BAYWIDE ENVIRONMENTAL MONITORING REPORT
1998-2001

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TAMPA BAY, FLORIDA

Tampa Bay Estuary Program, May 2003
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New Elements of the Tampa Bay Monitoring Program 1998-2001

Effective monitoring is essential to a successful bay restoration effort by allowing communities to measure return on investment, assess progress and fine-tune priorities as needed. The baywide monitoring program, initiated through a Tampa Bay Estuary Program (TBEP) effort and based on EPA's EMAP statistical design, is implemented by several of the TBEP partners and builds upon existing monitoring data to more clearly assess progress in the bay's recovery. Rather than emphasizing compliance with rigid laboratory standards for water quality, the monitoring program for Tampa Bay seeks to measure instead the health 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), Florida Marine Research Institute (FMRI), and the Southwest Florida Water Management District (SWFWMD). Continuous coordination between the various local governments and agencies 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 it now coordinated by the local governments who run the monitoring programs. RAMP meets quarterly to collect water samples from a common container. Each program has its own laboratory run the samples for a core group of parameters (TN, nitrate+nitrite, ammonia, TSS, TP, orthophosphate, color, turbidity, and chlorophyll *a)*, and the RAMP participants compare the results at a following meeting. To date, the RAMP participants have worked out differences between laboratories for several critical parameters (chlorophyll, TN, TP, TSS) and continue to work on others (color, for example).

This successful coordination effort has recently been joined by Charlotte, Sarasota, Lee, and Polk counties' monitoring programs, and has been recognized by the State of Florida as a core group for inclusion in the developing statewide program.

> **1998-2001 Update:** The water quality and benthic monitoring programs are ongoing. RAMP is continuing to meet quarterly to collect water quality samples and compare results among laboratories. RAMP participants have agreed to submit water quality data to STORET, and made a concerted effort to submit all data collected to date into STORET for inclusion in the state's 305(b) report and to support the state's TMDL effort.
>
> An important step in the Baywide Environmental Monitoring Program has been the agreement in 2001 by one of the partners, the Pinellas County Department of Environmental Management (PCDEM), to take the lead on providing statistical analyses of water quality and benthic data collected baywide using the EMAP-based algorithms currently being finalized for Tampa Bay by EPA's Gulf Breeze Laboratory. This effort completes the elements needed for long-term maintenance of a baywide monitoring plan, and follows leadership by the EPCHC for the benthic sample analyses; the Manatee County Environmental Management Department (MCEMD) for administering RAMP and baywide grain size analyses; the City of Tampa Bay Study Group for analyses of baywide seagrass transect data; the SWFWMD for aerial photographs and GIS maps of seagrass extent, and the Florida Fish and Wildlife Conservation Commission (FWC) FMRI for baywide fisheries monitoring.
>
> This cooperative approach coordinated through TBEP has allowed us to conduct a much more comprehensive monitoring program than any of the partners would be capable of doing independently. All partners provide field collection efforts (using standardized techniques and methods), but each partner has "specialized" to provide baywide analyses for a specific monitoring element.

The Tampa Bay region is fortunate to have the FWC's FMRI located in this area, which conducts monthly adult and juvenile fish monitoring at approximately 60 stations throughout the bay. Their program, which includes both random and fixed station design elements, provides excellent information on status and trends of fish populations in Tampa Bay, and the statistical design is compatible with the EMAP-based design of the water quality and benthos elements. FMRI supports an extensive statewide data base which is available upon request, and also reports status and trends of important fish species in the TBEP's Environmental Monitoring Report.

SWFWMD is continuing aerial photography and GIS mapping of seagrass extent every two years, which provides the basis for measuring progress toward the TBEP long-term seagrass restoration goal. SWFWMD develops Arc-Info GIS coverages for all bay segments, which are distributed to TBEP, FMRI, and other partners as requested. Status and trends of seagrass acreage in Tampa Bay is reported in the Tampa Bay Environmental Monitoring Report.

1998-2001 Update: In 1999, an important new element was added to the Baywide Environmental Monitoring Program. Randomly located seagrass transects (70 baywide) are monitored by divers on an annual basis to monitor seagrass condition throughout the bay. Species composition, percent cover, degree of epiphyte cover, incidence of the slime mold *Labyrinthula*, and depth at the deep edges of the grassbeds are collected along the transects. Ten agencies and non-profit partners are participating in this new program.

In addition, due to the finding that seagrass growth in some areas of the bay appears to be slowing or is halted, an intensive monitoring program in "problem areas" and reference sites is currently being designed, with implementation to begin in summer 2001.

