surface and bottom samples. Bottom depths at these stations range from 8 to10m.

	COT95			COT41		
Year	Surface	Bottom	Difference Surface-Bottom	Surface	Bottom	Difference Surface-Bottom
1995				28.97	9.08	19.89
1996	3.58	3.06	0.52	29.65	9.71	19.94
1997	4.20	3.83	0.37	17.79	7.28	10.51
1998	6.80	6.55	0.25	21.99	7.14	14.86
1999	4.77	5.09	-0.32	16.13	7.48	8.65
2000	4.27	5.01	-0.74	19.87	8.22	11.65
2001	6.02	5.56	0.46	16.80	7.61	9.19
2002	3.98	4.15	-0.17	19.75	5.39	14.37
2003	4.89	4.37	0.53	26.63	5.11	21.52
2004	4.99	4.59	0.40	14.89	5.28	9.62
2005	9.11	5.56	3.54	12.72	8.02	4.70

with considerable salinity stratification of the water column and marked halinoclines are often present below the upper several meters. The salinity stratification may act as a barrier and prevent the often dense phytoplankton population in the upper low salinity layer to actively migrate, or be dispersed by turbulence, to deeper depths. In addition, light attenuation is often high in EB in summer and fall, and phytoplankton present in the deep high salinity layer may be severely growth limited by low light conditions i.e. they are located below the photic zone where respiration exceeds primary production. Consequently, to determine accurate estimates of ambient chlorophyll-a concentrations in EB, or other areas with frequent salinity stratification, a minimum effort must include chlorophyll-a sampling of the upper and lower portions of the water column and detailed characterization of the salinity profile.

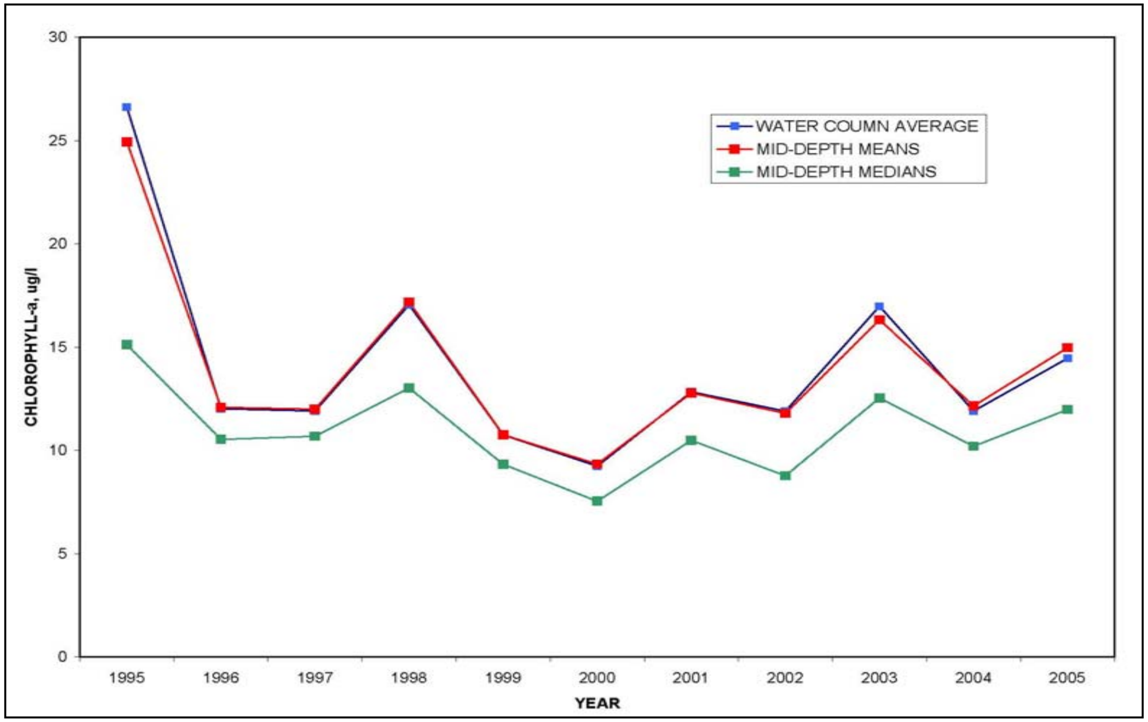
Annual Medians as a Potential Alternate Approach

High vertical variability of chlorophyll-a occurs during periods when dense phytoplankton blooms are present in the bay. At these times, even one sample from a specific depth with high cell concentrations can have a large impact on the calculated annual mean used for the annual TBEP chlorophyll-a evaluation. It has been suggested that bay segment annual medians, calculated from the HCEPC mid-depth chlorophyll-a data, could be used to reduce the influence of the dense bloom values and provide a better characterization of annual concentrations than those derived from mean calculations.

This suggestion was examined using the weekly water column chlorophyll-a data from station COT4 in central HB for the period 1995 through 2005. HB data were selected because dense phytoplankton blooms appear to occur more often in this segment than the other three major bay segments. It was assumed, a priori, that the water column average chlorophyll-a concentrations calculated from the samples collected at 1m intervals from surface to near the bottom provide an accurate estimate of average water column concentrations. This average was then compared to annual mean and median concentrations calculated from mid-depth (2m) samples. Results from this comparison are shown in Figure 3.

The comparison clearly indicates that the annual mean chlorophyll-a concentrations calculated from the mid-depth samples are very similar to the water column averages calculated from the 1m interval samples. The differences are small even

Figure 3. Comparison of annual chlorophyll-a concentrations estimated from samples collected at station COT4 in central Hillsborough Bay. The blue line shows calculated concentrations from samples collected at 1m intervals from surface to near the bottom. The red and green lines show, respectively, mean and median concentrations calculated from the mid-depth (2m) samples.



during years with heavy phytoplankton blooms, i.e. 1995 and 2003 (also see Table 1). In contrast, the annual median estimates are consistently and substantially lower than the water column average and the mean estimates, confirming that the frequency distribution of the chlorophyll-a data is skewed towards relatively low concentrations (see Figure 2).

Median calculations, as expected, reduce the variability in the annual estimates. However, information from high chlorophyll-a events are suppressed in these calculations. Median estimates may, therefore, be less well suited for use by management programs that aim to evaluate and ultimately reduce ecological impacts associated with elevated chlorophyll-a levels that generally occur during phytoplankton bloom events.

CONCLUSIONS

The long-term COT monitoring record of chlorophyll-a distribution in Tampa Bay waters was analyzed to determine the vertical variability of chlorophyll-a in the water column. It was specifically examined if samples collected from a single depth level in the water column provide representative estimates of average water column conditions.

Weekly measurements of the vertical chlorophyll-a distribution in central HB show that the vertical variability most often is relatively small. However, elevated chlorophyll-a levels are generally found near the surface when dense phytoplankton blooms are present.

Estimates of annual mean chlorophyll-a concentrations calculated from samples collected at single discrete depth levels (surface or mid-depth) in the four major Tampa Bay segments generally provide representative estimates of annual average water column concentrations. Less representative annual means can be expected for years with abundant phytoplankton blooms.

Determination of average water column chlorophyll-a concentrations in areas of Tampa Bay which are relatively deep and subject to frequent salinity stratification should include sampling the upper and lower portions of the water column for chlorophyll-a and detailed characterization of the salinity profile.

Mean annual chlorophyll-a concentrations calculated from mid-depth samples provide a more accurate, and ecologically relevant, representation of average annual water column concentrations, than similar median estimates.

ACKNOWLEDGEMENTS

Walter Avery, Kerry Hennenfent, John Pacowta, and former members of the City of Tampa Bay Study Group are recognized for their devoted efforts in collecting and analyzing water quality information used in this report. Walter Avery and Kerry Hennenfent also reviewed the manuscript and provided valuable suggestions. Finally, Holly Greening of the Tampa Bay Estuary Program is acknowledged for her support of this examination. All work involved with this report was funded by the City of Tampa.

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Redesigned Water Quality Monitoring Program

Keli Hammer-Levy (Pinellas County Dept. of Env. Mgmt)

In 2003, the Pinellas County Department of Environmental Management (PCDEM) redesigned their water quality monitoring program to include the coastal waters of the Tampa Bay. Since the Environmental Protection Commission of Hillsborough County's (EPCHC) long term monitoring program covered the deeper waters of Tampa Bay, PCDEM designed their program to include the Bay's shallow waters (≤2m) within the County's jurisdictional boundaries. The improved monitoring coverage of the bay allows for statistical comparisons of water quality in shallow vs deep environments. This analysis includes the distribution of bottom dissolved oxygen, Chlorophyll-a, and turbidity during the wet and dry seasons in PCDEM stratum E1 – E7 (Figure 1). The wet season was defined as June – September and the dry season from October – May. Locations include PCDEM's shallow sites and those EPCHC deeper water sites within the County's eastern strata from 2003-2005.

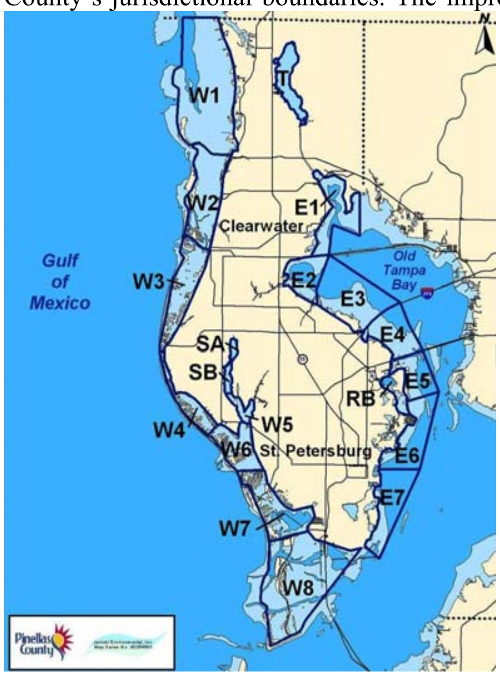

Figure 1. PCDEM Monitoring Strata

The analysis suggests that there is no significant difference in bottom dissolved oxygen (DO) distributions between shallow and deep waters during the dry season. However, during the wet season, the mean and median DO concentrations are lower and the distribution of the data is more variable in both shallow and deep waters compared to dry season values. During the wet season, mean and median DO values at the shallow sites are slightly higher in all strata compared to deeper water locations; furthermore, the variability in the shallow areas is much more pronounced than in the deeper areas, likely due to

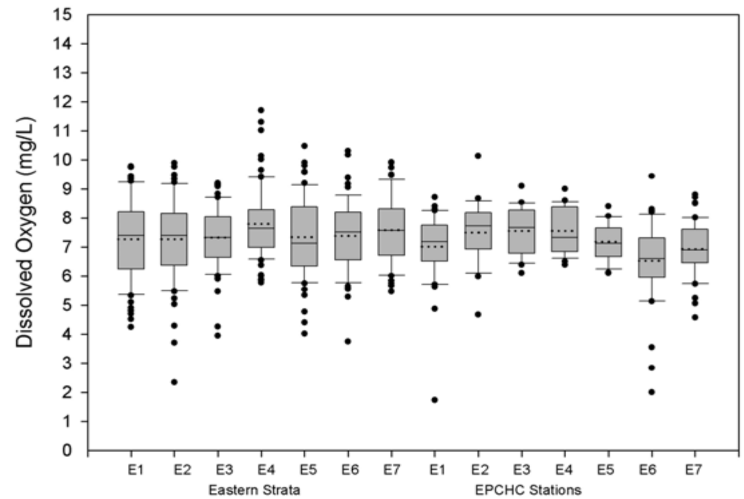

Figure 2.a. Distribution of bottom dissolved oxygen for Pinellas County Eastern Strata and EPCHC fixed stations during dry seasons (2003-2005).

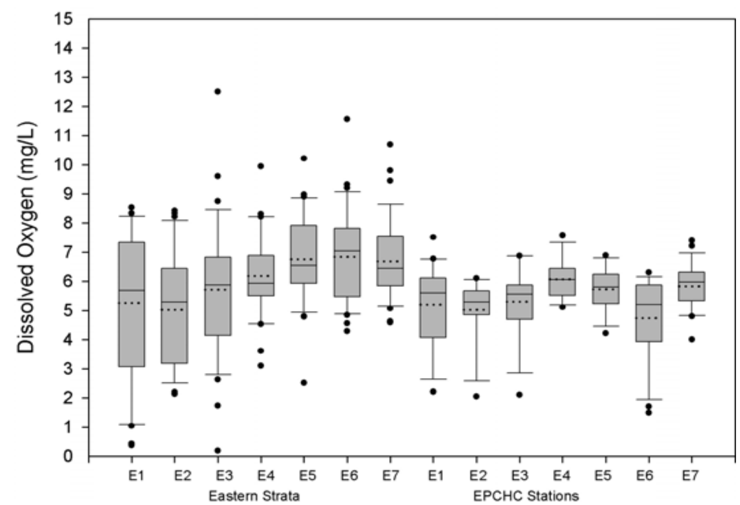

Figure 2.b. Distribution of bottom dissolved oxygen for Pinellas County Eastern Strata and EPCHC fixed stations during wet seasons (2003-2005).

the large volumes of fresh water entering the system.

A comparison of Chlorophyll-a (Chl-a) data show slightly lower mean and median Chl-a values in shallow waters compared to deep waters during the dry season. During the wet season, the variability in the data and the mean and median concentrations are greater in both shallow and deep waters in upper Tampa Bay strata E1 and E2 and in shallow waters in E3 and E5. This data includes documented algae blooms that occurred during the 2004 hurricane season which skewed the mean values and the distributions. The median Chl-a values are more representative of this area. Additionally, strata E5 is heavily influenced by high nutrient loads from Lake Seminole, the Seminole Bypass Canal, and the Cross Bayou Canal. The distribution of the shallow and deep water data in middle Tampa Bay (E6 and E7) was not significantly different from the dry season analysis.

The last comparison was for turbidity. The distributions during the dry and the wet seasons were comparable to Chl-a; lower mean and median values in the shallow water samples and greater variability in the deep areas.

In conclusion, when comparing bottom DO, Chl-a, and turbidity on a seasonal scale, water quality is generally better in the shallow areas. Additionally, bottom DO in shallow areas seems to be the parameter most affected in the wet season. Overall, the data show a general trend of improving water quality from north to south in all parameters reviewed. Lastly, that data suggests that the wet season signal lasted longer in the deeper waters by approximately one month, extending into October.

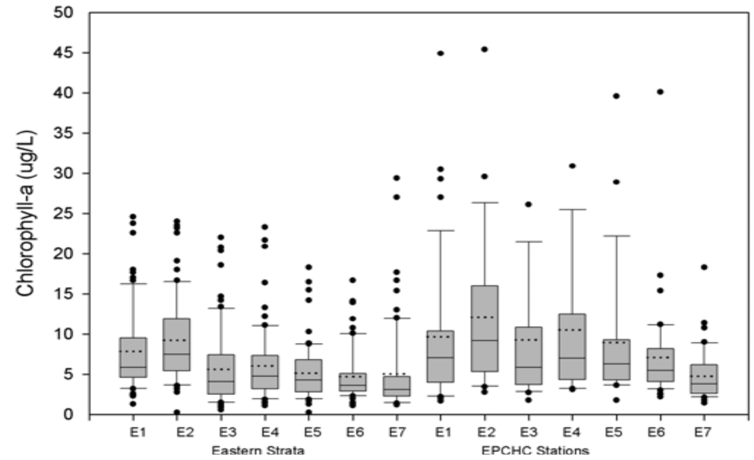

Figure 3.a. Distribution of chlorophyll-a for Pinellas County Eastern Strata and EPCHC fixed stations during dry seasons (2003-2005).

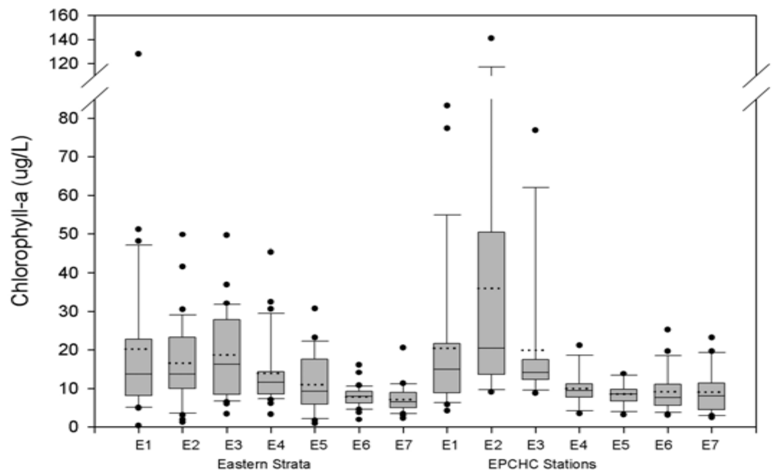

Figure 3.b. Distribution of chlorophyll-a for Pinellas County Eastern Strata and EPCHC fixed stations during wet seasons (2003-2005).

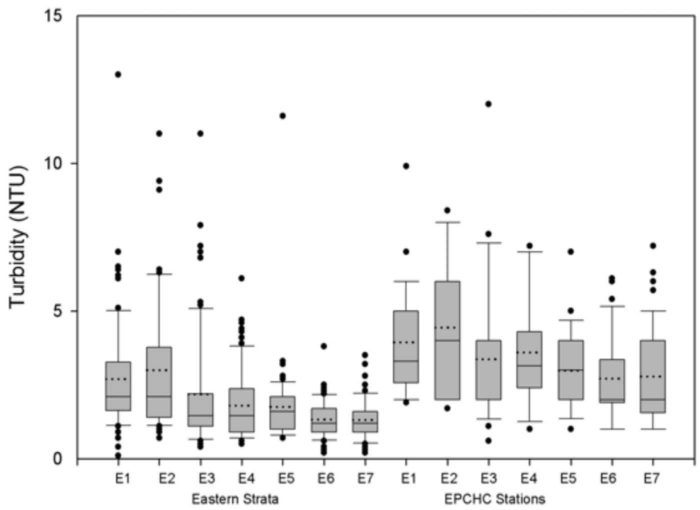

Figure 4.a Distribution of Turbidity for Pinellas County Eastern Strata and EPCHC Fixed Stations during dry seasons (2003-2005).

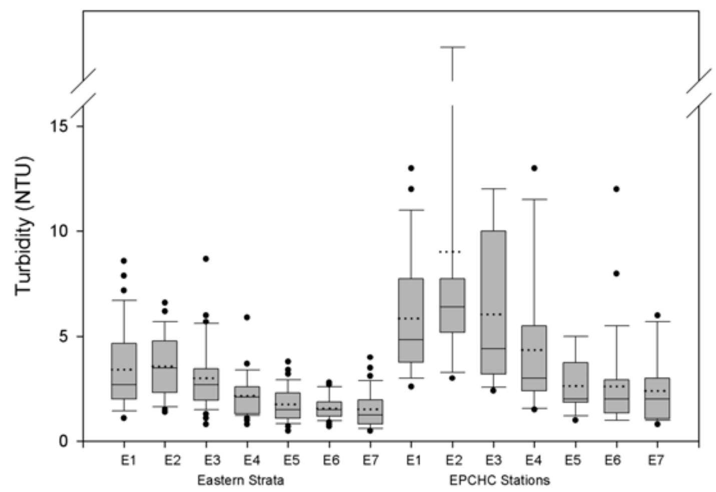

Figure 4.b Distribution of Turbidity for Pinellas County Eastern Strata and EPCHC Fixed Stations during wet seasons (2003-2005).

Construction of a Bridge to Re-establish Circulation in the Ft. Desoto Park & Aquatic Habitat Management Area

Eric Fehrmann (Pinellas County Dept. of Env. Mgmt)

This project resulted from a long history of generally unsuccessful attempts at ecological

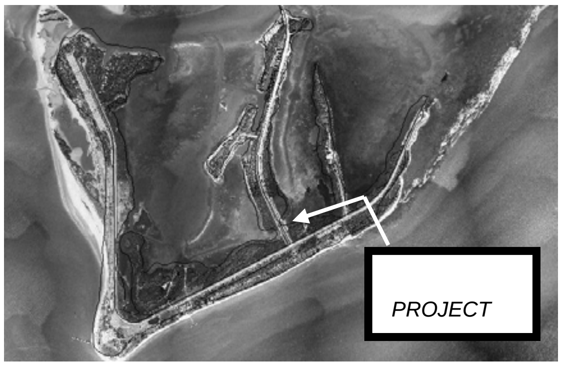

Figure 1. Mullet Key at Ft. DeSoto Park in Pinellas County, Florida

restoration of the "back-bays" of Mullet Key in Ft. DeSoto Park. The Park was once a group of separate islands. During the Park's development in the late 1950's to early 1960's, the main island was connected to the smaller islands by filling two causeways. This activity cut off circulation between the bays, killing seagrass and harming marine life. Water temperatures were found to peak as high as 41 degrees (106 F) during summer months.

While initial designs for a structure to allow water circulation centered on the installation of double 3-meter (9 foot) box culverts, engineers later determined that a bridge with a minimum clear span of 12 meters (40 feet) would allow sufficient water to pass between the cells to provide flushing while maintaining a velocity that would minimize erosion and be safe. The channel bottom was over-excavated and lined with native Florida limestone. Stormwater ponds were constructed to filter road runoff prior to release into the bays.

Constructed between February and November of 2004, the "Recirculation Project" re-established the connection between the back-bays with the goal of improved water quality and environmental recovery of seagrass and animal life within these areas. Marine organisms colonized the area within days of the opening of the channel and fishermen have been catching mullet, Snook and Spanish mackerel from the bridge. These species were previously absent from the back-bay areas. Conversations with anglers have confirmed the site as an excellent fishing location that produces fish when other areas do not. Kayakers and canoeists enjoy being able to pass under the road rather than making a much more dangerous portage across the road.

The project was a collaborative effort between Pinellas County's Department of Environmental Management and Public Works Department, the Southwest Florida Water Management District (SWFWMD), the Pinellas County Environmental Fund (PCEF), the Environmental Protection Agency's (EPA) Gulf of Mexico Program, the National Oceanic & Atmospheric Administration (NOAA), the U.S. Fish and Wildlife Service (USFWS), the U.S. Department of Commerce NOAA Coastal Impact Assistance Program, the University of South Florida and Delta-Seven Environmental Consulting. Native vegetation was planted in the tidal and high marsh zones by Tampa Baywatch to attract wildlife and provide stabilization.

Analysis of the preliminary water quality data has produced mixed results. Although water temperatures have not declined as much as we had expected, flow through the channel has been excellent. Much of the sediment within the area of the channel, primarily mucky-sand, has been reduced and a clean sand bottom now exists. The seagrass appears healthier, but no conclusion can be formed until more sampling has been conducted.

Figure 2. Completed Bridge

Overall, the project has been a great success. Long-term studies are being conducted under a separate NOAA grant by Dr. Thomas Cuba, an Associate Professor at USF and President of Delta Seven Environmental. These studies will document changes in water quality as well as floral and faunal composition within the restoration area.

Salinity Patterns in Hillsborough County's Tidal Rivers and Streams

Gerold Morrison (Environmental Protection Commission of Hillsborough County)

In addition to the open waters of the bay itself, the Tampa Bay estuary includes tidal portions of five rivers — the Hillsborough, Palm, Alafia, Manatee and Little Manatee — and more than 30 smaller streams that drain coastal portions of Hillsborough, Pinellas and Manatee counties (TBRPC 1986). The tidal reaches of these rivers and streams play an important role in the ecology of the bay, providing reduced-salinity habitats that are used as nursery areas by the immature stages of a number of estuarine-dependent species including shrimp, blue crabs, seatrout, anchovies, silver perch, menhaden, spot, striped mullet, red drum and snook (Flannery 1989, Browder 1991, Edwards 1991, Estevez et al. 1991, Peebles et al. 1991). Protection and restoration of these low-salinity habitats has been identified as a priority issue by the Tampa Bay Estuary Program and its partners (TBEP 2006).

Several urban centers are located along the shoreline of Tampa Bay, including the cities of Tampa and St. Petersburg and their associated suburbs. Much of the low-salinity habitat that historically occurred in and along tributary streams in these areas has been physically removed or altered by activities such as dredging, filling, channelization and shoreline hardening (TBRPC 1986, Clark 1991). Extensive physical modifications — including the construction of shipping channels, dredge disposal islands, and causeways and bridges — have also occurred in the bay itself, particularly between the 1880s and early 1970s, altering the circulation and flushing characteristics of several bay segments (Goodwin 1989, Galperin et al. 1991, Weisberg and Zheng 2006). In addition to these direct physical impacts the construction of urban infrastructure, including regional transportation, flood protection, stormwater conveyance, potable water supply and municipal wastewater treatment systems, have resulted in hydrologic modifications that have altered the quantity, quality, location and timing of freshwater inflows to the tidal reaches of many tributaries (Flannery 1989, Flannery et al. 1991, Zarbock 1991, Stoker et al. 1996).

Freshwater discharge in several Tampa Bay tributaries has shown significant upward or downward trends over the past several decades. Flannery et al. (1991) noted that flows in the Little Manatee River increased during the period 1940 - 1989, apparently as a result of agricultural practices that discharged groundwater, which had been used to irrigate crops, to the river during the dry season. Freshwater discharge in the Hillsborough River and the Alafia River have declined over the period 1939 – 1992 and 1933 – 1992, respectively, due to a complex mix of natural and anthropogenic factors (Stoker et al. 1996). These changes in freshwater discharge have presumably caused changes in the salinity regimes of these rivers' tidal reaches.

In the tidal reaches of the Hillsborough and Alafia rivers, the reductions in annual freshwater inflows from gaged portions of these watersheds that have occurred since the 1930s have — unless mitigated by increased freshwater inflows from ungaged coastal sub-basins — presumably caused low-salinity habitats to shift in an upstream direction. Because the volumes of tidal streams in the Tampa Bay area tend to be largest at their mouths and become smaller upstream, upstream shifts in low salinity habitats are expected to lead, over time, to a reduction in the overall size of those habitats (Estevez et al. 1991). In streams where dams or salinity barriers have been constructed within the tidal reach, upstream movement of higher salinity zones may cause some important low-salinity habitats to become severely compressed or lost altogether (Estevez et al. 1991).

Conceptually, important nursery areas for estuarine-dependent organisms are believed to occur in locations where favorable "dynamic habitats" — defined by salinity and other water quality attributes — coincide with favorable "stationary habitats" which are defined by shoreline and bottom types, dominant plant communities, and related physical and biological attributes (Browder 1991). This widely-used conceptual model suggests that salinity and other water quality characteristics play an important role in determining the environmental quality and productivity of the habitats present in tidal rivers and streams (Edwards 1991, Estevez et al. 1991).

Recent Salinity Levels and Trends in Smaller Tributaries

EPC has monitored the following tidal tributary stations on a consistent, monthly basis since at least 1985 (Morrison and Boler 2005):

- Station 101, Double Branch Creek at Hillsborough Avenue
- Station 102, Channel "A" at Hillsborough Avenue
- Station 103, Rocky Creek at Hillsborough Avenue
- Station 104, Sweetwater Creek at Hillsborough Avenue
- Station 105, Hillsborough River at Rowlett Park Drive

- Station 137, Hillsborough River at Columbus Drive
- Station 109, Palm River at U.S. Highway 41
- Station 133, Delaney Creek at U.S. Highway 41
- Station 74, Alafia River at U.S. Highway 41
- Station 112, Little Manatee River at U.S. Highway 41

Based on the interquartile ranges of monthly mid-depth salinity measurements made at these locations during the years 2002 through 2005, salinity regimes at the 10 monitoring sites would be characterized as follows during that period:

- Sta. 101 (Double Branch Creek at Hillsborough Avenue): oligohaline to mesohaline (0.5 to 18 psu)
- Sta. 102 (Channel "A" at Hillsborough Avenue): mesohaline to polyhaline (5 to 30 psu)
- Sta. 103 (Rocky Creek at Hillsborough Avenue): oligohaline to mesohaline
- Sta. 104 (Sweetwater Creek at Hillsborough Avenue): mesohaline to polyhaline
- Sta. 105 (Hillsborough River at Rowlett Park Drive): oligohaline (0.5 – 5 psu)
- Sta. 137 (Hillsborough River at Columbus Drive): mesohaline to polyhaline
- Sta. 109 (Palm River at U.S. Highway 41): polyhaline (18 – 30 psu)
- Sta. 133 (Delaney Creek at U.S. Highway 41): oligohaline
- Sta. 74 (Alafia River at U.S. Highway 41): mesohaline to polyhaline
- Sta. 112 (Little Manatee River at U.S. Highway 41): mesohaline (5 – 18 psu).

In order to test for multi-year trends in salinity at the 10 tidal stream monitoring stations listed above, over the period 1985 through 2005, EPC staff used stepwise regression models of the form:

annual mean mid-depth salinity = $\beta_0 + \beta_1$(annual rainfall) + β_2(year),
where β_0 , β_1, and β_2 are fitted regression coefficients.

Rainfall data used in these analyses were provided by the Southwest Florida Water Management District (SWFWMD), which tabulates summaries of annual rainfall for each of the major hydrologic basins addressed by its Comprehensive Watershed Management (CWM) program. EPC staff used the following approach to generate annual rainfall estimates for the catchments discharging to the 10 tidal tributary monitoring stations:

- rainfall values reported by SWFWMD for the Tampa Bay/Coastal CWM Basin were used for EPC stations 101, 102, 103 and 104, which are located on streams discharging to upper Old Tampa Bay;
- rainfall values from the Hillsborough River CWM Basin were used for the EPC stations located on the Hillsborough River and Palm River (stations 105, 109, and 137);
- rainfall values from the Alafia River CWM Basin and the Little Manatee River CWM Basin were used, respectively, for EPC stations 74 (Alafia River) and 112 (Little Manatee River); and
- for EPC station 133, located on Delaney Creek, annual rainfall values were calculated by averaging the annual values reported by SWFWMD for the Hillsborough River and Alafia River CWM basins.

The final regression equations generated using this approach are summarized in Table 6-1. As expected, highly significant inverse relationships were found at all stations between annual mean salinity and annual rainfall, reflecting the diluting effects of rainfall and its associated freshwater runoff on in-stream salinity. In addition, significant ($p<0.05$) multi-year salinity trends (β_2 values) were found at three sites. At station 102 (Channel A) the estimated β_2 values were negative, indicating that — once the effects of year-to-year variations in annual rainfall were included in the regression model — annual mean salinities at this site trended downward during the period 1985 through 2005. At stations 74 (Alafia River) and 133 (Delaney Creek) the estimated β_2 values were positive, indicating that annual mean mid-depth salinity levels increased over time at these stations once variations in annual rainfall were included in the model

No significant ($p<0.05$) trends in annual or seasonal rainfall are evident in the CWM basin rainfall data over the 1985-2005 period. Results of nonparametric (Kendall tau-b) tests for trend, applied to annual, wet-season and dry-season rainfall during that period are summarized in Table 6-x2. Marginally-significant ($p\leq0.10$) increasing trends in annual and wet-season rainfall occurred in the Alafia and Little Manatee River CWM basins during the period (Table 6-2).

Given the absence of significant rainfall trends, and the fact that year-to-year fluctuations in rainfall are included in the regression equations shown in Table

6-1, the salinity trends observed at the three EPC monitoring stations during the 1985-2005 period were apparently caused by factors other than changing rainfall patterns. They may have been due to anthropogenic hydrologic impacts, such as modifications in surface drainage patterns (e.g., due to roadway construction), changes in discharge volumes from point or non-point sources, or changes in water withdrawals from the watersheds of the affected streams.

Because of the importance of low-salinity habitats to the ecology of Tampa Bay (TBEP 2006), the changes in freshwater inflow and salinity regimes that have occurred in the tidal reaches of bay tributaries over the past several decades, and in recent years, represent a complex challenge for bay managers and the bay's living resources.

Table 1. Regression models describing annual mean mid-depth salinity at 10 EPC tidal stream monitoring stations, for the period 1985 through 2005, using two potential explanatory variables (rainfall and year). Data source: EPC.

Location	Fitted Regression Model	R^2 and Significance Levels
Alafia River at U.S. 41	salinity = -365.08 - 0.27(annual rainfall) + 0.2(year)	0.47 (<0.005)
Double Branch at Hillsborough Ave.	salinity = 26.74 - 0.31(annual rainfall)	0.42 (<0.005)
Channel A at Hillsborough Ave.	salinity = 687.39 - 0.23(annual rainfall) - 0.33(year)	0.59 (<0.005)
Rocky Creek at Hillsborough Ave.	salinity = 20.86 - 0.24(annual rainfall)	0.33 (<0.01)
Sweetwater Creek at Memorial Pkwy	salinity = 32.45 - 0.31(annual rainfall)	0.38 (<0.05)
Hillsborough River at Rowlett Park Dr.	salinity = 11.29 - 0.16(annual rainfall)	0.37 (<0.005)
Palm River at U.S. 41	salinity = 33.96 - 0.22(annual rainfall)	0.36 (<0.005)
Little Manatee River at U.S. 41	salinity = 19.63 - 0.14(annual rainfall)	0.25 (<0.05)
Delaney Creek at U.S. 41	salinity = -354.96 - 0.17(annual rainfall) + 0.18(year)	0.39 (<0.05)
Hillsborough River at Columbus Dr.	salinity = 31.59 - 0.33(annual rainfall)	0.39 (<0.01)

Table 2. Temporal trends (Kendall tau-b values and significance levels) in annual and seasonal rainfall during the years 1985 through 2005 in four CWM watersheds that drain to Tampa Bay. (Data source: SWFWMD)

CWM Watershed	trend in annual rainfall	trend in wet-season rainfall	trend in dry-season rainfall
Tampa Bay/Anclote	0.05 (0.76)[1]	0.20 (0.20)[1]	-0.05 (0.72)[1]
Hillsborough River	0.09 (0.59)[1]	0.15 (0.33)[1]	-0.10 (0.55)[1]
Alafia River	0.26 (0.10)[1]	0.28 (0.08)[1]	0.02 (0.90)[1]
Little Manatee River	0.26 (0.10)[1]	0.27 (0.09)[1]	0.04 (0.81)[1]

[1]Trend not significant at the p<0.05 level.

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J. O. R. Johansson (Bay Study Group, City of Tampa)
Susan Janicki, Keith Hackett, and Ray Pribble (Janicki Environmental, Inc.)

- CHAPTER HIGHLIGHTS -

- *Examination of the TN loadings data suggests that much of the increase in TN loadings could be explained by the higher rainfall and resultant hydrologic loadings observed in 2002 and 2003.*

- *TN loading has ranged between 5,000 and 7,500 US tons during wet years and between 2,000 and 4,000 US tons during relatively dry years.*

- *Nonpoint sources supply the greatest portion of all estimated loads to Tampa Bay.*

INTRODUCTION

The flow of freshwater, nutrients, and sediments to Tampa Bay from the surrounding land and atmosphere is a natural result of the hydrologic cycle and is essential for the maintenance of the estuarine bay ecosystem. However, industrial development and population growth in the watershed, and the increased use of fertilizers and fossil fuels, have all influenced the export of these materials to the bay.

The excessive loading of nutrients, primarily nitrogen, is of special concern because the enrichment of this nutrient to estuaries like Tampa Bay generally results in deteriorated water quality and an over-all loss of biological diversity and system productivity. Nutrient enrichment, or eutrophication, of Tampa Bay waters appears to have been most serious from the late 1960s to the early 1980s. Records of water quality and biological indicators, such as phytoplankton biomass and seagrass coverage, show that the severest degradation occurred in the upper portions of the bay, while areas closer to the Gulf of Mexico were less impacted.

Regulatory actions directed at several large point sources, and voluntarily conducted improvements as well, greatly reduced the loading of nutrients and suspended solids to Tampa Bay during the late 1970s and early 1980s. Reductions of nitrogen are of particular interest because of the link between this nutrient and eutrophication. Large nitrogen reductions occurred in Hillsborough Bay as a result of the upgrade of treatment at the City of Tampa's domestic wastewater plant and pollution abatement actions at several agricultural fertilizer producing plants. These actions resulted in a more than 50% reduction of nitrogen loading to Hillsborough Bay and a substantial reduction to Tampa Bay as a whole. Additional decreases in nitrogen loading have occurred in other sections of the bay as other domestic wastewater plants either upgraded their treatment or terminated discharges to the bay.

Efforts to reduce the impact of stormwater discharge have also been undertaken during the last decade. Phosphorus and suspended solids reductions resulting from these efforts may be substantial. However, with the exception of actions taken at several agricultural fertilizer facilities, nitrogen loading reduction as a result of stormwater management has, to this date, probably been minor in comparison to the reductions from the point sources.

The Tampa Bay Estuary Program (TBEP) currently directs a major program to control eutrophication in Tampa Bay through reductions in nitrogen loading. The partners of the program have agreed on a goal to "hold the line" of nitrogen loading to Tampa Bay at the rate estimated for the 1992-94 period.

Parallel with the ongoing effort to control eutrophication in Tampa Bay, programs are also underway to ensure that the bay receives a sufficient supply of freshwater necessary to sustain a productive estuarine ecosystem. The ongoing rapid development of the Tampa Bay region has resulted in an increased demand for this limited resource.

It is important to periodically estimate freshwater inflow and loading of nutrients and solids to Tampa Bay in order to document the progress of bay management and to help explain ambient bay conditions. This chapter will primarily discuss annual loading estimates of freshwater inflow, total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) from seven major source categories for each of the seven major Tampa Bay segments for the 17 year period, 1985-2003. Several environmental consulting groups working under contract with the TBEP have compiled most of the data presented in this chapter.

Table 7-1. Percentage contribution by each bay segment to the total Tampa Bay loading of freshwater inflow, TN, TP, and TSS. Percentages are calculated from 1999-2003 data for all parameters.

Bay Segment	Freshwater Inflow (percentage)	TN Loading (percentage)	TP Loading (percentage)	TSS Loading (percentage)
Old Tampa Bay	16.6	12.6	8.3	16.0
Hillsborough Bay	27.8	36.5	67.8	37.5
Middle Tampa Bay	21.4	18.5	9.1	12.9
Lower Tampa Bay	11.9	7.0	1.4	1.9
Boca Ciega Bay	7.0	6.7	2.3	13.7
Terra Ceia Bay	1.2	0.9	0.3	0.9
Manatee River	14.1	17.7	10.8	17.1

The primary intent of the chapter is to provide a summary of loading and inflow magnitudes and observed trends over the study period. For a detailed analysis of the information presented please see Zarbock et al. (1996), Pribble et al. (2001) and Poe et al. (2005).

METHODS USED TO CALCULATE LOADINGS

Seven major categories of sources of freshwater inflow and loadings of TN, TP, and TSS have been identified by the TBEP. These include nonpoint sources (stormwater runoff and base flow), domestic and industrial point sources, atmospheric deposition (wetfall-rainfall and dryfall delivered to the open bay surface), groundwater, springs, and material losses (material lost during handling and shipping of fertilizer products). The contribution from each source of these categories is summed to yield individual bay segment inflows and loads, and the total load to Tampa Bay.

Detailed methods used to estimate inflows and loads have been described in Zarbock et al. (1996) for the period 1992-1994 in Pribble et al. (2001) for the period 1995-1998 and in Poe et al (2005) for the 1999-2003 period.

RESULTS AND DISCUSSION

Loading by each bay segment is shown in Table 7-1. Hillsborough Bay has the greatest watershed area of all bay segments, and also receives discharges from several large point sources and the major fraction of fertilizer facilities located within the Tampa Bay watershed. As a result, Hillsborough Bay contributes a major portion of the total Tampa Bay loading of all parameters. During the period of 1999-2003 Hillsborough Bay supplied 36% of TN, 68% of TP and 38% of TSS loading (Table 7-1). Tierra Ceia Bay, which is the smallest bay segment with the smallest watershed area, only supplies one percent or less of any parameter to Tampa Bay.

Annual loadings from 1999-2003 were generally lower or equal to those observed during the "hold the line period" of 1992-1994 (Figures 7-2 to 7-4). Overall loading of TN, TP and TSS occurred during 2003 when freshwater loading was highest (Figure 7-1 through 7-4). The annual variation for all measured loading parameters (TN, TP,TSS) are affected by freshwater inflow (Figure 7-1). Higher freshwater inflow results in higher loadings specifically in TN as seen through high non point source loading.

Loadings from each source category are shown in Figures 7-6 through 7-9. Highest loading occurred from non point source loading for all parameters followed by atmospheric deposition for TN and domestic point source of TP (Figure 7-7 and Figure 7-9).

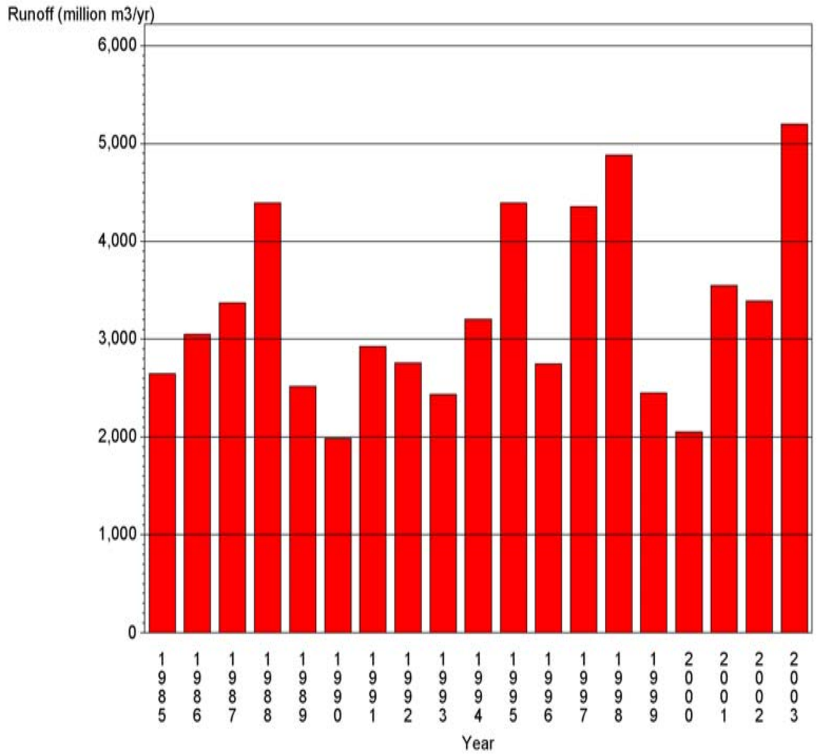

Figure 7-1. Annual freshwater inflow to Tampa Bay, 1985-2003.

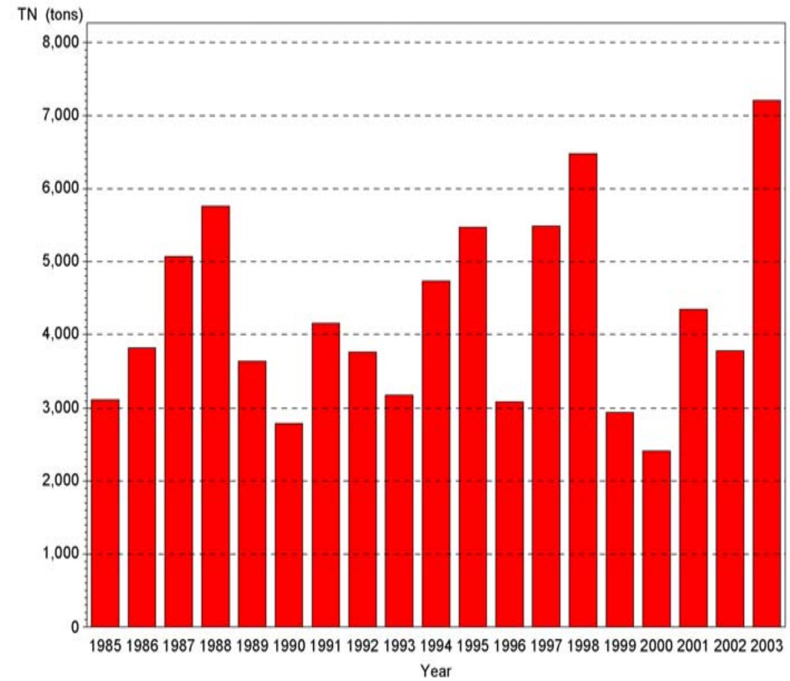

Figure 7-2. Annual TN loading to Tampa Bay, 1985-2003.