The atmospheric deposition monitoring program is coordinated by TBEP and FDEP as an element of the Tampa Bay Atmospheric Deposition Study (TBADS), and sample collection is conducted by the EPCHC and Pinellas County. The TBADS intensive site (wet deposition measurements) is included in the National Atmospheric Deposition Program (NADP) network, using NADP sample analyses QA/QC procedures and techniques. Core parameters include ambient air (sulfate, nitrate-N, and ammonium-N) and wet deposition measurements for sulfate, nitrite, chloride, ammonium, phosphate, calcium, magnesium, sodium, and potassium. A companion meteorological station located in the center of the bay collects wind speed and direction, relative humidity, and water and air temperature for input into a "buoy model" developed by NOAA for TBADS to estimate dry deposition from ambient air and meteorological conditions. Data are currently being delivered to NADP (wet only) in addition to being available from the TBEP Data Library. The wet deposition data from the Tampa Bay site is available on the NADP website.

1998-2001 Update: TBEP's funding support of the intensive wet and dry deposition of nutrients and sulfur was assumed by the FDEP in August 2000, thus ensuring a continuous atmospheric deposition monitoring program in Tampa Bay through 2004. A short-term (18 month) data collection project for toxic materials (heavy metals, PAHs, PCBs, and OGCs), funded by EPA Region 4 RGI grant, was complete in 2001.

FDEP will also be conducting additional intensive surveys of air quality and deposition in urban areas of Tampa, with the specific objective of further quantifying deposition of airborne materials to Tampa Bay. This project, called the Bay Regional Atmospheric Chemistry Experiment, or BRACE, is being funded through a settlement agreement with Tampa Electric Company.

Tampa Electric will be refueling one of the large power plants on Tampa Bay, switching from coal to natural gas, which is expected to reduce local emissions significantly over the next 5 years. It will be critical to maintain adequate atmospheric deposition and water quality monitoring to "catch" this dramatic local emissions reduction, and its potential impacts on air quality and water quality. TBEP will work with local, state and federal partners to ensure adequate monitoring is in place.

TBEP will continue to provide coordination between the atmospheric deposition monitoring programs and local governments, agencies and private companies through the continuation of the TBADS advisory committee.

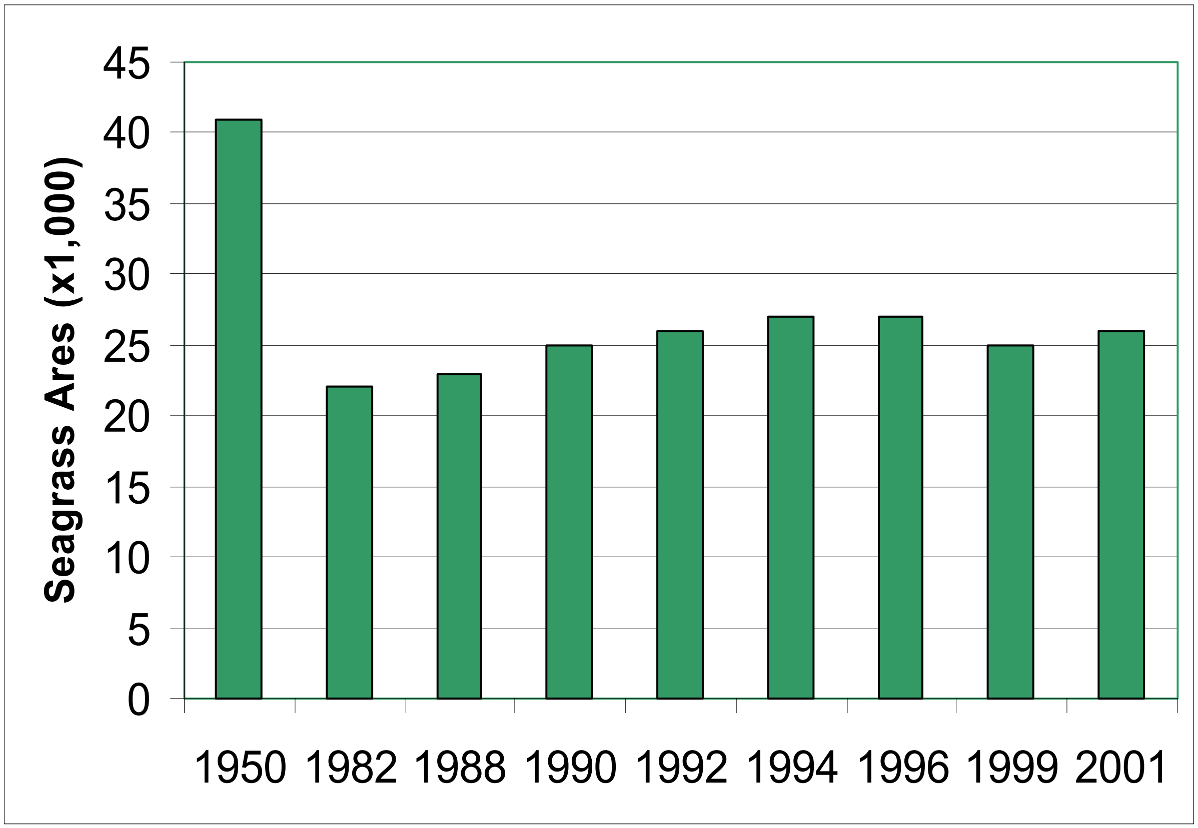
The Baywide Benthic Monitoring Program, initiated in 1993, is based on EMAP design and sampling protocols, and is being implemented in Tampa Bay by the EPCHC, Pinellas County, and Manatee County, with taxonomic assistance from FMRI and some funding support from TBEP. Over 100 stations are collected using the EMAP stratified random hexagonal design once a year in September-October. Sediment quality parameters (metals, PAHs, PCBs, organic pesticides and grain size fractions), benthic community structure (taxonomic sorting to species) and water quality measurements (24-hour *in-situ* dissolved oxygen, salinity, conductivity, pH and temperature) are included in the sampling protocols. Results of the program are compiled and interpreted by EPCHC and distributed as TBEP technical publications. Data are stored in the TBEP Data Library and distributed to the participating programs and others as requested.

1998-2001 Update: Annual data collection at over 100 stations baywide continued through this reporting period. A quality-assured database containing records for all benthic parameters measured in Tampa Bay since 1990 has been finalized. This database is considered by national members of the Tampa Bay Sediment Quality Assessment Group, originally convened by TBNEP in 1992 to help guide our benthic and sediment quality monitoring program, to be one of the most extensive in the country.

Key results of the monitoring program are highlighted in a Biennial Environmental Monitoring Report (BEMR) compiled every several years by TBEP. In addition to the core baywide monitoring program results, status and trends on manatees, dolphins, sea turtles, and wading birds in Tampa Bay are included in the BEMR. The first BEMR was produced in 1996; the second was published in 1998.

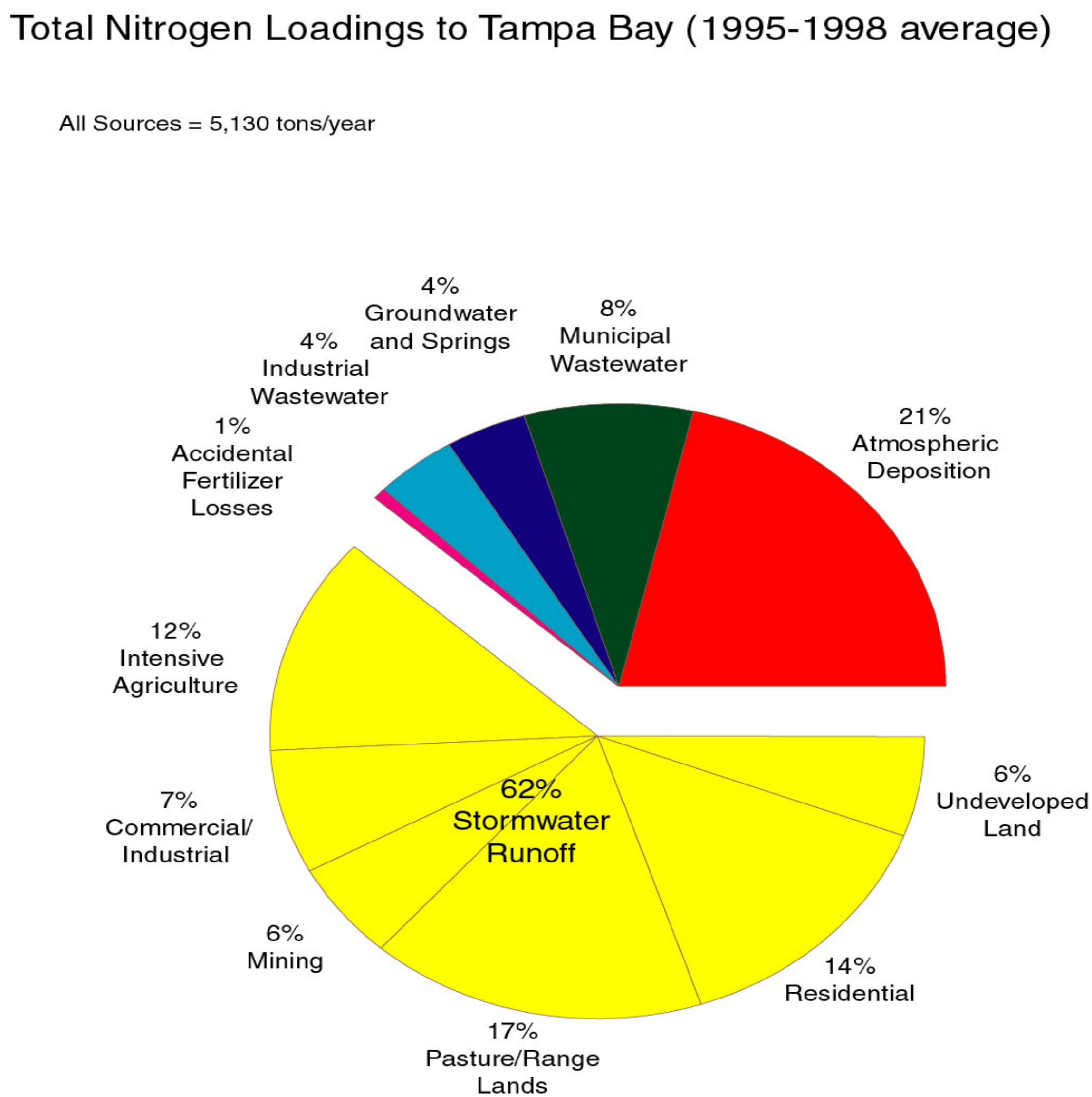
1998-2001 Update: This document is the third BEMR. Discussions will be held this year to determine an appropriate reporting period for this full document. Suggestions include reporting the full suite of monitoring programs every 5 years (just preceding the revision of goals and targets), with annual monitoring reports for water quality and seagrass extent.