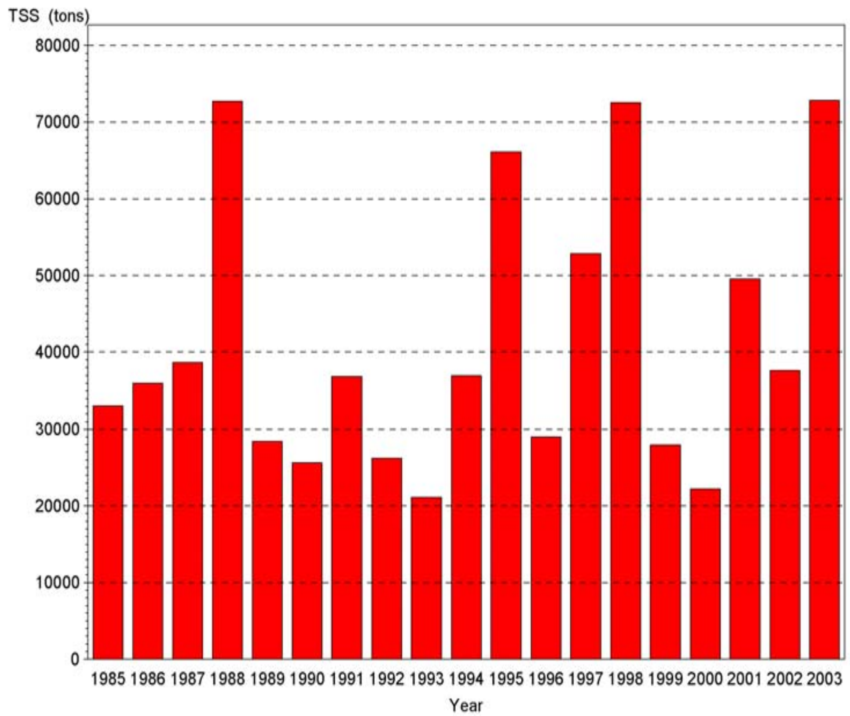

Figure 7-3. Annual TSS loading to Tampa Bay, 1985-2003.

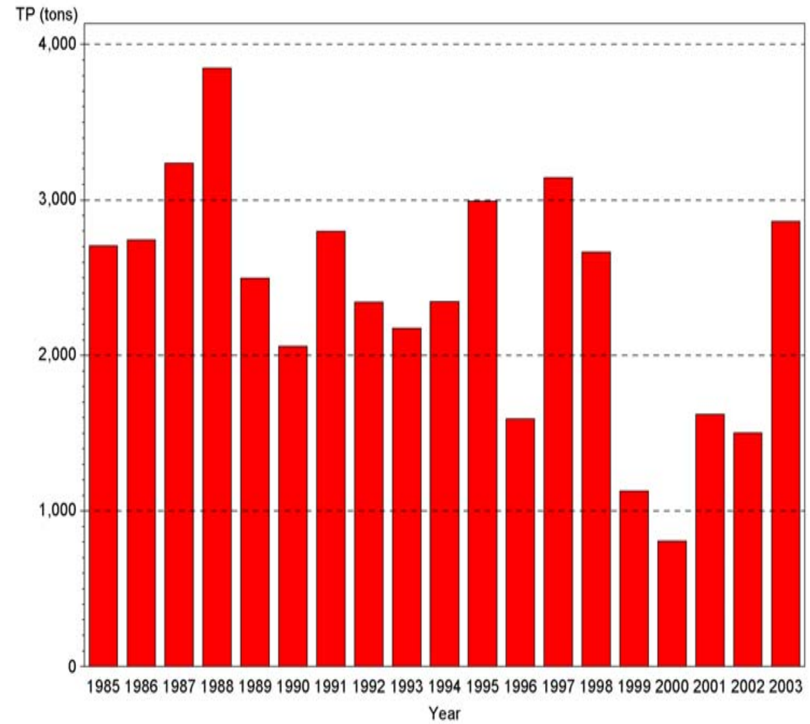

Figure 7-4. Annual TP loading to Tampa Bay, 1985-2003.

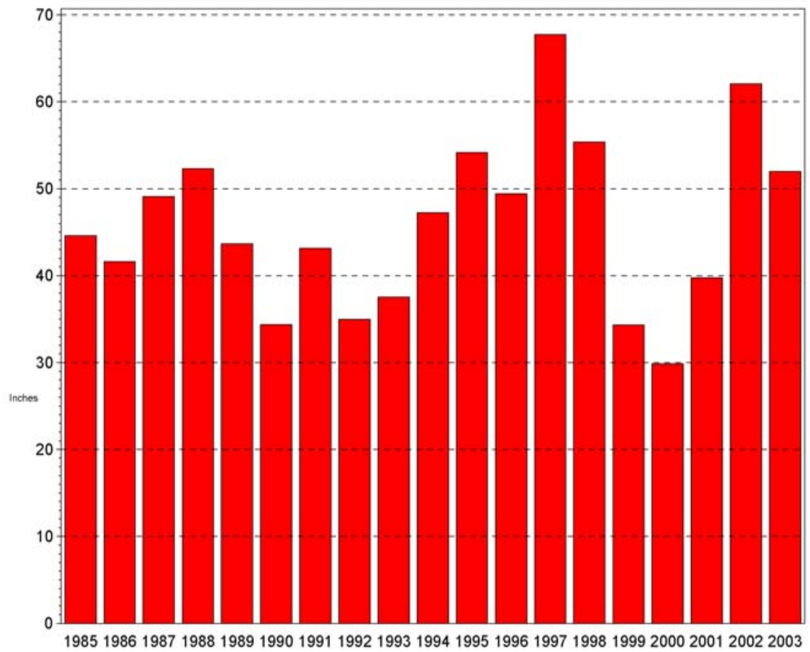

Figure 7-5. Annual Tampa Bay rainfall, 1985-2003.

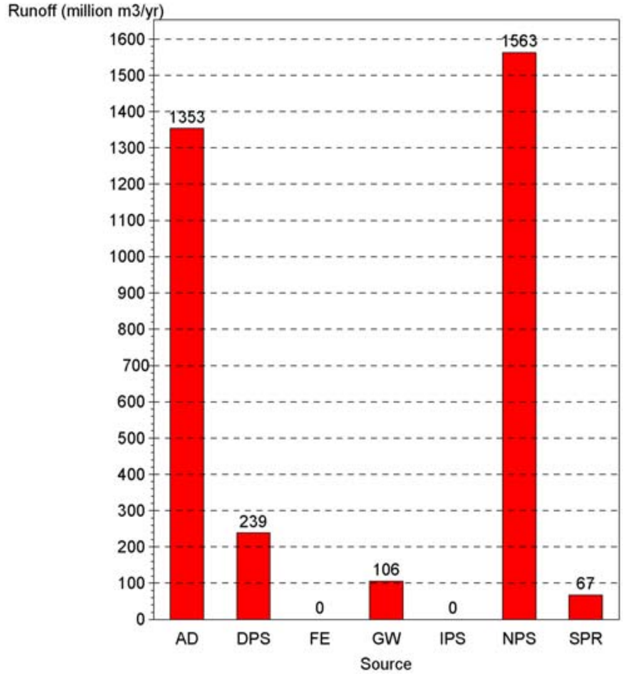

Figure 7-6. Average annual freshwater inflow from the seven major loading source categories for the period 1999-2003 (AD=Atmospheric Deposition; DPS=Domestic Point Sources; FE =Fertilizer Material Loss; GW=Groundwater; IPS=Industrial Point Sources; NPS=Nonpoint Sources; SPR=Springs).

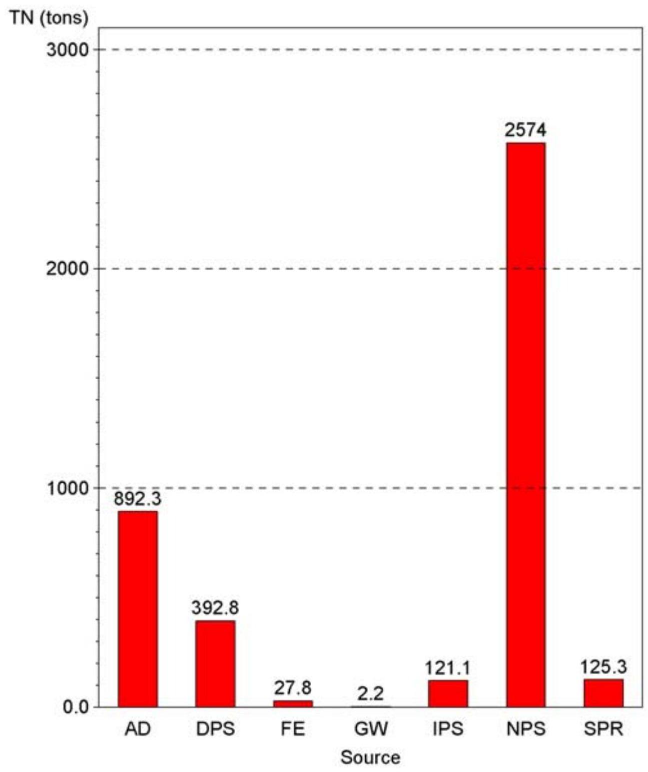

Figure 7-7. Average annual TN loading from the seven major loading source categories for the period 1999-2003 (AD=Atmospheric Deposition; DPS=Domestic Point Sources; FE=Fertilizer Material Loss; GW=Groundwater; IPS=Industrial Point Sources NPS=Nonpoint Sources; SPR=Springs).

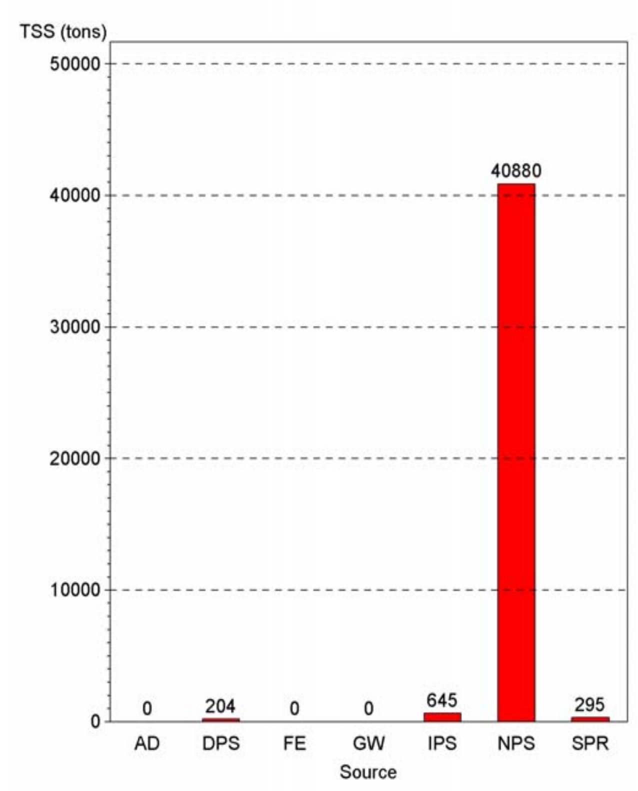

Figure 7-8. Average annual TSS loading from the seven major loading source categories for the period 1999-2003 (AD=Atmospheric Deposition; DPS=Domestic Point Sources; FE=Fertilizer Material Loss; GW=Groundwater; IPS=Industrial Point Sources; NPS=Nonpoint Sources; SPR=Springs).

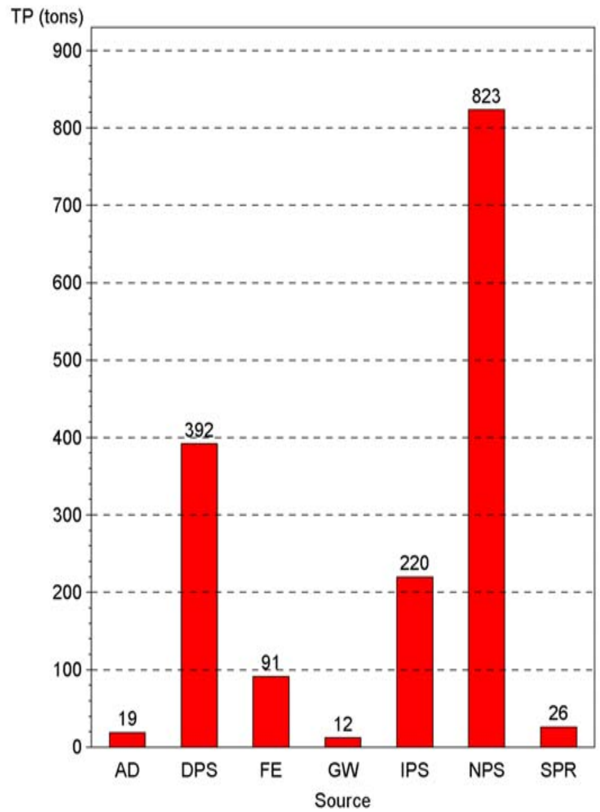

Figure 7-9. Average annual TP loading from the seven major loading source categories for the period 1999-2003. (AD=Atmospheric Deposition; DPS=Domestic Point Sources; FE =Fertilizer Material Loss; GW=Groundwater; IPS=Industrial Point Sources; NPS=Nonpoint Sources; SPR=Springs).

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Estimate of Domestic Wastewater Collection System Spills in Tampa Bay Watershed

Andy Squires (Pinellas County Dept. of Env. Mgmt.) and Keith Hackett (Janicki Environmental, Inc.)

Domestic wastewater collection system total nitrogen spills in the Tampa Bay watershed from September 2002 to October 2003 were estimated from available records filed at Florida Department of Environmental Protection (FDEP) Southwest District and Environmental Protection Commission of Hillsborough County (EPC) offices. This investigation represents a first-cut rough estimate of the potential impact domestic wastewater spills may have relative to total nitrogen loads from other external sources. A conservative approach was used such that worst-case potential loadings were calculated. It is probable that considerable amounts of nitrogen spilled did not reach Tampa Bay waters.

The estimates indicated that the potential annual nitrogen load to Tampa Bay waters from reported wastewater spills is small and likely not a significant concern relative to the total annual nitrogen load delivered to Tampa Bay from other sources that include stormwater runoff and atmospheric deposition. Monthly total nitrogen spill volume relative to "best estimate" mean monthly loads calculated by the Tampa Bay Estuary Program (1999-2003) were low for most bay segments ranging from 0-2% in Hillsborough Bay, 0-4% in Middle Tampa Bay, and 0-8% in Boca Ciega Bay. The range increased to 0-26% in Old Tampa Bay. Most of the spills volumes occurred during December and January likely resulting from extreme rain events. Specific spill events may have had near shore localized water quality impacts; however, no conclusive evidence was found to support this conclusion.

It was found that: 1) most reported spill volumes were very rough approximate estimates, 2) spill volume and spill nutrient data records filed by regulatory agencies required careful scrutiny to interpret the information correctly, 3) an abnormally high volume of spills occurred during the assessed year, 4) a few spills from a small number of wastewater plant collection systems accounted for a very large fraction of total reported spill volumes estimated, and 5) FDEP and EPC have existing corrective mechanisms to address and abate repeat occurrences of large spills.

It was recommendations that: 1) FDEP and EPC use standardized forms to report spills, 2) nitrogen loading from spills be estimated for at least one additional year, 3) checks be made for impacts to bay water quality from reported spills, and 4) spill estimate calculations use same day wastewater treatment plant influent nitrogen concentration data to estimate loads from storm event spills.

Seagrass Monitoring using Aerial Photography

Kris Kaufman (Southwest Florida Water Management District)

-CHAPTER HIGHLIGHTS-

- ☞ *In Tampa Bay, increases in seagrass coverage have been linked to improved water quality. The improvements in water quality have been attributed to reductions in phytoplankton levels that in turn have been linked to reductions in anthropogenic nitrogen loads.*

- ☞ *Results of the seagrass mapping projects are used as a performance evaluator for ongoing water quality improvement efforts.*

- ☞ *It is estimated that seagrass meadows covered 40,400 acres of bay bottom in the 1950s. By 1982, that number had dropped to 21,653 acres. Seagrass acreage increased almost 4 percent per year in the late 1980s; acreage from 1990 to 1996 increased no more than 1.5 percent per year. In 1999, Tampa Bay experienced a bay-wide decrease of almost 3 percent. Since then, seagrass acreage has increased at a rate of 1.8 percent or more per year, rates higher than those observed in the 1990s. The 2004 seagrass coverage represents 67 percent of the 1950 estimates.*

INTRODUCTION

In Tampa Bay, increases in seagrass coverage have been linked to improved water quality. The improvements in water quality have been attributed to reductions in phytoplankton levels that in turn have been linked to reductions in anthropogenic nitrogen loads (i.e., Johansson, 1991; Avery, 1997; Johansson and Ries, 1997; Johansson and Greening, 1999). Seagrass maps created from aerial photography are utilized by the Southwest Florida Water Management District (District) and its cooperators as a measure of the response to water quality improvement in Tampa Bay and other estuaries. Results of the seagrass mapping projects are used as a performance evaluator for ongoing water quality improvement efforts.

Lewis et. al. (1985) estimated Tampa Bay seagrass coverage for the 1800s. Aerial photography from the 1950s (Tampa Bay Regional Planning Council, 1986) and 1982 (Haddad, 1989) was used to map seagrass in Tampa Bay. Subsequently, the District began a formal mapping program, producing seagrass maps on a roughly biennial basis, for the years 1988, 1990, 1992, 1994, 1996, 2002, and 2004. The ongoing objective is to create spatially and thematically accurate GIS map products that describe the distribution of seagrass and provide associated coverage data. The District conducts these efforts by obtaining a consultant to acquire aerial photography. The consultant then completes photointerpretation, groundtruthing, and GIS based mapping as the major components of the project. Agra-Baymont, Inc completed the 1999 and 2002 efforts. The successful respondent for the 2004 and upcoming 2006 effort was Photo Science, Inc.

MATERIALS AND METHODS

Each seagrass mapping effort requires several components to complete the project, which include aerial photography acquisition, photointerpretation, photosignature verification in the field, and GIS based analysis. Acquisition of aerial photography is conducted during the late fall or early winter. This time of year is associated with good water clarity, acceptable atmospheric conditions, and relatively high seagrass biomass. True color photography is taken at a scale of 1:24,000. Specific environmental and atmospheric conditions must be met in order to fly photography; Secchi disk depths must be at least two meters in every estuary flown, wave height must be less than two feet, and wind speed must be less than 10 miles an hour. Additional restrictions include, sun angle (must be greater than 35 percent) and minimal cloud cover. Once photography is obtained, the process of photointerpretation begins. Distinct photographic signatures within the new photography are used to identify and classify the presence of seagrass. Once recognized, seagrass signatures equal to at least the minimum mapping unit of 0.5 acres are categorized into two different coverage classes. Coverage is classified as either continuous (less than 25 percent unvegetated bottom is visible within a polygon) or patchy (greater than 25 percent unvegetated bottom can be visible within a polygon). Throughout the photointerpetation process, photographic signatures are evaluated and verified in the field to successfully differentiate seagrass signatures.

Mapping and GIS technologies are rapidly advancing and thus methodologies for this program have attempted to evolve with the field. The seagrass maps produced from 1988 through 1996 were created by individually delineating polygons onto mylar overlays, cartographically transferring to USGS quadrangle using a Zoom Transfer Scope, and then digitally transferring them to an ARC/Info database. New mapping photogrammetric techniques and digital workstations to capture digital linework and data. classification accuracy. This assessment is conducted independently of the consultant and 90 percent accuracy is required during the exercise. In 2004, 96 percent accuracy was achieved, when 55 of the 57 stations visited were correctly identified as having seagrass present.

RESULTS

It is estimated that seagrass meadows covered 40,400 acres of bay bottom in the 1950s (Tampa Bay Regional Planning Council, 1996). By 1982, that number had dropped to 21,653 acres (Table 8-1). District seagrass data from 1988 through 2004 indicate rates of change in seagrass coverage have varied over the years (Table 8-2, Fig 8-1). While seagrass acreage increased almost four percent per year in the late 1980s, acreage from 1990 to 1996 increased no more than 1.5 percent per year (Fig 8-1). In 1999, Tampa Bay experienced the only bay-wide decrease since the inception of the monitoring program. Since then, seagrass acreage has increased at a rate of 1.8 percent or more per year, rates higher than those observed in the 1990s. In reviewing the most recent data from 2004, the rates of change for the individual bay segments are all positive increases (from 1 to 18 percent), except in Old Tampa Bay. Old Tampa Bay experienced a decrease in acreage of 12 percent from 2002 to 2004. In 2004, four of the seven segments increased in acreage at rates higher than those in 1988. The status of Tampa technology employed during the 1999 and 2002 mapping projects incorporated the use of analytical stereo plotters that produced georeferenced digital files for use in ARC/Info. Seagrass maps for 1999 through 2004 have met 1:12,000 scale accuracy standards. The final Bay total seagrass coverage in 2004 was 27,024 acres. The 2004 total represents 67 percent of the 1950 estimates.

Further analysis seeks to determine if there are trends by year or by bay segment for Tampa Bay seagrass acreages. In order to complete meaningful comparisons of the data on a common scale, two different approaches to normalize the data were utilized. The dataset for these analyses only include acreages from the years the District completed a mapping effort.

First, bay segment acreages were normalized within the segments themselves, using z-scores, to look for trends over time. A mean and standard deviation for each bay segment's acreages from 1988 through 2004 were calculated. The z scores were then calculated by subtracting the segment's mean from the observed acreage and dividing by the segment's standard deviation. The z score is a measure of how much a segment deviates from its distribution's mean. By definition, the distribution of each segment results in a mean of zero and a standard deviation of one. Years with seagrass acreages less than the long-term average will have negative z scores. Once normalized by z score, data for all basins were pooled (Figure 8-2). A one-way ANOVA found a statistically significant difference between years ($F=5.3$, $p=0.0002$). The significantly different z score pairs are identified in Table 8-3 and indicate that Tampa Bay seagrass Further advancements in technology used in 2004 included scanning hardcopy photography to produce orthorectified digital imagery. This imagery was used in coordination with soft copy component of the mapping process is post map production assessment of the map's coverage in 1988 and 2004 were statistically different from the other years. As early as 1994 and 1996, a significant positive change in seagrass had occurred when compared to 1988. It is interesting to note the negative change in seagrass in 1999 was not a significantly different drop compared to prior years. The 2004 data differed significantly from the first two years of the project and shows a significant positive recovery from z scores of 1999.

In order to detect patterns in spatial responses, bay segments were compared. The fraction of bay segment bottom that had seagrass was calculated to normalize the dataset (Fig 8-3, Fig 8-4). The original acreage for a bay segment was divided by the segment's total acreage of bay bottom (as determined by Janicki Environmental, *personal communication with Lindsay Cross*). A one-way ANOVA, with bay segments as a factor, found a statistically significant difference between bay segments ($F=868.47$, $p=0.000$) but the assumption of equal variance was violated by this analysis, rendering the results suggestive but not conclusive. As a confirmation of the parameter's ANOVA results, a non-parametric Kruskal-Wallis test was completed. The test found a statistically significant difference in the medians of the bay segments. Boca Ciega Bay and Terra Ceia Bay differ from the rest of the bay segments because of the high percent cover of seagrass (between 20 and 35 percent) in these segments.

Table 8-1. Acreage totals of seagrass coverage in Tampa Bay

BAY SEGMENTS	YEAR 1950	1982	1988	1990	1992	1994	1996	1999	2002	2004
Hillsborough Bay	2,300	0	7	47	46	147	193	192	480	566
Old Tampa Bay	10,700	5,943	5,006	5,561	5,877	5,911	5,763	4,395	5,272	4,636
Middle Tampa Bay	9,600	4,042	5,205	5,307	5,270	5,775	5,541	5,639	5,723	6,269
Lower Tampa Bay	6,100	5,016	5,515	6,143	6,242	6,205	6,381	5,847	5,611	6,319
Boca Ciega Bay	10,800	5,770	6,258	6,805	6,952	7,116	7,699	7,464	7,673	7,731
Terra Ceia Bay	700	751	947	1,000	1,003	999	973	929	938	1,055
Manatee River	200	131	347	363	363	365	366	375	381	448
BAY TOTAL	**40,400**	**21,653**	**23,285**	**25,226**	**25,753**	**26,518**	**26,916**	**24,841**	**26,078**	**27,024**

Table 8-2. Rates of change in seagrass coverage by segment. Calculated by subtracting the "old observation" from the "new observation" and dividing by the "old observation."

BAY SEGMENTS	Rates of Change 82-88	88-90	90-92	92-94	94-96	96-99	99-02	02-04
Hillsborough Bay		571%	-2%	220%	31%	-1%	150%	18%
Old Tampa Bay	-16%	11%	6%	1%	-3%	-24%	20%	-12%
Middle Tampa Bay	29%	2%	-1%	10%	-4%	2%	1%	10%
Lower Tampa Bay	10%	11%	2%	-1%	3%	-8%	-4%	13%
Boca Ciega Bay	8%	9%	2%	2%	8%	-3%	3%	1%
Terra Ceia Bay	26%	6%	0%	0%	-3%	-5%	1%	12%
Manatee River	165%	5%	0%	1%	0%	2%	2%	18%
BAY TOTAL	**8%**	**8%**	**2%**	**3%**	**2%**	**-8%**	**5%**	**4%**
TOTAL % PER YEAR		**3.8%**	**1.0%**	**1.5%**	**0.7%**	**-2.9%**	**2.4%**	**1.8%**

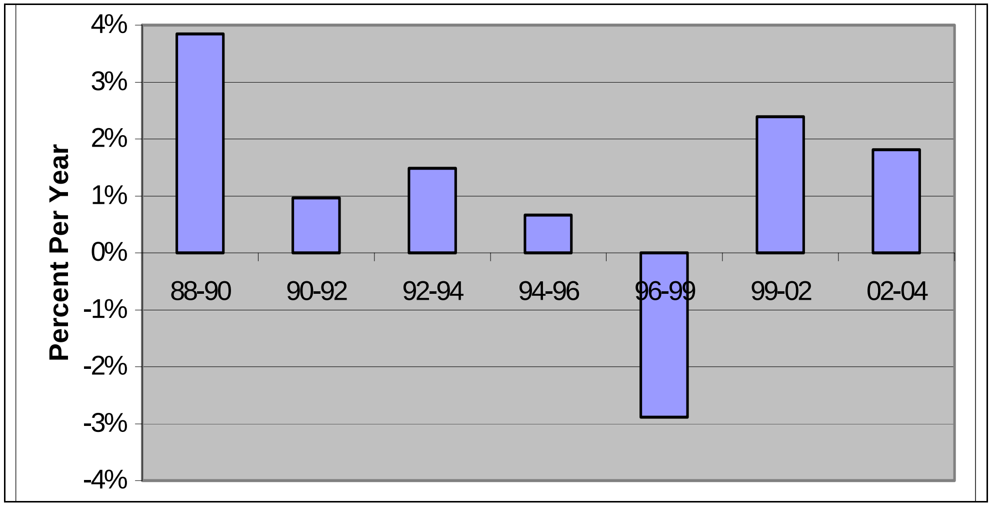

Figure 8-1. Rates of change per year in Tampa Bay seagrass acreage. Values are calculated by dividing the time periods' rates of change by the number of years between acquisitions of photography for each mapping event.

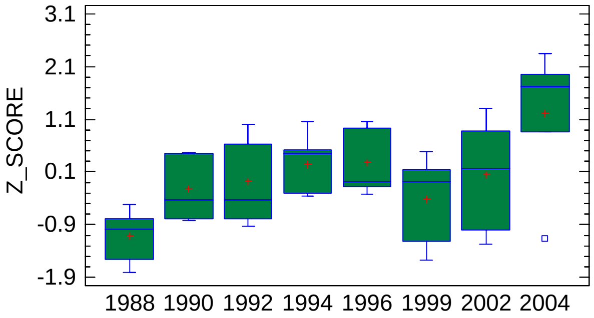

Figure 8-2. Box and Whisker Plot of z score by year.

Table 8-3. Z score pairs identified with "Yes" are significantly different at p≤0.05

		1988	1990	1992	1994	1996	1999	2002	2004
		1	2	3	4	5	6	7	8
1998	1								
1990	2								
1992	3								
1994	4	Yes							
1996	5	Yes							
1999	6								
2002	7								
2004	8	Yes	Yes				Yes		

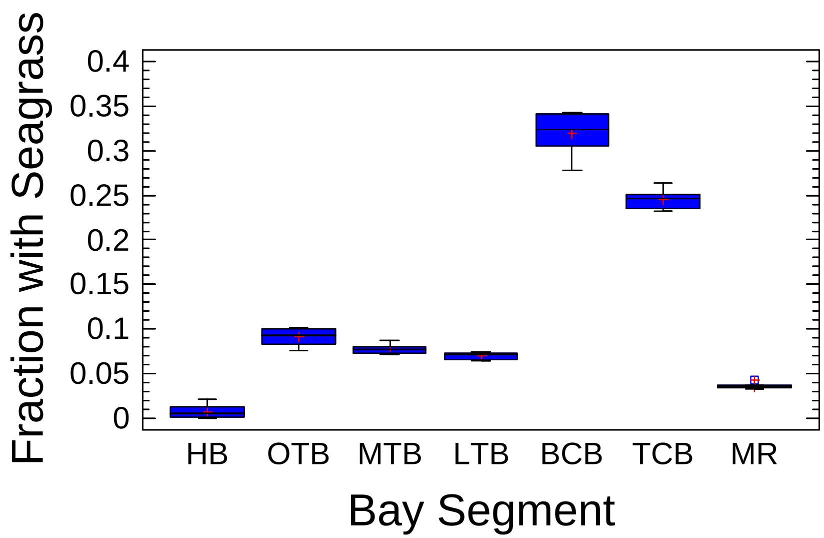

Figure 8-3. Box and Whisker Plot of fraction of bay segment with seagrass.

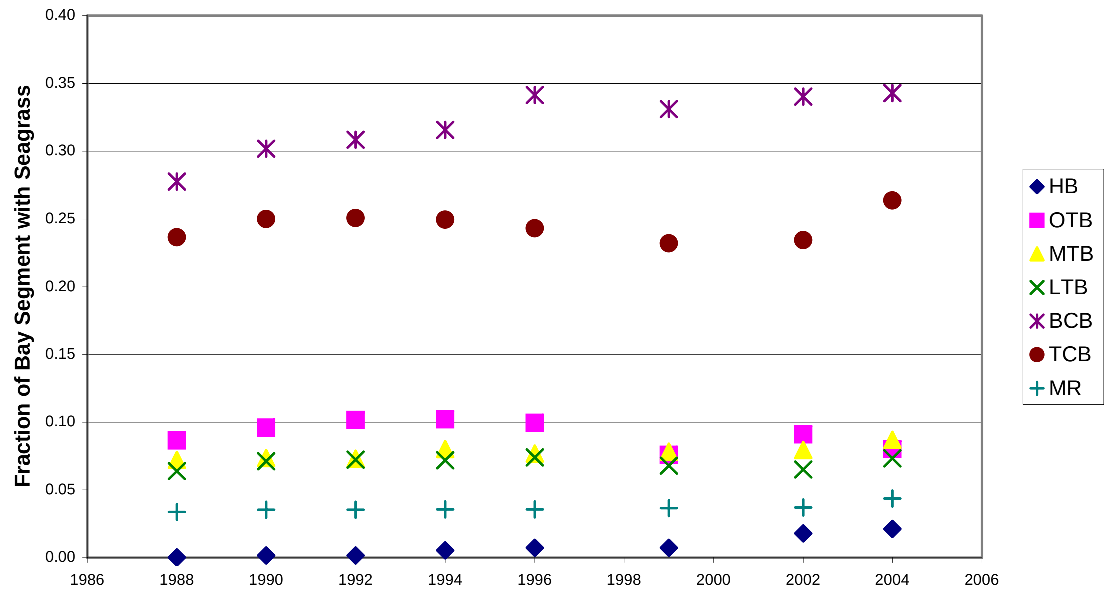

Figure 8-4. Fraction of bay segment bottom with seagrass, by year.

DISCUSSION

Tampa Bay's seagrass coverage has generally increased over time from the 1980s to present. Seagrass has been shown to be positively responding to the improved water clarity that has accompanied massive reductions in anthropogenic nitrogen loads (i.e., Johansson, 1991; Avery, 1997; Johansson and Ries, 1997; Johansson and Greening, 1999). The 1999 mapping effort documented an unexpected eight percent decline in seagrass coverage. As previously discussed in the 1998-2001 Baywide Environmental Monitoring Report, it is likely that the 1997 to 1998 El Niño event caused the declines, with significant increases in nutrient and suspended solids loads that accompanied the event. Following the 1999 decline, the 2002 mapping effort documented seagrass acreages rebounded to 26,078 acres, regaining nearly 97 percent of 1996 values. In 2002, only Lower Tampa Bay experienced decreases. By 2004, Tampa Bay seagrass coverage increased to its highest documented acreage since 1950. While 2004 marks a significant increase over 1999 values, both Old Tampa Bay and Lower Tampa Bay have not regained the acreage they each contained in 1996 (Figure 8-4). Old Tampa Bay was the only bay segment to decrease in coverage, by 12 percent, in 2004. Although most bay segments exhibit patterns of seagrass losses and gains over time, Old Tampa Bay is the only segment that appears to have less seagrass at present than it did in 1988. This may suggest a more serious condition in this part of the bay.

Over the past few years, the rapid rate of increase in seagrass coverage experienced in the late 1980s has moderated. At this time, it remains unknown whether this trend of decreasing recovery rates is indicative of the need for additional water quality improvements, or whether factors other than water quality alone are now limiting further seagrass expansion. The continuation of existing seagrass mapping and monitoring efforts is necessary to allow resource managers to monitor the results of ongoing efforts to improve water quality and seagrass coverage in Tampa Bay.

ACKNOWLEGEMENTS

This paper represents an analysis of results made possible only through the dedicated work of numerous individuals. Special thanks to Mike Heyl for his assistance with the statistical analysis and results portion of this chapter. Consultant services were performed by Gary Florence and Richard Eastlake of Photo Science, Inc. Previous project managers for the District's seagrass mapping efforts are Dave Tomasko, Ray Kurz, and Tom Ries. Analysis of results was greatly aided by discussions with Walt Avery, Holly Greening, Roger Johansson, and Robin Lewis.

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Walt Avery (Bay Study Group, City of Tampa)

-CHAPTER HIGHLIGHTS-

- *A multi-agency consortium, under the auspices of the TBEP, has been monitoring seagrass composition and abundance from 1998 to the present along more than 60 transects in Tampa Bay.*
- *In Old Tampa Bay, Halophila engelmanni, Halodule wrightii, Ruppia maritima, and the alga C. prolifera, have driven the changes seen in SAV areal coverage.*
- *Halodule wrightii has been the major seagrass constituent in Hillsborough Bay, however, coverage has declined since attaining 85ha in 2002. Caulerpa prolifera has also been a major SAV component.*
- *Halodule wrightii areal coverage in Middle Tampa Bay has been variable. In contrast, Syringodium filiforme and Thalassia testudinum meadows have been relatively stable.*
- *Stable seagrass meadows in Lower Tampa Bay have been dominated by Thalassia testudinum.*

INTRODUCTION

The state of Tampa Bay's seagrass meadows have become an important issue in the past three decades as scientists and environmental managers have worked to reverse the detrimental effects of eutrophication upon this important habitat within the estuarine ecosystem. Seagrass coverage in Tampa Bay declined from about 16,000ha in 1950 to near 8800ha in 1982. This decline was a result of anthropogenic impacts such as dredge and fill operations and excessive nutrient discharge to the bay. However, nutrient load reductions began to ameliorate eutrophic conditions during the 1980s and as water clarity improved, seagrass began to recolonize several areas of the bay.

The Tampa Bay National Estuary Program (now named Tampa Bay Estuary Program or TBEP) established restoration goals for Tampa Bay by advocating control of nutrients discharged to Tampa Bay thus controlling conditions that potentially could allow Tampa Bay to digress back into a more eutrophic system. Seagrass was chosen as the "biological barometer" to gauge the effectiveness of the nutrient reduction strategy. It was postulated that improved water clarity resulting from reduced phytoplankton biomass would allow restoration of seagrass coverage. Using the nutrient reduction paradigm, the TBEP set a restoration goal of similar seagrass acreage to that found in 1950.

In 1997, the TBEP coordinated the creation of a bay-wide fixed transect seagrass monitoring program. The primary goal of the program is to document temporal and spatial changes in seagrass species composition, abundance, and distribution along a depth gradient. Several bay area agencies committed personnel and equipment to the program. Data collection began along sixty transects in 1998.

We now have eight years of data from ca 60 transects located throughout Tampa Bay (Figure 9-1). This paper will present a discussion of major changes detected with the annual seagrass monitoring program. Annual summary reports reviewing Tampa Bay seagrass trends through 2005 are available through the TBEP.

SEAGRASS TRENDS

Old Tampa Bay

Within the twelve transects monitored in Old Tampa Bay (Figure 9-2), five species of seagrass have been found (Table 9-1): *Halophila engelmanni* (star grass), *Halodule wrightii* (shoal grass), *Ruppia maritima* (widgeon grass), *Syringodium filiforme* (manatee grass), and *Thalassia testudinum* (turtle grass). In addition, the attached alga, *Caulerpa prolifera* has been a prominent constituent of the submerged aquatic vegetation (SAV), especially in western Old Tampa Bay.

Generally, *H. wrightii* has been the dominant species with regards to areal coverage. However, *H. wrightii* coverage has been seen to vary temporally, particularly in the Feather Sound area in northwest Old Tampa Bay (Figure 9-2). Recently, this area has been the site of an intensive study to investigate potential factors that may affect seagrass recolonization (TBEP 2004).

In other areas of Old Tampa Bay, areal coverage fluctuations have been seen with *R. maritima*, *H. engelmanni*, and *C. prolifera*. Further, these species, along with *H. wrightii*, often co-exist with or succeed each other. These four species have driven the major coverage changes documented in

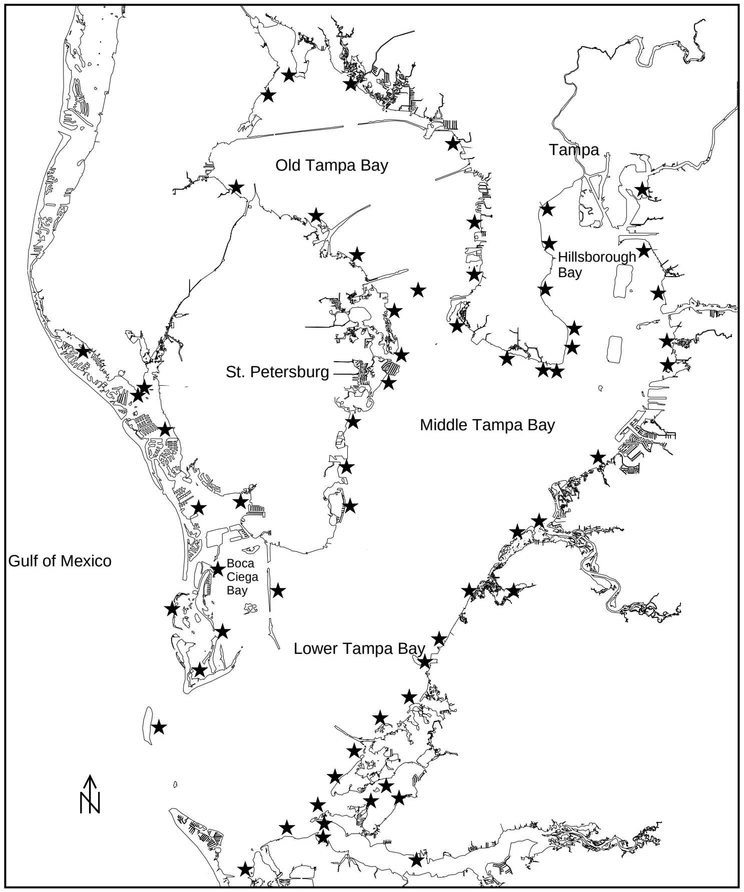

Figure 9-1. Location of the fixed seagrass transects (star) in Tampa Bay.

Old Tampa Bay seagrass.

S. filiforme and *T. testudinum* are found throughout Old Tampa Bay. Coverage of these two species is generally sparse in the northern portions of the bay; however, large meadows become more prevalent down bay. In contrast to the variable coverage seen with *H. engelmanni*, *H. wrightii*, and *R. maritima*, coverage of *S. filiforme* and *T. testudinum* appear to be fairly stable though changes in density have been noted.

Lewis et al. (1985) described a fringe perennial seagrass meadow associated with a long shore bar. This feature is found in several Old Tampa Bay locations with inshore seagrass consisting of inshore *H. wrightii*/*R. maritima* coverage transitioning to a stable *S. filiforme/T. testudinum* community. In northeastern Old Tampa Bay, recent loss of *H. wrightii* on the seaward edge of the seagrass coverage may have allowed erosion of the long shore bar. It is postulated that the degradation of long shore bars eventually may lead to loss of inshore seagrass coverage (Lewis 2002).

Hillsborough Bay

Eleven Hillsborough Bay transects have been monitored for SAV since 1997 (Figure 9-3). Two species of seagrass, *H. wrightii* and *R. maritima*, have been documented in Hillsborough Bay. In addition, *C. prolifera* has been a major constituent, often dominating Hillsborough Bay SAV coverage (City of Tampa, 2004).

H. wrightii is the dominant seagrass in Hillsborough Bay (Table 9-2), however, coverage has been extremely variable. Large *H. wrightii* meadows developed and then disappeared along southwestern Interbay Peninsula between 2000-2003. Areal coverage reached a maximum of ca 85ha during 2002 (City of Tampa, 2004), and has since declined to ca 45ha in 2005.

The loss of *H. wrightii* along Interbay Peninsula in 2003 was succeeded by *C. prolifera* colonization in most areas. In 2005, ca 60ha of *C. prolifera* had colonized the flats around Gadsden Point (Figure 9-3).

R. maritima coverage has generally been a minor

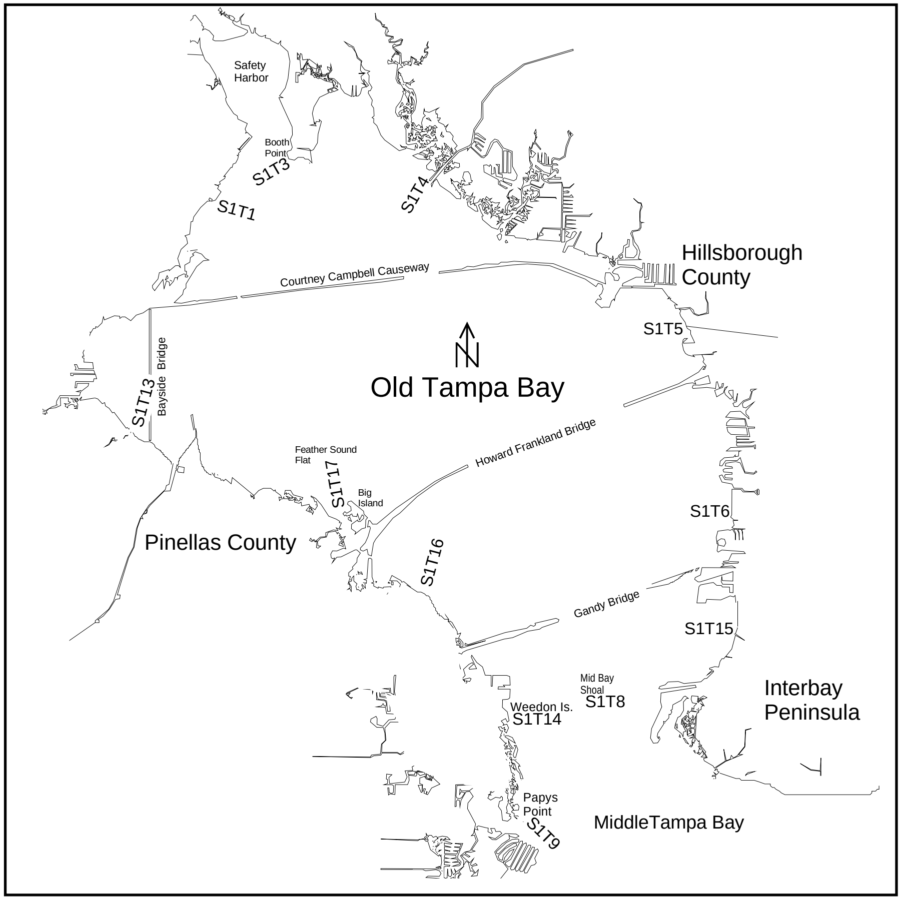

Figure 9-2. Location of seagrass transects in Old Tampa Bay.