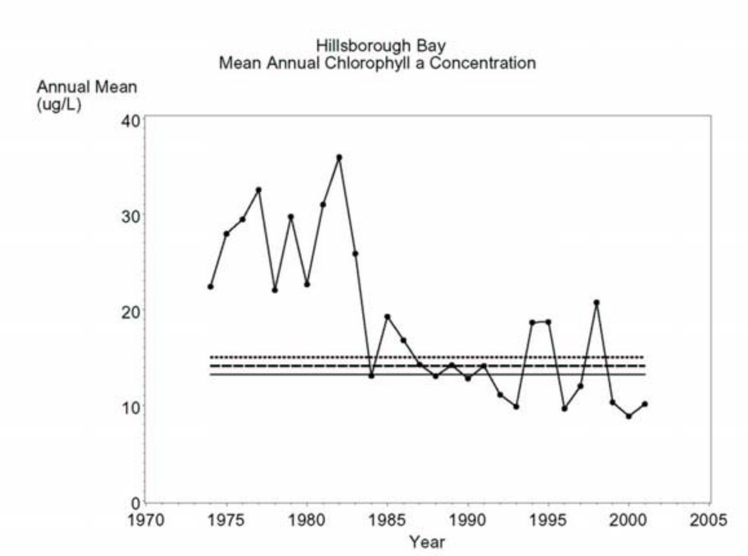
TRACKING PROGRESS TOWARDS TBEP'S GOALS

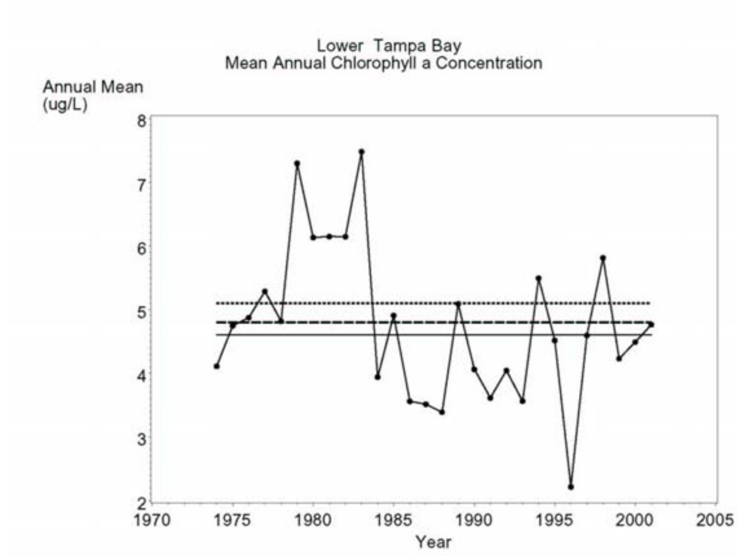


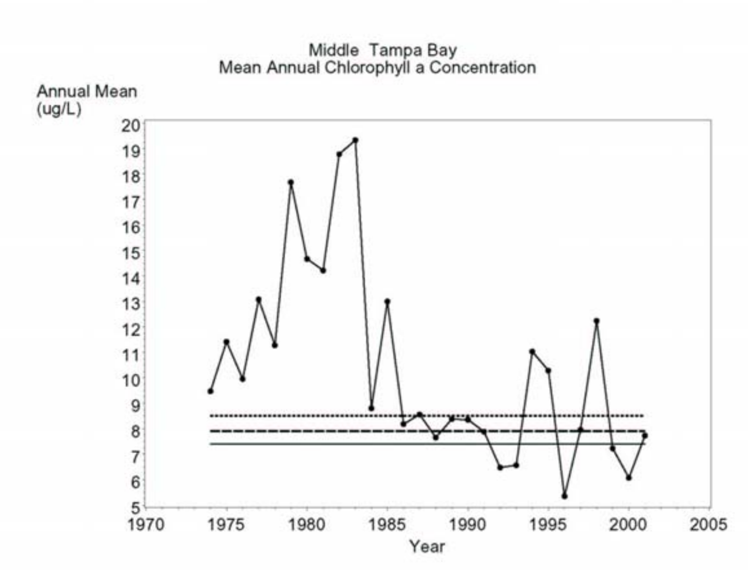
GOAL: Recover an additional 11,922 acres of seagrass over 2001 levels, while preserving the bay's existing 26,078 acres.

STATUS: Between 1988-1996, seagrass acreage increased at about 350 acres per year. El Niño rains resulted in seagrass losses of about 2,000 acres between 1996-1999. In January 2002, seagrass acreage had increased by 1,237 acres to 26,078 acres baywide, a 5% increase from 1999.


Total Nitrogen Loadings to Tampa Bay (1995-1998 average)
All Sources = 5,130 tons/year
4% Groundwater and Springs
8% Municipal Wastewater
4% Industrial Wastewater
1% Accidental Fertilizer Losses
21% Atmospheric Deposition
12% Intensive Agriculture
7% Commercial/ Industrial
62% Stormwater Runoff
6% Undeveloped Land
6% Mining
14% Residential
17% Pasture/Range Lands


Hillsborough Bay
Mean Annual Chlorophyll a Concentration
Annual Mean (ug/L)
0
10
20
30
40
1970 1975 1980 1985 1990 1995 2000 2005
Year


Lower Tampa Bay
Mean Annual Chlorophyll a Concentration
Annual Mean (ug/L)
2
3
4
5
6
7
8
1970 1975 1980 1985 1990 1995 2000 2005
Year


Middle Tampa Bay
Mean Annual Chlorophyll a Concentration
Annual Mean (ug/L)
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
1970 1975 1980 1985 1990 1995 2000 2005
Year

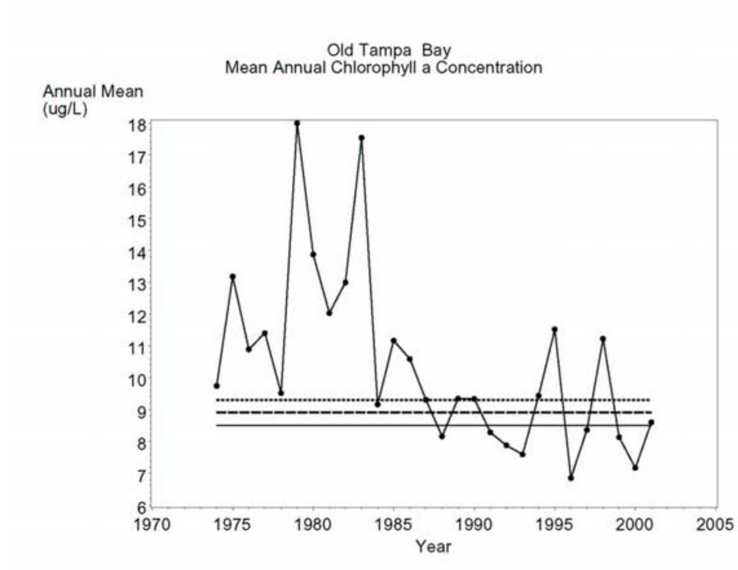

Old Tampa Bay
Mean Annual Chlorophyll a Concentration
Annual Mean (ug/L)
6 7 8 9 10 11 12 13 14 15 16 17 18
1970 1975 1980 1985 1990 1995 2000 2005
Year

Table 3. Decision matrix results.

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

Tampa Bay Goals at a Glance
Water and Sediment Quality
1998-2001 Update

GOAL	STATUS	
	ACTION INDICATORS	ENVIRONMENTAL INDICATORS
Prevent increases in the bay's nitrogen levels to provide water clarity suitable for the gradual recovery of 12,350 acres of seagrass. To maintain existing water quality conditions, local governments and industries will need to reduce their future nitrogen contributions to the bay by about 7 percent by the year 2010, or approximately 17 tons per year. **1998-2001 Update:** After review of models and updates of loading estimates and bay response, the TAC and Management Board have recommended that the 17 ton per year reduction goal remain unchanged through 2010.	1995-1999 reduction goals for all bay segments are expected to be met by the end of 1999, through implementation of projects specified by public and private partners in the Tampa Bay Nitrogen Management Consortium Action Plan *Partners for Progress* **1998-2001 Update:** Action Plan Updates, received from all partners in 2000, confirmed that projects completed met reduction goals through 2000. 2001-2005 Action Plans from all partners, outlining expected projects and anticipated reductions, will be due in Fall 2003. An electronic tracking system is under development, and will be used by the partners to enter their projects.	Nitrogen loadings to the bay are scheduled to be updated with 1995-1999 data in the year 2000. **1998-2001 Update:** Updated nitrogen loading estimates (1995-1999) showed that nitrogen loading during this time period was higher than for the previous period (1985-1994), primarily due to heavy rains and runoff associated with El Niño in 1997-1998. When adjusted for rainfall, however, nitrogen loadings showed no trend since 1985.