Table 9-1. Seagrass species percent composition along the Old Tampa Bay transects during 2005.

Transect #	L	N	% Bare	% He	% Hw	% Rm	% Sf	% Tt
S1T1	450	54	2	9	85	0	6	0
S1T3	400	96	6	52	48	0	0	0
S1T4	860	73	44	1	43	0	0	1
S1T5	460	24	8	0	54	33	4	29
S1T6	400	84	8	0	58	0	18	58
S1T8	180	32	9	0	13	0	44	9
S1T9	700	57	12	0	58	0	32	12
S1T13	1100	86	24	0	74	2	0	0
S1T14	660	60	15	0	38	0	35	23
S1T15	630	113	4	0	63	0	26	39
S1T16	1000	67	21	0	22	33	16	12
S1T17	2700	100	64	0	27	0	5	0

L=transect length (m); N=total number of meter square placements; He=*Halophila engelmanni*; Hw=*Halodule wrightii*; Rm=*Ruppia maritima*; Sf=*Syringodium filiforme*; Tt=*Thalassia testudinum.*

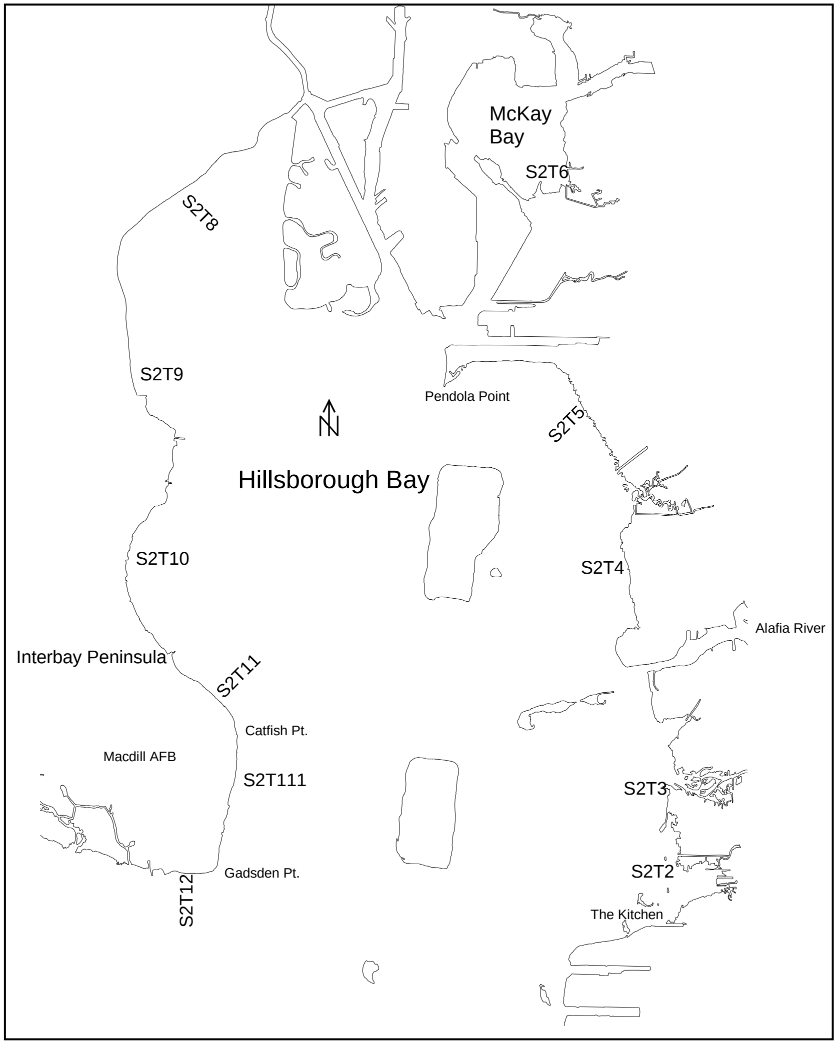

Figure 9-3. Location of seagrass transects in Hillsborough Bay.

Table 9-2. Seagrass species percent composition along the Hillsborough Bay transects during 2005.

Transect #	L	N	% Bare	% He	% Hw	% Rm	% Sf	% Tt
S2T2	1375	68	47	0	47	12	0	0
S2T3	900	54	69	0	31	0	0	0
S2T4	400	17	100	0	0	0	0	0
S2T5	700	23	61	0	35	4	0	0
S2T6	400	17	76	0	0	24	0	0
S2T8	200	9	100	0	0	0	0	0
S2T9	400	25	76	0	24	0	0	0
S2T10	350	25	88	0	12	0	0	0
S2T111	500	29	90	0	10	0	0	0
S2T112	550	23	100	0	0	0	0	0
S2T12	800	41	5	0	20	0	0	0

L=transect length (m); N=total number of meter square placements. He=*Halophila engelmanni*; Hw=*Halodule wrightii*; Rm=*Ruppia maritima*; Sf=*Syringodium filiforme*; Tt=*Thalassia testudinum.*

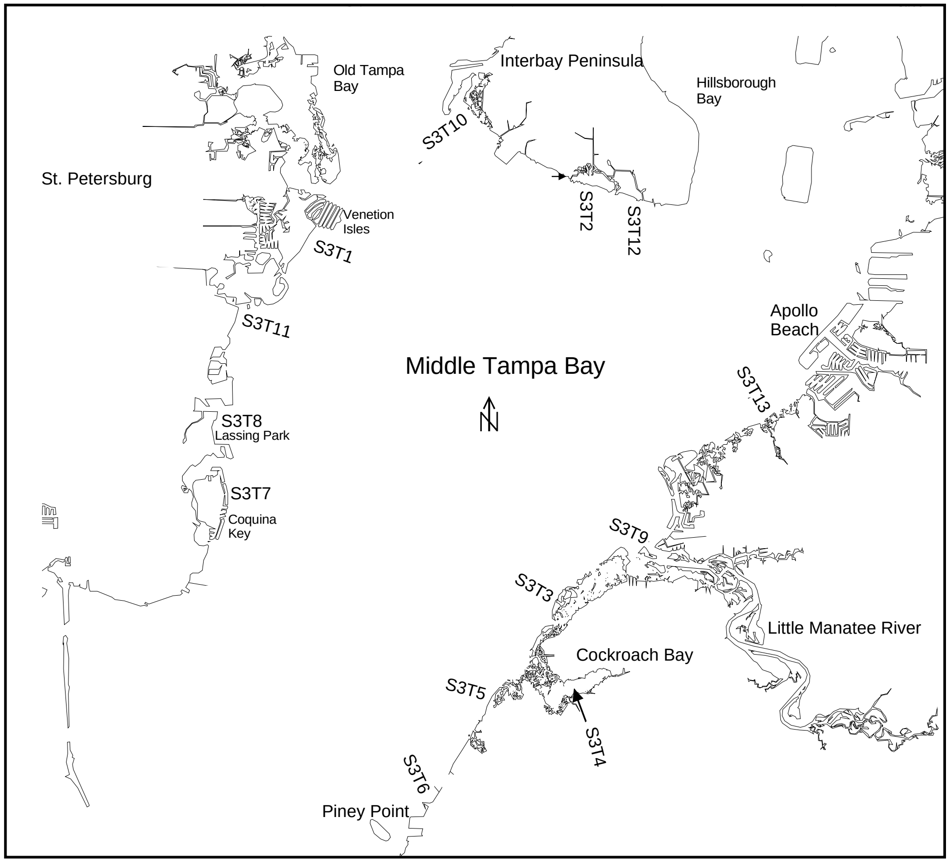

Figure 9-4. Location of seagrass transects in Middle Tampa Bay.

Table 9-3. Seagrass species percent composition along the Middle Tampa Bay transects during 2005.

Transect #	L	N	% Bare	% He	% Hw	% Rm	% Sf	% Tt
S3T1	700	52	63	0	15	0	19	2
S3T2	860	44	36	0	57	2	0	5
S3T3	350	23	57	0	30	0	9	26
S3T4	250	20	30	0	65	0	0	20
S3T5	675	39	33	0	28	0	24	31
S3T6	310	27	63	0	26	0	19	0
S3T7	300	31	52	0	6	0	35	19
S3T8	450	37	59	0	16	0	5	8
S3T9	445	32	91	0	9	0	0	0
S3T10	1000	40	28	0	50	0	0	18
S3T11	1000	54	22	0	19	0	54	19
S3T12	1000	49	4	0	80	2	0	0
S3T13	1200	53	41	0	25	4	0	6

L=transect length (m); N=total number of meter square placements; He=*Halophila engelmanni*; Hw=*Halodule wrightii*; Rm=*Ruppia maritima*; Sf=*Syringodium filiforme*; Tt=*Thalassia testudinum*.

wrightii in the northern part of Middle Tampa Bay. *S. filiforme* and *T. testudinum* becomes a more important component of the seagrass meadows down bay. Data indicate that *H. wrightii* coverage has been somewhat variable, but not to the extreme seen in Hillsborough Bay. However, at the mouth of the Little Manatee River, most of the *H. wrightii* coverage was lost between 2002-2003. Similar to the trends seen in Old Tampa Bay, the *S. filiforme* and *T. testudinum* meadows have been fairly stable.

C. prolifera has been documented on seven Middle Tampa Bay transects. The algae has recently colonized many of these transects and coverage has generally been sparse. However, a large, dense meadow has persisted at Lassing Park since 2001.

Longshore bars are prominent features in two areas of western Middle Tampa Bay. Coquina Key (Figure 9-4) is one area with the fringe perennial *H. wrightii*/*S. filiforme*/*T. testudinum* meadow affiliated with a pronounced offshore bar feature. Also, there is a longshore bar in the Venetian Isles area of Middle Tampa Bay (Figure 4), which is associated with predominately *S. filiforme* coverage on the seaward face. On the south end of this feature (transect S3T11, Figure 4), a *H. wrightii*/*S. filiforme*/*T. testudinum* meadow is located shoreward of the bar. However, in contrast to seagrass coverage proximate to other Tampa Bay long shore bars, coverage shoreward of the north end of the bar (transect S3T1, Figure 4) is meager with no distinct zonation.

Lower Tampa Bay

Fifteen transects have been established in Lower Tampa Bay including Terra Ceia Bay and the lower Manatee River (Figure 5). *H. engelmanni*, *H. wrightii*, *R. maritima*, *S. filiforme*, and *T. testudinum* have been found in Lower Tampa Bay (Table 9-4).

Seagrass species composition in Lower Tampa Bay has been dominated by *T. testudinum*. *S. filiforme* is common in the proximity of Terra Ceia Bay and Egmont Key and patchy coverage has been documented near the mouth of the Manatee River. *H. wrightii* has been present on all transects.

Generally, seagrass coverage has been stable along most transects during the course of the project. However, one area of potential concern may be the loss of offshore *T. testudinum* just south of Bishops Harbor after 2000. The most variable coverage has been noted at the up river site in the Manatee River where the coverage has consisted of *H. engelmanni*, *H. wrightii*, and *R. maritima*.

Boca Ciega Bay

Eleven transects have been monitored in Boca Ciega Bay since 1998 (Figure 9-6). *H. wrightii*, *S. filiforme*, and *T. testudinum* have been found in Boca Ciega Bay (Table 9-5). *H. wrightii* is the dominant species in the northern part of the bay and the species composition transitions to predominately *T. testudinum* further south.

Generally, seagrass coverage in this bay segment is stable, however, there are instances of coverage change. For example, *S. filiforme* is now the prevalent species at a site near the Skyway Bridge that was predominately *T. testudinum* in 1999. Also, *H. wrightii* coverage expanded into a deeper portion of a flat in northern Boca Ciega Bay.

SUMMARY

Examination of seagrass transect data has shown that among the five seagrass species found in Tampa Bay, *H. wrightii* has been the most variable in terms of areal coverage. In areas such as Hillsborough Bay where *H. wrightii* dominates species composition, this variability results in large annual changes in seagrass areal coverage estimates. In addition, *H. engelmanni* and *R. maritima* have been shown to be ephemeral species that contribute to coverage variability.

Generally, there has been little change noted in *S. filiforme* and *T. testudinum* coverage in Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay. *T. testudinum* has been a major seagrass component in the lower portion of Tampa Bay.

C. prolifera has continued to be a major SAV contributor in Hillsborough Bay, Middle Tampa Bay, and Old Tampa Bay. In Hillsborough Bay, this alga was the major SAV component during 2005.

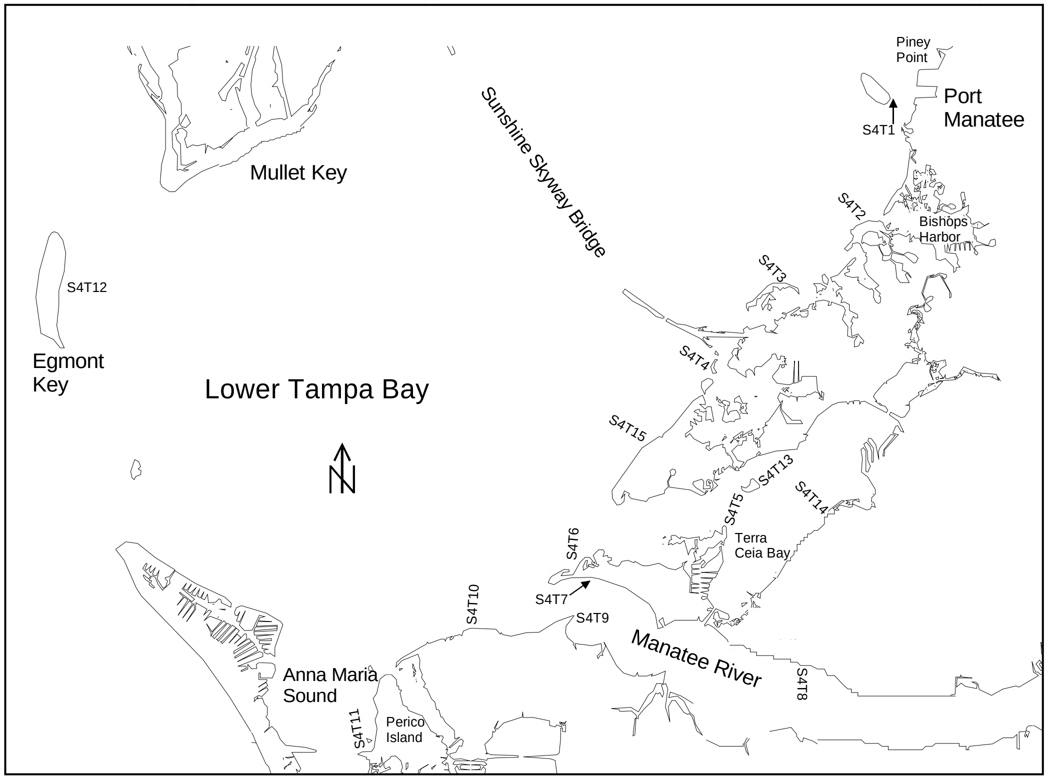

Figure 9-5. Location of seagrass transects in Lower Tampa Bay.

Table 9-4. Seagrass species percent composition along the Lower Tampa Bay transects during 2005.

Transect #	L	N	% Bare	% He	% Hw	% Rm	% Sf	% Tt
S4T1	333	36	61	0	11	0	0	36
S4T2	450	42	67	0	10	0	0	24
S4T3	200	14	36	0	29	0	7	50
S4T4	520	30	77	0	3	0	0	23
S4T5	500	23	22	0	52	0	26	78
S4T6	390	16	31	0	19	0	31	63
S4T7	89	9	33	0	22	0	33	67
S4T8	180	19	89	0	11	0	0	0
S4T9	60	8	38	0	50	0	0	50
S4T10	300	31	23	0	32	0	6	55
S4T11	200	21	14	0	48	0	10	67
S4T12	247	24	25	0	42	0	29	21
S4T13	75	9	33	0	22	0	44	33
S4T14	150	16	31	0	38	0	25	31
S4T15	134	15	40	0	27	0	0	33
L=transect length (m); N=total number of meter square placements; He=*Halophila engelmanni*; Hw=*Halodule wrightii*; Rm=*Ruppia maritima*; Sf=*Syringodium filiforme*; Tt = *Thalassia testudinum*.								

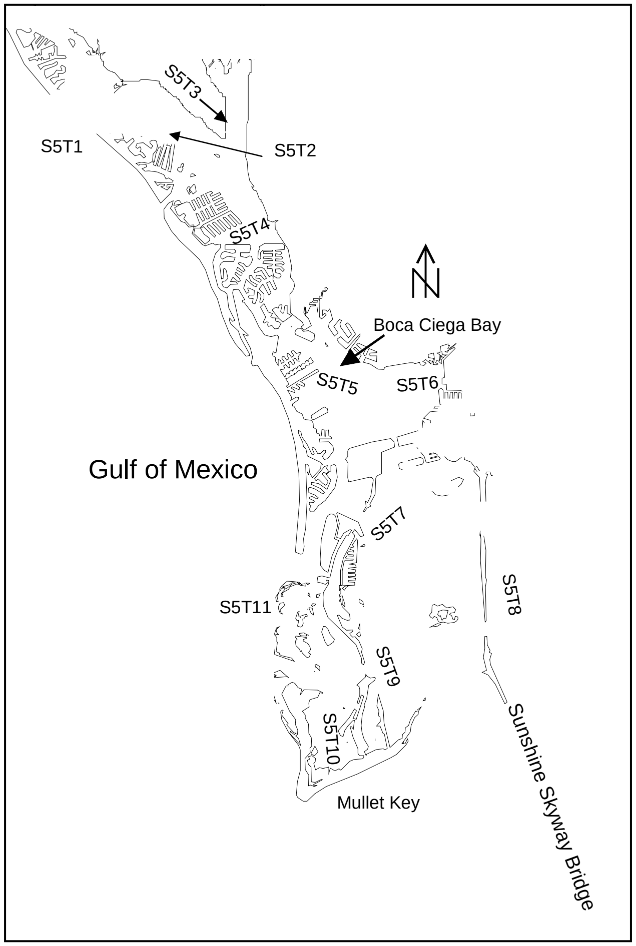

Figure 9-6. Location of seagrass transects in Boca Ciega Bay.

Table 9-5. Seagrass species percent composition along the Boca Ciega Bay transects during 2005.

Transect #	L	N	% Bare	% He	% Hw	% Rm	% Sf	% Tt
S5T1	220	24	12	0	88	0	0	0
S5T2	245	15	0	0	100	0	0	20
S5T3	42	5	0	0	100	0	0	0
S5T4	135	6	17	0	83	0	0	0
S5T5	55	8	0	0	100	0	0	0
S5T6	243	13	8	0	92	0	0	23
S5T7	200	18	6	0	39	0	0	94
S5T8	126	14	7	0	7	0	79	50
S5T9	500	21	5	0	29	0	0	95
S5T10	179	10	0	0	100	0	0	80
S5T11	125	10	10	0	90	0	0	0

L=transect length (m); N=total number of meter square placements; He=*Halophila engelmanni*; Hw=*Halodule wrightii*; Rm=*Ruppia maritima*; Sf=*Syringodium filiforme*; Tt=*Thalassia testudinum*.

ACKNOWLEDGEMENTS

This project has been made possible through the auspices of the Tampa Bay Estuary Program. Special thanks are extended to Holly Greening who has facilitated the coordination and implementation of the seagrass monitoring program. Also, Tom Reis (Scheda Ecological Associates, Inc.), Dave Tomasko and Ray Kurz (Post, Buckley, Shue, and Jernigan), provided guidance in the initial design of the monitoring protocols. Personnel from Florida Fish & Wildlife Conservation Commission - Florida Widlife Research Institute, Hillsborough County Cockroach Bay Aquatic Preserve, Hillsborough County Environmental Protection Commission, Manatee County Environmental Management Department, Pinellas County Department of Environmental Management, Tampa BayWatch, Inc., and City of Tampa Bay Study Group, conducted field collections. The generous contributions from these agencies and the hard work by their personnel have ensured the success of this project. Finally, Robin Lewis (Lewis Environmental Services, Inc.) is acknowledged for early on advocating the need to establish permanent seagrass transects in Tampa Bay and for his continued support of this program.

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- CHAPTER HIGHLIGHTS -

- *The Artificial Reef Program has increased the availability of hard-bottom habitat by placing over 46,000 metric tons of concrete substrate in a series of artificial reefs throughout Tampa Bay, covering an approximate area of 0.51 km^2.*
- *The community structure and seasonality of epibenthic organisms for the artificial reefs in Tampa Bay has never been studied.*
- *A total of 124,180 organisms, representing over 441 taxa, and 14 phyla were identified from the 60 sites.*
- *The overall average density of epibenthic organisms on the artificial reefs during the study period was 54,049/m^2.*

INTRODUCTION

The goal of the Environmental Protection Commission of Hillsborough County's (EPC) Artificial Reef Program is to increase biological diversity and productivity in Tampa Bay by providing hard-bottom substrates and communities which might not otherwise be available. The program has increased hard-bottom habitat by placing over 46,000 metric tons of concrete substrate in a series of artificial reefs throughout Tampa Bay, covering an approximate area of 0.51 km^2. Determining the success of the program is, in part, dependent on the benthic species diversity and benthic biomass found on the artificial reefs.
The community structure and seasonality of epibenthic organisms on the artificial reefs in Tampa Bay have never been studied. One other study was done on the hard bottom communities in Tampa Bay, but was on natural hard or rocky substrates (Derrenbacker & Lewis, 1982). A similar study was also conducted in Delaware Bay (Foster et al., 1994) which served as a model for this study. The objective was to compile a comprehensive list of epibenthic organisms that make up the fouling community on the artificial reefs in Tampa Bay and to evaluate their community structure. In 2003, EPC's Artificial Reef Program received a grant from the Florida Fish and Wildlife Conservation Commission (FWCC) to study the epifauna on its artificial reefs in Tampa Bay. The EPC's Benthic Monitoring Lab was enlisted to help conduct the study and process the samples collected.

METHODS

Study sites: Three artificial reefs were chosen for the study: One artificial reef was selected from Old Tampa Bay, Middle Tampa Bay and Lower Tampa Bay. The Howard Frankland Reef (Old Tampa Bay) center is at 27° 54.70' N and 82° 33.25' W and its dimensions are 182.8 m by 365.8 m for a total area of 0.067 km^2. The Bahia Beach Reef (Middle Tampa Bay) center is at 27° 44.89' N and 82° 30.92'W and its dimensions are 182.8 m by 365.8 m for a total area of 0.067 km^2. The Egmont Key Reef (Lower Tampa Bay) center is at 27° 35.00' N and 82° 44.60' W and its dimensions are 365.8 m by 365.8 m for a total area of 0.134 km^2. The chosen reef sites provide an opportunity to compare and contrast reef communities from each of the three major bay segments and verify anecdotal evidence that suggested differences in community makeup among similarly constructed reefs within the same estuarine system. Ten samples were collected by SCUBA divers from each reef from March-April 2004 (dry season) and again in August 2004 (wet season) for a total of 60 samples (Figure 10-1).

Sample sites: Ten sampling locations were selected at each reef from random coordinates. The boat was anchored at each sample location and the coordinates, time, date, and conditions were recorded. Sample sites on the reef were also randomly selected for one of three different reef levels: top of reef, middle of reef, and bottom of reef. Also the sample sites were randomized for one of three surface orientations: reef face in the horizontal position towards the surface (horizontal), with reef face in horizontal position towards the bottom (inverted), or reef face in the vertical position (vertical).

RESULTS

Nearly 450 species were identified, including: 11 sponges; 119 polychaetes; 100 molluscs (58 gastropods, 42 bivalves); 8 barnacles; 63 amphipods; 42 decapods; 15 bryozoans; and 14 ascidians. As shown in Table 10-1 and Figure

10-2 below, each reef had a unique assemblage of species and relative percent biomass, which also varied by season. Figure 10-2, a multidimensional scaling plot (MDS), also demonstrates the differences between each reef (lack of similarity) and the seasonal differences within a single reef.

Of particular interest was the distribution of the Asian Green Mussel (*Perna viridis*) on the reefs. The Asian Green Mussel is an invasive species that was first recorded in Hillsborough Bay in 1999. Since then, it has spread throughout Tampa Bay and its range has extended around the entire state of Florida. The mussels were nearly absent on the Egmont Key Reef, being represented by only a few small juveniles during both seasons. On the Howard Frankland and Bahia Beach Reefs, however, green mussels were very common. The Howard Frankland Reef had fewer mussels overall, but the individuals were large adults, 3-4 inches in length, and they dominated the biomass of that reef. The Bahia Beach Reef had more individual mussels, however, they were mainly small juveniles and accounted for less biomass. On both reefs, the mussel population was higher in the fall than in the spring.

Species Composition

A total of 124,180 organisms, representing 441 taxa, and 14 phyla were identified from the 60 samples. Arthropods represented 31% of the total number of taxa followed by annelids (27%), and molluscs (23%). The arthropods were the most numerous individual organisms

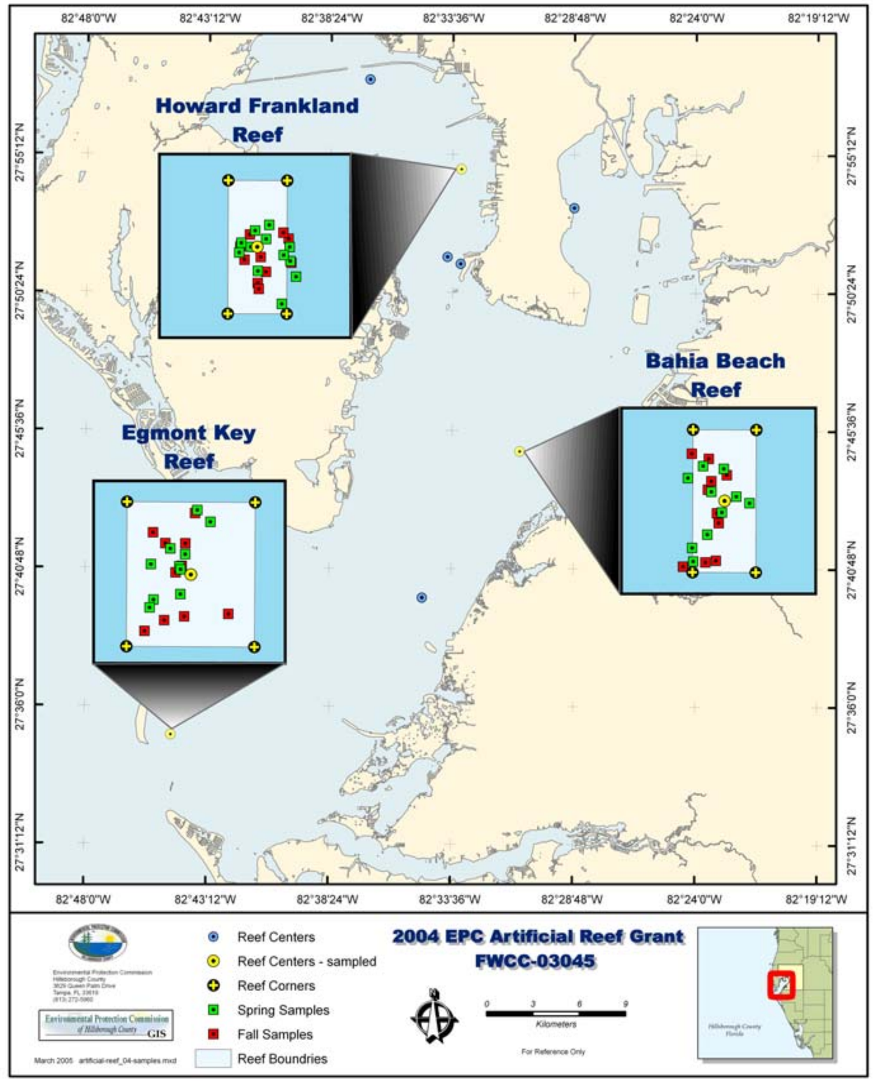

Figure 10-1. Artificial reef sample sites.

representing 43% of the total assemblage, followed by molluscs (17.5%), annelids (15.5%), and cnidarians (7.6%).

There were 46 taxa that were common to all reefs and seasons. The greatest number of taxa found at a single reef and season was 240 (Egmont Key Reef / Spring) and the least was 142 (Howard Frankland Reef / Fall). A total of 170 taxa had a single occurrence throughout all reefs and seasons.

The average density of organisms ranged from a low of 30,119/m^2 (Howard Frankland Reef / Fall) to a high of 108,316/m^2 (Bahia Beach Reef /Spring). The seasonal average for all three reefs ranged from 37,527/m^2 in the fall to 70,570/m^2 in the spring, a 47% increase. The overall average density of epibenthic organisms on the artificial reefs during the study period was 54,049/m^2.

Statistically, there was no apparent difference in community structure based on the orientation of the settling surface (horizontal, inverted, or vertical) or based on substrate depth (top, middle, or bottom). The hypothesis behind this particular aspect of the study design was to determine if, in fact, certain organisms preferred one settling surface orientation over another or if ambient light vs. shaded surfaces were factors in an organism's relative location on the substrate. It is likely that this study did not incorporate enough samples of each orientation or location to provide an adequate amount of statistical power to determine differences/preferences in settling surfaces.

Table 10-1. Average relative percent biomass by reef and season for each phylum.

Phylum	Howard Frankland Reef		Bahia Beach Reef		Egmont Key Reef	
	Spring	Fall	Spring	Fall	Spring	Fall
Arthropoda	1.27%	9.24%	24.26%	37.77%	45.99%	42.25%
Annelida	0.31%	0.39%	1.44%	1.98%	3.50%	4.59%
Mollusca	90.98%	75.33%	47.05%	26.54%	20.28%	17.27%
Bryozoa	2.60%	0.14%	0.81%	0.18%	0.33%	0.01%
Cnidaria	2.44%	1.22%	2.72%	6.88%	4.20%	4.93%
Platyhelminthes	0.003%	0.01%	0.01%	0.01%	0.04%	0.01%
Nemertea	0.008%	0.00%	0.01%	0.01%	0.05%	0.01%
Porifera	1.87%	12.82%	16.46%	15.86%	7.44%	8.95%
Chordata	0.52%	0.82%	7.18%	10.43%	17.99%	21.82%
Chaetognatha	0.001%	0.00%	0.01%	0.001%	0.01%	0.00%
Echinodermata	0.00%	0.04%	0.04%	0.16%	0.12%	0.09%
Sipuncula	0.00%	0.00%	0.003%	0.17%	0.04%	0.05%
Echiura	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%
Brachipoda	0.00%	0.00%	0.00%	0.00%	<0.001%	0.00%

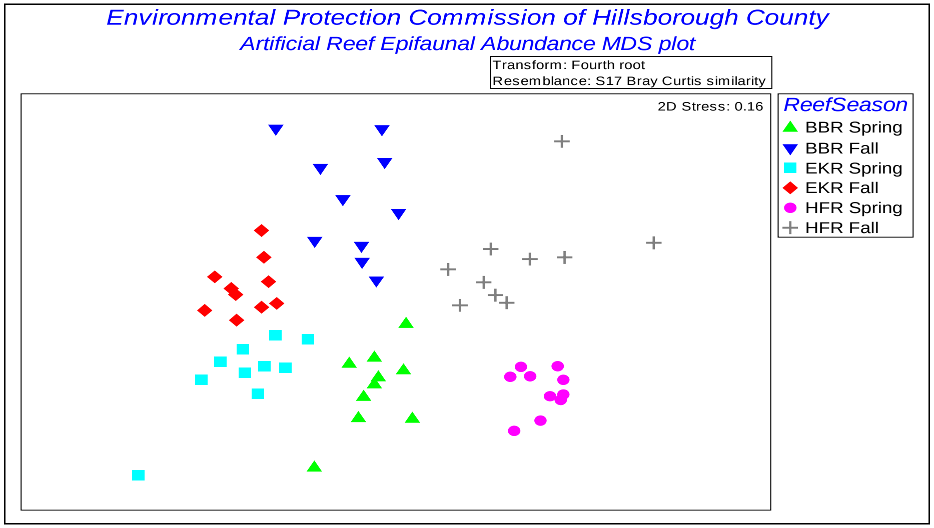

Figure 10-2. Artificial reef epifaunal abundance MDS plot.

Hydrographic Results

The bottom water quality measures, including temperature, salinity, dissolved oxygen (DO), pH, Secchi depth, and the photosynthetically active radiation (PAR) as well as sample depth and station depth for the sites were measured and are available upon request. Due to space constraints, a summary of these data are presented here. The station depth ranged from 4.3 m to 7.1 m with the sample depth ranging from 3.3 m to 6.5 m. The Howard Frankland Reef sites were shallower than the Bahia Beach Reef and Egmont Key Reef sites and Bahia Beach had the deepest sites.

The temperature for the spring ranged from 20.2 °C to 22.3 °C while the fall temperatures ranged from 29.8 °C to 31.3 °C. The Bahia Beach Reef sites had the highest temperatures during the spring while Egmont Key had the lowest. The Egmont Key Reef sites had the highest temperatures during the fall while the Bahia Beach Reef sites had the lowest.

The salinity for the spring ranged from 23.6 ‰ to 33.1‰ while the fall salinity ranged from 20.3‰ to 32.5‰. The highest salinities were at the Egmont Key Reef sites for both the spring and fall while the Howard Frankland sites had the lowest salinities during both seasons.

The dissolved oxygen (DO) for the spring ranged from 6.4 mg/l to 7.2 mg/l while the fall DO ranged from 3.9 mg/l to 6.2 mg/l. The Howard Frankland sites had the highest DO during the spring while the Egmont Key sites had the highest DO during fall. The Bahia Beach sites had the lowest DO during the spring and fall.

The pH for the spring ranged from 8.0 to 8.1 while the fall pH ranged from 8.1 to 8.3. The pH is generally higher in the fall than spring. The pH values at Egmont Key were highest while the Bahia Beach sites were the lowest.

The Secchi depth for the spring ranged from 1.8 m to 4.5 m while the fall Secchi depth ranged from 0.4 m to 3.7 m. The Egmont Key Reef sites had the highest Secchi depth in the spring and fall while the Howard Frankland Reef sites had the lowest Secchi depth in the spring and the Bahia Beach sites were the lowest in the fall. The iridescence at the sample depth (I_{SD}) values for the spring ranged from 0.55 to 253.06 while the fall sample depth I values ranged from 0 to 169.73. More light reached the Egmont Key Reef sites during the spring and fall than the other reefs. The Bahia Beach sites received more light during the spring than the Howard Frankland sites but the opposite was true during the fall.

A more detailed analysis and comparison of the hydrographic data measured on the reefs vs. the monthly ambient water quality monitoring data compiled by EPC will be presented in future publications.

CONCLUSIONS

Variations in community structure between reefs in different bay segments as well as seasonal differences on individual reefs were apparent. The Howard Frankland Reef in Old Tampa Bay was notably different from the Egmont Key Reef in the mouth of the bay, yet both shared many similarities with the Bahia Beach Reef in Middle Tampa Bay. “Wet Season” / “Dry Season” comparisons often showed marked differences in an organism’s average relative biomass from season to season within a single reef. Documented changes in community structure such as these, within the same estuarine system, seem to suggest that artificial reefs are far more dynamic habitats than once thought and tend to contribute a great deal to the overall diversity of the estuary. There is little doubt that this study has greatly increased our knowledge and understanding of the artificial reef communities in Tampa Bay, as well as throughout the state. The authors, therefore, wish to acknowledge the Florida Fish and Wildlife Conservation Commission, Division of Marine Fisheries for their funding and cooperation.

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Creating Hard Bottom Benthic Habitat for Oyster Bar Restoration in Tampa Bay

Chris Sutton, Peter Clark, Kendall Sanderson (Tampa Bay Watch)

Tampa Bay Watch (TBW) has begun a series of community-based habitat restoration and enhancement programs to create oyster bars on spoil islands, natural shorelines and urbanized seawalled areas. Oyster communities help stabilize shorelines, provide hard bottom habitats for fish and wildlife resources and promote water quality improvements in the Tampa Bay ecosystem.

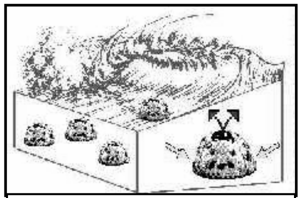
Tampa Bay Watch's Community Oyster Reef Enhancement (CORE) program creates fossilized oyster shell reefs constructed in similar structure to natural oyster communities found along shoreline areas throughout Tampa Bay. Fossilized oyster shell is purchased from a local shell mine and delivered to the closest boat ramp the day before the event. On the day of the construction, the shell is shoveled into 5 gallon buckets or 20" shell bags by community volunteers and than transported by local boaters to shoreline areas where it is placed intertidally to attract oyster spat.

Tampa Bay Watch's CORE program is also designed to promote the growth of oysters along residential canals and eroding natural shorelines of Tampa Bay. Residential finger fill construction has left extensive shoreline areas devoid of natural communities. Canals are often too deep for mangrove or saltmarsh establishment and have unsuitable water quality for seagrass growth. Marine friendly concrete oyster domes are constructed by community volunteers, youth groups and students. On larger projects, oyster domes (Reef Balls) are purchased from Reef Innovations, Inc. of Sarasota. Once created, oyster domes are then placed at the toe of seawalls or along eroding natural shorelines in permitted locations to facilitate oyster settlement. Reef Balls are 24" at the base and 18" tall weighing nearly 100 lbs. These domes are created using a marine friendly concrete which balances the pH allowing oysters to attach quickly on to the textured concrete.

These newly created oyster bars and seawall reefs benefit Tampa Bay in many ways. They promote water quality benefits through biological filtering of the water, provide habitat for small organisms, prevent further erosion, and create foraging areas and sanctuary for many species of fish and wildlife. The projects also benefit the community by promoting environmental awareness and offering hands on experience in habitat restoration.

Tampa Bay Watch has been installing oyster communities in all areas of the Bay since the late 1990's. TBW staff usually selects project sites according to the need for oyster habitats. Areas that are devoid of oyster communities have eroding shorelines, or have been hardened by seawalls are usually good candidates for oyster restoration projects.

The southeastern shoreline of Mac Dill Air Force Base (AFB) has been an on going shoreline stabilization project that Tampa Bay Watch initiated with the AFB in early 2004. This area is currently losing at least one foot of shoreline per year. This loss is believed to be caused by an increase in ship traffic in Hillsborough Bay, just to the east of the site. As large waves pound the shoreline, the excess water is sent back into the bay carrying shoreline sediment with it. With this in mind, TBW's goal is to trip incoming waves before they hit the shoreline by creating oyster bars using Reef Balls and fossilized shell. These reefs create a hard substrate on which oyster larvae attach and mature, creating a larger wave break. Sediment will collect behind the reef as it washes back into the bay or drifts down the shoreline.



Dome as a breakwater

Mac Dill Oyster Domes

Currently, TBW has installed 1510 domes and approximately 90 tons of shell along Mac Dill AFB's shoreline. The project will resume in the winter of 2007 with the installation of an additional 969 permitted domes and close to 20 tons of shell. These projects are usually constructed where the water is typically 1.5' to 2' deep at mean high water (MHW) for optimal oyster growth. Tampa Bay Watch monitors all newly created oyster reef units every six-months for the following parameters: oyster shell migration, new oyster colonization, sediment right in front and landward of the oyster reefs and wildlife usage of the new oyster reef communities.

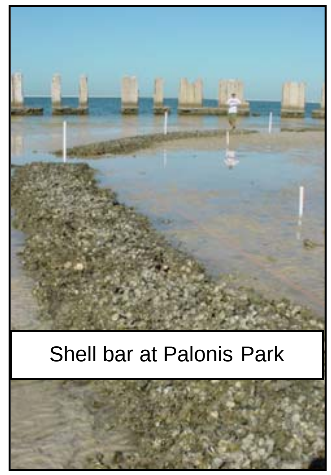
Initial monitoring data has demonstrated excellent sediment accretion behind the domes and bars, with a positive average of at least 6 to 8 inches in rise of sediment. This increase is a great sign of shoreline reestablishment. It provides a more natural slope enabling salt marsh to grow and protect the shoreline from further erosion, provides shelter for aquatic species, and acts as a natural buffer for storm water runoff into the bay.

Oyster colonization of the domes and shell has been extensive. In a two year period, oyster shell size has grown from 0mm to an average of 52mm. Each bar that had 0% oyster coverage in the initial installation now has 90% coverage on all domes and shell bars.

It is evident that this shoreline, once barren of any hard bottom benthic habitat, is now abundant with oysters and many aquatic species. Monitoring visits have proven that these bars are attracting many types of crustaceans, juvenile baitfish, wading and shore birds and larger game fish.

In recent monitoring events, Tampa Bay Watch has recorded small patches of *Halodule wrightii* emerging behind and in the front of the oyster bars. Seagrass was not present in these areas in the recent past. The lack of segrass was believed to be associated with the vast amount of shoreline erosion caused by waves. These waves were constantly changing the shoreline by shifting sediments and not allowing seagrasses to grow. This increase in seagrass shows positives signs of a stabilized shoreline and better water quality.

Other areas of the bay have also shown great success for oyster colonization on our bars. Areas such as Palonis Park, Whiskey Stump Key, and Green Key in Hillsborough County and Tarpon Key, Ft. De Soto Park and Little Bird Key in Pinellas County had limited hard bottom habitat. Now man made oyster habitats are believed to be improving water quality and providing structure for species who utilize these communities. The Oyster bars at Palonis Park also reveal the presence of seagrass which was non existent before the oyster bars were placed.



Shell bar at Palonis Park

Projects such as the one at Palonis Park are a great way to show the community the importance of hard bottom habitat, not only for recreational purposes, but for awareness of the importance of habitat restoration in general. Other areas include reef balls along Bayshore Boulevard, Ballast Point, Cunningham Key and many canals at residential home sites.

Tampa Bay Watch has installed approximately 4000 reef balls and 347.5 tons of shell throughout Tampa Bay (Figure 1). A continued increase in oyster habitat will keep Tampa Bay on its healthy path for future years to come.

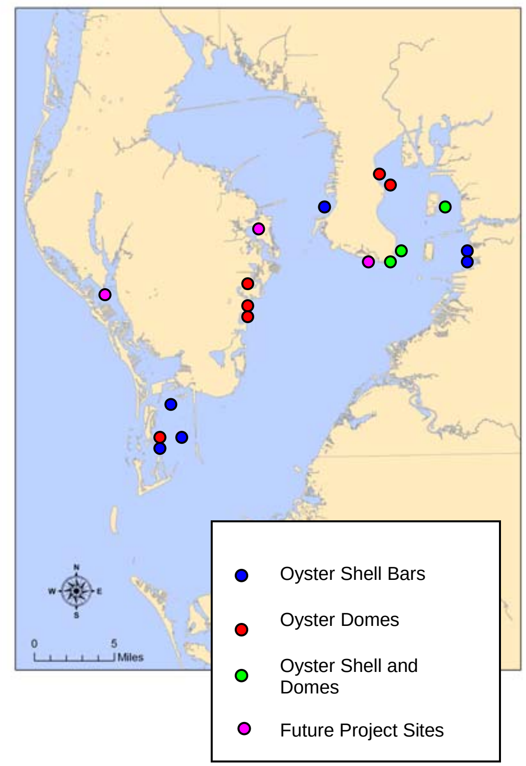


Figure 1. Map of location of oyster project.

Review of the Tampa Bay Dredged Hole Habitat Assessment Project

Lindsay M. Cross (Tampa Bay Estuary Program)

A study of 11 dredged holes in Tampa Bay, involving scientists and local anglers, was undertaken to assess the current ecological habitat values of the selected holes and to support the Tampa Bay Estuary Program and U.S. Army Corps of Engineer's (ACOE) dredging and dredged material management plan. When appropriate, restoration using dredged material may enhance dredged holes with poor fisheries, poor benthic habitat value and/or contaminated sediments, or to facilitate seagrass recovery. However, despite their anthropogenic origins, dredged holes may provide suitable habitat for aquatic organisms and may be utilized by local anglers.