Tampa Bay Goals at a Glance
Water and Sediment Quality
1998-2001 Update

GOAL	STATUS	
	ACTION INDICATORS	ENVIRONMENTAL INDICATORS
Interim target: Maintain segment-specific chlorophyll a concentrations equal to the lowest of either the annual average of 1992-1994 or the concentration that supports the seagrass restoration goal. **1998-2001 Update:** The TAC and Management Board have recommended that the chlorophyll *a* concentration targets remain the same through 2010, based on review of water quality data and application of the TBEP models.	See action indicators for nitrogen loading above.	Average annual chlorophyll *a* levels for each bay segment have fluctuated above and below specific targets since 1994. No obvious trends over time are evident. **1998-2001 Update:** Updated trend analyses through 1998 show that chlorophyll *a* concentrations continue to fluctuate around the target levels in response to rainfall, with no obvious trends over time. Each bay segment met chlorophyll *a* targets in 2001, although three of the four segments did not meet light targets (see attached Decision Matrix)

Tampa Bay Goals at a Glance
Water and Sediment Quality
1998-2001 Update

GOAL	STATUS	
	ACTION INDICATORS	ENVIRONMENTAL INDICATORS
Gain a better understanding of the role that atmospheric deposition plays in the bay's water quality, and identify and address the sources of air pollution.	Eight research and monitoring projects addressing atmospheric deposition in the Tampa Bay area are ongoing. **1998-2001 Update:** In 2000, FDEP assumed responsibility for continuing the intensive wet/dry deposition monitoring at the Gandy Bridge site, and initiated a much more extensive project (the Bay Region Atmospheric Conditions Experiment-BRACE). Atmospheric toxics deposition sampling was complete in April 2001. A major local reduction in atmospheric emissions of NO_x is expected when a large Tampa Electric Company power plant is converted from coal to natural gas by 2008. However, the relationship between emissions and deposition remains highly uncertain, and careful monitoring will be needed to track any changes in deposition to the bay.	**1998-2001 Update:** 1995-1998 estimates of the contribution of TN from atmospheric deposition loadings to Tampa Bay showed a decrease over the previous time period. Atmospheric deposition contributions during 1995-1998 accounted for 21% of the TN loadings, compared to 29% during the 1992-1994 period (see attached TN loading figure)

Tampa Bay Goals at a Glance
Water and Sediment Quality
1998-2001 Update

GOAL	STATUS	
	ACTION INDICATORS	ENVIRONMENTAL INDICATORS
Reduce bacterial contamination now present in the bay to levels safe for swimming and shellfish harvesting.	**1998-2001 Update:** Results of the "Healthy Beaches Tampa Bay" study, complete in February 2001, recommended that a combination of indicators be used in Tampa Bay: 1. Fecal coliform bacteria combined with enterococcus should be used for routine monitoring; 2. For areas where source tracking is needed, multiple antibiotic resistance for fecal coliform bacteria should be used, and coliphage should be added as a third indicator in areas with freshwater inputs. 3. *Clostridium* may be useful for one-time sanitary surveys. *Bacteriodes* can be useful in identifying septic tank inputs.	Number of beach closures and percent shellfish beds open (not yet compiled for Tampa Bay) **1998-2001 Update:** The Healthy Beaches one-year survey showed that, baywide, most of the study sites showed little sign of human health risk. However, of 22 sites around the bay and the beaches, samples from two sites consistently exceeded suggested guidelines for human health. One of these sites was a tributary in a rural area with multiple septic systems, the other a residential tributary to Old Tampa Bay. Specific indicators for this goal have not yet been compiled. The Healthy Beaches project did not address shellfish harvesting areas.

Tampa Bay Goals at a Glance
Water and Sediment Quality
1998-2001 Update

GOAL	STATUS	
	ACTION INDICATORS	ENVIRONMENTAL INDICATORS
Reduce the amount of toxic chemicals in contaminated bay sediments and protect relatively clean areas of the bay from contamination.	**1998-2001 Update:** Numeric targets are still being developed, due to unanticipated delays in preparation of the database. Targets will be finalized by summer 2003. EPA EMAP is working with TBEP to develop probabilistic algorithms to estimate areal extent of benthic conditions. Annual baywide monitoring is continuing, with additional focus in tributaries in 1999-2001.	"Hot spots" of contaminated sediments occur in relatively concentrated areas around large marinas, ports and urban stormwater outfalls. To date, no trends in sediment quality since monitoring was initiated in 1993 have been observed. **1998-2001 Update:** 1995-2000 samples in the bay show no significant changes since 1993. However, additional "hot spots" have been located in larger tributaries (not previously sampled).

Tampa Bay Goals at a Glance
Habitat
1998-2001 Update

GOAL	STATUS	
	ACTION INDICATORS	**ENVIRONMENTAL INDICATORS**
Recover an additional 12,350 acres of seagrass over 1992 levels, while also preserving the bay's existing 25,600 acres and reducing propellor scarring of seagrasses. **1998-2001 Update:** The overall TBEP seagrass goal of 38,000 acres baywide still stands. However, to reflect the 2001 estimates, the goal has been reworded as " Recover an additional 11,922 acres over 2001 acres, while preserving the bay's existing 26,078 acres and reducing propellor scarring of seagrasses".	Nitrogen management goals are being met (see Water & Sediment Status). Channels through seagrasses have been marked in heavily scarred areas. Aerial photos and mapping occurs every 2 years, and biannual seagrass conditions monitoring was initiated in fall 1998. **1998-2001 Update:** Nitrogen load reduction goals continue to be met by the Nitrogen Management Consortium baywide, although El Niño rains resulted in the delivery of excess nitrogen to the bay in 1997-1998. A Seagrass Restoration Strategy is being implemented to address those areas where seagrass recovery is lagging. Several "go slow" areas in shallow seagrass habitat have been adopted at the county levels. Seagrass conditions monitoring (70 transects baywide) has been increased to annual frequency.	Since 1992, seagrass acreage increased at about 350 acres per year. At this rate, the goal will be reached in 30-40 years. **1998-2001 Update:** Heavy rains associated with El Niño in 1997-1998 resulted in excess nitrogen loading and chlorophyll a concentrations above target levels in all bay segments. Almost 2000 acres of seagrass were lost baywide during this period. In January 2002, seagrass acreage increased by 1,237 acres to 26,078 acres baywide, a 5% increase from 1999.

Tampa Bay Goals at a Glance
Habitat
1998-2001 Update

GOAL	STATUS	
	ACTION INDICATORS	**ENVIRONMENTAL INDICATORS**
"Restore the historic balance" of coastal wetland habitats in Tampa Bay by restoring at least 100 acres of low-salinity (oligohaline) tidal marsh every five years, for a total increase over time of 1,800 acres. **1998-2001 Update:** With 378 acres restored between 1995-2001, the total increase of oligohaline habitat over time is 1422 acres.	**1998-2001 Update:** More than twenty coastal habitat restoration projects were initiated or completed between 1998 and 2001 in cooperation between SWFWMD and local government partners. Tampa BayWatch collated and developed a system to prioritize the 43 future habitat restoration sites around Tampa Bay, as identified during a Habitat Restoration Workshop (July 1998).	Approximately 378 acres of oligohaline habitat were restored between 1995 and 2001, far exceeding the original goal of 100 acres every 5 years. Oligohaline restoration will occur in all bay segments. **1998-2001 Update:** All oligohaline projects identified in the Action Plans have been completed or are underway, meeting and exceeding the first five-year restoration goal. Total coastal habitat restoration from SWFWMD/local partners in 1995-2000 =250 acres, and in 2001=128 acres at Wolf Branch. A total of 1,340 acres of mangrove/salt marsh habitat was restored in 1995-1999, with an additional 678 acres restored in 2000 and 2001.

Tampa Bay Goals at a Glance
Habitat
1998-2001 Update

GOAL	STATUS	
	ACTION INDICATORS	ENVIRONMENTAL INDICATORS
Preserve and enhance the bay's 18,800 acres of existing mangrove/salt marsh habitats, including the 28 coastal habitat sites designated as priorities for protection, either through public purchase or methods such as conservation easements.	All 28 priority sites identified in the TBEP Habitat Masterplan have been given the highest priority for the State's Save Our Rivers or P2000 land acquisition programs by the Southwest Florida Water Management District. **1998-2001 Update:** SWFWMD and FDEP are progressing with acquisition of the priority projects outlined in Tampa Bay Estuarine Ecosystem Protection Program.	A total of 1,833 acres of the 13,434 acres identified as the "Tampa Bay Estuarine Ecosystem" have been acquired for preservation and restoration in 995-1997. **1998-2001 Update:** An additional 60 acres of coastal habitat around Tampa Bay was acquired in 2000 by SWFWMD.