Holes were selected based on their location, proximity to available fill material, perceived habitat value, proximity to other important habitats, current use by commercial and recreational anglers, and feasibility of restoration. Each dredged hole was studied for one year for a variety of parameters, including physical characteristics, water quality, benthic and sediment quality, and fisheries resources. The study culminated with individual management recommendations for each hole.

The Environmental Protection Commission of Hillsborough County performed water quality sampling and benthic and sediment analyses during the fall and spring sampling periods. Water quality parameters included salinity, stratification, dissolved oxygen, and the percent silt + clay. These results were used to compare the dredged holes to both surrounding areas and other similar habitats throughout the bay, such as polyhaline mud areas. Sediments were also analyzed for a suite of contaminants, including eight heavy metals, 19 organochlorine pesticides, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). The health of the benthic community was determined based on the number, abundance, and diversity of benthic organisms, using indices such as the Shannon-Weiner Diversity Index. Benthic community metrics, such as the number of benthic species counted compared to the number of species expected for the sample site salinity, were combined with sediment contamination results to yield the Tampa Bay Benthic Index.

The Fish and Wildlife Research Institute (FWRI) studied the fisheries resources in the dredged holes using both dependent and independent sampling. FWRI directly sampled at 26 sampling sites and assessed the rates and fishing pressures by recreational anglers and commercial fishers. Fisheries-Independent Monitoring was conducted using 6.1-meter otter trawl samples both inside and outside the dredged holes and 21.3-meter bag seine samples outside the holes in waters less than 1.5 meters in depth. For each gear, the number of fish was counted and the catch data were converted to a number per 100 square meters. Average animal abundance was calculated both for all species and for economically important species, as determined by the FWRI.

The Advisory Team developed a ranking equation that accounted for the current ecological habitat value for both benthic and fisheries species. A combined ranking for each of the holes was calculated based on an equal weighting of both the benthic and fisheries rankings. The final rankings, from #1 (best) to #11 (worst), were used independently, as well as to compare the present ecological habitat value of the dredged holes to each other. The Advisory Team then developed individual management recommendations for each hole (Figure 1). The recommendations were intended to assess the current ecological habitat value of the holes only. Physical characteristics collected by the U.S. ACOE, such as the volume of the hole or the proximity to available fill material, were not used in the ecological assessment.

Overall, each hole studied was unique, although there were some similarities between holes. Most of the holes were characterized as polyhaline mud habitats and only two were density stratified or highly stratified during one or both sampling periods. The benthic quality for most holes was similar to other polyhaline mud habitats throughout the bay. In general, average DO levels were above 4.0 mg/L, except for three holes. However, four holes dropped below 4.0 mg/L for at least 15 minutes during a sampling period. Only two holes experienced hypoxic conditions. There was some degree of sediment contamination for each of the 11 holes, most often expressed as anthropogenic enrichment of cadmium and lead. The benthic indices were generally higher during the spring sampling period than during the fall.

Fisheries resources were generally more species and numerically abundant within the dredged holes compared to adjacent areas outside, considering trawl results only. Differences were most often due to blue crab and pink shrimp, with both tending to be more abundant inside the holes than in adjacent outside areas. Seine samples collected outside the holes in shallow areas tended to contain smaller baitfish, although many larval forms of economically important species were also collected. Additionally, commercial and recreational fishers appeared to be utilizing the dredged holes to varying degrees and they collected/targeted several economically important species. These results suggest that, in general, many of the dredged holes had favorable habitat conditions for either benthic or fisheries organisms or both.

Due to the differences in each hole, further study of the remaining Tampa Bay dredged holes should be completed prior to developing management recommendations for them. The final report is available at www.tbeptech.org or by contacting the Tampa Bay Estuary Program.

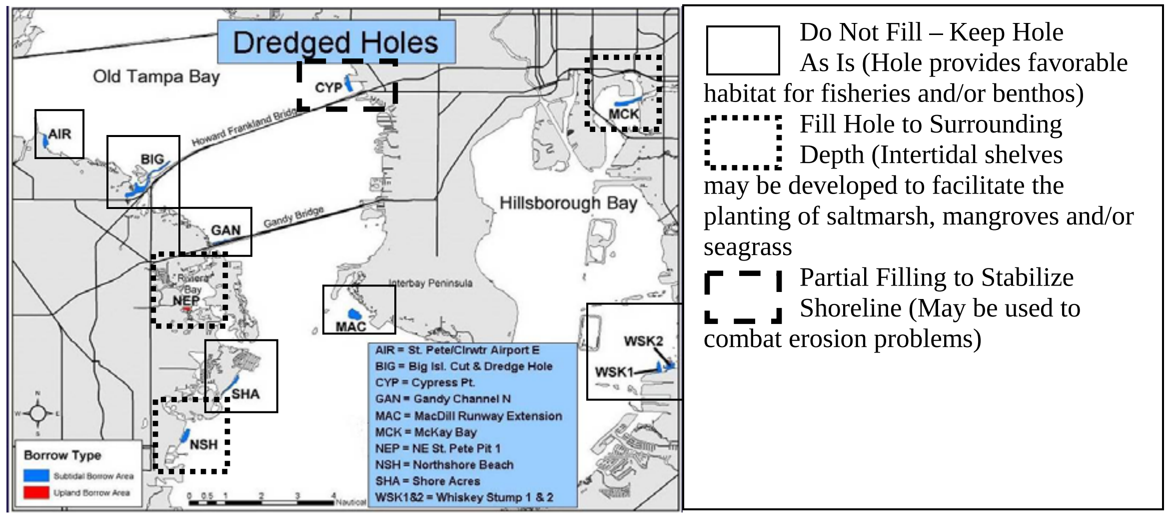


Figure 1. Location sites of dredged holes and management strategies.

Sediment Contaminants and Benthic Assemblages in the Lower Hillsborough, Palm, Alafia, and Little Manatee Rivers.

S. A. Grabe (Janicki Environmental,Inc.)
D. J. Karlen, (Environmental Protection Commission of Hillsborough County)

-CHAPTER HIGHLIGHTS-

- *Wet-season near-bottom salinities differed by year and among tributaries. Tributary salinities generally increased from 1997-2002, a consequence of regional drought conditions. Salinities were generally highest in the Palm River and lowest in the Little Manatee River*

- *Wet-season near-bottom dissolved oxygen (DO) concentrations varied spatially within individual tributaries. The Palm River and the Lower Hillsborough River exhibited widespread hypoxia (DO<2 mg/l).*

- *Sediment contamination (metals, pesticides, PAHs) was generally highest in the Lower Hillsborough River and lowest in the Little Manatee River. Some contaminants were detected at concentrations likely to be toxic to aquatic life: PAHs, the pesticides chlordane and DDT, and zinc in the Lower Hillsborough River and PCBs in the Palm River were particularly high relative to the other tributaries.*

- *Wet-season benthic community structure differed among tributaries. Mean diversity and mean numbers of taxa were highest in the Little Manatee River and lowest in the Palm River. The Little Manatee River was primarily dominated by crustaceans while polychaete worms were dominant in the Lower Hillsborough and Alafia rivers. The Palm River had a relatively high frequency of depauperate samples—a consequence of DO stress within this tributary.*

- *Community structure was examined within four resource-based salinity classes: <8 PSU; 8-15 PSU; 16-28 PSU; and >28 PSU.. The <8 PSU salinity class) was characterized by the polychaete* Laeonereis culveri *and tubificid oligochaetes in all four rivers. The 8-15 PSU salinity class was also dominated by polychaetes in the Lower Hillsborough, Palm and Alafia rivers, while crustaceans were more prevalent in the Little Manatee River. Polychaetes and crustaceans composed the benthic community in the 16-28 PSU salinity class in all but the Hillsborough River. The >28 PSU salinity was dominated by the polychaete* Monticellina cf. dorsobranchialis *in the Hillsborough River, while the amphipod* Ampelisca abdita *characterized this salinity zone in the Alafia and Palm Rivers.*

- *Tampa Bay Benthic Index scores were relatively low in all four rivers relative to samples from Tampa Bay proper. This may be due more to the naturally higher abundance of capitellid polychaetes and overall lower species diversity found in lower salinity systems. The TBBI was found to be negatively associated with depth, % silt + clay content of the sediments, and several sediment contaminants in the Palm River, and with sediment contaminants in the Little Manatee River.*

INTRODUCTION

In 1995, the Lower Hillsborough, Palm, and Alafia rivers were added, as separate strata, to the baywide benthic/sediment contaminant monitoring program. This was in anticipation of these tributaries being exploited for their water resources; the Little Manatee River was added in 1996. For 1998-2000, the Southwest Florida Water Management District (SWFWMD) provided partial support. As a response to Tampa Bay Water's (TBW) "Master Water Plan", which intended to develop the Hillsborough, Palm and Alafia rivers as sources of drinking water to the region, the Hillsborough County Board of County Commissioners requested that the Hillsborough County Water Resource Team and EPCHC staff develop a monitoring program independent of TBW's permit requirements. The EPCHC proposed enhanced sampling of benthic macroinvertebrates in the Lower Hillsborough, Palm, and Alafia. The Little Manatee River was added as a "reference" estuary. This chapter summarizes data collected through 2002.

METHODS

A total of 497 samples were collected for benthic macroinvertebrates during the summer wet season over the eight year period. period. Of these, 201 samples were analyzed for trace metals and 174 samples were analyzed for polycyclic aromatic hydrocarbons (PAH's), organochlorine pesticides, and polychlorinated biphenyls (PCBs). Sample locations were randomly selected from computer-generated coordinates provided by Janicki Environmental, Inc. (St. Petersburg, FL). Benthic and sediment samples were collected using a Young grab sampler following the field protocols outlined in Courtney et al. (1993). Laboratory procedures followed the protocols set forth in Courtney et al. (1995). Statistical analysis (Kolmogorov – Smirnov two-sample test; Pearson Correlation) was conducted using SYSTAT ver. 11 (SYSTAT Software, Inc. 2004).

The relationships between the benthos and salinity within and across each of the rivers were adapted from Janicki Environmental, Inc. (2006). Principal components analysis was used to identify salinity classes across eight tidal rivers in the region based upon the occurrence of the benthos.

The extent of sediment contamination was determined based on the Threshold Effects Level (TEL) and Probable Effects Level (PEL) as defined by MacDonald Environmental Sciences, Ltd., (1994). The PEL is the concentration above which a contaminant has a high (>50%) likelihood of being toxic to aquatic life.

RESULTS

Physico-Chemical and Sediment Characteristics:

Table 11-1 shows the summary statistics for depth, temperature, salinity, dissolved oxygen (DO) and the percent silt/clay (%SC). The Palm River had the greatest average depth, while the deepest sampling location was in the Alafia River. Near-bottom salinities were highest in the Palm River, with >>90% of the observations in the polyhaline range (18 to 30 PSU). The Little Manatee River had the lowest mean salinity. There was no significant difference in the salinity between the Alafia and Hillsborough Rivers [Kolmogorov-Smirnov (KS) two-sample test].
Median concentrations were lowest in the Palm and Lower Hillsborough rivers and highest in the Little Manatee River. More than 70% of the Palm River samples and approximately 65% and 50% of the Lower Hillsborough and Alafia river samples respectively had near-bottom DO measurements that were indicative of hypoxia (DO<2 mg l^{-1}) . By contrast, <10% of the Little Manatee River samples had DO measurements <2 mg l^{-1}. Statistical analysis (KS) showed no significant difference between the dissolved oxygen levels in the Palm and Hillsborough rivers, while the Little Manatee River was significantly higher than the other three tributaries.

The %SC was highest in the Palm River and was significantly higher than the other tributaries. The Little Manatee River had significantly lower %SC than the other three systems, while there was no significant difference between the Hillsborough and Alafia Rivers.

Trace Metals: Trace metal concentrations were generally highest in the Lower Hillsborough River and lowest in the Little Manatee River (Table 11-2). The Hillsborough River exhibited PEL exceedences for cadmium (10% of the samples), copper (30%), lead (45%) and zinc (15%). Cadmium concentration exceeded the PEL in 30% of the Alafia River samples. The Palm River had PEL exceedences for cadmium (20%), chromium (15%), nickel (10%), lead (20%) and zinc (25%). The Little Manatee River was the least contaminated tributary for trace metals, with only cadmium exceeding the PEL (10% of the samples).

Table 11-1. Summary of depth (m) near-bottom temperature (°C), salinity (PSU), dissolved oxygen (mg l^{-1}) and sediment silt/clay content (%) in four tributaries to Tampa Bay, 1995-2002. HR= Lower Hillsborough River; PR=Palm River; AR= Alafia River; LMR=Little Manatee River

	DEPTH				TEMPERATURE				SALINITY				DISSOLVED OXYGEN				SILT/CLAY			
	HR	**PR**	**AR**	**LMR**	**HR**	**PR**	**AR**	**LMR**	**HR**	**PR**	**AR**	**LMR**	**HR**	**PR**	**AR**	**LMR**	**HR**	**PR**	**AR**	**LMR**
MIN	0.2	0.3	0.1	0.1	25.5	25.5	25.3	25.2	0.0	0.4	0.0	0.0	0.0	0.0	0.1	0.3	0.3	1.3	0.5	0.0
MAX	4.4	6.0	10.4	2.5	31.1	31.9	30.6	31.3	28.3	28.1	29.4	26.9	7.0	12.5	6.1	8.5	71.3	97.0	93.3	74.4
MEDIAN	2.2	2.5	1.2	1.0	29.4	30.3	29.0	28.8	15.7	24.9	14.8	9.7	1.2	0.7	2.3	3.8	11.1	16.3	13.6	4.2
MEAN	2.3	2.9	1.6	1.0	29.2	29.8	28.6	28.7	13.1	23.2	13.4	11.2	1.9	1.8	2.7	3.9	14.9	27.7	20.0	6.9

Table 11-2. Trace Metal summary statistics (ppm) by Tributary: 1995-2002. TEL = Threshold Effects Level; PEL = Probable Effects Level (MacDonald Environmental Sciences, Ltd., 1994)

Alafia River 1995-2002								
	AG	AS	CD	CR	CU	NI	PB	ZN
TEL	0.73	7.20	0.68	52.30	18.70	15.90	30.20	124.00
PEL	1.77	41.60	4.20	160.00	108.00	42.80	112.00	271.00
Minimum	0.08	1.08	0.20	0.73	0.40	1.27	1.30	2.43
Maximum	1.25	7.12	9.54	187.18	42.93	57.40	106.70	311.00
Median	0.47	2.34	3.07	23.34	9.67	13.68	16.27	25.12
Mean	0.46	2.87	3.39	50.77	13.26	15.98	29.10	54.31

Hillsborough River 1995-2002								
	AG	AS	CD	CR	CU	NI	PB	ZN
TEL	0.73	7.20	0.68	52.30	18.70	15.90	30.20	124.00
PEL	1.77	41.60	4.20	160.00	108.00	42.80	112.00	271.00
Minimum	0.08	1.16	0.06	1.68	2.25	0.86	2.95	2.83
Maximum	2.09	16.20	5.06	90.10	286.50	36.95	374.30	511.19
Median	0.34	3.22	2.22	24.68	54.92	11.79	96.51	116.86
Mean	0.43	3.93	2.11	29.04	79.09	12.66	116.67	136.75

Palm River 1995-2002								
	AG	AS	CD	CR	CU	NI	PB	ZN
TEL	0.73	7.20	0.68	52.30	18.70	15.90	30.20	124.00
PEL	1.77	41.60	4.20	160.00	108.00	42.80	112.00	271.00
Minimum	0.08	0.94	0.08	3.00	0.40	0.85	1.30	4.45
Maximum	1.43	8.10	10.17	273.44	80.31	72.25	191.10	574.00
Median	0.33	2.50	2.29	15.30	3.46	11.57	8.91	21.08
Mean	0.43	3.09	2.36	57.93	15.68	17.69	38.89	136.55

Little Manatee River 1996-2002								
	AG	AS	CD	CR	CU	NI	PB	ZN
TEL	0.73	7.20	0.68	52.30	18.70	15.90	30.20	124.00
PEL	1.77	41.60	4.20	160.00	108.00	42.80	112.00	271.00
Minimum	0.08	0.78	0.02	0.81	0.40	0.64	1.04	3.00
Maximum	2.63	8.04	5.10	101.70	129.10	22.33	17.82	50.40
Median	0.15	2.03	0.15	5.59	5.88	4.93	4.87	6.46
Mean	0.35	2.56	1.44	10.38	10.31	7.74	5.05	9.83

Table 11-3. Pesticide, PCB and Polycyclic Aromatic Hydrocarbon summary statistics (ppb) by Tributary: 1995-2002. TEL = Threshold Effects Level; PEL = Probable Effects Level (MacDonald Environmental Sciences, Ltd., 1994)

Alafia River 1995-2002								
	LINDANE	DIELDRIN	DDT	CHLORDANE	PCBs	LOW MOLECULAR WT. PAHs	HIGH MOLECULAR WT. PAHs	TOTAL PAHs
TEL	0.32	0.72	3.89	2.30	21.60	312.00	655.00	1680.00
PEL	0.99	4.30	51.70	4.80	189.00	1440.00	6680.00	16800.00
Minimum	0.01	0.02	0.08	0.06	0.63	12.20	11.60	23.80
Maximum	2.80	14.22	6.02	5.70	67.60	1026.96	9469.36	10496.32
Median	0.05	0.07	0.32	0.26	6.80	40.00	203.60	245.50
Mean	0.17	0.32	0.71	0.54	8.89	72.22	407.83	480.06

Hillsborough River
1995-2002

	LINDANE	DIELDRIN	DDT	CHLORDANE	PCBs	LOW MOLECULAR WT. PAHs	HIGH MOLECULAR WT. PAHs	TOTAL PAHs
TEL	0.32	0.72	3.89	2.30	21.60	312.00	655.00	1680.00
PEL	0.99	4.30	51.70	4.80	189.00	1440.00	6680.00	16800.00
Minimum	0.01	0.02	0.16	0.06	2.70	74.80	568.80	643.60
Maximum	17.68	27.26	1044.75	247.14	161.40	4433.87	35962.90	39711.50
Median	0.08	0.06	19.11	11.72	31.85	1268.45	10232.50	11566.68
Mean	0.91	1.20	122.38	25.29	44.92	1352.08	11682.43	13034.52

Palm River
1995-2002

	LINDANE	DIELDRIN	DDT	CHLORDANE	PCBs	LOW MOLECULAR WT. PAHs	HIGH MOLECULAR WT. PAHs	TOTAL PAHs
TEL	0.32	0.72	3.89	2.30	21.60	312.00	655.00	1680.00
PEL	0.99	4.30	51.70	4.80	189.00	1440.00	6680.00	16800.00
Minimum	0.01	0.02	0.08	0.06	0.47	11.43	18.00	35.00
Maximum	0.73	8.50	12.50	17.50	1075.20	1308.00	8554.00	9862.00
Median	0.08	0.07	0.65	0.20	11.70	40.00	242.20	287.10
Mean	0.11	0.52	1.50	1.01	82.74	119.17	991.83	1111.00

Little Manatee River
1996-2002

	LINDANE	DIELDRIN	DDT	CHLORDANE	PCBs	LOW MOLECULAR WT. PAHs	HIGH MOLECULAR WT. PAHs	TOTAL PAHs
TEL	0.32	0.72	3.89	2.30	21.60	312.00	655.00	1680.00
PEL	0.99	4.30	51.70	4.80	189.00	1440.00	6680.00	16800.00
Minimum	0.01	0.02	0.08	0.06	0.45	12.20	11.60	23.80
Maximum	0.50	0.30	3.31	1.51	15.70	359.00	1272.00	1370.00
Median	0.05	0.05	0.26	0.09	2.70	26.30	26.00	59.75
Mean	0.07	0.07	0.44	0.21	3.78	39.88	101.45	141.33

Organochlorine Pesticides: The Lower Hillsborough River had the highest levels of pesticides (Table 11-3) and had significantly higher concentrations of DDT and chlordane. Pesticide PEL exceedences of the Hillsborough River samples included lindane (10%), DDT (25%; figure 11-1) and chlordane (65%; figure. 11-2). Pesticide contamination was relatively low in the other tributaries, with only a couple of isolated samples exceeding the PEL for lindane in the Alafia River and chlordane in the Palm River. There were no PEL exceedences in the Little Manatee River for pesticides, and only one sample exceeded the TEL for lindane.

Polychlorinated Biphenyls (PCBs): PCB concentrations were generally highest in the Palm and Hillsborough rivers and lowest in the Little Manatee River (Table 11-3). The PEL was exceeded in 10% of the Palm River samples, while 100% of the Little Manatee River were <TEL.

Polycyclic Aromatic Hydrocarbons (PAHs): Total PAH concentrations were highest in the Lower Hillsborough and lowest in the Little Manatee River. In the Lower Hillsborough River, 40% of the samples were above the PEL for low molecular weight PAHs, 75% for high molecular weight PAHs and 30% for total PAHs (Figure 11-3).

Benthic Community*:* Species richness (numbers of taxa), numbers of individuals (# m^{-2}), and the Shannon Diversity Index were highest in the Little Manatee River and lowest in the Palm River (Table 11-4). A total of 523 taxa were identified from the four tributaries during 1995-2002. Ninety-seven taxa were common to all four tributaries; the percentage of taxa identified from only a single tributary ranged from 13.4% (Palm River) to 25.0% (Alafia River). Approximately 30% of the taxa were polychaete worms and >17% were crustaceans. The Lower Hillsborough River had proportionately more species of polychaetes than did the other tributaries and the Little Manatee River had proportionately more crustaceans. Approximately 17% of the taxa identified from all of the tributaries can be considered as primarily freshwater species with the highest proportion found in the Alafia River and lowest in the Palm River.

The Lower Hillsborough River was dominated primarily by polychaete species (*Stenoninereis martini*) and tubificid oligochaetes (Table 11-5a). Polychaetes were the most abundant and most speciose group during each year except 1995, 1996 and 1998. During those years, the most abundant taxa were freshwater or low salinity bivalves (*Corbicula fluminea*, *Mytilopsis leucophaeata*). Subdominants varied from year to year and included bivalves, gastropods, tubificid oligochaetes, and, insect larvae. The Palm River was also dominated primarily by polychaete worms (*Streblospio gynobranchiata*) and bivalves (*Mysella planulata* and *Mytilopsis leucophaeata*) (Table 11-5b). Amphipod crustaceans were less important and insect larvae were rare. Overall, approximately 40% of the Palm River samples were depauperate.

The dominant taxa in the Alafia River included tubificid oligochaetes, a spionid polychaete *(Streblospio gynobranchiata*.), the brachiopod Glottidia *pyramidata* and a bivalve *Mytilopsis leucophaeata* (Table 11-5c). There were inter-annual differences in the most abundant taxa: bivalves in 1995 and 1999, crustaceans in 1996, oligochaetes in 1997, polychaetes in 1998, 2000, and 2001 and *Glottidia pyramidata* in 2002. Aquatic insect larvae were also an important component of the benthic community in the lower salinity samples.

The dominant taxa in the Little Manatee River were primarily amphipod crustaceans and tubificid oligochaetes (Table 11-5d). Amphipod crustaceans were the most abundant taxa during each year except 1999 (tubificid oligochaetes). With respect to taxonomic composition, polychaetes, crustaceans, and bivalves were generally the most speciose groups, although aquatic insect larvae were abundant at the low salinity sites.

Comparison of Benthos Assemblages by Salinity Class

Janicki Environmental, Inc. (2006) developed a regional salinity classification based upon the distribution of the benthos within eight southwest Florida tidal rivers, including the Lower Hillsborough, Palm, Alafia, and Little Manatee Rivers. The four salinity classes were:

- <8 PSU
- 8 to 15 PSU
- 16 to 28 PSU
- >28 PSU

Presence-absence data and the "SIMPER" (similarity percentage analysis) program in PRIMER v. 5 (PRIMER-E Ltd., 2000) was used to identify the taxa that explained at least 50% of the similarity within each salinity class for each of the four rivers.

The polychaete *Laeonereis culveri* and tubificid oligochaetes were typical members of the benthos in the <8 PSU salinity class (Table 11-6). The benthic assemblage of the Alafia River was similar to that of the Palm, Lower Hillsborough and Little Manatee rivers. Other inter-river comparisons of the benthic assemblages were statistically significant.

Polychaetes were characteristic of the 8 to 15 PSU salinity class in three of the rivers; peracarid crustaceans were subdominants, after tubificid oligochaetes, in the Little Manatee River. Within the Tampa Bay area, the assemblages within this salinity class did not differ between the Little Manatee and both the Alafia and Lower Hillsborough rivers. The benthic communities of the Lower Hillsborough River and Palm River were also similar.

Polychaetes continued to dominate in the 16 to 28 PSU class in each river, although amphipods were also ranked in all but the Lower Hillsborough River. The Palm River was similar in structure to the Little Manatee River. The >28 PSU salinity class in the Lower Hillsborough River was dominated by the polychaete *Monticellina cf. dorsobranchialis*; *Ampelisca abdita* was a dominant in both the Palm and Alafia rivers. The Palm River assemblage was not considered to be different from the Lower Hillsborough River.

Tampa Bay Benthic Index (TBBI): The Tampa Bay Benthic Index has been recently revised to account for the effect of salinity on benthic diversity (Janicki Environmental, Inc. 2005). The current version of the TBBI was developed and calibrated using data form Tampa Bay proper, and values calculated for the tributaries tended to be depressed relative to bay samples. The Little Manatee River had the highest mean TBBI score, while the Palm River had the lowest (Table 11-4) The TBBI frequency distributions differed by tributary (Figure 11-4). The frequency distributions within the Palm River, with its high frequency of azoic samples, and Little Manatee River differed significantly from those of the other tributaries, while the Hillsborough and Alafia rivers were similar to each other (Figure 11-4). Approximately 70% of the Hillsborough, Alafia and Palm River samples and 60% of the Little Manatee River samples had TBBI scores indicative of degraded habitat (TBBI < 73) (Figure 11-4), Approximately 20% of the Little Manatee River samples had TBBI scores in the healthy range (TBBI > 87; figure 11-4).

TBBI and Abiotic Variables: Pearson correlation coefficients for the association between the TBBI and the measured abiotic variables (untransformed data) found no significant correlations in for the Lower Hillsborough, Alafia, or Little Manatee Rivers. Within the Palm River, the TBBI was negatively associated with depth and %SC.

TBBI and Sediment Contaminants: Pearson correlation coefficients for the association between the TBBI and sediment contaminants showed a negative correlation in the Palm River with several trace metals (CR, CU, NI, PB, and ZN) and organics (DDT and PAHs). Negative associations were also found in the Little Manatee River with several trace metals (CR, CU, NI) and DDT.

Table 11-4. Summary of benthic community measures (1995-2002): total numbers of individuals (number m^{-2}), species richness, Shannon-Wiener diversity and the Tampa Bay Benthic Index (TBBI. HR= Lower Hillsborough River; PR=Palm River; AR= Alafia River; LMR=Little Manatee River

	NUMBERS OF INDIVIDUALS				SPECIES RICHNESS				SHANNON DIVERSITY				TBBI			
	HR	PR	AR	LMR	HR	PR	AR	LMR	HR	PR	AR	LMR	HR	PR	AR	LMR
MIN	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MAX	50,175	14,600	21,725	158,925	69	53	49	71	3.2	3.3	2.9	3.1	92.2	91.1	90.4	96.5
MEDIAN	1,438	75	975	3,275	6	2	9	15	1.1	0.6	1.4	1.8	66.2	56.9	66.3	70.9
MEAN	4,568	1,843	3,174	8,265	11	9	11	20	1.1	1.0	1.3	1.7	61.7	41.8	61.2	70.7

Table 11-5a. Five dominant macroinvertebrate taxa by year: Lower Hillsborough River

RANK	1995-1998	1999	2000	2001	2002
1	*Stenoninereis martini (P)*	*Laeonereis culveri (P)*	*Monticellina cf. dorsobranchialis (P)*	*Stenoninereis martini (P)*	*Tubificidae(O)*
2	*Tubificidae(O)*	*Mytilopsis leucophaeata (B)*	*Tubificidae(O)*	*Grandidierella bonnieroides (A)*	*Stenoninereis martini (P)*
3	*Mytilopsis leucophaeata (B)*	*Stenoninereis martini (P)*	*Laeonereis culveri (P)*	*Tubificidae(O)*	*Melinna maculate (P)*
4	*Corbicula fluminea (B)*	*Tubificidae(O)*	*Ampelisca holmesi (A)*	*Laeonereis culveri (P)*	*Tubificoides brownae (O)*
5	*Grandidierella bonnieroides (A)*	*Monticellina cf. dorsobranchialis (P)*	*Ampelisca abdita (A)*	*Melinna maculate (P)* *Streblospio gynobranchiata.(P)*	*Laeonereis culveri (P)*

Table 11-5b. Five dominant macroinvertebrate taxa by year: Palm River. A= Amphipoda; I=Isopoda; B=Bivalvia; Br=Brachiopoda G=Gastropoda; O=Oligochaeta; P=Polychaeta

RANK	1995-1998	1999	2000	2001	2002
1	*Mysella planulata (B)*	*Mytilopsis leucophaeata (B)*	*Paraprionospio pinnata (P)*	*Glottidia pyramidata (Br)*	*Ampelisca holmesi (A)*
2	*Streblospio gynobranchiata(P)*	*Tagelus plebeius (B)*	*Streblospio gynobranchiata.(P)*	*Mysella planulata (B)*	*Mysella planulata (B)*
3	*Stenoninereis martini (P)*	*Streblospio gynobranchiata.(P)*	*Stenoninereis martini (P)*	*Ampelisca holmesi (A)*	*Acteocina canaliculata (G)*
4	*Ampelisca abdita (A)*	*Mysella planulata (B)*	*Mulinia lateralis (M)*	*Podarkeopsis levifuscina (P)* *Scoloplos rubra (P)*	*Streblospio gynobranchiata.(P)*
5	*Mytilopsis leucophaeata (B)*	*Macoma constricta (B)*	*Ampelisca holmesi (A)*	*Acteocina canaliculata (G)*	*Amygdalum papyrium (B),* *Xenanthura brevitelson (I)* *Ampelisca vadorum (A)*

Table 11-5c. Five dominant macroinvertebrate taxa by year: Alafia River.A= Amphipoda; B=Bivalvia; Br=Brachiopoda; I=Isopoda; O=Oligochaeta; P=Polychaeta

RANK	1995-1998	1999	2000	2001	2002
1	*Streblospio gynobranchiata (P)*	*Mytilopsis leucophaeata (B)*	*Streblospio gynobranchiata (P)*	*Monticellina cf. dorsobranchialis (P)*	*Glottidia pyramidata (Br)*
2	*Mytilopsis leucophaeata (B)*	*Ampelisca abdita (A)*	*Tubificidae (O)*	*Glottidia pyramidata (Br)*	*Littoridinops sp. (G)*
3	*Grandidierella bonnieroides (A)*	*Glottidia pyramidata (Br)*	*Ampelisca abdita(A)*	*Tubificidae (O)* *Chironomus sp.(In)* *Streblospio gynobranchiata (P)*	*Tubificidae (O)* *Streblospio gynobranchiata (P)*
4	*Ampelisca abdita (A)*	*Tubificidae (O)*	*Mulinia lateralis (B)*	*Sigambra tentaculata (P)*	*Monticellina cf . dorsobranchialis (P)*
5	*Laeonereis culveri (P)*	*Streblospio gynobranchiata (P)*	*Prionospio perkinsi (P)*	*Grandidierella bonnieroides (A)*	*Tubificoides brownae (O)* *Paraprionospio pinnata (P)*

Table 11-5d. Five dominant macroinvertebrate taxa by year: Little Manatee River

RANK	1996-1998	1999	2000	2001	2002
1	*Grandidierella bonnieroides (A)*	*Tubificidae (O)*	*Cerapus sp. C (A)*	*Cerapus sp. C ((A)*	*Apocorophium louisianum (A)*
2	*Tubificidae (O)*	*Ampelisca abdita (A)*	*Ampelisca holmesi (A)*	*Ampelisca holmesi (A)*	*Tubificidae (O)*
3	*Apocorophium louisianum (A)*	*Xenanthura brevitelson (I) Cyathura polita (I)*	*Grandidierella bonnieroides (A)*	*Apocorophium louisianum (A)*	*Grandidierella bonnieroides (A)* *Laeonereis culveri (P)*
4	*Cyathura polita (I)*	*Glottidia pyramidata (Br)*	*Tubificidae (O)*	*Tubificidae (O)*	*Tubificoides brownae (O)* *Cerapus sp. C (A)* *Glottidia pyramidata (Br)*
5	*Mytilopsis leucophaeata (B)*	*Ampelisca holmesi (A)* *Aricidea philbinae (P)*	*Monticellina cf. dorsobranchialis (P)* *Ampelisca abdita (A)*	*Monticellina cf. dorsobranchialis (P)*	*Xenanthura brevitelson (I)* *Aricidea philbinae (P)*

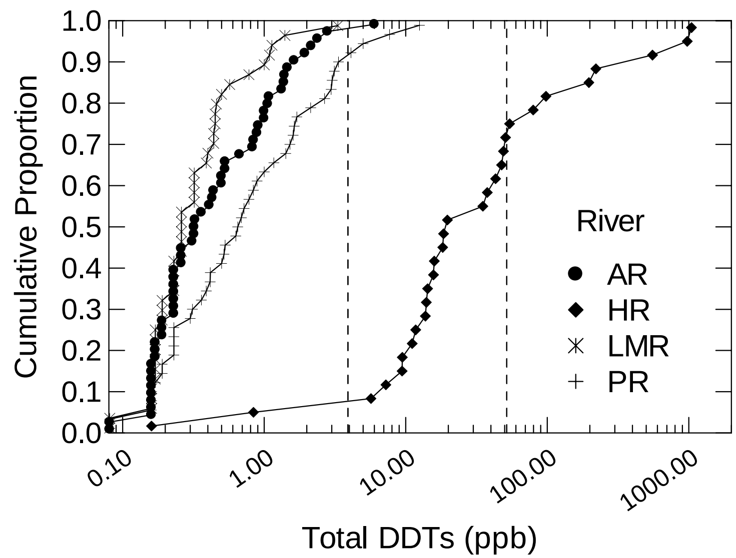


Figure 11-1. Total DDT cumulative distribution plot. Vertical lines demarcate the TEL (3.89 ppb) and the PEL (51.7 ppb).

Table 11-6. Taxa explaining at least 50% of the similarity within salinity class by river: Lower Hillsborough, Palm, Alafia, and Little Manatee rivers.

SALINITY CLASS (PSU)	**LOWER HILLSBOROUGH**		**PALM**		**ALAFIA**		**LITTLE MANATEE**	
<8	*Laeonereis culveri*	29.2	Tubificidae	32.1	Tubificidae	19.0	Tubificidae	27.4
	Tubificidae	19.3	*Laeonereis culveri*	23.7	*Laeonereis culveri*	18.9	*Cyathura polita*	17.7
	Stenoninereis martini	10.8			*Chironomus sp.*	12.6	*Laeonereis culveri*	10.0
					Mytilopsis leucophaeata	9.6		
8-15	*Laeonereis culveri*	19.0	*Tagelus plebeius*	20.9	*Streblospio gynobranchiata*	18.5	Tubificidae	28.0
	Tubificidae	17.4	*Leitoscoloplos robustus*	12.0	*Grandidierella bonnieroides*	12.3	*Cyathura polita*	8.0
	Stenoninereis martini	17.1	*Eteone heteropoda*	11.6	*Stenoninereis martini*	10.1	*Grandidierella bonnieroides*	7.1
			Nereis succinea	11.2	*Laeonereis culveri*	8.2	*Laeonereis culveri*	5.5
					Mytilopsis leucophaeata	7.4	*Xenanthura brevitelson*	4.0
16-28	*Stenoninereis martini*	27.3	*Paraprionospio pinnata*	11.6	*Streblospio gynobranchiata*	18.5	Tubificidae	8.2
	Tubificidae	12.6	*Ampelisca abdita*	8.0	*Grandidierella bonnieroides*	11.8	*Monticellina cf. dorsobranchialis*	7.5
	Melinna maculata	12.2	*Stenoninereis martini*	7.9	*Ampelisca abdita*	9.8	*Aricidea philbinae*	7.2
			Streblospio gynobranchiata	7.0	*Paraprionospio pinnata*	9.5	*Ampelisca holmesi*	5.2
			Capitella capitata complex	6.6	*Stenoninereis martini*	8.0	*Amygdalum papyrium*	4.4
			Laeonereis culveri	6.2			*Nassarius vibex*	3.3
			Nereis succinea	6.2			*Xenanthura brevitelson*	3.2
							Cerapus spp.	3.0
							Cyathura polita	2.9
							Ampelisca vadorum	2.7
							Mysella planulata	2.7
>28	*Monticellina cf. dorsobranchialis*	65.2	*Ampelisca abdita*	25.7	Nemertea	32.3	**NO SAMPLES**	
			Stenoninereis martini	21.6	*Ampelisca abdita*	29.3		
			Podarkeopsis levifuscina	6.6				

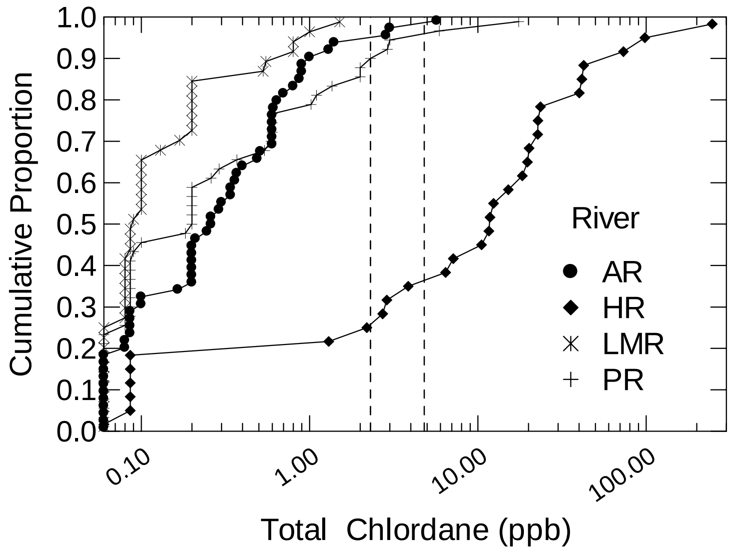


Figure 11-2. Total Chlordane cumulative distribution plot. Vertical lines demarcate the TEL (2.3 ppb) and the PEL (4.8 ppb).

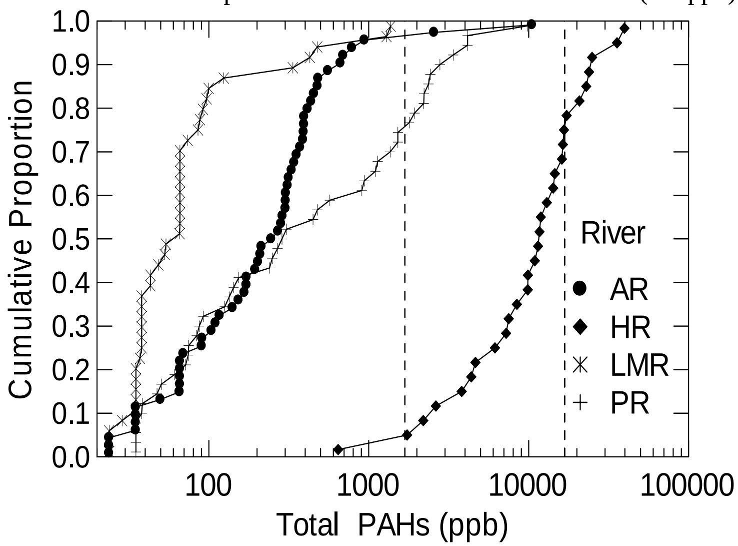


Figure 11-3. Total Polycyclic Aromatic Hydrocarbons (PAHs) cumulative distribution plot. Vertical lines demarcate the TEL (1660 ppb) and the PEL (16800 ppb).

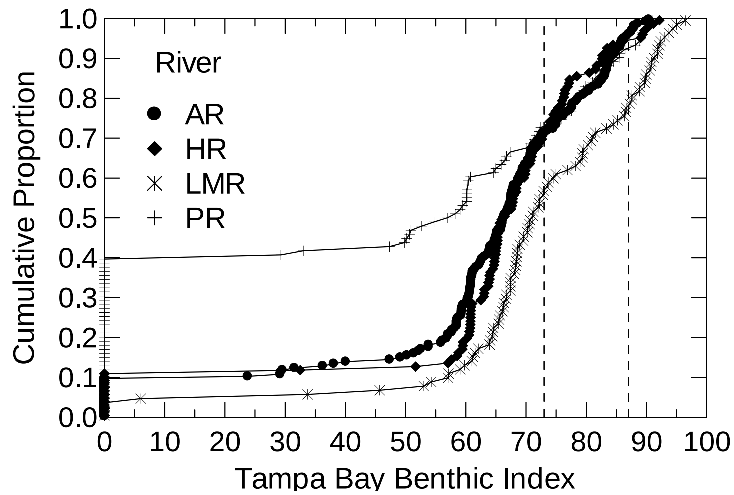


Figure 11-4. Tampa Bay Benthic Index cumulative distribution plot. TBBI < 73 = "Degraded"; 73-87 = "Marginal"; > 87 = "Healthy"

DISCUSSION

Each of these four tributaries has been modified to some extent by anthropogenic activities. These modifications are manifest as alterations (i.e., reductions) in freshwater inflow, agricultural, industrial, residential, and urban development, increased sedimentation, and lowered dissolved oxygen. The data collected during the period 1995-2002 in these tributaries show degradation of the sediments and sedimentary biota in each system. The extent and types of impacts differ by tributary.

The Lower Hillsborough River is essentially an urban estuary impacted by stormwater discharges and reduction of freshwater inflow. A consequence of these man-made modifications to this system has been increased salinity, the accumulation of fine-grained sediments and associated contaminants, as well as lowered DO levels.

The Palm River system has also been affected by dredging, and channelization, stormwater discharges, reduction of freshwater inflow, and diminished flushing. The results, include increased salinity, accumulation of fine-grained sediments, and lowered DO levels. The northern shoreline of the Palm River has several industrial facilities, whereas the southern shoreline is more residential. Both the Palm and Lower Hillsborough rivers show evidence of stress from low dissolved oxygen. Extremely low dissolved oxygen concentrations are particularly common in waters deeper than two meters in the Palm River because of low flow and density stratification.

The Alafia River system has been heavily impacted by residential development in the lower reaches; agriculture and phosphate mining have affected the upper reaches. Impacts from the latter industries can be detected downstream (PIRG 2001; SWFWMD 2001). The Alafia is subject to surface water withdrawals to help meet agricultural and industrial needs (SWFWMD 2001). These withdrawals are augmented, in part, by surface water discharges into the Alafia River from phosphate industry related activities upstream of the estuary (SWFWMD 2001).

The Little Manatee River has been the least impacted of these four tributaries, although the watershed has been modified by agriculture and residential development. The portion of the river below I-75 is suburban/urban (especially Marsh Branch & Ruskin Inlet) and farther upstream there are agricultural (pastureland, citrus, tomatoes) and phosphate mining activities (Fernandez 1985; PBS&J 2001).

The Tampa Bay Benthic Index scores were relatively low for all four tributaries relative to samples from Tampa Bay proper. The current version of the TBBI was developed using samples from the bay-wide Tampa Bay Benthic

Monitoring Program collected from 1993-2000 (Janicki Environmental, 2005). Data for lower salinity sites was under represented in the TBBI calibration. Factors used in the calculation of the TBBI include species richness and the relative abundance of spionid and capitellid polychaetes. The depressed TBBI scores observed in the tributaries is likely due to the lower species richness and higher abundance of capitellid polychaetes that naturally occur in lower salinity systems, rather than a reflection of the "health" of the benthic habitat. This is especially apparent in the Little Manatee River, a relatively unimpacted system, where approximately 60% of the samples had TBBI scores below the cutoff for impacted habitats. Future revisions of the TBBI will be improved by the inclusion of these tributary monitoring data.

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Cross Bayou Sediment Contaminant Survey

Steve Grabe (Janicki Environmental) and Robert McWilliams (Pinellas County Department of Environmental Management)

Pinellas County, Southwest Florida Water Management District and the municipalities of Largo, Pinellas Park, and Seminole, began work in Fall 2003 on a comprehensive management plan for the Cross Bayou Watershed. Pinellas County is integrating this management plan and its implementation with the County's Brownfields program.

The Cross Bayou Canal, constructed during 1916-1917 (St Petersburg Times 1964), extends almost 17 kilometers (10.5miles), from Boca Ciega Bay on the southwest to Old Tampa Bay on the northeast, bisecting Pinellas County. The estimated area of the Cross Bayou basin is 31.2 km^2 (7,700 acres) (Pinellas County, 2005a). The smaller red basin attached to Cross Bayou (Figure 1) is Pinellas Park Ditch #1. It is regarded as a water quality point source because it drains directly into the Cross Bayou Canal. The Joe's Creek basin was also included because of the similar reasons, but was actually included in the sediment study due to its size and potential source for contamination to the Cross Bayou Canal system. The Joe's Creek Basin includes approximately 18 km (11.2 mile) of channels and drains approximately 38.4 km^2 (9,500 acres) (Pinellas County, 2005a). The Joe's Creek basin includes Joe's Creek proper (11.3 km; 7.1 mi), Pinellas Park Ditch #5, Pinellas Park Ditch #4 (or Bonn Creek; 5.8 km; 3.6 mi), and the Miles Creek system.

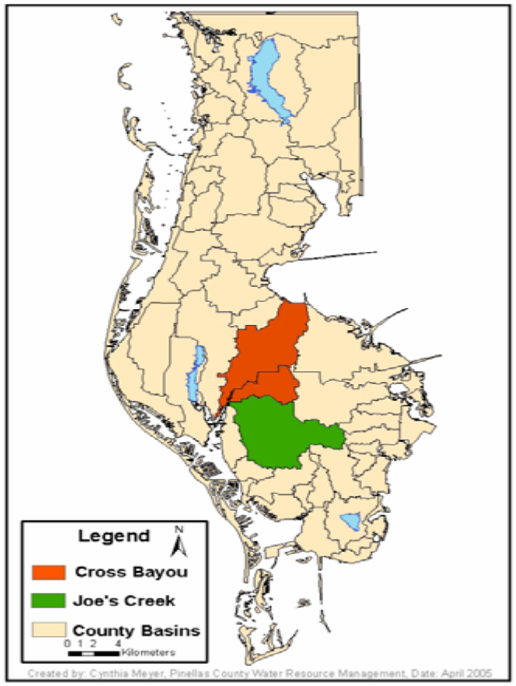

Figure 1. The Cross Bayou (with Pinellas Park Ditch #1 attached) and Joe's Creek basins

Related to the development of the watershed management plan, Pinellas County's Department of Environmental Management [PCDEM] (Pinellas County 2005b) developed a sediment contaminant screening project in the Spring of 2005. The four major objectives of the project are to:

- Conduct a literature review and assemble a database of existing sediment contaminant data from the Cross Bayou watershed, including Joe's Creek and adjoining areas of Boca Ciega and Old Tampa bays;

- Collect sediment samples for analysis of trace metals, organochlorine pesticides, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) as well as characterize the percentage of fine grained sediments (<0.62 mm) in these samples;

- Estimate the spatial distribution of the detected sediment contaminants, including station-specific evaluations; and

- Determine both the most likely as well as possible sources of these contaminants in the Cross Bayou watershed as a whole, as well as adjoining areas of Old Tampa Bay.

To meet the objectives of the project, PCDEM and Janicki Environmental Inc. [JEI] developed a "directed" sampling program to target areas of potential impacts.

Field sampling methods were modified from those described by PCDEM (Water Resources Management Section 1996) and were similar to those used in the baywide benthic monitoring program. The primary difference was the manual deployment of the Young grab sampler (absent its frame) to facilitate collection of sediments in areas not accessible by boat.

Every station sampled (Figure 2) showed some evidence of impaired sediment quality, ranging from anthropogenic enrichment by a single metal, to Sediment Quality Assessment Guidelines

[SQAGs] that indicate a high likelihood that the sediments are toxic from Polycyclic Aromatic Hydrocarbons (PAHs) and the pesticide Chlordane (Figures 3, 4 and 5, Table 1).

Five sites (CB02, CB06, CB11, CB13, and JC04) only showed evidence of enrichment by between one (CB13- Zinc) and four (JC04-Copper, Nickel, Silver, and Zinc) metals.

Four stations (CB14, JC01, JC02, and JC05) were impaired both by enrichment by two to four metals as well as concentrations of metals and PAHs greater than the Threshold Effect Level/Threshold Effect Concentration (TEL / TEC). JC01 had three metals and two PAHs greater than their threshold levels and JC05 had five PAHS above their thresholds.

Sediments at stations CB05, CB09, CB12, and JC07 were enriched by metals, and had concentrations of several metals and/or PAHs >TEL/TEC as well as the Probable Effect Level/Probable Effect Concentration (PEL/PEC).

The two stations that appeared to be the most impaired were CB08 (off 66th Street N and Bryan Dairy Road) and JC03 (south of 54th Avenue). These stations had five and six organic contaminants at concentrations >PEL as well as seven and one contaminants respectively >TEL and enrichment by two and three metals.

This screening study showed that some level of sediment degradation was evident at each of the 19 stations sampled. The extents of degradation ranged from anthropogenic enrichment by one or more trace metals (not necessarily indicative of toxicity) to concentrations of Silver and several organic contaminants, which exceeded their PELs. These sediments are generally more degraded than adjacent areas of Tampa Bay (Boca Ciega Bay and Western Old Tampa Bay), but were somewhat comparable to the conditions found in the 2003 Special Study of Long and Cross Bayous (TBEP unpublished data).

Figure 2. Location of sampling stations in Cross Bayou and Joe's Creek basins.

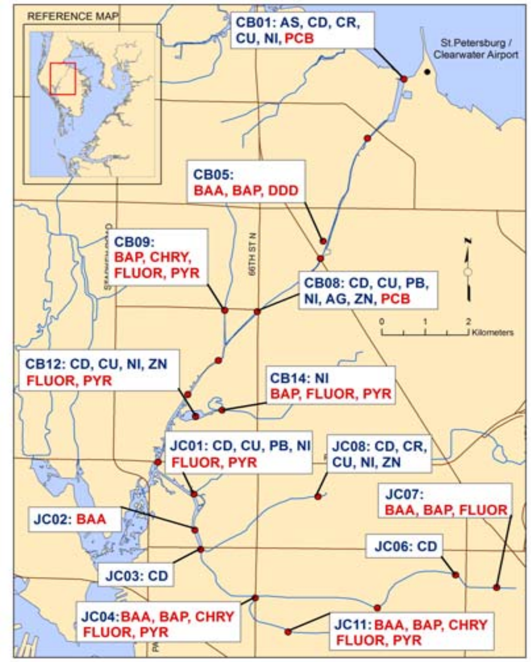

Figure 3. Stations exceeding Threshold Effects Level and Threshold Effects Concentrations for sediment contaminants in Cross Bayou Watershed, June 2005.

KEY: AS=ARSENIC; CD=CADMIUM; CR=CHROMIUM; CU=COPPER; PB=LEAD; NI=NICKEL; AG=SILVER; ZN=ZINC; PCB=TOTAL PCBS x2; BAA=BENZ(a)ANTHRACENE; BAP=BENZO(a)PYRENE; CHRY=CHRYSENE; FLUOR=FLUORANTHENE; PHEN=PHENATHRENE; PYR=PYRENE;CHLD=TOTAL CHLORDANE; DDD=DDD

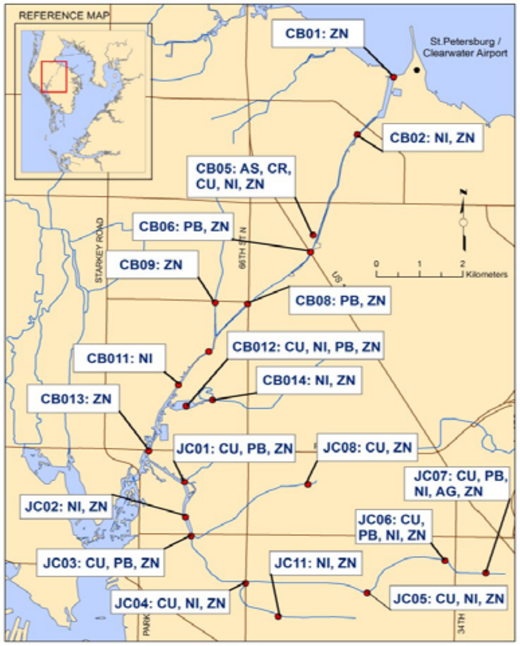

Figure 4. Anthropogenic metals enrichment by station in Cross Bayou Watershed, June 2005. KEY: AS=ARSENIC; CD=CADMIUM; CR=CHROMIUM; CU=COPPER; PB=LEAD; NI=NICKEL; AG=SILVER; ZN=ZINC

Table 1. Summary of sediment contaminant status, by station, Cross Bayou watershed, June 2005.

	METAL ENRICHMENT	>TEL/TEC (METALS)	>TEL/TEC (ORGANICS)	>PEL/PEC (METALS)	>PEL/PEC (ORGANICS)
CROSS BAYOU BASIN					
CB1	ZN	AS,CD,CR,CU,NI	PCB	AG	
CB2	NI,ZN				
CB5	AS,CR,CU,NI,ZN		BAA, BAP,DDD		CHRY, FLUOR
CB6	CU,NI,PB,ZN				
CB8	PB,ZN	CD,CU,PB,NI,AG ,ZN	PCB		BAA,BAP,PHEN, CHRY, FLUOR,PYR
CB9	ZN		BAP,CHRY,FLUOR, PYR	AG	
CB11	NI				
CB12	CU,NI,PB,ZN	CD,CU,NI,ZN	FLUOR, PYR		BAP,CHRY
CB13	ZN				
CB14	NI,ZN	NI	BAP,FLUOR,PYR		
JOE'S CREEK BASIN					
JC1	CU,PB,ZN	CD,CU,PB,NI	FLUOR,PYR		
JC2	NI,ZN		BAA		
JC3	CU,PB,ZN	CD			CHLD,BAP,CHRY, FLUOR,PYR
JC4	CU,NI,ZN				
JC5	CU,NI,ZN		BAA,BAP,CHRY,FLUOR, PYR		
JC6	CU,PB,NI,ZN	CD			
JC7	CU,PB,NIAG,ZN		BAA,BAP,FLUOR	AG	CHRY, PYR
JC8	CU,ZN	CD,CR,CU,NI,ZN			
JC11	NI,ZN		BAA,BAP,CHRY,FLUOR, PYR		CHLD
KEY: AS=ARSENIC; CD=CADMIUM; CR=CHROMIUM; CU=COPPER; PB=LEAD; NI=NICKEL; AG=SILVER; ZN=ZINC; PCB=TOTAL PCBS x2; BAA=BENZO(a)ANTHRACENE; BAP=BENZO(a)PYRENE; CHRY=CHRYSENE; FLUOR=FLUORANTHENE; PHEN=PHENATHRENE; PYR=PYRENE;CHLD=TOTAL CHLORDANE; DDD=DDD					

CONCLUSIONS

- The MDLs for Silver, Antimony, all of the organochlorine pesticides, low molecular weight PAHs, and some high molecular weight PAHs were unacceptably high. Problems reported to contribute to this problem included interferences from "non-target" compounds and the high moisture content of some sediment samples
- There was evidence of widespread anthropogenic enrichment of sediments by metals, especially Cadmium
- Silver exceeded the PEL at two locations; no other metal exceeded its PEL
- TEL/TEC exceedences were most often from metals associated with the use of motor vehicles
- There was no compelling evidence of an industrial source for any of the metals
- Organochlorine pesticides detected at concentrations above their MDLs included DDD (>TEL), Chlordane (>PEL) and Methoxychlor. Methoxychlor concentrations were >20 ppb at three locations, higher than concentrations in other areas of Tampa Bay
- Total PCB concentrations were >TEL at only a single station.

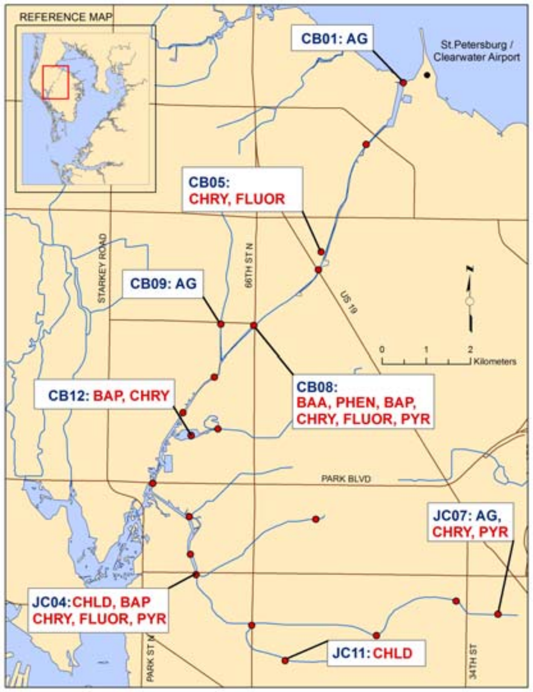

Figure 5. Stations exceeding Predicted Effects Level and Predicted Effects Concentrations for sediment contaminants in Cross Bayou Watershed, June 2005.

KEY: AG=SILVER; BAA=BENZ(a)ANTHRACENE; BAP=BENZO(a)PYRENE; CHRY=CHRYSENE; FLUOR=FLUORANTHENE; PHEN=PHENATHRENE; PYR=PYRENE;CHLD=TOTAL CHLORDANE

- PAHs were the contaminants most often detected at concentrations >PEL/PEC, even though the MDLS for the lower molecular weight PAHS were inordinately high.
- Isomer ratio analyses suggest that the PAHs present reflect a typical "urban mixture" that is most closely related to automotive emissions.
- PCB concentrations are generally low. Two pesticides, Methoxychlor and Chlordane, occurred at a small number of stations at concentrations that are problematic.

To address the MDL problem mentioned above, sites of concern and areas adjacent to them will be resampled in the fall of 2006. Samples will be analyzed with more sensitive MDLs.

Finally, with respect to metals and PAHs, roadway runoff is the most likely source of these classes of contaminants. In fact, the mixture of contaminants approximated what has been termed an "urban mixture" or an "urban cocktail." There did not appear to be evidence of industrial or other sources (*e.g.*, application of arsenicals to golf courses, Copper for control of algae). This does not, however, preclude sources other than stormwater runoff contributing to sediment contamination in this watershed.

K. M. Fischer (FWC Fish and Wildlife Research Institute)

- CHAPTER HIGHLIGHTS -

- *The Fisheries-Independent Monitoring program has used seines and trawls to sample finfish and select macroinvertebrate populations in Tampa Bay since 1989.*
- *Relative abundance estimates of young-of-the year red drum peaked in 1991, 1995, and 2003 and were relatively constant from 1996 to 2001.*
- *Recruitment of young-of-the-year sheepshead appears to have occurred in three-year cycles, with a year of relatively higher recruitment (1991, 1994, 1997, and 2000) followed by two years of moderate to low recruitment.*
- *Relative abundance estimates of young-of-the-year snook remained fairly constant from 1989 to2005 with the exception of a peak in 1999.*
- *Recruitment of young-of-the-year spotted seatrout was relatively stable from 1991 to 2004. Recruitment of young-of-the-year spotted seatrout was relatively lower than previous years in 2005.*
- *Relative abundance estimates of young-of-the-year blue crab were lowest in 1990 and peaked in 1989, 1992, 1995, 1998, and 2003.*

INTRODUCTION

Since 1983, the Florida Fish and Wildlife Conservation Commission (FWC) at the Fish and Wildlife Research Institute (FWRI) has been developing a systematic and continuing program to monitor commercial and recreational marine fisheries and to collect and integrate essential information used in the management and enhancement of Florida's marine resources. Five basic components currently compose Florida's Marine Fisheries Monitoring Program: the Florida Marine Fisheries Information System (marine fisheries trip tickets), the Trip Interview Program (TIP), the National Marine Fisheries Service's (NMFS) Marine Recreational Fisheries Statistics Survey (MRFSS), the Gulf States Marine Fisheries Commission's (GSMFC) Fisheries Information Network (FIN), and the Fisheries-Independent Monitoring (FIM) program. Each component monitors the status of a different aspect of Florida's marine fisheries. This chapter will focus on the Fisheries Independent Monitoring program.

Fisheries-Independent Monitoring (FIM) Program

The Fisheries-Independent Monitoring program at FWRI was initially developed to assess the recruitment of resource species that use estuarine and near-coastal waters as nursery areas, and as such, was designed to sample finfish during pre-fishery life stages. Such an approach allows researchers to avoid many of the problems inherent in fisheries-dependent monitoring and provides stock estimates that are of much greater predictive utility than are estimates determined from fisheries-dependent monitoring. Long-term fisheries-independent monitoring of finfish in pre-fishery life stages should allow managers to formulate fisheries-management policies proactively rather than reactively, which has often been the traditional approach.

The FIM program's holistic sampling design provides data not only on commercially and recreationally important finfish stocks, but also on select macroinvertebrates and finfish stocks of indirect importance to Florida's fisheries. Furthermore, the program records extensive information on environmental and biological variables at each sampling site, which allows researchers to evaluate species interactions, habitat dependencies, and the effects of environmental influences on fishery recruitment processes.

Stratified-random-sampling surveys, in which multiple sampling gears are used (21-m seines, 6-m otter trawls, 183-m purse seines [ended in 2004], and 183-m haul seines), are conducted year-round by the FIM program in Tampa Bay. Estimates of the relative abundance and information on the length-frequencies of populations of resource species are provided by this survey. Biological samples are collected from a randomly selected subsample of the catch so that information can be gathered on the sex-ratio, age distribution, and reproductive condition of designated species, including snook, spotted seatrout, red drum, and sheepshead. To gather background information on and to monitor the status of fish health, large specimens are examined for external abnormalities (e.g., tumors, lesions, parasites) and tissue samples from select species are analyzed for mercury content.

The FIM program was originally developed with funding provided by a Department of the Interior, U.S. Fish and Wildlife Service's Federal Aid to Sportfish Restoration grant. Although funding under the federal grant continues, the program is now primarily supported by state funds generated from the sale of saltwater fishing licenses. The program is intended to be sustained on a continuing basis and eventually to be expanded to include all major estuarine and coastal nursery areas in the state. Routine monitoring programs have been established in Tampa Bay (1989), the northern half of Charlotte Harbor (1989), the northern and southern portions of the Indian River Lagoon (1990 and 1997, respectively), Florida Bay (1994-1997), Cedar Key (1996), Apalachicola Bay (1997), and St. John's River (2000).

Table 12-1. The FIM program's stratified-random sampling survey, 1989-2005; number of samples, animals, and taxa and the mean sizes of animals collected, by gear type

Gear	*Years sampled*	*No. samples*	*No. animals*	*No. taxa*	*Mean size (mm)*
21-m seine	1989-2005	9,472	7,301,163	193	33
6-m otter trawl	1989-2005	4,865	729,304	174	47
183-m haul seine	1996-2005	2,335	349,932	136	152
183-m purse seine	1997-2004	2,050	226,036	110	167
Total	-	18,722	8,606,435	-	-

RESULTS

Over eight and a half million animals (fishes and select macro-invertebrates) have been collected and released in the 18,722 stratified-random samples (Table 12-1) collected by the FIM program in Tampa Bay since 1989. In the 2005 stratified-random-sampling survey alone, more than 1,200 samples were taken and all of Tampa Bay's major areas were sampled (Figure 12-1). The 21-m seine has collected nearly 85% (n= 7,301,163) of the animals since 1989 and has sampled the most diverse species assemblage (193 taxa; Table 12-1). The 183-m haul and purse seines, which are designed to collect subadult- and adult-sized finfish, collected animals with larger mean sizes than did any of the other gear types. Survey results concerning five economically important species (red drum, sheepshead, spotted seatrout, snook, and blue crab) collected by the FIM program are discussed in this chapter.

Red drum (*Sciaenops ocellatus*)

The red drum is a popular recreational species in Florida. Overfishing by recreational and commercial fisheries depleted adult populations of red drum throughout the Gulf of Mexico during the late 1980's. Strict federal and state regulations effectively eliminated the inshore and offshore fisheries, both commercial and recreational, from 1987 to1988. In 1989, a limited recreational fishery in state waters was reestablished.

Adult red drum spawn in offshore waters during the early fall, and small young-of-the-year red drum recruit into lower-salinity backwater areas of Tampa Bay from October to December. Red drum grow quickly during their first two years, reaching approximately 308 mm (12”) total length by age one and entering the fishery at 462 mm (18”) total length between the ages of one and two years. Red drum typically remain in the Tampa Bay estuary until they reach an age of about 3 years, at which time they move offshore and join the spawning population of adult red drum.

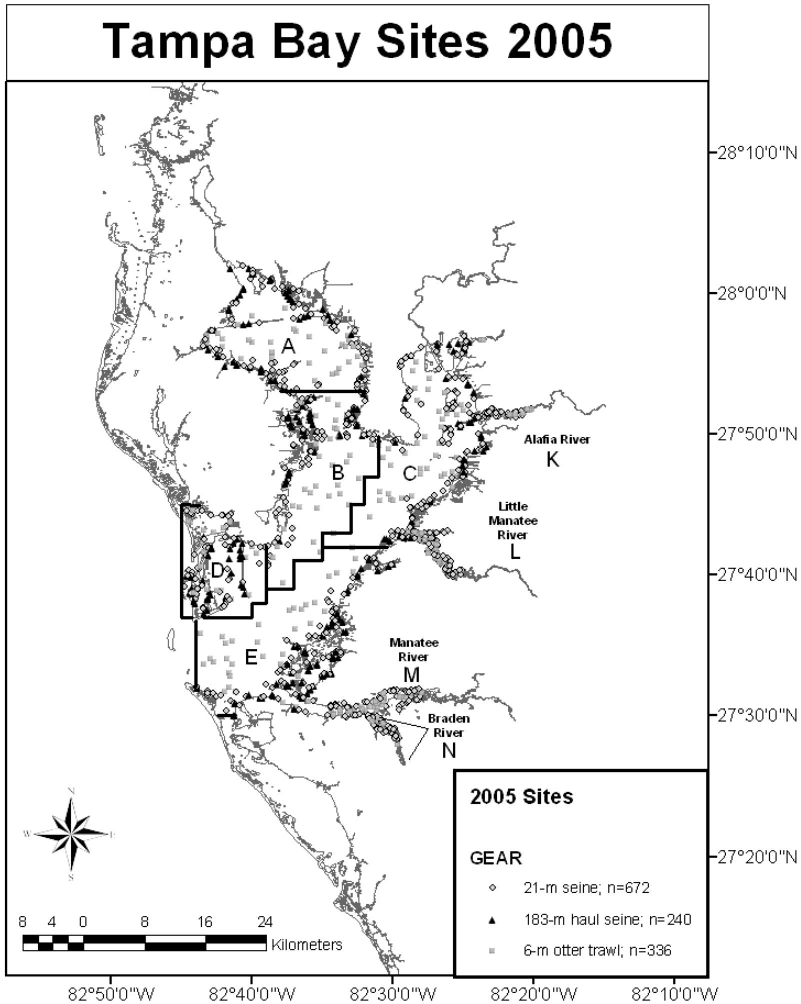

Figure 12-1. Zones (designated by capital letters *A*-*E* and *K*-*N*) and sites sampled by the Fisheries-Independent Monitoring program during stratified-random sampling in Tampa Bay, 2005. In the key, "n" denotes the number of samples taken.

Relative abundance estimates (median number of fish per set) of small young-of-the-year (≤35 mm standard length) red drum and of red drum that have not yet entered the fishery (pre-fishery; 275-400 mm standard length) are valuable management tools. In Tampa Bay, the annual relative abundance estimates for small young-of-the-year red drum peaked in 1991and1995, fluctuated very little from 1996-2001, and peaked again in 2003 (Figure 12-2). Annual relative abundance estimates have declined from the peak in 2003 to the lowest recorded levels in 2005. Relative abundance estimates of pre-fishery-sized red drum, which are mostly one-year-old fish, had a similar trend to that of the small young-of-the-year fish. However, even though 2004 to 2005 showed a sharp decline, relative abundance estimates were lowest in 2001.

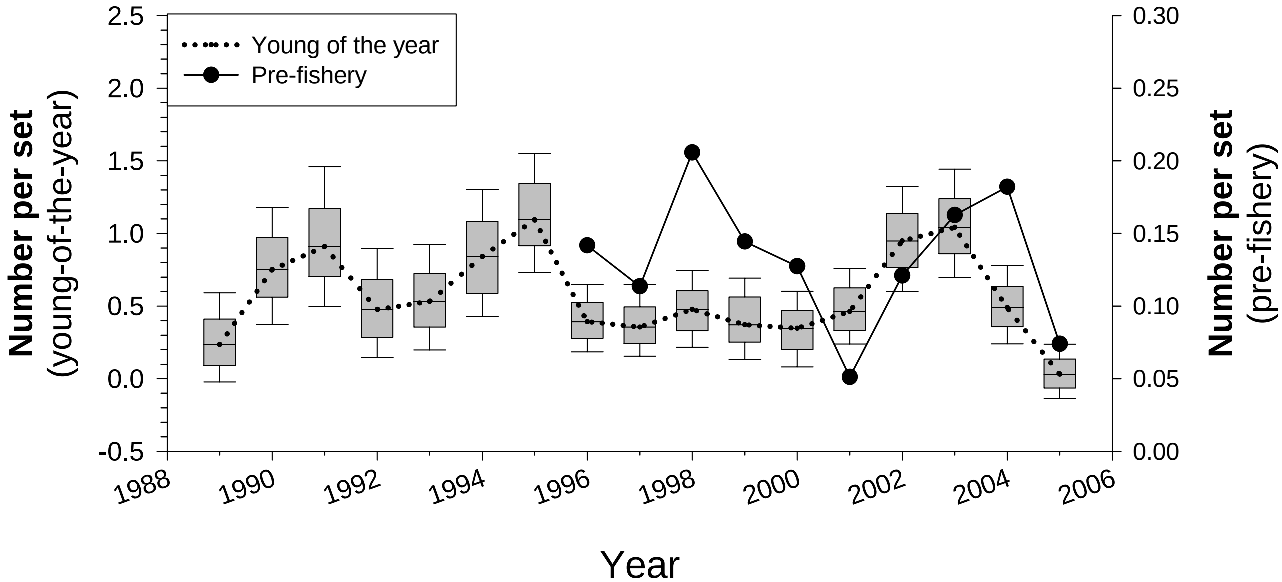

Figure 12-2. Annual estimates of relative abundance of red drum collected in Tampa Bay. Numbers of young-of-the-year (≤35 mm standard length) red drum collected per set in 21-m seines between October and December and of pre-fishery (275-400 mm standard length) red drum collected per set in 183-m haul seines between September and April are presented. The dotted line (young-of-the-year) and circles (pre-fishery) represent the median number of fish collected per set and the vertical line extends from the 25th to 75th percentile.

Sheepshead (*Archosargus probatocephalus*)

The sheepshead is commonly associated with submerged structures such as bridge pilings, oyster beds, and offshore reefs, but it can also be abundant in shallow inshore areas of Florida's estuaries. Small young-of-the-year sheepshead (≤40 mm standard length) tend to recruit during the spring and are common in shallow inshore waters through July. Sheepshead grow relatively slowly, reaching only about 150 mm fork length by age one, and enter the fishery at 308 mm (12") fork length between the ages of two and five years.Young-of-the-year sheepshead recruitment into Tampa Bay appears to have followed a three-year, cyclical pattern since 1989; two years of low to moderate relative abundance have typically been followed by a year of higher relative abundance (Figure 12-3). The lowest relative abundance estimates for young-of-the-year sheepshead in Tampa Bay occurred during 1989, and relative abundance estimates peaked during 1991, 1994, 1997, 2000 and 2004. Estimates of the relative abundance of pre-fishery-sized sheepshead (131-267mm standard length), which are mostly fish ages one to four years old, peaked in 1996, 1999, and 2003.

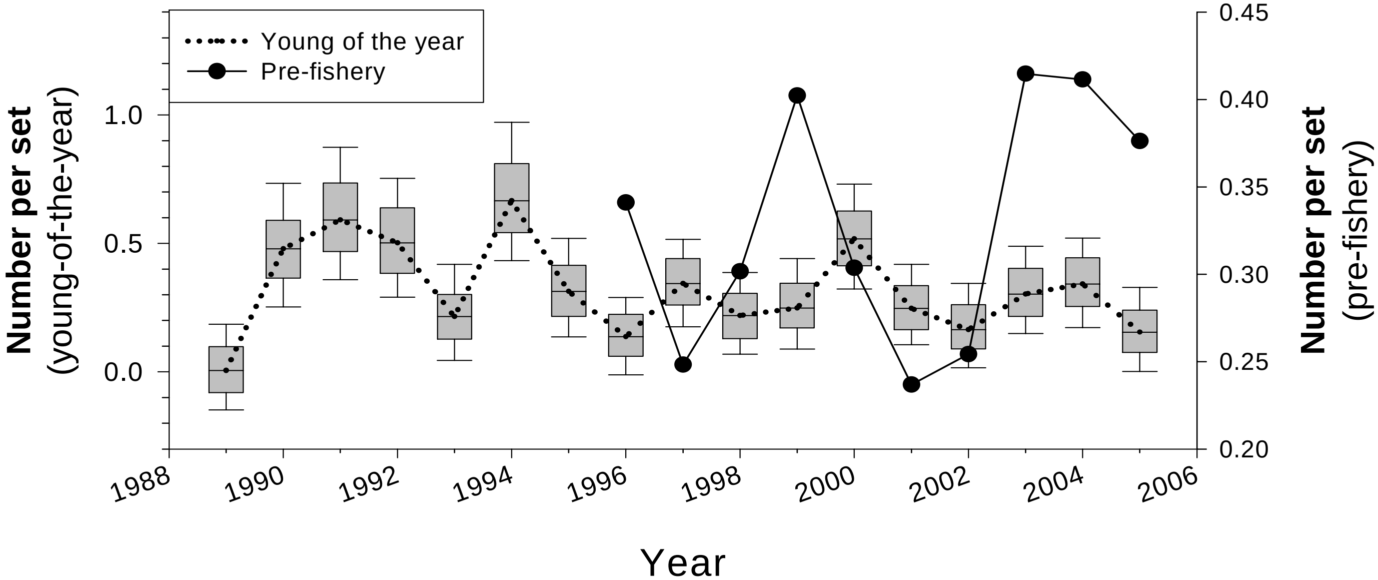

Figure 12-3. Annual estimates of relative abundance of sheepshead collected in Tampa Bay. Numbers of young-of-the-year (≤40 mm standard length) sheepshead collected per set in 21-m seines between April and July and of pre-fishery (131-267 mm standard length) sheepshead collected per set in 183-m haul seines between April and March are presented. The dotted line (young-of-the-year) and circles (pre-fishery) represent the median number of fish collected per set and the vertical line extends from the 25^{th} to 75^{th} percentile.

Snook (*Centropomus undecimalis*)

Snook are one of the most sought after and elusive recreational species in Florida waters. In Florida, snook are common from Tampa Bay southward along the Gulf Coast and then northward to Ponce Inlet on the East Coast. Its northern range is limited by the snook's intolerance for prolonged, cool water temperatures. Fisheries management has reduced the capture of snook by imposing recreational bag limits, slot limits, closed seasons, and by prohibiting commercial harvest.

Snook spawn from April to December, with peak activity during the summer months in the passes of the Tampa Bay estuary. Typical nursery habitats of early young-of-the-year snook (≤150 mm standard length) are shallow, brackish streams and canals with overhanging vegetation or marsh grasses – habitats that are most efficiently sampled by the 21-m seine. Young-of-the-year snook are most abundant from August to February. Since seasonal fall and spring sampling prior to 1996 did not effectively cover the recruitment months for young of the year snook, annual estimates of abundance were based on monthly sampling from 1996 to 2005 (Figure 12-4). Annual estimates of the relative abundance of young-of-the-year snook have shown little variation from 1996 to 2005, with the exception of a peak in 1999 (Figure 12-4).

Snook become susceptible to capture by the 183-m haul seine as they mature and move from their young-of-the-year nursery habitats to shallow seagrass beds, deeper water channels, and mangrove fringe habitats. Annual estimates of relative abundance of snook that have not yet entered the fishery (pre-fishery; 200-500 mm standard length) were lowest in 1997 and relatively higher in 1999 and 2000 (Figure 12-4). Estimates of relative abundance remained fairly constant from 2001 to 2005. Abundance estimates in this time period were slightly lower than the peaks in 1999 and 2000 but relatively higher than the 1996 and 1997 estimates (Figure 12-4).

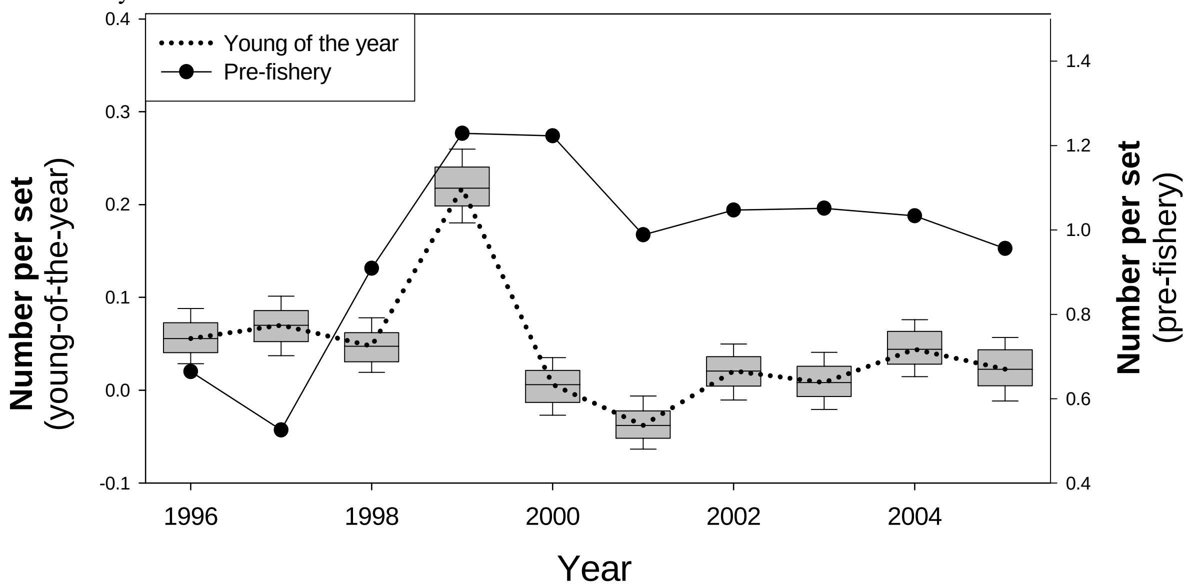

Figure 12-4. Annual estimates of relative abundance of snook collected in Tampa Bay. Numbers of young-of-the-year (≤150 mm standard length) snook collected per set in 21-m boat set seines between August and February and of pre-fishery (200-500 mm standard length) snook collected per set in 183-m haul seines between July and June are presented. The dotted line (young-of-the-year) and circles (pre-fishery) represent the median number of fish collected per set and the vertical line extends from the 25^{th} to 75^{th} percentile

Spotted Seatrout (*Cynoscion nebulosus*)

The spotted seatrout is found along the Atlantic Coast south of Delaware, and throughout the Gulf of Mexico. Throughout its range, it is an important recreational and commercial species. In July 1995, the state of Florida implemented a ban on the use of entangling gears (gillnets and trammel nets) within state waters, reducing commercial landings of spotted seatrout by more than 90%. At about the same time, recreational size and bag limits were changed to reduce the recreational harvest of this species.

In Florida, spotted seatrout have a very protracted reproductive season: small young-of-the-year (≤65 mm standard length) fish recruit into the Tampa Bay estuary from May to October. Newly recruited spotted seatrout tend to settle in shallow estuarine areas, where the 21-m seine most efficiently samples them. Annual recruitment of young-of-the-year spotted seatrout into Tampa Bay was highest in 1989 and 1995 and lowest in 1990 and 2005 (Figure 12-5). Aside from those years, annual recruitment has shown relatively little variation. Relative abundance estimates of pre-fishery-sized spotted seatrout (100-330 mm standard length) peaked in 1996, remained relatively constant from 1997 to 2003, peaked again in 2004, and dropped to the lowest estimates recorded in 2005 (Figure 12-5). Due to the termination of purse seine sampling after 2004, some decline in the estimates of relative abundance in pre-fishery-sized trout was expected in 2005.

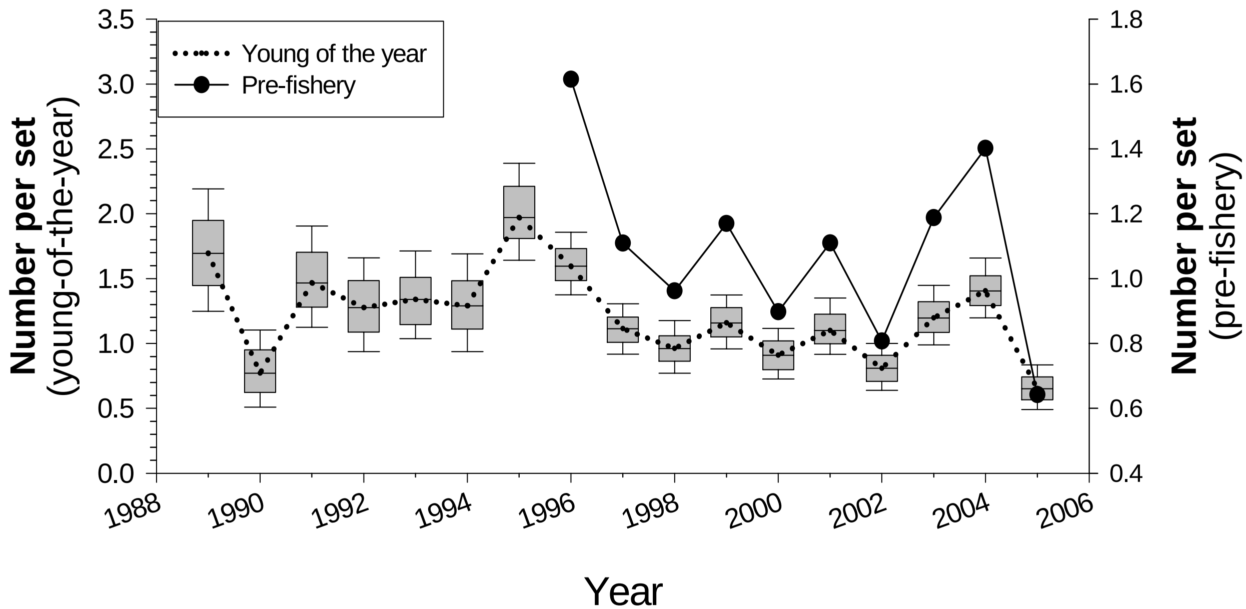

Figure 12-5. Annual estimates of relative abundance of spotted seatrout collected in Tampa Bay. Numbers of young-of-the-year (≤65 mm standard length) spotted seatrout collected per set in 21-m seines between May and October and of pre-fishery-size (100-330 mm standard length) collected per set in the 183-m haul seines (all years) and purse seines (1997-2004) between May and April are presented. The dotted line (young-of-the-year) and circles (pre-fishery) represent the median number of fish collected per set and the vertical line extends from the 25^{th} to 75^{th} percentile.

Blue Crabs *(Callinectes sapidus)*

The blue crab represents an important commercial and recreational fishery in Florida's inshore waters. The potential for increased fishing pressure on blue crab populations caused concern in the mid 1990's when the net ban amendment caused commercial fishermen who had been catching fish with entangling gears to shift their effort to the blue crab fishery. Estimating the annual relative abundance of young-of-the-year blue crabs provides one method of assessing the status of the blue crab stocks.

Although the FIM program was established to collect information on finfish stocks, it also records data on selected macroinvertebrate species (penaeid shrimp, blue crabs, stone crabs, and horseshoe crabs) during its routine sampling. Small young-of-the-year blue crabs (≤40 mm carapace width) are collected in 21-m-seine samples throughout the year but are most abundant between September and April. Annual relative abundance estimates appear to have occurred in three-year cycles since 1989. Years with relatively higher abundance (1989, 1992, 1995, 1998, and 2003; Figure 12-6) have typically been followed by one to three years of relatively lower abundance. Relative abundance estimates from 1989 to1995 and from 1996 to 2000 were similar, suggesting that changes in the blue crab fishery since the enactment of the net-ban have not adversely affected the recruitment of young-of-the-year blue crabs into the Tampa Bay estuary.

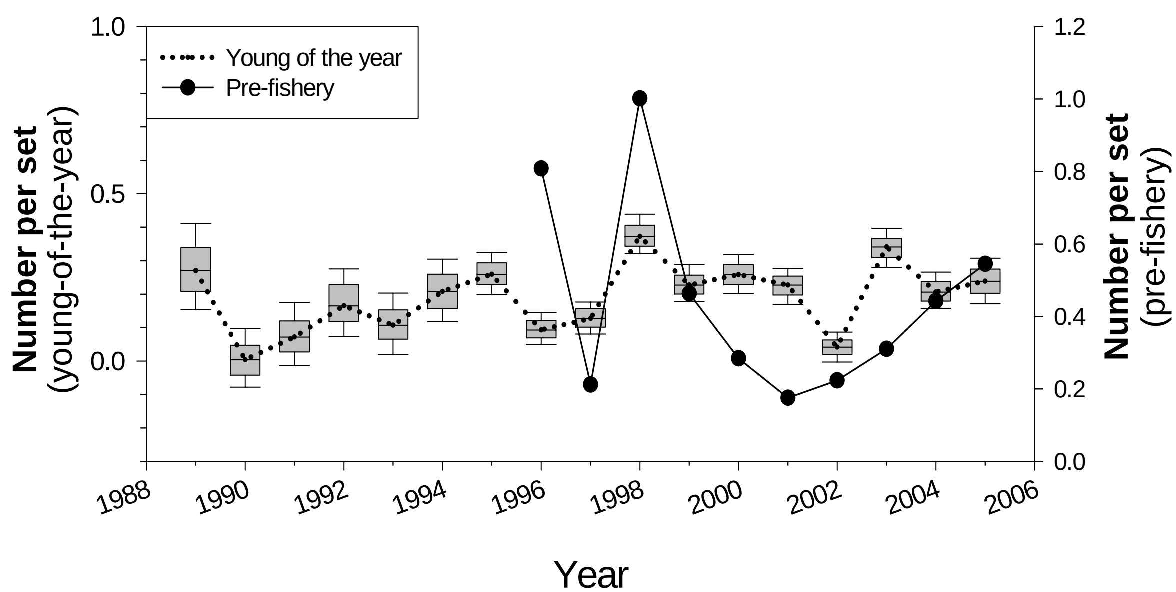

Figure 12-6. Annual estimates of relative abundance of blue crabs collected in Tampa Bay. Numbers of young-of-the-year (≤40 mm carapace width) blue crabs collected per set in 21-m seines between September and April and pre-fishery (>80 mm carapace width) collected per set in 183-m haul seines for all months are presented. The dotted line (young-of-the-year) and circles (pre-fishery) represent the median number of crabs collected per set and the vertical line extends from the 25th to 75th percentile.

Examining Habitat Use of Tidal Creeks and Man-made Ditches by Fishes and Macrocrustaceans in Tampa Bay's Mangrove Wetlands

C. C. McIvor (U.S. Geological Survey)
J. M. Krebs, A. B. Brame (ETI Professionals)

☞ *Shallow tidal creeks in Tampa Bay provided habitat for 78 taxa of fishes, pink shrimp, and blue crabs and supported greater mean±S.E. nekton densities (370±35.8 individuals) than man-made ditches (270±18.6).*

☞ *Man-made ditches constructed for mosquito control and stormwater drainage supported similar nekton densities (261±24.5 and 286±27.1, respectively), though fewer taxa were observed in mosquito-control ditches (n=45) compared to stormwater-drainage ditches (n=66).*

☞ *Ninety-five percent of the nekton assemblage in both tidal creeks and stormwater ditches was represented by 19 taxa. In comparison, mosquito ditches supported a less even species distribution (14 taxa comprised 95%).*

☞ *Nekton density in wetland ponds (463±44.1) was greater than that observed in tidal creeks and ditches, though fewer taxa (n=10) comprised the majority (95%) of the pond assemblage.*

Programs to monitor Tampa Bay's nekton community (fishes and crustaceans) have provided critical data for assessment and management of this valuable ecological resource. However, until recently, monitoring efforts have focused on the Bay proper and its larger tidal tributaries while the smaller tidal tributaries (both naturally-formed and man-made) have remained understudied. With the current rate of residential and commercial development, many of the Bay's smaller wetland systems, potentially important habitat for small nekton and juveniles of economically valuable species, are quickly disappearing.

METHODS

In an effort to better understand the wetland component of the Bay's nekton community, the U.S. Geological Survey (U.S.G.S.) is currently sampling nekton in naturally-formed and man-made mangrove habitats in Tampa Bay. The primary goal of the U.S.G.S. study is to assess the comparative value of naturally-formed tidal creeks and two types of altered mangrove habitats (i.e., mosquito-control ditches and stormwater-drainage ditches) as habitat for fishes, pink shrimp, and blue crabs. A secondary goal is to determine species composition and habitat use of wetland ponds as it relates to tidal connectivity with the larger estuary.

Seasonal seine sampling of tidal creeks, ditches, and ponds has been ongoing since December 2003 at wetland sites in state and county preserves located throughout Tampa Bay. Fixed sample sites were randomly selected at Mobbly Bayou County Preserve at the northernmost extent of Tampa Bay, Grassy Creek at Feather Sound and Weedon Island County Preserve in the central part of the estuary, and Terra Ceia State Aquatic Buffer Preserve near the mouth of Tampa Bay. At each creek and ditch site, nekton are collected using a 9-m or 15-m center bag seine set between block nets used to retain nekton and improve gear efficiency. Wetland ponds (n=14 ponds) are also sampled using a 15-m bag seine at randomly selected sites within each pond. Habitat parameters describing the degree of connectivity between the pond and Tampa Bay are being used to characterize the relative value of the ponds as habitat for species which migrate between shallow water wetland habitats and deeper-water habitats of Tampa Bay and the Gulf of Mexico. For all samples, size and abundance data are recorded for fishes, pink shrimp, and blue crabs and are being related to physical habitat data which are also recorded at each site. Habitat data include parameters describing water depth, velocity, and quality (i.e., temperature, salinity, pH, dissolved oxygen), substrate, shoreline vegetation and bottom vegetation.

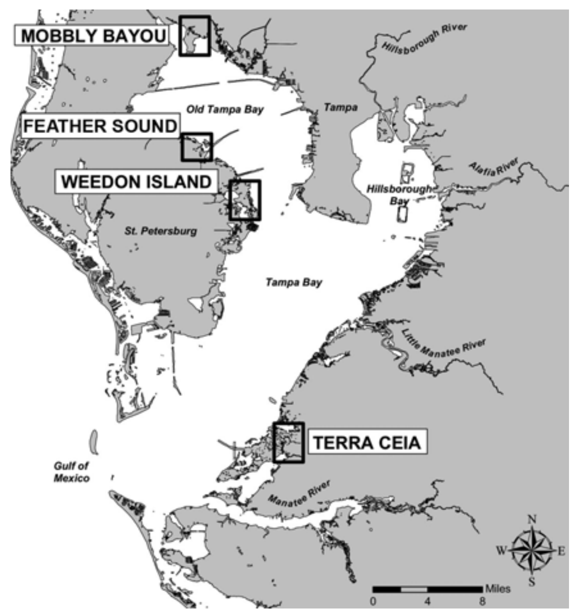

Figure 1. Sample regions for the U.S. Geological Survey's study of nekton habitat use.

Figure 2. "Center-bag seine and block net" method used to sample fishes and crustaceans in tidal creeks and ditches during the U.S.G.S. study of nekton habitat use. A mosquito-control ditch is seen here.

In addition to relating nekton abundance with typical measures of habitat (i.e., water quality, substrate type, vegetation), supplementary hydrological data are being collected at nekton sampling sites (though not in association with routine nekton samples). Simultaneous measurements of water depth, velocity, salinity and temperature over many tidal cycles within creeks, mosquito ditches, stormwater ditches, and ponds are being collected to help us decide if hydrological differences between natural and altered habitats may provide a better explanation of habitat use patterns for nekton.

RESULTS

During 2004 and 2005 sampling, 376 seine samples were collected in three types of small tidal tributaries (i.e., tidal creeks, mosquito-control ditches, stormwater- drainage ditches) resulting in 122,478 individuals representing 89 taxa. Mean±S.E. nekton density per 100m^2 in these shallow water habitats was 315±19.1 individuals. Greatest mean densities were observed in tidal creeks (370±35.8) where 19 species of nekton comprised 95% of the assemblage. Nekton densities in mosquito-control ditches (262±24.5) and stormwater-drainage ditches (286±27.1) were similar to one another, but in general, these man-made habitat types supported lower densities compared to naturally-formed tidal creeks. In stormwater ditches, 19 taxa comprised 95% of the nekton assemblage (similar to tidal creeks), but the majority of individuals (95%) in mosquito ditches were represented by fewer species (14 taxa).

Dominant species occurring in tidal creeks, mosquito ditches, and stormwater ditches were *Poecilia latipinna* (sailfin molly), *Lucania parva* (rainwater killifish), *Menidia* spp. (silverside), and *Gambusia holbrooki* (mosquitofish). While several species, including *Eucinostomus harengulus* (tidewater mojarra), *Fundulus grandis* (gulf killifish), and *Anchoa mitchilli* (bay anchovy) were considerably more abundant in stormwater ditches, several resident taxa common to both creeks and mosquito ditches, including *G. holbrooki*, were much less abundant there.

In comparison, the Bay's larger tributaries and offshore seagrass and unvegetated habitats are often dominated by several species common to smaller tidal tributaries, including *Anchoa* spp., *Menidia* spp., *Eucinostomus* spp., and *Leiostomus xanthurus* (spot). However, two species that are not commonly collected in smaller tidal tributaries, *Harengula jaguana* (scaled sardine) and *Lagodon rhomboides* (pinfish), are often highly abundant in Bay and river samples (data from the State's Fisheries-Independent Monitoring Program 2001-2003), likely the result of deeper water and seagrass habitat.

Recreational and commercial species, like *L. xanthurus*, *Mugil* spp. (mullet), *Sciaenops ocellatus* (red drum) and *Callinectes sapidus* (blue crab) were the most abundant economically important species in smaller tidal tributaries (i.e., creeks and ditches) as well as in Bay and river samples. However, two species, *Farfantepenaeus duorarum* (pink shrimp) and *Cynoscion nebulosus* (spotted seatrout) were dominant in Bay and river samples but were not nearly as abundant in smaller tidal tributaries. The greater abundance of *F. duorarum* and *C. nebulosus* in Bay and river samples compared to smaller tidal tributaries is probably a result of species associations with seagrass habitat not commonly found in creeks and ditches.

In wetland ponds, 312 samples were collected during the 2 year study period and yielded 144,344 individuals from 79 taxa. Mean nekton density in ponds was 463±44.1. The pond assemblage was dominated by *G. holbrooki* (49.6% of total), but also included *P. latipinna*, *Menidia* spp., *Anchoa* spp., *L. parva*, *Cyprinodon variegatus* (sheepshead minnow), and *L. xanthurus* (latter six species equal 41.8% of total). Differences in species composition and abundance were apparent between ponds, suggesting differential habitat use of ponds depending on degree of connection to Tampa Bay. Ponds with limited connection were habitat for a relatively low number of species and were dominated by resident forage fishes such as *G. holbrooki*, *P. latipinna*, *L. parva*, and *C. variegatus*. Wetland ponds with a persistent connection to Tampa Bay were habitat for a greater number of taxa including

Menidia spp., *Mugil cephalus* (striped mullet) and *Centropomus undecimalis* (snook) that migrate between the ponds and other estuarine habitats and were common here. The occurrence of juvenile and subadult stages of recreationally and commercially important species such as *C. sapidus*, *C. undecimalis*, and *Megalops atlanticus* (Atlantic tarpon) suggests that even the most isolated ponds may be utilized by transient species that spend only a portion of their life cycle in shallow estuarine habitats.

Wetland restoration has been an important tool in the conservation of Tampa Bay's shallow water habitats. Because the habitat value of smaller tidal tributaries for fishes and macrocrustaceans remains unclear, it is essential that more focused study of these habitats continues so that the contribution of juveniles from smaller tidal tributaries to fisheries in the Bay and coastal waters can be assessed. The ongoing U.S.G.S. study has been useful as a step in this direction by providing baseline ecological information from which restoration projects are currently being planned. These data will also be beneficial in evaluating the success of those restoration projects. More specifically, data from the U.S.G.S. study will be used to describe seasonal and inter-annual patterns of habitat use for nekton in naturally-formed tidal creeks compared to mosquito-control and stormwater-drainage ditches prior to restoration. These data can then be compared with data from post-restoration samples as a measure of restoration success. Nekton use of wetland ponds with varying degrees of tidal connection to Tampa Bay will also examined. The resulting peer-reviewed studies will be available following publication.

K K. Yates, T. M. Cronin, M. Crane, M. Hansen, A. Nayeghandi, P. Swarzenski, T. Edgar, G. R. Brooks, B. Suthard, A. Hine, S. Locker, D. A. Willard, D. Hastings, B. Flower, D. Hollander, R. A. Larson, K. Smith (United States Geological Survey)

- *CHAPTER HIGHLIGHTS* -

- *The extent of urbanization in the Tampa Bay watershed is predicted to double from 1992 to 2025, with agricultural land becoming reduced by 58% and forested land reduced by 80%. By the year 2025, 38% of the watershed is predicted to be covered by urban development.*
- *Submarine groundwater discharge rates into Tampa Bay are estimated as 1.6 to 10.3 m^3 m^{-2} d^{-1}.*
- *Nitrate and nitrate were not detectable in submarine groundwater sampled in Tampa Bay. Dissolved inorganic nitrogen in submarine groundwater discharge (SGD) samples consisted almost exclusively of ammonium (NH_4^+) with concentrations in SGD exceeding river input by up to an order of magnitude.*
- *Seasonal and interannual variability in total suspended solid concentrations decreased from 1990 to present,, however the cause remains unknown.*
- *Tampa Bay was formed when collapse features developed as a result of dissolution of underlying carbonates during mid to late Miocene sea-level low-stand resulting in the formation of depressions that make up the subbasins of Tampa Bay. Tampa Bay was inundated with seawater during post-glacial sea level rise approximately 6.8 to 7.5 ka.*
- *Data from sediment cores indicate that nitrogen concentrations have increased in Hillsborough Bay sediments over the past 100 years with a 15-fold increase in nitrogen. Sediments from Safety Harbor and near Terra Ceia show 5-fold and 3-fold increases, respectively.*
- *Feather Sound, Safety Harbor, Lake Maggiore, Hillsborough Bay, Middle Tampa Bay, and Southeast Tampa Bay (near Terra Ceia) show increases in organic carbon including a recent 8-fold increase at Safety Harbor and Feather Sound, a 30-fold increase at Lake Maggiore, and 2 to 3-fold increases in Central Tampa Bay and Hillsborough Bay. Carbon isotope data indicates the widespread development and influence of anaerobic recycling processes.*
- *Recent sediments in Safety Harbor and Lake Maggiore show the selective onset of anaerobic conditions due to the enhanced input of labile organic matter from algal, zooplankton, and sewage sources.*
- *The onset of anaerobic conditions enhances the potential for remobilization of toxic metals, release of carcinogenic organic contaminants, and the deterioration of benthic floral and faunal communities.*

INTRODUCTION

Many of the nation's estuaries have been environmentally stressed since the turn of the 20th century and will continue to be impacted in the future. Tampa Bay, one of the Gulf of Mexico's largest estuaries, exemplifies the threats that our estuaries face (EPA Report 2001, Tampa Bay Estuary Program-Comprehensive Conservation and Management Plan (TBEP-CCMP)). More than 2 million people live in the Tampa Bay watershed, and the population continues to grow. Demand for freshwater resources, conversion of undeveloped areas to residential and industrial uses, increases in storm-water runoff, and increased air pollution from urban and industrial sources are some of the known human activities that impact Tampa Bay. Beginning in 2001, additional anthropogenic modifications began in Tampa Bay including construction of an underwater gas pipeline and a desalinization plant, expansion of existing ports, and increased freshwater withdrawal from three major tributaries to the bay.

In January of 2001, the Tampa Bay Estuary Program (TBEP) and its partners identified a critical need for participation from the U.S. Geological Survey (USGS) in providing multidisciplinary expertise and a regional-scale, integrated science approach to address complex scientific research issues and critical scientific information gaps that are necessary for continued restoration and preservation of Tampa Bay. Tampa Bay stakeholders identified several critical science gaps for which USGS expertise was needed (Yates et al. 2001). These critical science gaps fall under four topical categories (or system components): 1) water and sediment quality, 2) hydrodynamics, 3) geology and geomorphology, and 4) ecosystem structure and function. Scientists and resource managers participating in Tampa Bay studies recognize that it is no longer sufficient to simply examine each of these estuarine system components individually. Rather, the interrelation among system components must be understood to develop conceptual and predictive modeling tools for effective ecosystem adaptive management. As a multidisciplinary organization, the USGS possesses the capability of developing and coordinating an integrated science strategy for estuarine research founded on partnerships and collaborative efforts, multidisciplinary teams of scientists, and integrated field work, data analysis and interpretation, and product development. The primary role of the USGS in Tampa Bay research was defined with our partners based upon this capability to address estuarine issues using an integrated science approach with a regional perspective and within a national context to complement the numerous ongoing science efforts by state and local agencies that address local issues within Tampa Bay. Six primary components of the USGS Tampa Bay Study address critical gaps within each of the four estuarine system components and focus on:

1.) Examining how natural and man-made physical changes affect ecosystem health through mapping and modeling.
2.) Identifying sources and quality of groundwater, surface water, and sediment,
3.) Determining current, historical, and pre-historical conditions in the bay to help serve as a guide for restoration planning,
4.) Assessing the natural and man-made changes affecting wetland health and restoration,
5.) Identifying and measuring the impact of urbanization on seafloor habitats,
6.) Providing a web-based digital information management system of information for scientists and the public, including a system that supports the work of those officials who must make decisions that affect the state of the bay.

The Tampa Bay Study is in its sixth year and will continue through September 2007. This paper presents a non-inclusive summary of key findings associated with the six primary project components listed above. Component 4 (above) is described in detail in the following chapter 13. More information on the Tampa Bay Study is available from our on-line digital information system for the Tampa Bay Study at http://gulfsci.usgs.gov.

MAPPING AND MODELING

Objectives of the Tampa Bay Estuary Program's Comprehensive Conservation and Management Plan focus on identifying and minimizing anthropogenic impacts to the Tampa Bay ecosystem and the wildlife it sustains. Both natural and anthropogenic changes in the physical structure of the Tampa Bay region inevitably impact all ecosystem processes. While the effects of some anthropogenic impacts are well understood (e.g. nitrogen loading), others remain to be identified and characterized.

Regional scale and high-resolution maps provide the physical context, background and baseline information for all other research, monitoring, and modeling activities in the Tampa Bay Study. Two seamless digital elevation models (DEM) have been developed for the Tampa Bay watershed and estuary by combining topographic data collected using a Light Detecting and Ranging (LiDAR) system over subaerial and intertidal areas, and baythmetric data collected by NOAA (add more) and USGS. Bathymetric data was collected using a towed acoustic sensor for Shallow and Nearshore Depth Surveys (SANDS). This system enable mapping in water depths as shallow as 0.3m, has a narrow seafloor foot print of 15cm at 3m water depth, and is accurate to within 8cm. An Experimental Advanced Airborne Research LiDAR (EAARL) system was used to collect togographic data in the nearshore tidal and subtidal zone up to 0.5m of water depth.

Regional scale and high-resolution bathymetric mapping of Tampa Bay has been performed by the USGS. This data provides the physical context, background, and baseline information for all other research and monitoring. In addition, bathymetric data provides critical information for the development of circulation, hydrologic, sediment transport, and water quality components of an integrated numerical model for predicting the system-wide impact of natural and anthropogenic changes in Tampa Bay. This data can be linked to wetland and sea grass distribution data, and groundwater data to understand the impacts and links between groundwater movement, elevation change, and habitat distribution and health. Updated and accurate bathymetry is necessary in order to facilitate the development and proper implementation of these integrated numerical models.

Two methods that have been developed by the U.S. Geological Survey and National Aeronautical and Space Administration (NASA) were used in the mapping process. The USGS method is an acoustic based system called System for Accurate Nearshore Depth Surveys (SANDS), and the NASA method is an airborne LIDAR system named Experimental Advanced Airborne Research Lidar (EAARL). The USGS SANDS system is specifically designed to map in very shallow water. The system can acquire data in water depths of ~25cm. Depth measurements are collected at 3m intervals along the survey line. The horizontal and vertical accuracies of the system are +/- 6cm and +/- 4cm, respectively. The SANDS survey line pattern selected for the Tampa Bay region consisted of parallel lines trending west to east at 500 m spacing and a denser pattern of 250m spacing for all navigation channels in the bay. The SANDS survey lines end at the 1 m contour near the shoreline and/or in environmentally sensitive areas (Figure 13-1).

The EAARL surveys focus on shallow areas of the bay primarily from the shoreline offshore to the 2 to 3 m contour. The EAARL lidar system uses a raster-scanning, pulsed, blue-green (532 nm wavelength) laser transmitter mounted on a low-cost, twin-engine Cessna 310 aircraft, or other equivalent aircraft of opportunity. The EAARL laser can penetrate water slightly more than one Secchi disk depth, allowing the sensor to map submerged and sub-aerial topography simultaneously. The geo-positioning of the each laser sample is obtained by dual-frequency kinematic carrier-phase GPS measurements of the primary EAARL GPS antenna made relative to a fixed GPS antenna back at the departure airport or a nearby location. The attitude information that accounts for aircraft motion effects is determined from an integrated digital inertial measurement unit (IMU) mounted with the laser optics. EAARL surveys were conducted in February 2003 and March 2004 to provide high-resolution topography in shallow submerged regions for the Tampa Bay Study (Figure 13-2). The flights were based at Albert Whitted airport in St. Petersburg, Florida and the GPS base station was mounted atop the U.S. Geological Survey building roughly 1 mile west of the airport. During data collection, the aircraft maintained a speed of 60 m/s at an altitude of 300 m. This resulted in approximately 240 m swaths over the survey area. Post-flight processing was accomplished using a custom-built processing system known as the Airborne Lidar Processing System (ALPS). The data were processed for submerged topography and bare-Earth topography under sub-aerial vegetated areas.

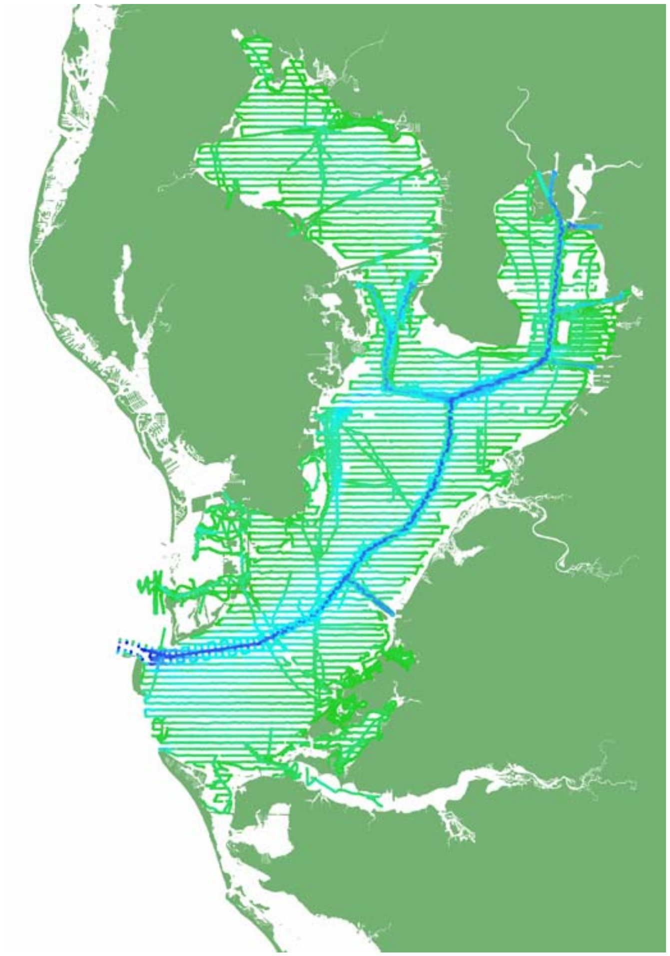

Figure 13-1. Track line for collection of bathymetric data using a towed acoustic sensor for Shallow and Nearshore Depth Surveys (SANDS). 3600 kilometers of data were collected at 500 m trackline spacing.

The data were referenced to the NAD83 horizontal datum and NAVD88 vertical datum based on the GEOID99 model. This sampling scheme provides complete survey coverage in shallow waters where more geomorphic detail is required and wider survey coverage in deeper waters where less detail in required. Also, this scheme takes advantage of the limitations of both systems providing an accurate and cost effective survey of the entire bay. The Tampa Bay bathymetry

An integrated Digital Elevation Model (DEM) was created for the Tampa Bay watershed at 10m horizontal resolution. DEMs for land surface were acquired from the USGS National Elevation Database and NOAA bathymetry data was resampled at 10 m to develop a 10m grid for bathymetry and landsurface elevation. EAARL Lidar data collected by NASA and USGS was used to interface bathymetric and land surface topography to create a seamless DEM. Figure 13-3 shows the DEM covering the entire Tampa Bay water shed at a resolution of 10 m (1/3 arc second), while the inset shows the second DEM focusing on the Port Manatee region of Tampa Bay at a resolution of 3.3m (1/9 arc second). These maps are used as boundary conditions for numerical modeling activities associated with other components of the Tampa Bay Study.

Figure 13-2. Track line for collection of topographic and bathymetric data in the intertidal and nearshore areas of Tampa Bay using the Experimental Advanced Airborne Research LiDAR (EAARL) system. Red lines were collected in 2003, yellow lines were collected in 2004.

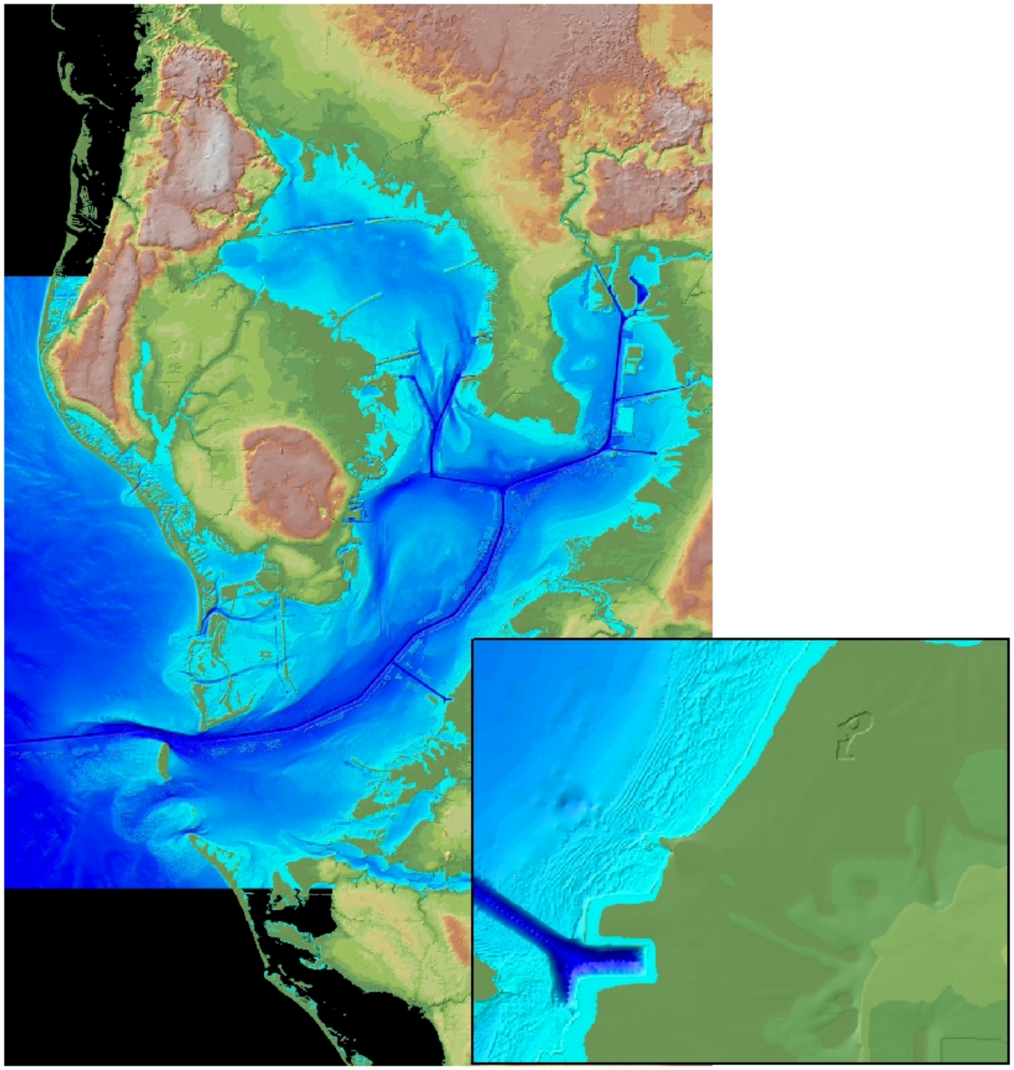

Figure 13-3. Two seamless Digital Elevation Models (DEMs) have been created for Tampa Bay – the one shown here that focuses on the estuary at 1/9 arc second (3.3m), and another at 1/3 arc second (10m) covering the entire Tampa Bay watershed. Source: http://gisdata.usgs.net/website/topobathy/, http://chartmaker.ncd.noaa.gov/bathytopo, http://chartmaker.ncd.noaa.gov/bathytopo/spatial/spatialdata.html

Predicting urban growth and land-use/land-cover change

Characterizing urban evolution and resulting perturbations at each stage in history are critical for understanding how the ecosystem has responded to such changes, and for predicting how the ecosystem will respond in the future. Urbanization history and modeling, and hazard assessments provide the context within which to assess past, current, and future anthropogenic influences at the regional scale on all estuarine system components including surface and groundwater quality and movement, sediment quality and movement, and habitat distribution and health. An urbanization model was developed as a foundation with which to couple historical and current data on changes in water and sediment quality, seagrass distribution, sediment accumulation rates and quality, wetland distribution, and geophysical structure.

A dynamic urban-growth model, SLEUTH (Clarke et al., 1997) was used to model and study the process of urbanization and associated land use and land cover changes in the Tampa Bay area (Xian et al., 2005). Detailed procedures and results of this modeling activity are available in Xian et al. (2005) and Xian and Crane (2005). The SLEUTH urbanization model applies six geospatial themes (slope, land use, exclusion, urban extent, transportation, and hillside) to define four types of urban growth: spontaneous, breed, spread, and road influence. The SLEUTH Urbanization model of Tampa Bay was calibrated using historical urban spatial extent, land-use/land-cover, slope, and transportation data for selected dates ranging between 1940 and 1992, and remote sensing data including Landsat Mulitspectral Scanner and Thematic Mapper data to model urban land-use/land-cover change. Historical urban extent data was obtained from historic zoning maps, slopes were derived from the USGS 10 m digital elevation model, transportation data was acquired from Florida transportation department historic maps, and land-used/land-cover data were acquired from USGS LULC and NLCD92 data sets. Calibration testing was performed by using 1946 urban extent to initialize model runs that create growth prediction out to 1992. After calibration, best-derived model parameters from the historical data run were selected to run the urbanization model in a predictive mode to the year 2025. Figure 13-4 shows predicted urban growth in the years 2015 and 2025. Following the current trend in urbanization, the extent of urbanization in the Tampa Bay watershed is predicted to double from 1992 to 2025, agricultural land will be reduced by 58%, and forested land will be reduced by 80%. Results indicate that two major centers of rapid growth will occur between Tampa and Plant City, paralleling Interstate 4, and on the eastern side of Tampa Bay parallel to Interstate 75. By the year 2025, 38% of the Tampa Bay watershed may be covered by urban development (Xian and Crane, 2005).

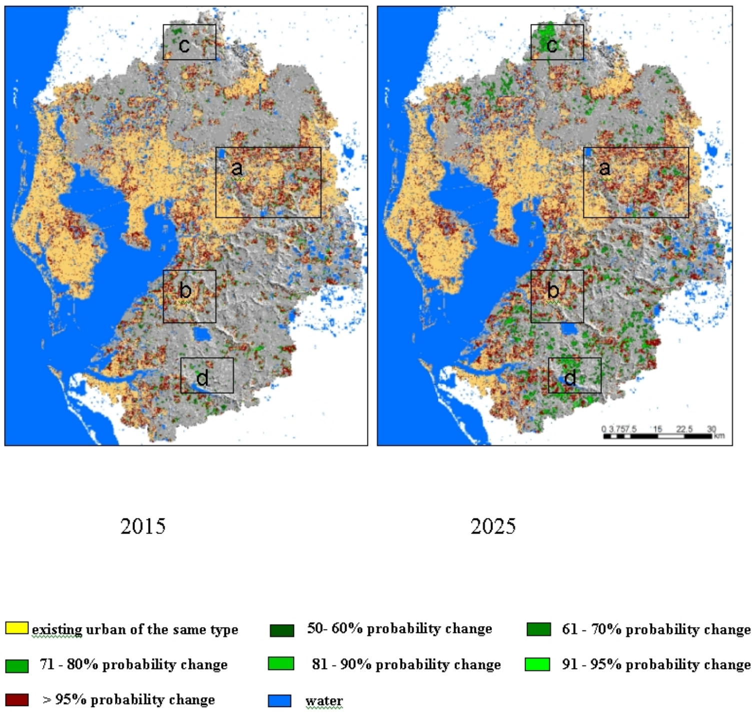

Figure 13-4. Predicted urban growth in the years 2015 and 2025. Yellow is existing urban area in 1992, brown is new urban areas after 1992, green may become urban area in each predicted year. From Xian et al. 2005.

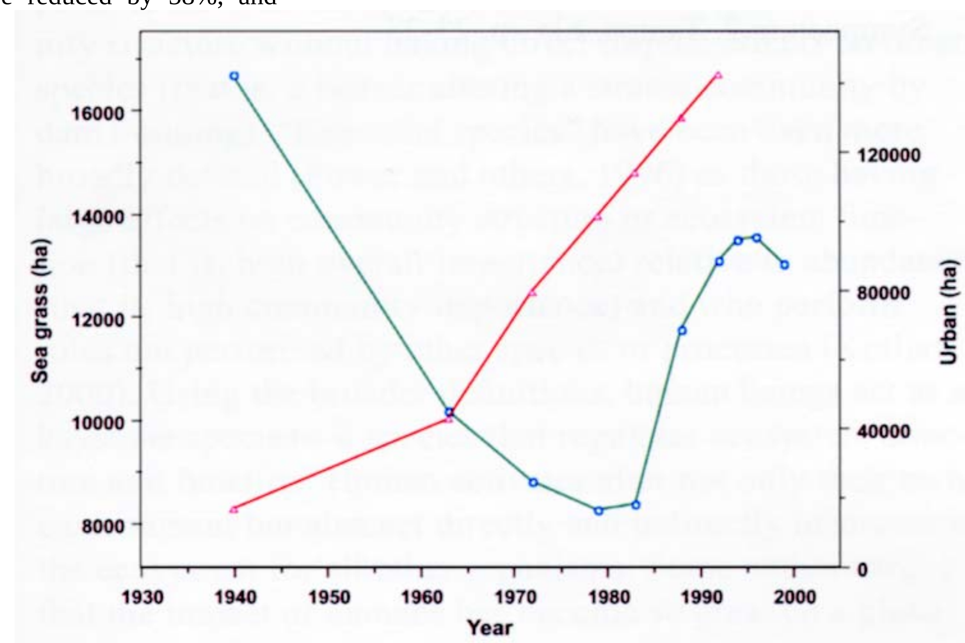

Figure 13-5. This graph compares urban growth and seagrass distribution in Tampa Bay. The red line represents urban growth, the green line show the extent of seagrass coverage. From Crane and Xian (2006).

Impact of urbanization on seagrass distribution

Results depicting stages of urban growth from the calibration phase of the SLEUTH urbanization model were combined with historical seagrass distribution data from the Southwest Florida Water Management District to examine the influence of urban development on seagrass distribution in Tampa Bay (Crane and Xian, 2006). Results of this comparison (Figure 13-5) show a general decrease in seagrass distribution from 1940 to 1982 linked to destruction of habitat (Stowers et al. 2002, Zarbock 1991), decreased water clarity (Boler et al. 1991), and declining water quality (Carlson et al. 2002). This negative correlation reverses beginning in 1982 reflecting the successful implementation of the Tampa Bay Nitrogen Management Strategy. However, the correlation reverses again in 1996 suggesting that impacts other surface water nitrogen concentrations may be impacting the ability of seagrass to recover in select areas of Tampa Bay.

Sources and Quality of Groundwater

In addition to surface water runoff, an additional runoff component in Tampa Bay includes baseflow – or groundwater flow. Submarine groundwater discharge (SGD) into coastal waters has, historically, been overlooked in the development of nearshore material and water budgets (Swarzenski et al. in press). The abundant and reversible exchange of groundwater and surface water complicates water budget estimates and may also play an important role in the delivery of contaminants and nutrients to the bay. Seismic mapping was used to identify geologic features below the seafloor (such as depressions in bedrock) that may act as conduits for groundwater flow to the bay. Specific locations of interest were then surveyed using streaming resistivity to determine whether or not freshened water masses were located below the seafloor. Streaming resistvity is performed using an array of sensors, towed behind a boat, that send an electrical pulse to the seafloor. The information conveyed when the electrical signal bounces back to detectors is used to determine if water below the seafloor is fresh or salty. Figure 13-6 shows track lines for resistivity surveys performed in Tampa Bay. Results from resisivity mapping show several regions within the bay that are characterized by freshening, with depth, of water contained within the sediments below the seafloor. These regions include areas adjacent to and south of the Alafia River, near the mouth of the Little Manatee River, Feathersound, and areas located near the shipping channels in Old Tampa Bay and Hillsborough Bay. Figure 13-7 shows a three dimensional profile of resistivity in an area ranging from 0 to 3600 m perpendicular to the Little Manatee and running 3000 m parallel to the river.

Analysis of naturally-occurring radionuclides (including a variety of Radon and Radium isotopes) in Tampa Bay was used to evaluate groundwater contribution. This work is described in detail in Swarzanski et al. (in press). Water samples for Radium isotope and nutrient analyses were collected during June 2003 and August 2003 at 17 locations throughout the bay. Groundwater samples were collected from shallow (approximately 15m depth) wells at three locations in the bay including Feathersound, and south of the Alafia River. Radium-223 and -224 activities were determined using delayed-coincidence alpha counting techniques as described in Swarzenski et al. (in press). Nutrient concentrations (including NO_3^-, NO_2^-, NH_4^+, PO_4^{-3}, and SiO_4^-) were measured using a Lachat Quick Chem 8000 Flow Injection Analyzer at the Woods Hole Oceanographic Institute using the methods of Charette and Buesseler (2004).

Radon-222 analyses were performed in situ using commercially available RAD-7 air radon detectors routed through air-water exchangers during wet and dry seasons in 2005. Groundwater samples were collected along the Alafia River and sites adjacent to the perimeter of the bay using a RAD-H2O extension of the RAD-7. Radon and Radium activities for surface water and groundwater samples are available in Swarzenski et al. (in press).

Swarzenski et al. (in press) developed a radon-derived submarine groundwater discharge model based on mass balance of source and removal terms for Radon-226, and dynamic transit time of a water parcel in Tampa Bay calculated from a comparison of excess isotopic ratios (Radium-223/Radium-228) in bay surface waters to ratios in groundwater. Results from this model estimate a submarine groundwater discharge rate of 1.6 to 10.3 $m^3\ m^{-2}\ d^{-1}$ into Tampa Bay. A comparison of Radon-222 activities in surface water and groundwater samples indicates a clear groundwater signal during low tides, and a dilution effect on groundwater during high tides suggesting that the rate of groundwater discharge to the bay is a function of tidal stage

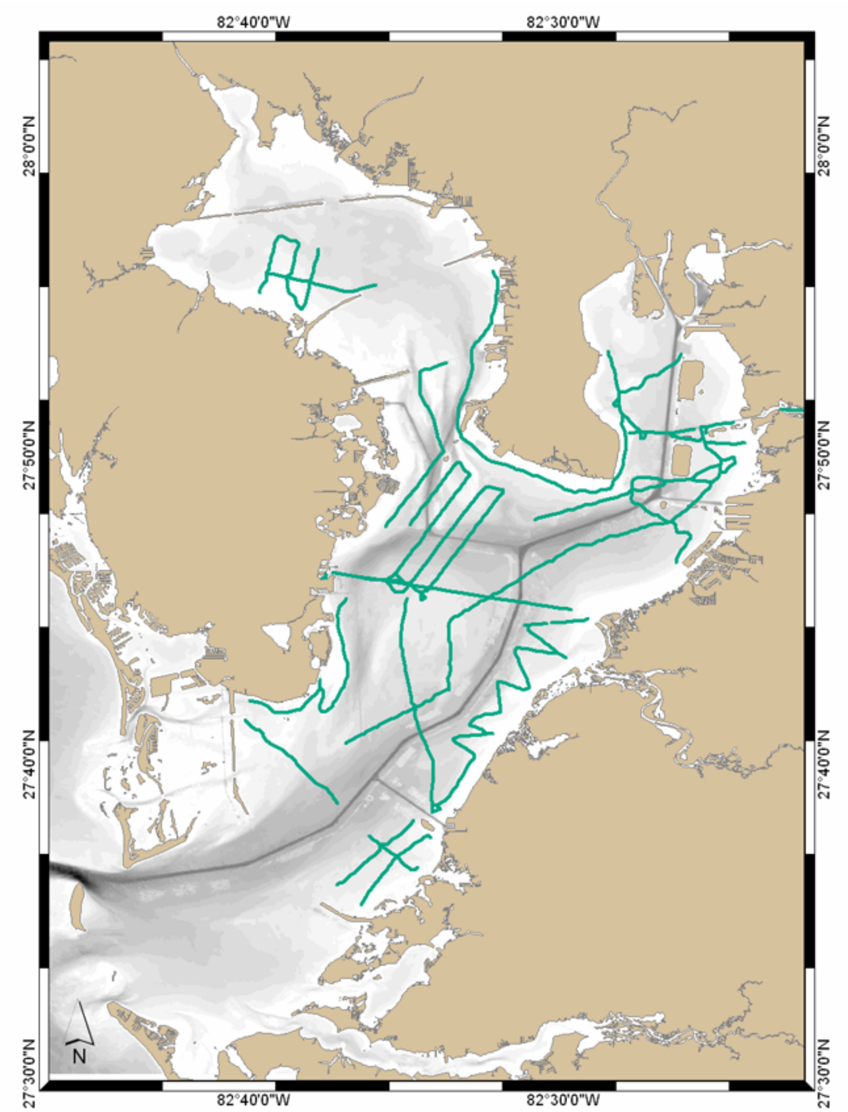

Figure 13-6. Track lines for resistivity surveys performed in Tampa Bay.

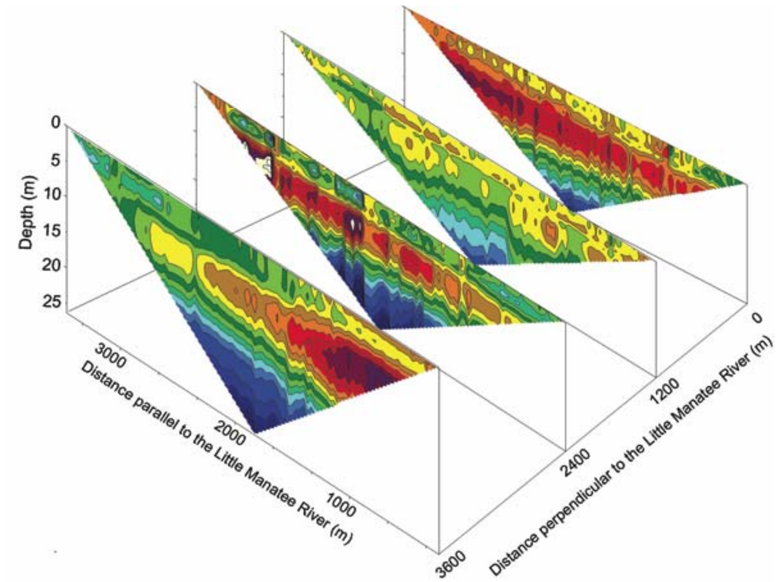

Figure 13-7. Three dimensional profile of resistivity in an area ranging from 0 to 3600 m perpendicular to the Little Manatee and running 3000m parallel to the river.

Swarzenski et al. (in press) also estimated nutrient loading from submarine groundwater discharge by multiplying average groundwater nutrient concentrations by the range in SGD rates. Results indicate that NO_3^- + NO_2^- were not detectable in shallow groundwater samples, that dissolved inorganic nitrogen consisted almost exclusively of NH_4^+, and that dissolved organic nitrogen (DON) makes up approximately 35% of the total dissolved nitrogen pool. A comparison of NH_4^+ from SGD and riverine input indicates that the contribution of NH_4^+ from submarine groundwater is an order of magnitude greater that the contribution from rivers in Tampa Bay. Groundwater fluxes and nutrient concentrations are presented in Table 13-1.

Table 13-1. Estimated range in nutrient loads to Tampa Bay from submarine groundwater discharge as well as from river discharge (uM m-2 d-1 and moles d-1). The SGD rate utilized in these load calculations reflects both Radon and model-derived transit time estimates.

	average concentration[c] (μM; n = 39)	+/-	SGD nutrient flux[a] ($\mu M\ m^{-2}\ d^{-1}$)	SGD nutrient flux[b] ($\mu M\ m^{-2}\ d^{-1}$)	SGD nutrient flux[a] (moles d^{-1})	SGD nutrient flux[b] (moles d^{-1})	river nutrient flux (moles d^{-1})
PO_4^{-3}	9	10	132	20	1.4E+05	2.0E+04	n.d.
SiO_4^-	420	71	6062	902	6.2E+06	9.3E+05	n.d.
NO_2^-+NO_3^-	0	0	0	0	0.0	0.0	4.6E+05
NH_4^+	60	59	872	130	9.0E+05	1.3E+05	1.7E+04
DON	34	25	486	72	5.0E+05	7.5E+04	2.1E+05
TDN	95	73	1366	203	1.4E+06	2.1E+05	6.9E+05

Current, Historical, and Pre-Historical Conditions in The Bay

Understanding the impact of urbanization on any ecosystem relies upon the ability to de-convolve natural versus anthropogenic change in the pre-historical and historical (past 100 years) geologic record. The TBEP and its partners identified geologic studies as one of the key missing elements in the long history of research in Tampa Bay, particularly in relation to the on-going restoration activities in Tampa Bay's Aquatic Preserves. Reliable and credible historical and predictive modeling, and effective restoration planning lies in the ability to accurately evaluate the past.

Modeling the physical and environmental evolution of the bay provides the foundation for identifying and characterizing historical anthropogenic impacts. Of particular importance is the characterization of vegetation evolution; variations in climate (precipitation), which is a control on salinity, organic and contaminant input, and nutrients; and sea level rise which is critical for long-term management of coastal restoration (particularly in the low-lying coastal areas of Florida). Climate also affects sediment type, accumulation rate, and distribution, all of which are important in providing reliable data on the concentration and distribution of contaminants and nutrients though out the bay.

Through a combination of bay-wide sediment core analysis and seismic data collection, historical and pre-historical environmental conditions (including salinity, temperature, sediment contaminants, nutrients, vegetation distribution, and sea-level rise) at key time periods can be reconstructed to help understand the evolution of the bay. Coarse sampling resolution of cores was used to identify the historic and prehistoric sediment records, and distinguish between natural and anthropogenic environmental change. High-resolution sampling of the sediment cores was performed to reconstruct environmental parameters at key time periods in the history of urban evolution in Tampa Bay.

Modern Surface Sediment Distribution

As a large shallow estuary, Tampa Bay is blanketed by sediment carried into the bay mainly from the adjacent continental shelf, eroding shorelines, and rivers, or eroded from older geological formations. Because the bay is home to considerable subaquatic vegetation (SAV,

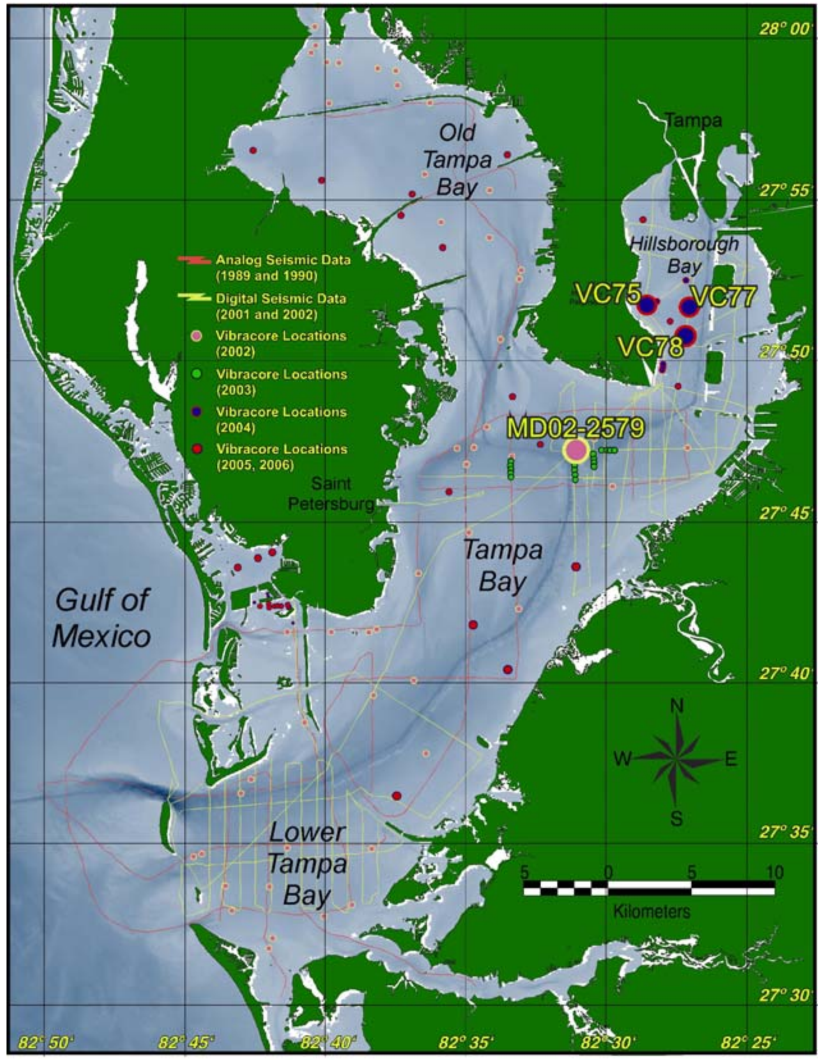

Figure 13-8. Map showing location of sediment cores used in stratigraphic, paleoclimatic and sea-level studies. Light yellow and red lines indicate seismic profile lines.

including various grasses and macrobenthic algae), the distribution of bottom sediment is critical for evaluating SAV-related environmental problems in the bay. For example, particulate material that can attenuate light needed by bay grasses to photosynthesize originates in part from re-suspension of detrital sediment on the bay bottom by tides, currents or human activities such as dredging. In addition, the bay bottom serves as a substrate for SAV and various benthic species of invertebrate organisms many having ecological preferences for particular bottom types.

More than 85 sediment cores taken in Tampa Bay between 2002 and 2006 have been used to construct bottom sediment maps of the bay, as well as the geological and climatic studies described in sections below (Figure 13-8). The uppermost 1-2 centimeters of sediment were analyzed for grain size analysis and Figure 13-9 shows the grain size characteristics of Tampa Bay bottom sediment in Phi (ϕ) Units (higher phi units are generally finer grained sediment). Additional maps of mud, silt, sand and carbonate content are available online at http://gulfsci.usgs.gov . The maps clearly show that finer grained material (mostly mud) dominates in the Hillsborough Bay region while coarser material (sand) dominates the outer part of Tampa Bay near its mouth.

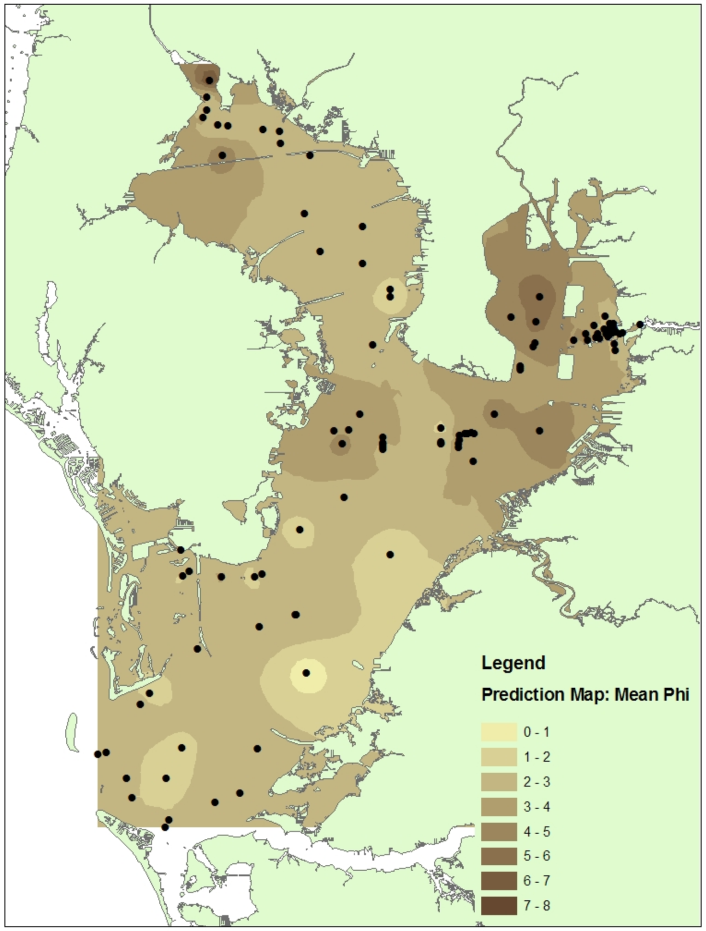

Figure 13-9. Bottom sediment in Tampa Bay shown in Phi Units. Darker shades indicate finer grained sediments. Black dots are core locations. Analysts: G. Brooks and R. Larson

Spatial and Temporal Patterns of Total Suspended Solids

Using data sets from the Hillsborough Bay Environmental Protection Commission dating back to 1974, we evaluated the temporal and spatial distribution of total suspended solids (TSS) in Tampa Bay. The goal was to evaluate factors that might influence its distribution over seasonal to inter-annual timescales (studies of TSS over shorter timescales are treated in tasks in the

Tampa Bay Project). We emphasize that the relationships between TSS and processes such as climatic and hydrological variability, river discharge, tides and currents, and human activities are complex and poorly understood such that our results must be viewed as preliminary. Nonetheless, our qualitative results suggest several tentative conclusions.

While there is a clear positive correlation between rainfall and river discharge over seasonal and inter-annual timescales, the relationship between TSS and discharge seems to vary over the 30-year period of record (Figure 13-10). For example, while there is large variability in TSS concentrations from 1974 until 1990, at times seemingly related to river discharge, since 1990 TSS concentrations have been relatively low, generally less than 20 mg/Liter. It is not clear what factor is responsible for this shift but it suggests a change in the factors controlling TSS around 1990. In addition, the results suggest that compared to other large estuaries, such as Chesapeake Bay, TSS concentrations in Tampa Bay are relatively low and are not directly linked to rainfall and river discharge as in some other estuaries.

We also investigated seasonal TSS variability in 1997 and 1998, two years representing contrasting climatological conditions dominated by the stong El Niño event in winter of 1997-1998. Figure 13-11 shows a map contrasting TSS concentrations during the two years, showing higher winter and summer concentrations in 1998 probably due to higher precipitation, streamflow and perhaps coastal erosion during the El Niño event.

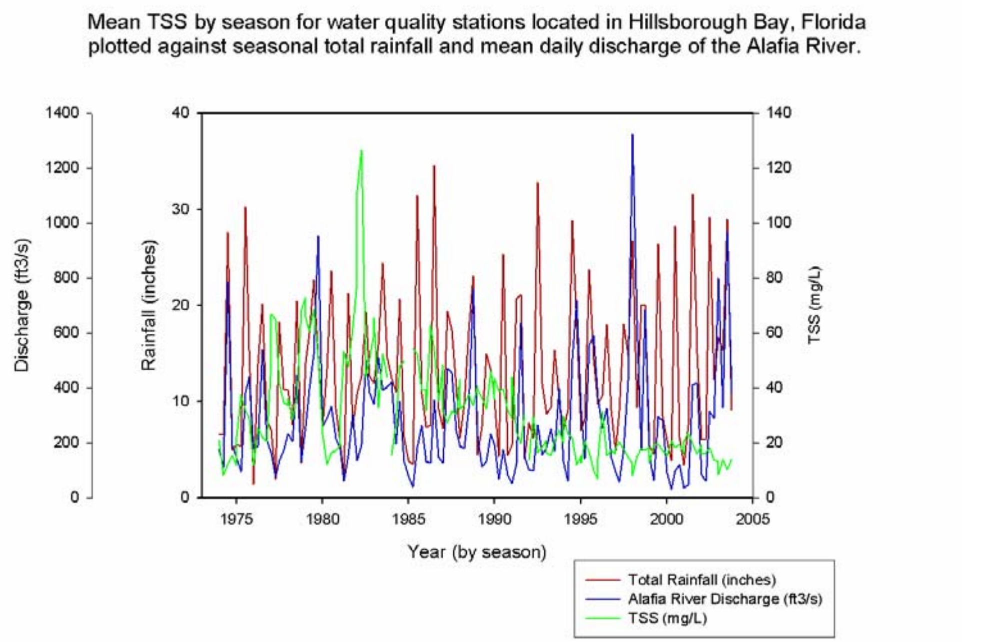

Figure 13-10. Relationships between total rainfall, river discharge and mean seasonal TSS. Sources: TSS: Hillsborough County EPCHC Stations 2, 7, 8, 44, 52, 54, 55, 58, 70, 71, 73, 74, and 80; Discharge: seasonal mean daily discharge for Alafia River; USGS Station 02301500; Rainfall: Southwest Florida Water Management Stations 206, 232, 259. Analyst: K. E. Smith.

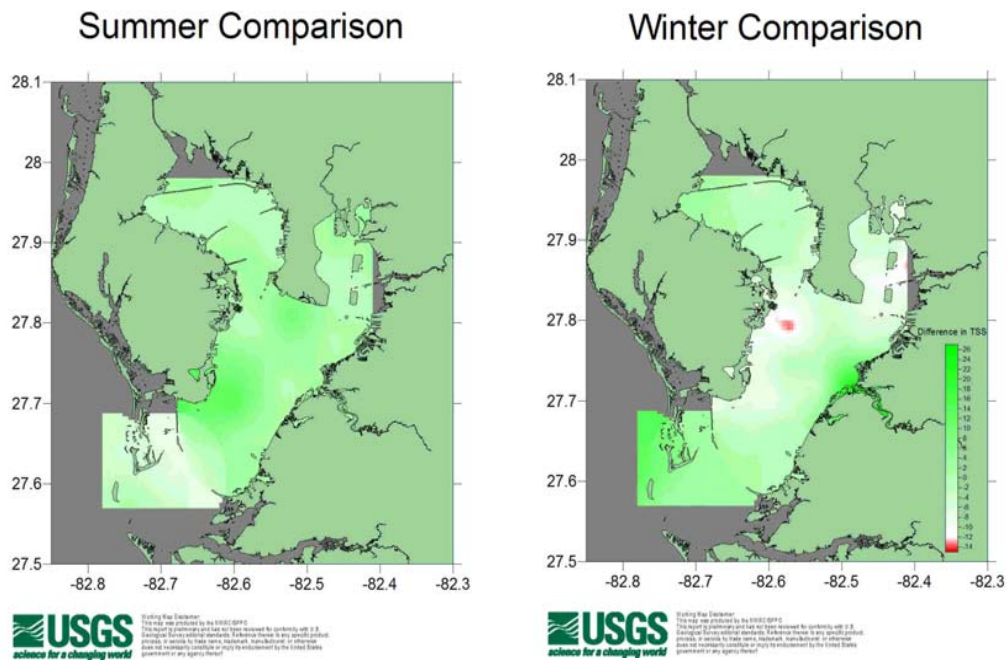

Figure 13-11. Difference between 1998 and 1997 total suspended solids (TSS) concentrations in Tampa Bay. Shades of green generally show higher values during 1998, top figure is Winter, bottom figure summer season. Source: Hillsborough County Environmental Protection. Analyst: K. E. Smith.

Stratigraphy and Geological History

The geological framework of Tampa Bay has been investigated using combined stratigraphic, geophysical, and geochronological methods to elucidate the origin of the bay and the nature of its sediments. High-resolution seismic-reflection profile data was collected by the University of South Florida in closely-spaced lines along 1,000 line km in Tampa Bay (Hine et al. in press, Suthard 2005, and Duncan 2003). Seismic track lines were correlated with core and bore hole locations collected by the U.S. Army Corps of Engineers and the U.S. Geological Survey (Figure 13-12).

Seismic reflection and bore hole data indicate that Tampa Bay is underlain by several smaller, sediment-filled subbasins that are laterally restricted and do not extend seaward resulting in outcropping of basement bedrock near the mouth of Tampa Bay and in the west-central Florida shelf (Hine et al., in press). These infilled karst subbasins (including folds, sags, warps, and sinkholes of the basement bedrock) were formed by dissolution of carbonates at depth allowing the overlying stratigraphy to collapse creating a surficial depression during the mid to late Miocene sea-level lowstand. A lack of cross-shelf continuity in these features indicates that the subbasins within Tampa Bay are not shelf valleys carved by rivers (Hine et al., in press).

In addition to obtaining numerous short sediment cores between 2002 and 2006, we obtained a long (>11 meters) sediment core from central Tampa Bay in July, 2002 using the R/V *Marion-Dufresne*. The site was selected using geophysical data indicating a relatively thick Quaternary sequence of sediments deposited in one of many karst-like depressions that characterize this region of Florida. The stratigraphy and lithology of the MD02-2579 core is shown in Figure 13-13. Three primary stratigraphic units characterized by distinct lithology and microfaunas were identified. The lowermost (11.2-7.2 m core depth) consists of shelly sands and yielded radiocarbon ages on mollusks beyond the limit of ^{14}C dating (> 43 killoannum [ka]) and probably was deposited during the last interglacial, marine isotope stage (MIS-5). Estuarine and marine ostracodes from Unit 1 are dominated by inner shelf and estuarine species between 11.2 and 8.6 m and restricted brackish water assemblages between 8.6-7.2 m. The middle unit (7.2-2.9 m) consists of non-marine organic-rich mud at the base with an abrupt transition to calcareous mud at ~ 500 cm. These sediments and their microfossil assemblages signify deposition in a lake and other non-marine environments during times of lower global sea level and cooler climate. This data is consistent with seismic data indicating that

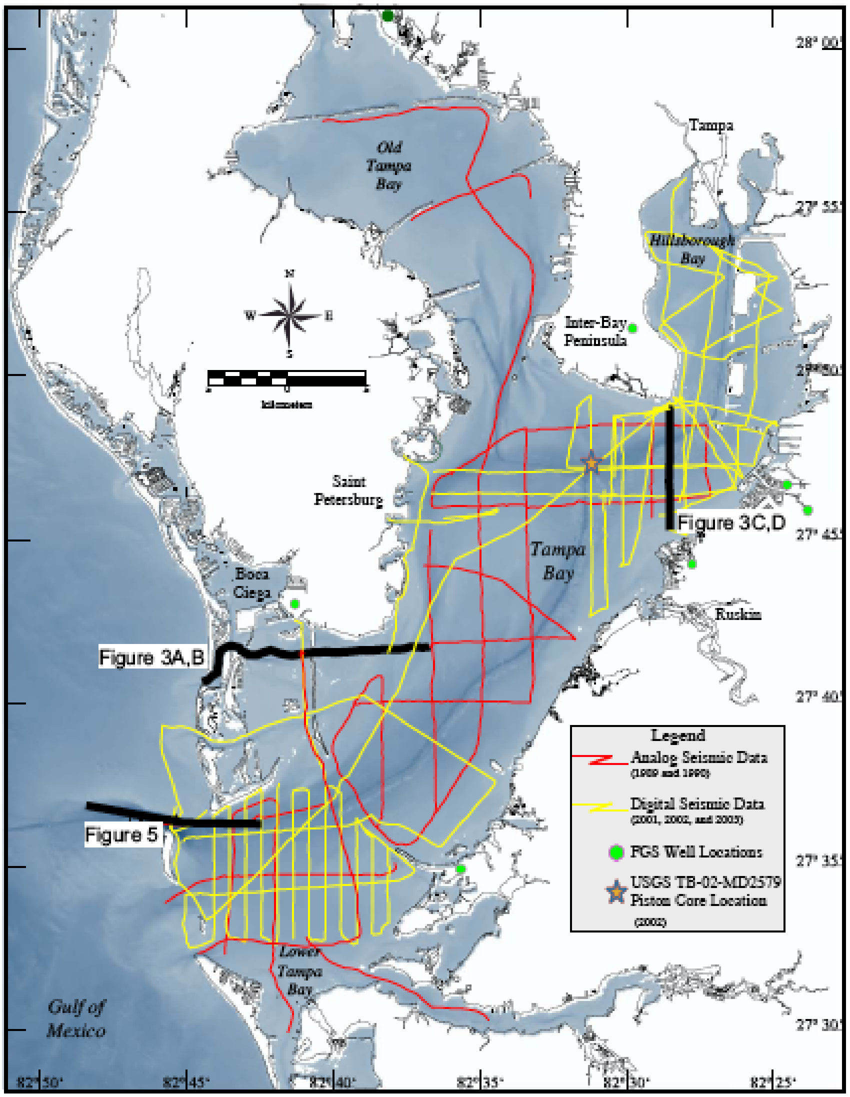

Figure 13-12. Seismic data and borehole locations in Tampa Bay. Adjacent boreholes on land were used provided lithologic and chronostratigraphic control for the seismic data. From Hine et al. (in press).

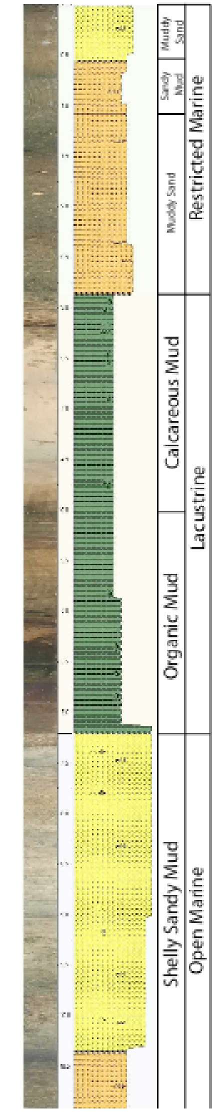

Figure 13-13. Photography, stratigraphy, and lithology of *Marion-Dufresne* core MD02-2579 taken from central Tampa Bay in July, 2002. Core is being used to study the paleoclimate and sea-level history of Tampa Bay.

subbasins resulted from karst depressions rather than incised river valleys. Accelerator mass spectrometric ^{14}C dates of non-marine mollusk shells and pollen residues show that Unit 2 was deposited between the last glacial maximum (~21 ka) and the end of the Younger Dryas cooling period (~11.5 ka). The youngest unit (upper 2.9-m) consists of a marine sandy mud, and represents Holocene deposition during the last few thousand years.

Climate and Sea-Level History

The MD02-2579 core contains an exceptional record of climate history during the transition from the last glacial period and the deglacial period between 21 to 11 ka including evidence that the Florida region can undergo extremely rapid climate shifts. This is exemplified in the pollen record showing rapid shifts from dominant pine- Additional studies of the geochemistry of fossil foraminifera and ostracodes and paleoecological studies of microfossil assemblages have been carried out. Results suggest that centennial-scale changes in salinity and temperature, as recorded by Strontium isotopes and magnesium-calcium and strontium-calcium (Mg/Ca; Sr/Ca) ratios and oxygen and carbon (^{18}O and ^{13}C) isotopic values of microfossils, provide a record of regional fluctuations in temperature and hydrology, which can be correlated with global climatic events. In sum, our results indicate rapidly changing hydrological and climatic conditions during the deglacial period and a high sensitivity of the Tampa Bay region to changing climate.

Given concerns about future climate change and rising sea level, the sea-level history of Tampa Bay is also an important aspect of our understanding of the bay's origin and potential sensitivity to future sea-level rise. We discovered a detailed stratigraphic record of the formation of modern Tampa Bay during the Holocene sea-level rise in the transition from non-marine (mainly lake) to estuarine sediments in modern Hillsborough Bay (cores VC75-78, Figure 13-4). Based on microfaunal assemblages and radiocarbon dates from these cores, we are able to constrain the timing of the inundation of Tampa Bay to about 6.8 to 7.5 ka, at the final phase of post-glacial sea level rise.

Ecosystem History

In addition to reconstructing the impacts of climate and sea level and environmental history over millennial timescales, we also used the sedimentary record of Tampa Bay to examine the last century of environmental change with particular attention to possible human influence on ecosystems. Focus was on comparative molecular organic geochemical and stable isotopic investigations of a suite of sediment cores from pristine (e.g., Terra Ceia) and anthropogenically altered (e.g. Hiillsborough and Central Bay, Feather Sound, Safety Harbor, Bishop Harbor and Lake Maggiore) regions of Tampa Bay. The objectives were to reconstruct and evaluate changes in carbon and nitrogen cycling, and population dynamics and bioassemblage succession of upland plants, macrophytes and phytoplankton. Using precisely dated sediment cores, the isotopic and molecular organic geochemical records can be correlated with historical records of changing land-use, nutrient loading, contaminant input, and changes in the distribution and abundance of estuarine fauna (mangroves, sea grasses and other macrophytes), surface-dwelling plankton populations and terrestrial plants ecosystems. Using this strategy we are attempting to test the hypotheses that: 1) anthropogenic influences in the Tampa Bay have resulted in a quantifiable and predictable change in the biogeochemical cycling of carbon and nitrogen, and 2) site-specific change in land-use, the degree of bay eutrophication and contaminant input has altered natural biological habitats leading to a long-term modification in the abundance, distribution, and succession of planktic-benthic organisms, and estuarine-terrestrial plant species. Although still ongoing, results to date suggest the following preliminary conclusions regarding ecosystem history.

Isotopic, elemental and radiometric data all indicate that sediment cores from Feather Sound, Safety Harbor, Lake Maggiore, Hillsborough Bay, Central Bay and Terra Ceia all contain a well-preserved sediment archive recording the most recent influences of anthropogenic inputs (Figure 13-14). All sites show significant changes in nitrogen cycling. The Terra Ceia, Feather Sound, and Hillsborough Bay sites are located adjacent to watersheds dominated by various types of land use, agricultural, residential and urban/industrial, respectively. There is also evidence for an increase in organic carbon and nitrogen concentrations at all sites with the Hillsborough Bay sediments exhibiting a 15-fold increase in N during the past 100 years most likely reflecting anthropogenic influence. Sediments from Safety Harbor exhibit a 5-fold nitrogen increase while Terra Ceia shows a 3-fold increase.

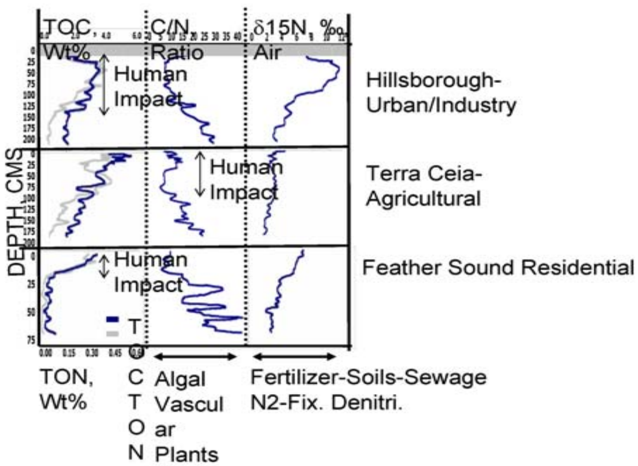

Figure 13-14. Weight percent organic carbon and nitrogen, elemental atomic C/N ratio and d15N composition of sedimentary organic matter in three sediment cores from A-Top panel) Hillsborough Bay, B-Middle Panel) Terra Ceia, and C-Bottom panel) Feather Sound. Note the increases in organic carbon and nitrogen concentrations and the transition from vascular to algal organic matter in all cores are coordinated with the timing of human impacts to the different regions. Note the influence that varying land use development in the different regions of Tama Bay has on the ^{15}N composition of sedimentary organic matter.

Analyses of the nitrogen isotopic composition of organic matter reflect a dominant input from terrestrial plant material. In Hillsborough Bay recent sediments show a transition to values up to 12‰ reflecting increasing inputs from treated wastewater, septic inputs or nitrogen contributions from livestock. In Terra Ceia, agricultural development in the watershed is exhibited in the nitrogen isotopic composition of the recent sediments. Which have an isotopic signature associated with the use of atmospheric N_2 for the synthesis of agricultural nutrients. Feather Sound displays intermediate values (+6‰) reflecting a combination of inputs from soil-derived nitrogen and some amount of treated wastewater.

All sites also show significant changes in carbon cycling, including a recent eight-fold in carbon at Safety Harbor and Feather Sound, a 30-fold increase at Lake Maggiore, and a 2-3-fold increase in Central Tampa Bay and Hillsborough Bay. Carbon isotopic composition of the organic matter reveals significant changes in biogeochemical cycling of carbon and the widespread development and influence of anaerobic recycling processes. For example, in Lake Maggiore, carbon isotopic composition shift over 20‰ in association with the historical record of nutrient loading and the relative importance of bacterial recycling processes associated with progressive lake eutrophication. Molecular organic geochemical studies reveal that, prior to anthropogenic changes to the aqueous and upland environments surrounding Safety Harbor and Central Bay, the distribution of organic compounds was strikingly similar suggesting that both sites were once influenced by the same biological, chemical and physical processes.

Finally, of particular note is the selective onset of anaerobic condition in the most recent sediments in Safety Harbor and Lake Maggiore. Molecular distributions indicate that the development of anoxic conditions is coincident with enhanced input of labile organic matter attributable to algal, zooplankton and sewage sources. The biological and chemical consequence and overall environmental implications associated with the onset of anaerobic sedimentary conditions is significant because of the potential for remobilization of toxic metals, the release of carcinogenic organic contaminants, and the deterioration and absolute demise of the benthic floral and faunal communities.

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- CHAPTER HIGHLIGHTS -

- *The Tampa Bay system supports 29 nesting species of colonial waterbirds totaling nearly 200,000 individuals, arguably the largest population in the state outside the Everglades.*
- *The breeding population totals 30,000-52,000 nesting pairs, averaging 39,000 annually at approximately 30 sites. Up to half the total nesting occurs in Hillsborough Bay; the remainder is distributed at colony sites around Tampa Bay.*
- *Most coastal species' populations have declined in the past thirty years, particularly those that forage primarily in freshwater wetlands; Roseate Spoonbill, American Oystercatcher, Caspian, Royal and Sandwich Tern populations appear to be increasing, while the status of many species is indeterminate and requires further study.*
- *Human disturbance at posted sanctuaries and unposted colonies, whether unintentional or deliberate, has become the most significant cause of nesting failure annually, while mammalian (raccoons, opossums, and feral cats) and avian (primarily fish crows) predation also greatly affects the size and stability of nesting colonies, and has been exacerbated by anthropogenically-induced predator population increases.*
- *El Niño Southern Oscillation (ENSO) events apparently dramatically affect nesting populations of ibis and small herons.*

INTRODUCTION

The Tampa Bay system supports home ranges and nesting territories of at least 29 colonial waterbird species, including beach-nesting birds, and allies, annually totaling about 30,000-52,000 breeding pairs and their young, or nearly 200,000 individuals. This population is among the largest and most diverse in Florida outside the Everglades. Maintaining the present diversity and overall numbers in a growing metropolitan area of over three million people is a daunting challenge that is not being met by the current efforts of both the public and private sectors.

Pelicans, herons, egrets, ibis, gulls, terns and skimmers, and other species that nest in groups (called "colonies") are among the most visible, beautiful, and charismatic wildlife species in Florida. Because of their large size and colonial habits, they are also fairly easily censused. Their populations are therefore widely regarded as useful indicators of the ecological integrity of coastal and wetland ecosystems. Audubon of Florida's Florida Coastal Islands Sanctuaries Program (a state program of the National Audubon Society) annually locates and censuses all known coastal and inland colonies in Tampa Bay. This report summarizes the coastal colony survey results from 1994-2006.

1994-2006 CENSUS

During the thirteen-year period, total numbers of colonial waterbirds ranged from 30,000-52,000 breeding pairs (Figure14-1). Two species, White Ibis and Laughing Gull, accounted for 60-70% of all individuals in most years (Figure 14-2). Inter-annual population fluctuations were attributable, in most cases, to rainfall patterns and forage availability. Longer-term changes, however, were likely in response to regional urbanization and loss of breeding sites and foraging habitats, especially coastal and freshwater wetlands. A few uncommon species (Roseate Spoonbill, American Oystercatcher, Caspian, Royal, and Sandwich Terns) have experienced gradually sustained population increases.

Twenty-seven active or recently active sites were censused (Figure 14-3). Twenty-one were on islands, five were on causeways along shorelines or on undeveloped lots (Isla, Courtney Campbell Causeway, Howard Frankland Causeway, Skyway Sandbar, and Tierra Verde), and one was on power line towers (Mobbly Bay power lines). Eight were abandoned during our study period (Table 14-1). Four causeway sites were abandoned due to raccoon predation (Courtney Campbell Causeway), human disturbance (Skyway Sandbar), and residential development (Isla and Tierra Verde). The Howard Frankland Causeway colony was eliminated when the Florida Department of Transportation planted grass on the gravel nesting area, purposefully discouraging Black Skimmer nesting to decrease their mortality from flying into traffic and prevent traffic accidents.

Two large, historically important, colonies where raccoons have avoided capture in recent years, Tarpon Key and Washburn Sanctuary (Terra Ceia Bird Key), have had below-normal numbers since 1994, with Brown Pelican nesting particularly reduced. Tarpon Key, which was designated the third most important colonial nesting waterbird colony by the Florida Fish and Wildlife Conservation Commission, historically supported approximately 3,000 pairs; however, species richness on Tarpon Key declined 50% in 2002 and the colony was abandoned in 2004.

Figure 14-1. Breeding birds of the Tampa Bay system, 1994-2006: Total annual population estimates *(breeding pairs)*.

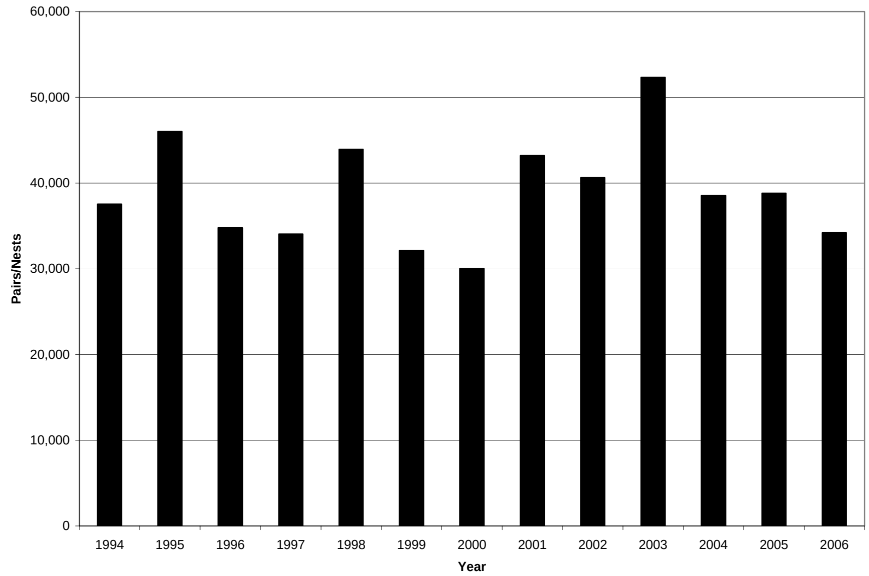
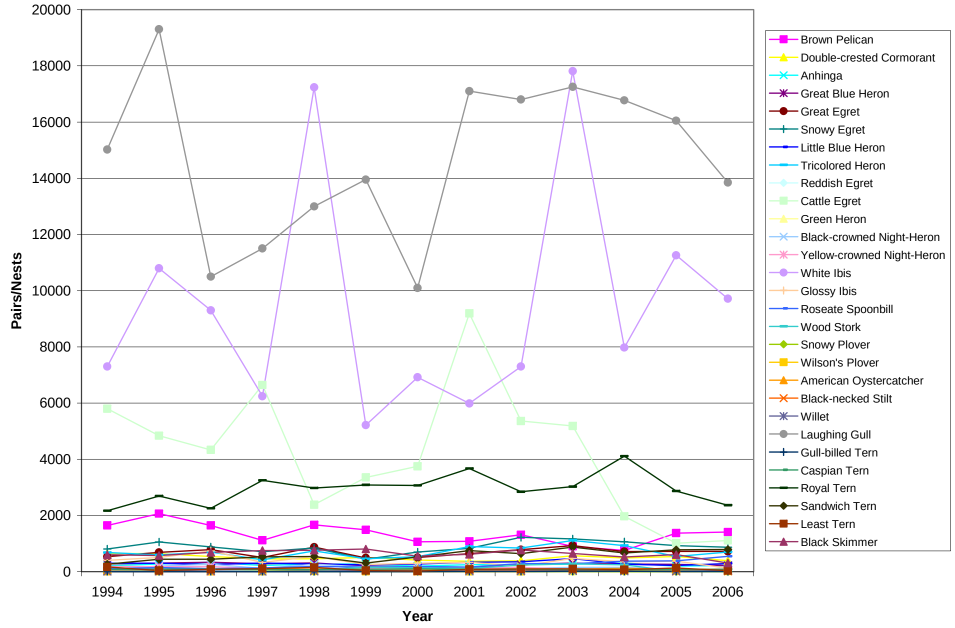


Figure 14-2. Breeding colonial waterbird species of the Tampa Bay system, 1994-2006: Annual population estimates *(breeding pairs*) by species.



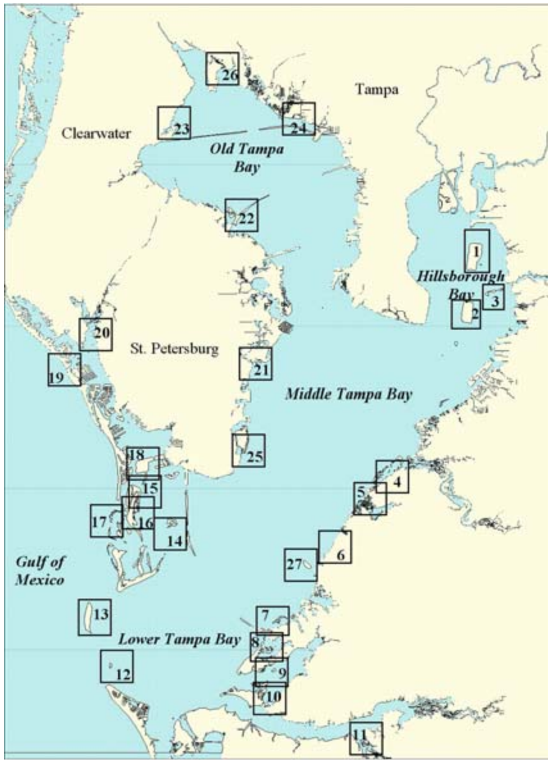


Figure 14-3. Bird colonies of Tampa Bay. Colonies identified by numbers designated in Table 14-1.

Birds select nesting locations that are isolated from mammalian predators, particularly raccoons. In Tampa Bay, most colonies (and all large, persistent ones) are located on islands. However, no island is completely inaccessible. During this study, raccoons reached at least twelve colonies. Numbers of breeding pairs at eleven colonies declined where predators were not removed. Annual raccoon trapping prior to the nesting season at the Richard T. Paul Alafia Bank Bird Sanctuary (the Alafia Bank), the largest regional wading bird colony, has allowed the colony to maintain productivity despite predators returning annually to the island. Intensive live trapping for raccoons on Shell Key allowed this colony to begin to recover in 2002. Similarly, Little Bird Key National Wildlife Refuge also recovered following removal of one raccoon in 2001. Trapping continues at Shell Key, Tarpon Key, the Alafia Bank, and Washburn Sanctuary, and remains an annual management priority. At the end of 2006, raccoons remained on three historically important colonies: Tarpon Key, Shell Key, and Washburn Sanctuary.

Breeding populations of several species of wading birds, particularly White Ibis, increased dramatically in 1998 and 2003 due to enhanced foraging conditions provided by the El Niño Southern Oscillation (ENSO) events of 1997-98 and 2002-2003. During ENSO events, there is a strong winter rain pattern, which fills the Tampa Bay region freshwater wetlands and triggers a hyper-reproductive response by invertebrates, herptiles, and fish populations. Above average winter rains were followed by extreme drought conditions from late March through June, causing rapid wetland dry-down and concentrating prey organisms. The increased prey availability during the spring nesting season typically increases brood sizes and fledging success among colonial waterbirds that depend on freshwater wetlands (especially White Ibis, Glossy Ibis, Wood Storks, and the small herons). These weather conditions also caused nesting failure in the Everglades during the winters. ENSO winter rains doom colonial waterbird nesting success in the Everglades by raising water levels above normal and dispersing prey when colonial waterbirds are nesting during the winter there, approximately 150 days earlier than the typical nesting season in the Tampa Bay area. We suspect that White Ibis and other birds that have failed in the Everglades during ENSO events leave the Everglades, move north to the Tampa Bay region, and attempt re-nesting at the Alafia Bank during the spring. This results in apparent abrupt population increases of some species during ENSO years. Drier fall and winter months in interim years apparently resulted in local declines noted in White Ibis, Glossy Ibis, Wood Storks, and Great Blue Herons; see species discussions below.

Colony Species Richness

Three of the colonies in Tampa Bay, Alafia Bank, Washburn Sanctuary, and Tarpon Key, are among the most diverse colonies in the U.S., with fifteen or sixteen nesting species annually (Table 14-2). Piney Point is also extremely diverse, with thirteen species. In 1994, twenty-one species were present on the Alafia Bank, including beach-nesting species, Laughing Gull, Black Skimmer and three tern species, all of which have since moved from the Alafia Bank to Tampa Port Authority Spoil Island 3D as the habitat on Sunken Island, the western island of the Alafia Bank, progressed through vegetative succession to shrub and forest communities, which are unsuitable for birds that require bare substrates. Generally, colonies of beach-nesting species had fewer species than colonies of wading birds and allies (Brown Pelicans, Double-crested Cormorants, and Anhingas). Among wading bird colonies, larger colonies tended to have greater richness. Dot-Dash had twelve nesting species, while Dogleg Key, Coffeepot Bayou, and Alligator Lake all had ten. This is outstanding richness in even modest colonies of 250-500 pairs.

Table 14-1. Protection and management of coastal bird colonies of the Tampa Bay system, 1994-2006: management entity, protection status, and management status.

Colony Name	Management Entity	Disturbance Factor									Comments
		1994-98	1999	2000	2001	2002	2003	2004	2005	2006	
1. Spoil Island 2D	TPA/NAS	R					R	R		O	Raccoon in 2003, 2004; opossum in 2006
2. Spoil Island 3D	TPA/NAS									R	Active trapping
3. Alafia Bank	NAS	R	R	R	R	R	R	R	R	R	Active trapping
4. Cockroach ELAPP Pits	HCRM										Alligator present
5. Hole in the Wall	AP/HCRM										
6. Piney Point	TECO										Alligator present
7. Skyway Sandbar	DEP-AP	X					A	A	A	A	Site used by fishermen; colony abandoned
8. Miguel Bay	DEP-AP										
9. Washburn	NAS	R	R	R	R			?	?	?	Active trapping
10. Washburn Jr.	NAS										
11. Dot-Dash	NAS								A	A	Colony abandoned, reason unknown
12. Passage Key NWR	FWS									A	Severe erosion - colony abandoned
13. Egmont Key SP/NWR	FPS/FWS										
14. Tarpon Key & Whale Key NWR	FWS	R	R	R	R	R	R	R	R/A	R/A	Colony abandoned, raccoons present
15. Little Bird Key NWR	FWS				R						
16. Tierra Verde		A	A	A	A	A	A	A	A	A	Colony site developed; now condominiums
17. Shell Key	PCP	R	R	R	R	R	R	R	R	R	Active trapping
18. Isla Colony										A	Colony site developed; now condominiums
19. Johns Pass	SSS/DEP-AP, City of Treasure Island	R	?							A	Colony abandoned, reason unknown, possible raccoon & human disturbance
20. Dogleg Key	DEP-AP/NAS										
21. Coffeepot Bayou	Private/NAS										
22. Howard Frankland	FDOT	?			A	A	A	A	A	A	Colony site deliberately made unattractive to Black Skimmers; colony abandoned
23. Alligator Lake	Town of Safety Harbor										Alligator present
24. Courtney Campbell	FDOT/TAS	R	O					A	A	A	Colony abandoned - human disturbance in mangroves
25. Little Bayou	DEP-AP/NAS										
26. Mobbly Bay Power lines	Progress Energy										
27. Port Manatee Key	Manatee County Port Authority										Habitat restored for bird use in 2002.

Notes: A=abandoned; O=opossum; F=fisherman; R=raccoon; ?=disturbance factor unknown.

Abbreviations:

TPA = Tampa Port Authority
HCRM = Hillsborough County Resource Management Team
AP = Aquatic Preserve, FDEP
FPS = Florida Park Service
SPAS = St. Petersburg Audubon Society
SSS = Suncoast Seabird Sanctuary
PF = Pelican Fund
FDOT = Florida Department of Transportation

NAS = National Audubon Society/Audubon of Florida
TECO = Tampa Electric Company
FWS = United States Fish and Wildlife Service
PCP = Pinellas County Parks
TBW = Tampa BayWatch
SH = Town of Safety Harbor
FP = Florida Power
TAS = Tampa Audubon Society

Table 14-2. Coastal bird colonies of the Tampa Bay System, 1994-2006: Species richness.

Colony	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1. Spoil Island 2D	3	2	3	1	1	4	3	2	4	3	1	2	4
2. Spoil Island 3D	5	7	7	6	8	7	8	8	8	8	6	8	7
3. Alafia Bank	22	22	18	18	18	17	16	16	16	16	17	16	17
4. Cockroach Bay ELAPP	7	10	ND	8	9	8	6	4	6	6	6	6	2
5. Hole in the Wall	ND	1	ND	1	ND	2	ND	2	3	3	ND	ND	ND
6. Piney Point	13	13	13	12	13	11	13	13	14	14	14	14	14
7. Skyway Sandbar	ND	0	ND	3	0	0	ND	A	A	A	A	A	A
8. Miguel Bay	ND	1	ND	2	1	1	ND	ND	1	1	10	0	ND
9. Washburn Sanctuary	17	17	17	17	17	16	16	16	16	16	A	10	10
10. Washburn Jr.	0	0	0	9	0	3	0	0	6	6	15	13	10
11. Dot-Dash	4	9	8	13	8	8	10	12	12	11	13	6	3; Wood Stork A
12. Passage Key NWR	8	8	8	10	9	8	9	7	8	8	5	6	1
13. Egmont Key SP/NWR	ND	2	0	3	2	3	4	9	7	7	8	6	9
14. Tarpon Key	16	17	16	17	17	14	15	15	6	6	A	A	A
15. Little Bird Key	1	ND	5	7	8	9	5	0	10	10	3	12	12
16. Tierra Verde	-	-	1	0	0	0	0	0	A	A	A	A	A
17. Shell Key	6	8	5	7	7	7	4	3	5	5	4	4	3
18. Isla Colony	1	0	0	0	0	0	0	2	A	A	A	A	A
19. Johns Pass	2	8	2	2	4	0	6	9	11	11	11	7	1
20. Dogleg Key	6	8	12	10	10	9	9	10	11	11	11	12	12
21. Coffeepot Bayou	11	11	11	11	12	10	9	10	12	12	12	12	13
22. Howard Frankland	1	A	A	A	A	A	A	A	A	A	A	A	A
23. Alligator Lake	9	12	10	11	9	10	9	10	9	9	12	12	11
24. Courtney Campbell	6	9	5	0	1	0	5	5	A	A	A	A	A
25. Little Bayou	ND	ND	ND	ND	ND	ND	ND	2	3	3	8	4	4
26. Mobbly Bay Power lines	ND	ND	ND	ND	ND	ND	ND	1	1	1	1	ND	1
Cow & Calf Keys	ND	ND	ND	ND	ND	ND	ND	ND	1	1	1	1	2
Port Manatee Key	-	-	-	-	-	-	-	1	4	4	4	4	5

Notes: A = abandoned; ND = no data; - = site not previously active

Species richness and abundance are not the only measures of a colony's significance. Some small colonies may harbor only one or two species, but those species may be particularly rare or vulnerable to disturbance. Such colonies may require special attention, and should not be overlooked by colony managers. Twelve colonial waterbird species are State of Florida listed as Endangered, Threatened, or Species of Special Concern, while others, such as the Gull-billed, Caspian, Royal, and Sandwich Terns, nest in a very small number of colonies statewide, and are extremely vulnerable to the effects of a single storm, high tide, or careless intrusion.

Tampa Bay Area Population Status

The Tampa Bay area breeding population of colonial waterbirds and beach nesting birds averaged 39,000 pairs during thirteen years from 1994-2006 (Table 14-3).

Table 14-3. Coastal bird colonies of the Tampa Bay System, 1994-2006: population size.

Colony Name	Breeding Pairs												
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1. Spoil Island 2D	6180	526	554	35	35	126	72	35	46	89	37	36	56
2. Spoil Island 3D	124	5301	4144	5018	7180	9580	6291	5618	5037	5916	3915	5436	5564
3. Alafia Bank	10500	13802	11076	7597	18123	6573	7316	6746	9036	18711	9731	12266	11048
4. Cockroach Bay ELAPP	120	145	ND	150	103	133	112	55	44	51	60	75	13
5. Hole in the Wall	ND	15	ND	9	ND	9	ND	31	40	33	ND	ND	ND
6. Piney Point	3866	3276	3321	3716	2996	3323	2621	4023	4458	6293	2164	2407	2395
7. Skyway Sandbar	ND	0	ND	17	0	0	ND	0	A	A	A	A	A
8. Miguel Bay	ND	11	ND	3	10	6	ND	ND	13	20	46	ND	ND
9. Washburn Sanctuary	3435	1994	2156	893	2062	1881	1689	2004	1572	822	A	320	250
10. Washburn Jr.	0	0	0	41	0	35	0	0	11	87	594	455	438
11. Dot-Dash	97	1158	831	2891	349	254	1571	5635	1388	1333	1334	51	41
12. Passage Key NWR	8682	8698	6447	9003	8325	7640	6079	2423	1296	3044	3178	534	1
13. Egmont Key SP/NWR	ND	162	0	142	49	902	2039	14,599	14948	12911	14953	14848	12268
14. Tarpon Key	2235	1721	1644	1130	888	856	762	480	526	79	A	A	A
15. Little Bird Key	3	ND	12	19	81	100	58	0	58	525	36	411	A
16. Tierra Verde	-	-	75	0	0	0	0	0	A	A	A	A	A
17. Shell Key	1192	7791	3194	2293	2401	477	90	21	197	339	220	181	96
18. Isla Colony	100	0	0	0	0	0	0	125	A	ND	A	A	A
19. Johns Pass	46	259	10	19	59	0	45	48	287	332	8	8	2
20. Dogleg Key	75	127	327	395	425	474	543	543	536	463	518	583	703
21. Coffeepot Bayou	67	186	143	241	316	333	220	285	518	442	465	628	482
22. Howard Frankland	90	A	A	A	A	A	A	A	A	A	A	A	A
23. Alligator Lake	458	499	782	448	553	340	358	464	398	609	568	165	325
24. Courtney Campbell	172	321	59	0	5	0	78	29	3	A	A	A	A
25. Little Bayou	ND	ND	ND	ND	ND	ND	ND	20	19	55	144	44	42
26. Mobbly Bay Power lines	ND	ND	ND	ND	ND	ND	ND	16	23	33	13	ND	18
27. Port Manatee Key	-	-	-	-	-	-	-	4	4	75	101	103	88

Notes: A = abandoned; ND = no data; - = site not previously active

Species Population Status

Population estimates for individual species are discussed in the following sub-sections. Mean population estimates for each species were computed for the thirteen year period of record (Table 14-4).

Brown Pelican - The Brown Pelican population declined dramatically from over 2,000 breeding pairs in 1995 to 750 pairs in 2004, then rebounded to about 1,350 pairs in 2005 and 2006 (Figure 14-4). The population decline may be correlated with reductions in small pelagic forage fish, as a high rate of nesting failure occurred early in nesting, and low average brood size were noted during this ten year period, even in nests that were successful. As the population increased, larger brood sizes and higher fledging success were noted. Two key colonies, Tarpon Key and Washburn Sanctuary, have not sustained Brown Pelican colonies since 2001 and 2004, respectively, and mammalian predator control there is needed urgently.

Table 14-4. Coastal bird colonies of the Tampa Bay System, 1994-2006: Descriptive statistics.

	N	Minimum	Maximum	Mean	
	Statistic	Statistic	Statistic	Statistic	Std. Error
Brown Pelican	13	759	2065	1349.23	100.311
Double-crested Cormorant	13	369	648	494.08	25.633
Anhinga	13	199	333	253.69	11.463
Great Blue Heron	13	161	333	259.92	15.425
Great Egret	13	492	932	685.38	39.809
Snowy Egret	13	441	1220	886.23	58.151
Little Blue Heron	13	222	470	299.85	17.356
Tricolored Heron	13	420	1112	704.69	55.603
Reddish Egret	13	52	85	66.38	2.523
Cattle Egret	13	1015	9190	4226.62	645.719
Green Heron	13	7	40	20.46	2.724
Black-crowned Night-Heron	13	69	266	154.85	17.280
Yellow-crowned Night-Heron	13	43	190	116.46	12.602
White Ibis	13	5217	17809	9465.23	1114.113
Glossy Ibis	13	130	740	380.62	44.268
Roseate Spoonbill	13	109	546	237.77	36.772
Wood Stork	13	0	277	117.23	25.115
Snowy Plover	13	0	4	.62	.311
Wilson's Plover	13	0	55	18.38	5.526
American Oystercatcher	13	67	121	88.77	3.761
Black-necked Stilt	13	0	60	22.15	6.588
Willet	13	3	46	24.23	3.510
Laughing Gull	13	10100	19300	14707.69	789.769
Gull-billed Tern	13	0	20	5.46	1.745
Caspian Tern	13	67	102	84.46	2.513
Royal Tern	13	2170	4112	2954.08	150.120
Sandwich Tern	13	270	874	582.08	52.146
Least Tern	13	25	170	89.46	12.189
Black Skimmer	13	307	810	633.54	37.174

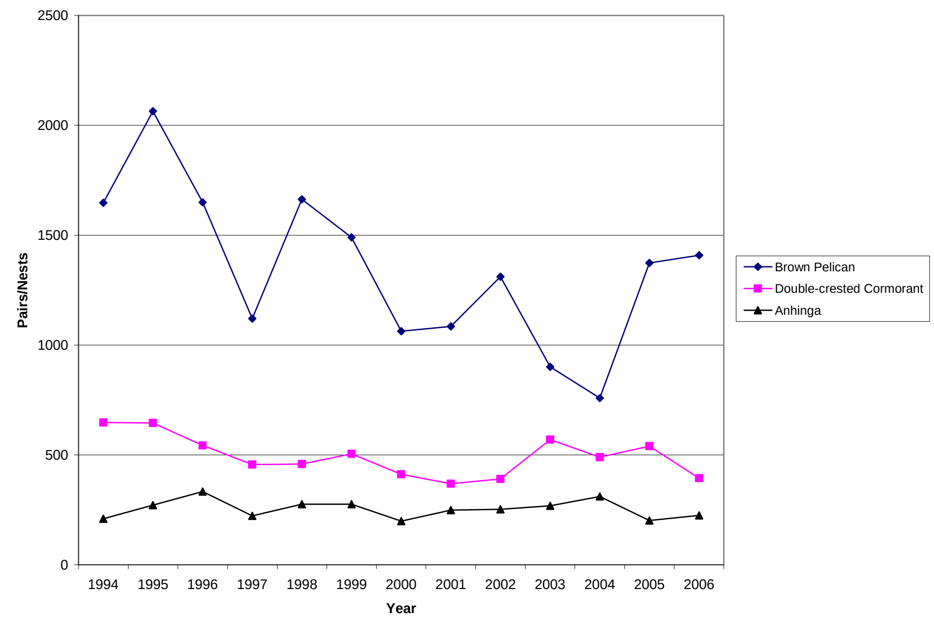


Figure 14-4. Population estimates for Brown Pelican, Double-crested Cormorant, and Anhinga.

Double-crested Cormorant - The Double-crested Cormorant population has declined from 650 to fewer than 400 pairs during the thirteen year census period (Figure 14-4). More intensive surveys are needed, since this species has a very long nesting season and early (or late) pairs may be under-represented.

Anhinga - About 200-330 Anhinga pairs have bred consistently at three colonies in Tampa Bay, with the largest numbers at Alligator Lake (Figure 14-4). Raccoon predation has decimated nesting at Tarpon Key and Whale Key National Wildlife Refuges, and Washburn Sanctuary. Anhingas are primarily freshwater nesters, with relatively small numbers of the total Florida population nesting in coastal estuaries.

Great Blue Heron - The population was stable through 1998, declined dramatically between 1999-2001, peaked at 310 pairs during the 2003 ENSO event, then declined to 225 pairs in 2006 (Figure 14-5). The actual population is somewhat higher, since peak nesting activity precedes Audubon censuses at most colonies on the Florida Gulf Coast. Many Great Blue Herons nest in the winter and the young fledge before the spring nesting surveys. We intend to survey colonies more thoroughly earlier in the nesting season in the future. Great Blue Herons are probably the most resilient, adaptable wading bird in the region; if this population declines, we should assume that other colonial waterbird populations are at serious risk.

Great Egret - Great Egret populations have fluctuated probably in response to ENSO weather patterns, but are generally stable or slowly increasing in the Tampa Bay area, and have ranged 440-930 nesting pairs for the past thirteen years (Figure 14-5).

Snowy Egret - Snowy Egrets have declined significantly since the early 1980s in Florida and, although they responded apparently to the ENSO weather patterns, have rapidly declined (35%) since 2002 in Tampa Bay (Figure 14-5). Snowy Egrets feed freshwater invertebrates, frogs, and fish to their unfledged young. The Snowy Egrets nesting at the Alafia Bank are probably declining in numbers due to wetland loss from development in Hillsborough County and impacts of tropical fish farmers killing egrets at their fishponds, whether through USDA/APHIS depredation permits or unpermitted taking.

Little Blue Heron - The Tampa Bay nesting population vacillates around 300 pairs apparently in response to ENSO, but declined significantly in 2004-2005, then rebounded slightly in 2006

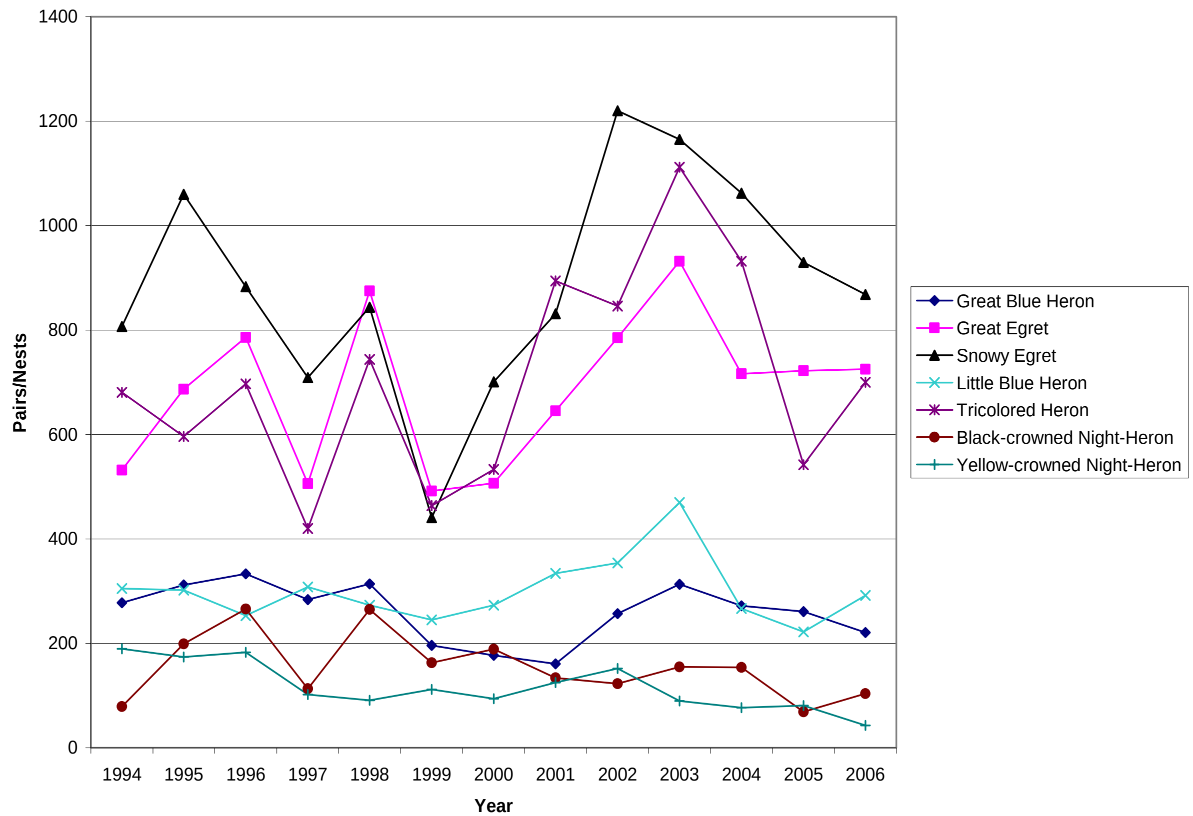


Figure 14-5. Population estimates for herons and egrets, except Reddish Egret and Cattle Egret.

(Figure 14-5). This species forages primarily in freshwater habitats, and is vulnerable to continuing alteration of wetlands due to regional land development and tropical fish farming practices.

Tricolored Heron - About 500-700 pairs of Tricolored Herons breed annually, with population increases in response to ENSO events (Figure 14-5). Along with the Snowy Egret and Little Blue Heron, this species has declined significantly in the last 30 years in Florida. This species forages primarily in freshwater habitats, and is vulnerable to continuing alteration of wetlands due to regional land development and tropical fish farming practices.

Reddish Egret - Hunted for their nuptial plumes and extirpated from Tampa Bay by 1900, this species was found nesting at the Alafia Bank in 1974. Since then, the population has increased to 60-75 pairs locally, about 15-20% of the state population (Figure 14-7). The Tampa Bay population seems to have stabilized, and we have noted a slow increase in the northern Pinellas colonies. Reddish Egrets remain a very uncommon bird regionally and statewide.

Cattle Egret - Cattle Egrets have been reported as the most abundant heron in Florida, peaking at over 9,000 pairs nesting in Tampa Bay colonies in 2001, then declining to slightly over 1,000 pairs in 2006 (Figure 14-6). Comparatively low numbers in 1998 (2,400 pairs) and 2005-2006 (1,000 pairs) may be due to the effects of strong spring droughts reducing insect prey and delaying nesting. This species nests later than other species, and may be underestimated in our surveys; they typically begin nesting in mid- to late May, while Audubon surveys are timed earlier to census peak nesting activity of other heron species. Emerging evidence suggests that Cattle Egrets, which immigrated to Florida in the 1940s, may adversely affect other small heron populations and ground nesting species including Eastern Meadowlarks, Common Quail, and various grassland sparrows. We will further evaluate management recommendations for this species, and may recommend against sustaining the population in Florida in the future.

Green Heron - Green Herons are secretive and generally not colonial nesters, so they are not censused comprehensively during annual Audubon surveys. A few nests are found annually during our surveys, and are tabulated in the survey results. Because colonial waterbird survey methods do not comprehensively assess Green Heron populations, we have not developed a trend analysis.

Black-crowned Night-Heron - The Tampa Bay population is estimated at 100-250 pairs (Figure 14-5). However, this species is most active at night and very difficult to census, so trends are difficult to establish. Black-crowned Night-Herons are believed to be declining in Florida and have declined in the Tampa Bay area over the past 30 years.

Yellow-crowned Night-Heron - Yellow-crowned Night-Herons are another species that defies census due to their crepuscular and nocturnal habits, and their frequent nesting in small mainland colonies that are not detected or reported. The recent population trend is not well defined. The estimates of less than 100 pairs since 2003 reflect reduced survey intensity in 2005-2006 when we did not survey Miguel Bay and

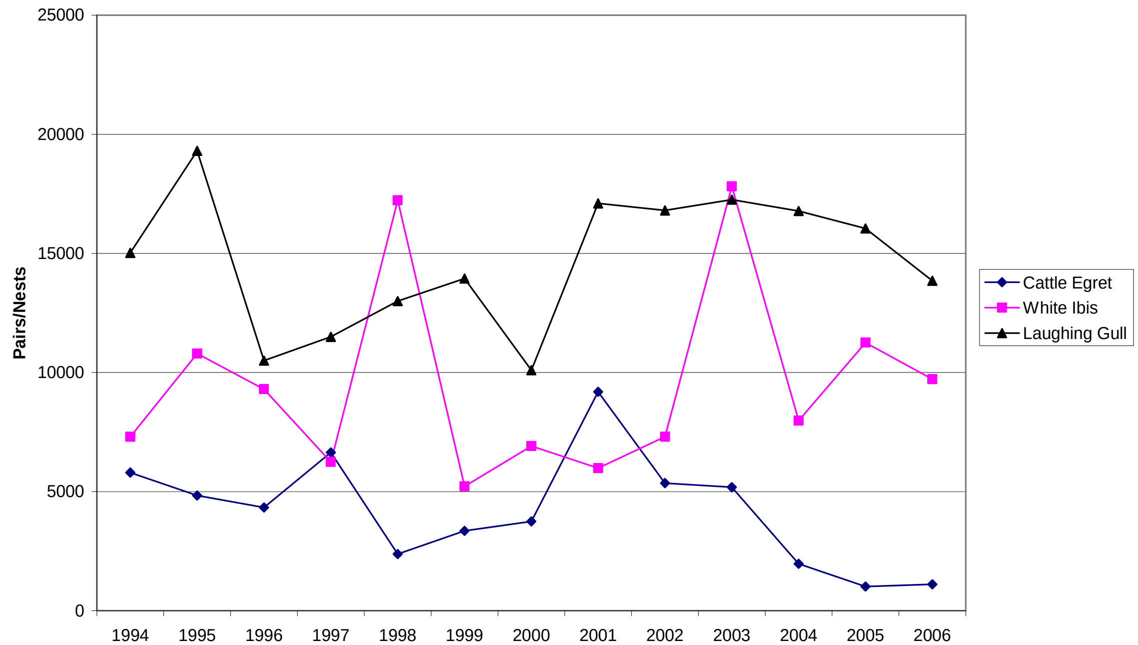


Figure 14-6. Population estimates for Cattle Egret, White Ibis, and Laughing Gull.

Hole in the Wall, but these colonies probably support about twenty pairs, so, overall, Yellow–crowned Night Herons appear to be declining, perhaps related to availability of local crab populations – their main prey item (Figure 14-5).

White Ibis - About 6,000-11,000 pairs of White Ibis nest locally, mostly at the Alafia Bank and Piney Point, with a remarkable increase to 17,000 in 1998 and 18,000 in 2003 due to ENSO (Figure 17-6). Annual numbers strongly reflected local wetland conditions, and numbers were sharply lower again in 1999-2001 and 2004-2006. We hypothesize that White Ibis nesting failures in the Everglades during ENSO winters may prompt birds to move north to Tampa Bay and attempt to nest again later in the spring when the drought draws down local surface waters, increasing forage availability. This species is believed to have declined in Florida by about 80% since the 1940s, due to the statewide loss of wetlands and wet pastures. The Alafia Bank population remains one of the largest in Florida. White Ibis young are salt-intolerant, and obligate consumers of freshwater prey. The availability of functioning inland freshwater wetlands is critical to the long-term maintenance of regional populations of White Ibis. Regional planning should emphasize protection of isolated and inter-connected freshwater wetlands. Better systematic planning must be undertaken immediately to implement Tampa Bay Estuary Program's "Charting the Course" goals, and protect this species.

Glossy Ibis - Before 1969, Glossy Ibis were known to nest only at Lake Okeechobee in Florida. They were first recorded nesting at the Alafia Bank in 1969, so they are a recent recruit to the Tampa Bay breeding fauna. Glossy Ibis have extended their breeding range north to New Jersey. They are primarily freshwater habitat inhabitants, with about 400-600 pairs (about 10% of the state population) nesting at two Tampa Bay colonies (Alafia Bank and Piney Point) (Figure 14-7). More nests were located during the ENSO events in 1998 and 2003 in Tampa Bay. Numbers have been declining generally over the last 20 years, and the overall population decline accelerated since 1994. Continuing urbanization and the loss of shallow, ephemerally flooded, pasture ponds and other freshwater wetlands in Hillsborough County due to development are the likely causes of this population decline in the Tampa Bay area.

Roseate Spoonbill - Nesting Roseate Spoonbills were absent from Tampa Bay for over 60 years, until they were re-discovered at the Alafia Bank in 1975. The population has increased exponentially (R^2=0.88) to 546 Tampa Bay breeding pairs (approximately 50% of the state breeding population) in 2006 (Figure 14-7). Audubon of

Figure 14-7. Population estimates for Reddish Egret, Glossy Ibis, Roseate Spoonbill, and Wood Stork.

Florida research begun in 2002 has shown that some Florida Bay birds disperse north to the Tampa Bay area and across Florida, and Tampa Bay birds also disperse throughout the state. The population appears to be adaptively using available habitat statewide, while the known breeding populations remain localized in Florida Bay, the Tampa Bay region, Merritt Island National Wildlife Refuge, and the Indian River Lagoon Aquatic Preserve. It appears likely that most of the increase in locally breeding birds is due to Tampa Bay fledglings recruiting to the nesting population in Tampa Bay, primarily at the Alafia Bank. A few pairs of Roseate Spoonbills also nest at five other known locations (Dogleg Key, Little Bird Key National Wildlife Refuge, Washburn and Washburn Jr. Sanctuaries, and Coffeepot Bayou Bird Key) in Tampa Bay.

Wood Stork - In Tampa Bay, this endangered species nests at a single site, the Dot-Dash colony at the mouth of the Braden River, plus four other small colonies in the watershed that are inland and not included here. The population averaged 120 pairs, ranging to 277 pairs in 2003 (Figure 14-7). Reproduction at the colony has been irregular. In 1994, the colony was abandoned following disturbance by jet skiers. In 2005, Wood Storks initiated nesting on the Dot island of the Dot-Dash colony, then abandoned the colony, leaving live chicks in their nests. In 2006, they initiated courtship and nest building, and then abandoned the colony before the eggs hatched; the causative factors were not determined.

Snowy Plover - Snowy Plovers are an obligate inhabitant of barrier beaches, particularly near passes and intertidal sand flats with adjacent mud flat areas for foraging. As a beach-nester, Snowy Plovers are highly vulnerable to human disturbance and raccoon predation. Three to four pairs of birds are found annually on the beaches of Tampa Bay (especially Ft. DeSoto and Shell Key), and no more than ten pairs are estimated for the entire region, so this species may be locally extirpated if regional management of this federally-listed species does not improve in the immediate future (Figures 14-8, 14-9).

Wilson's Plover - Wilson's Plover are more common than Snowy Plovers and slightly more flexible in their habitat requirements. They inhabit barrier island sand dunes, spoil islands, and salt barrens. We estimate the Tampa Bay population at about 100 pairs but, because of their cryptic coloration, non-colonial nesting and secretive nesting behavior, Wilson’s Plover have proved difficult to survey comprehensively across the region (Figures 14-8, 14-9). A large population of Wilson’s Plovers began nesting on Port Manatee Key after the spoil island was restored in 2002 as mitigation for the Gulfstream Natural Gas pipeline and berth development at Port Manatee.

American Oystercatcher - The American Oystercatcher population is stable or slightly increasing. Oystercatchers defend linear territories along beaches and spoil islands and, rarely, on gravel rooftops. The Tampa Bay population is at least 120 pairs, the largest local population in the state (note that the first-ever

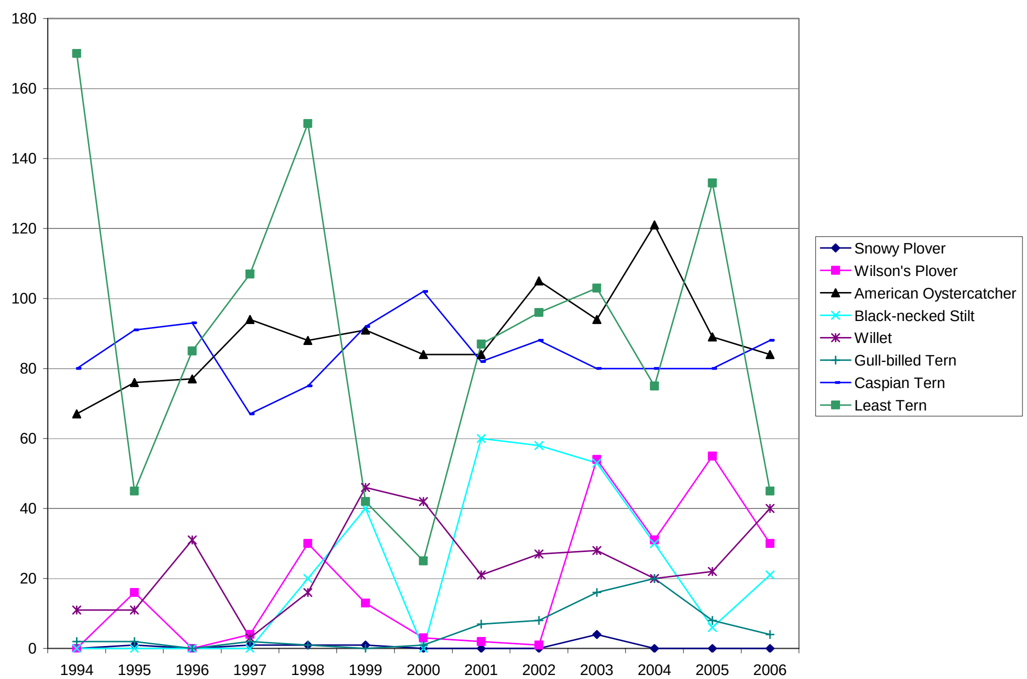


Figure 14-8. Population estimates for all beach-nesting birds, except Laughing Gulls.

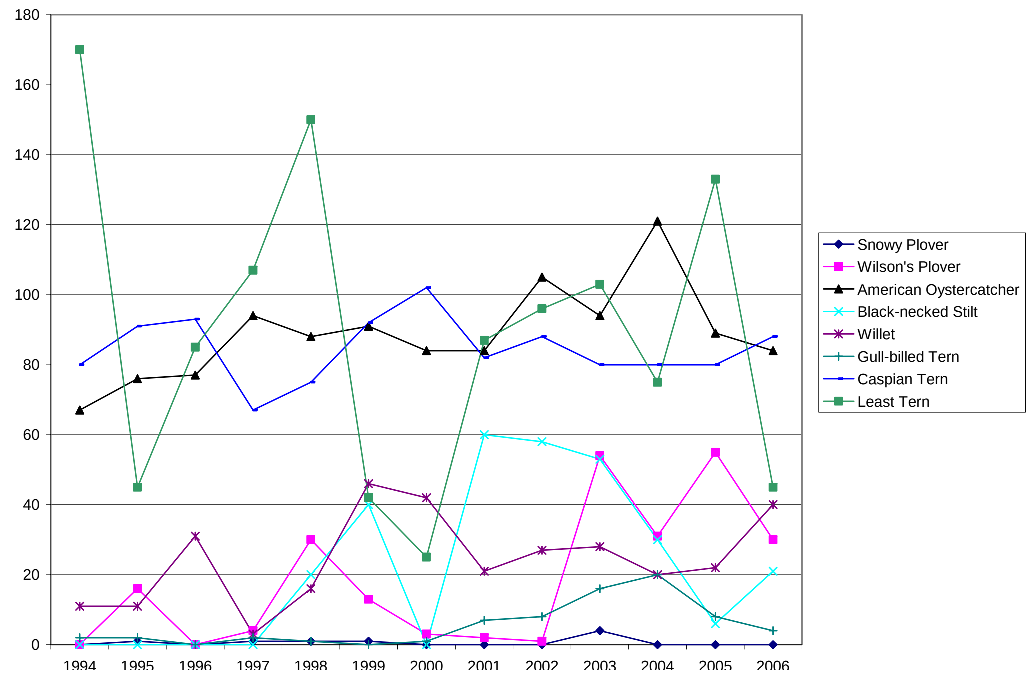


Figure 14-9. Population estimates for all beach-nesting birds, except Laughing Gulls, Royal Terns, Sandwich Terns and Black Skimmers.

statewide census in 2001 found 400 pairs) (Figures 14-8, 14-9). Shoreline erosion and ship-traffic generated bow pressure wakes threaten nesting habitat at several key sites, while human disturbance is a chronic problem at others.

Willet - Willets breed in high marsh habitats along islands and beaches, where they are very difficult to census. The local population size is unknown, but probably numbers less than 100 pairs (Figures 14-8, 14-9). These birds are highly vulnerable to disturbance from recreational boaters and dogs on islands in Hillsborough Bay.

Laughing Gull - Approximately 75% of all the Laughing Gulls in Florida nest in the Tampa Bay region. The population of Laughing Gulls has declined sharply in Tampa Bay from the early 1980s, when 50,000 pairs were censused. Currently, only 10,000-15,000 pairs occur locally (Figure 14-6). Key factors causing the significant population decline may be reduced food supply due to improved garbage disposal practices, and raccoon predation at Shell Key. Laughing Gulls nest in large numbers above the rack line where nests are obscured by dense, grassy clumps and are difficult to census, so the censuses are probably very conservative, and Laughing Gulls have been consistently under-counted. Currently, a very large colony is breeding at Egmont Key, possibly comprised of birds that relocated from Shell Key (due to raccoons) and Passage Key (due to erosion), and possibly Spoil Island 3D (due to plant succession and fire ants). Predation by imported fire ants may be significant, particularly on spoil islands, and should be assessed.

Gull-billed Tern - Nesting Gull-billed Terns are very rare and difficult to find in Tampa Bay. The species is a sporadic local nester with not more than ten nesting pairs found annually over last two decades (Figures 14-8, 14-9). They usually nest among Black Skimmers, Least Terns, or Black-necked Stilts, or near other tern species. Gull-billed Terns nest on open substrate areas where they have a clear view of the horizon, often on spoil island areas and construction material mounds resembling “moonscapes”. They are the only tern in our region that are not piscivorous – they forage on insects (grasshoppers (Orthopterans) and dragonflies (Odonates)), and crabs.

Caspian Tern - For over 20 years, from the mid-1970s to the mid-1990s, Hillsborough Bay supported the only Caspian Tern colony in the state. During that time, numbers increased from 10-15 to more than 80 pairs (Figures 14-8, 14-9). Now, there are three or four colonies in the state, with about 80 pairs (35%) on Tampa Port Authority Spoil Island 3D in Hillsborough Bay, and the statewide total is approximately 250 pairs.

Royal Tern - The two colonies of Royal Terns in Tampa Bay total about 2,500 pairs, about 60% of the state population. Numbers have increased steadily over the past two decades due to systematic protection at Passage Key and Egmont

Key National Wildlife Refuges, and Tampa Port Authority Spoil Island 3D. The population of over 4,000 nests recorded in 2004 represented the highest in Tampa Bay in over 100 years (Figures 14-8). The 2005 and 2006 population decrease should be carefully monitored, and protection of beach-nesting birds should become a community priority. The large colony formerly nesting on Passage Key NWR shifted to Egmont Key NWR in 2000 and 2001, since Passage Key eroded and is barely above the high tide line. The loss of Passage Key, a historically significant nesting site, and the shift of the nesting colony to Egmont Key, demonstrates the value of protecting "secondary" or alternate colony sites.

Sandwich Tern - Sandwich Terns nest with Royal Terns in dense colonies on beaches. In 2004-2006, the population was 800-900 pairs at two colonies (80% of the Florida population) (Figures 14-8). This represents a dramatic increase, as the known population statewide in the early 1980s was less than 20 pairs!

Least Tern - Typically, 100-150 pairs of Least Terns are censused annually in our surveys, which represent only a fraction of the local population (Figures 14-8, 14-9). Most pairs now nest on gravel rooftops in Pinellas County, and St. Petersburg Audubon Society volunteers began monitoring over 40 rooftop colonies in 2001. Many of these colonies will be displaced in the next few years, as recent building construction code changes require rubberized roofs without gravel, which will make the flat roofs unsuitable for tern nesting. Suitable alternative habitat near the existing colonies in Pinellas County must be identified imminently and congruently protected as the rooftop colonies are displaced. Colonies at the Skyway Sandbar, Isla, Fort DeSoto Park, and Tierra Verde have been lost to development or chronic human disturbance, while the Shell Key colony failed in 1988-2001, and has struggled since then due to raccoon predation. A colony of approximately 50 pairs recruited to Port Manatee Key after it was re-constructed in 2002.

Black Skimmer - About 600-700 pairs of Black Skimmers nest at six colonies locally. Including another 300 pairs at colonies near Clearwater, 60% of the state population nests regionally (Figures 14-8). Hurricanes destroyed nearly all of the nesting by Black Skimmers in Florida in 2004 and 2005, and raccoons, human disturbance and avian predators at Shell Key, Egmont Key National Wildlife Refuge, and Tampa Port Authority Spoil Island 3D are ongoing management problems at these colonies.

Black-necked Stilts - a few (20-60) Black-necked Stilts nest occasionally in Tampa Bay. Small colonies have nested on recently bull-dozed sand while Hooker's Point was under construction, on the sandy shoal in a Mosaic retention pond, and in the Corps of Engineers' fill cell on top of Spoil Island 2D. The nesting colony locations have been opportunistically tied to local construction events that created suitable bare sand with fresh or brackish standing water. Stilts should be specifically managed in the future through intensive habitat manipulation.

MANAGEMENT NEEDS

It is remarkable that virtually every active colony in the Tampa Bay system receives some measure of protection as of 2006 (Table 14-1). Regardless, these efforts must be expanded and improved. Certain sites, and species, are especially vulnerable to disturbance by humans, pet dogs, and avian and mammalian predators, especially raccoons.

Discarded fishing line continues to entangle and kill colonial waterbirds, especially at colonies near passes and along the Intracoastal Waterway, and is regarded as the single most significant cause of mortality of adult and juvenile Brown Pelicans, because of their tendency to congregate in popular fishing locations. In 2005, we discovered a Roseate Spoonbill fatally entangled in fishing line at the Alafia Bank, which further highlights the need to demand greater responsibility for lost fishing tackle by anglers.

Watershed issues remain extremely important to the long-term welfare of many colonial waterbird species. Waterbirds are highly mobile, and move throughout the watershed during the nesting season seeking adequate foraging habitat. Following nesting, they may disperse to other parts of the state, or even other states, and therefore are affected by wetland conditions and other factors well beyond the reach of the Tampa Bay Estuary Program. The estuary colonies have been well censused for the last fifteen years. A few inland colonies are now censused in the Tampa Bay watershed, and more effort is needed to comprehensively census all the inland colonies.

Even with strong state and local public support, local land acquisition programs have not kept pace with development, and critical wetlands and estuary habitats are being rapidly lost or functionally impaired. Clearly, the availability of suitable functioning foraging wetlands and estuarine habitats will remain of critical concern in an urbanizing region where wildlife competes with industrial, commercial, and residential construction for remaining open space.

In addition, boaters, anglers, tourists, and other bay and beach recreationists disturb colonial birds during the nesting season when they are highly vulnerable, and during migration. Resident and tourist beach users are disrupting beach-nesting bird colonies and causing the loss of eggs and young. These user groups must be more assertively educated and managed by the respective land managers of the colony sites to ensure compliance with the Migratory Bird Treaty Act. Unless the disruption is controlled during the 2007, and future, nesting seasons, it is very likely that many of the colonies may be abandoned and regional populations will be extirpated.

A long-term problem that has not been addressed is the legalized killing of heron and egrets, kingfishers, and other birds at tropical fish farms in the Gibsonton to Ruskin region of the east Bay. This area hosts the highest number of tropical fish farms in the United States and, while some farmers may be authorized by the U. S. Department of Agriculture Animal and Plant Health Inspection Service Wildlife Services (USDA APHIS/WS) to shoot birds raiding fish farm pools, alternative management practices must be initiated to sustain waterbird colonies in the Tampa Bay area.

With a rapidly growing human population, development and human use pressures on local natural systems are intense. Effective conservation strategies must include stronger protection of the remaining coastal areas and functional watersheds, especially wetlands, and restoration of degraded lands. Also critical is improving the water quality entering Tampa Bay, and protection of the water quantity, to ensure a freshwater / saltwater gradient central to estuarine ecological integrity and productivity.

We must find effective strategies to protect colonial waterbirds and beach-nesting birds, or we will be unable to sustain the diverse colonial waterbird assemblage that has recovered during the past 80 years since these spectacular, charismatic species were extirpated from Tampa Bay, and almost extirpated from the State of Florida. The crisis in protecting the colonies today is no less significant than the decimation of birds during the plume-hunting era at the turn of the century. Though diminished, a vibrant, diverse colonial waterbird population still exists in the Tampa Bay system. Maintaining the health, abundance, and diversity of these magnificent birds is a great challenge and an important institutional responsibility for our community.

Dedication

We dedicate this chapter update posthumously to Richard T. Paul, Sanctuary Manager of the Florida Coastal Islands Sanctuaries and the Tampa Bay area's strongest advocate for colonial waterbird conservation for over twenty-five years. Rich's infectious delight in colonial waterbirds, and his studious management of the regional colonies, have given us the opportunity to protect these charismatic birds for Florida's future.

Data Ownership

The data presented in this chapter are owned by Audubon of Florida and may not be used for other publications or re-interpreted by others without the express written consent of Audubon of Florida. Audubon of Florida's Florida Coastal Islands Sanctuaries Program is currently preparing a manuscript of this study for publication within the next twenty-four months. The Florida Coastal Islands Sanctuaries Program may be contacted at 410 Ware Blvd., Suite 702, Tampa, FL 33619, telephone 01-813-623-6826, email ahodgson@audubon.org.

H. Greening (Tampa Bay Estuary Program)

Goals adopted to restore and protect the living resources of Tampa Bay and results from the 2002-2006 Baywide Environmental Monitoring Report are collated here to provide a synthesis of current status and trends for goals and the resources they are designed to protect and/or restore. In addition, specific "flags" (indicating that additional attention and action may be needed) are highlighted.

Water and sediment quality:

- The dramatic water quality improvements that occurred in Tampa Bay during the mid-1980s have been maintained through 2005.

- Old Tampa Bay, Hillsborough Bay and Middle Tampa Bay have shown significant increases in water clarity and decreases in chlorophyll-*a* concentrations during 1980-2005. Dissolved oxygen concentrations have maintained their improved levels through 2005.

- Measures of benthic condition were relatively low in the four major rivers discharging to Tampa Bay relative to samples from Tampa Bay proper.

Nutrient and contaminant loading:

- Annual total phosphorus and total nitrogen loadings in 1999-2003 were generally lower or equal to those during the "hold the line" period of 1992-1994. Higher loadings occurred in 2003, associated with higher rainfall amounts.

- Total nitrogen loading ranged between 5,000 and 7,500 tons during wet years and 2,000 and 4,000 tons during relatively dry years for the period 1999-2003.

- Contribution to average annual total nitrogen loading from the seven major loading sources (1999-2003) were nonpoint sources (62.2%), atmospheric deposition (21.6%), domestic point sources (9.5%), springs (3.0%), industrial point sources (2.9%), accidental fertilizer release (0.7%), and groundwater (0.05%). Average annual TN loading from all sources for this time period was 4135 tons.

Habitats:

- Since 1999, seagrass acreage has increased at a rate of 1.8 percent or more per year, rates higher than those observed in the 1990s. The 2004 seagrass coverage represents 67 percent of the 1950 estimates. Seagrass species composition vary among bay segments and over time.

- The Artificial Reef Program has installed over 46,000 metric tons of concrete substrate in a series of artificial reefs throughout Tampa Bay, covering an approximate area of 126 acres. More than 144 taxa and 14 phyla were identified associated with the artificial reef sites.

Animal Populations:

- Most coastal bird species' populations have declined in Tampa Bay over the past thirty years, particularly those that forage in freshwater wetlands. However, Roseate Spoonbill, American Oystercatcher, Caspian, Royal and Sandwich Tern populations are increasing. The status of many species is indeterminate and requires further study.

- Fish population estimates as measured by the Fisheries Independent Monitoring Program since 1989 show species-specific patterns, including:

  - red drum juvenile abundances peaked in 1991, 1995 and 2003 and were relatively constant from 1996 to 2001.

  - snook juvenile abundance estimates remained fairly constant from 1989 to 2005 with the exception of a peak in 1999.

  - spotted seatrout juvenile recruitment was relatively stable from 1991 to 2004. Recruitment of spotted seatrout was lower in 2005, as compared to previous years.

  - Blue crab abundances were lowest in 1990 and peaked in 1989, 1992, 1995, 1998 and 2003.

- Shallow tidal creeks in Tampa Bay supported greater fish densities than man-made ditches. Fish density in wetland ponds was greater than that observed in tidal creeks and ditches, though fewer taxa comprised the majority of the pond assemblages.

Areas of potential concern

One of the most important functions of monitoring programs is to provide an indication of potential degradation in condition or change in trends. Based on the results of the 2002-2005 Baywide Environmental Monitoring Report, several areas indicate the need for careful consideration and action, including the following:

1. Although seagrass coverage increased baywide between 1999 and 2004, **seagrass acreage declined in Old Tampa Bay**. Water quality and clarity targets did not meet targets in several years in Old Tampa Bay. A research project is underway to assess factors associated with poor water quality and seagrass loss in this bay segment.

2. Tributaries to Tampa Bay exhibit higher levels of hypoxia and sediment contamination, and degraded benthic communities compared to Tampa Bay proper. Some contaminants were detected at concentrations likely to be toxic to aquatic life. A Tidal Tributaries research project is underway to examine some of these factors in small tributaries.

3. Results of modeling estimates from USGS indicate that the **extent of urbanization in the Tampa Bay watershed is predicted to double from 1992 to 2025,** with agricultural land becoming reduced by 58% and forested land reduced by 80%.

4. Most coastal bird species' populations have declined in the past thirty years, particularly those that forage primarily in freshwater wetlands. Human disturbance at posted sanctuaries and unposted colonies has become the most significant cause of nesting failure annually.