A.P. Squires (Pinellas County Dept. of Environmental Management)

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, 36 existing (1992) 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 of Hillsborough County (EPCHC), Pinellas County, Manatee County, and the City of Tampa. Ambient water quality monitoring by EPCHC 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. 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). Seagrasses are assessed by mapping the resource every two years and by conducting annual field visits of fixed seagrass transects. Seagrasses are mapped by the Southwest Florida Water Management District Surface Water Improvement and Management (SWFWMD SWIM) program using aerial photo-interpretation. Annual evaluations of seagrass transects are conducted by the City of Tampa, Pinellas County, Manatee County, EPCHC, FMRI, Tampa BayWatch, and the Hillsborough County Cockroach Bay Aquatic Preserve. Sediment toxicity studies are done by NOAA and watershed characterization and planning studies are done by Pinellas County. Sediment chemistry, grain size, and benthic macroinvertebrate communities have been monitored annually by EPCHC and Manatee and Pinellas counties.

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, including:

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

THE 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 evaluate the return on the investments allocated to protect and enhance bay resources. As CCMP effectiveness is evaluated, a vehicle is needed to inform the Tampa Bay community of the status of key bay resources. The report herein marks the third installment of that vehicle, the Baywide Environmental Monitoring Report.

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;
- freshwater flow and nutrient loadings;
- atmospheric deposition;
- water quality;
- seagrass coverage and health;
- artificial reef health;
- sediment quality;
- benthic quality;
- fisheries;
- marine mammals;
- bird populations; and
- sea turtles.

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 3-1). 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.

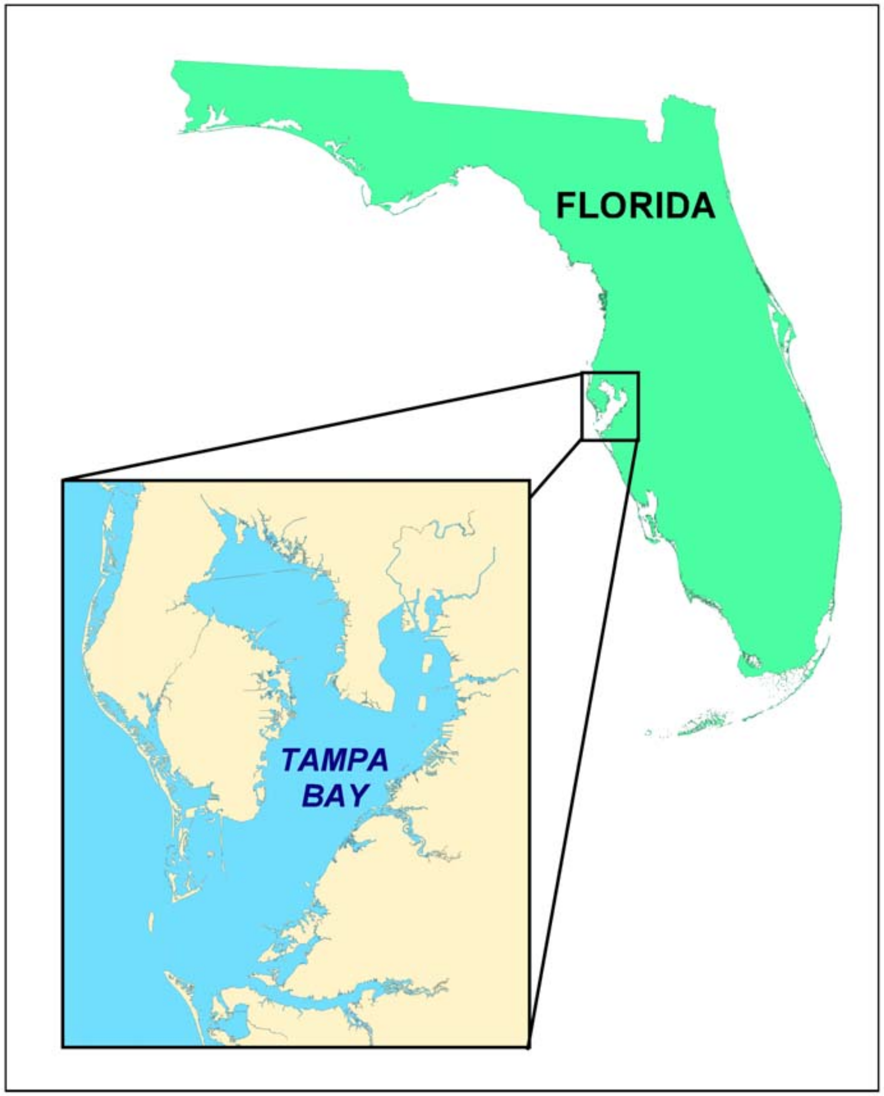


Figure 3-1. Location of the Tampa Bay estuarine system.

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 3-2). 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.

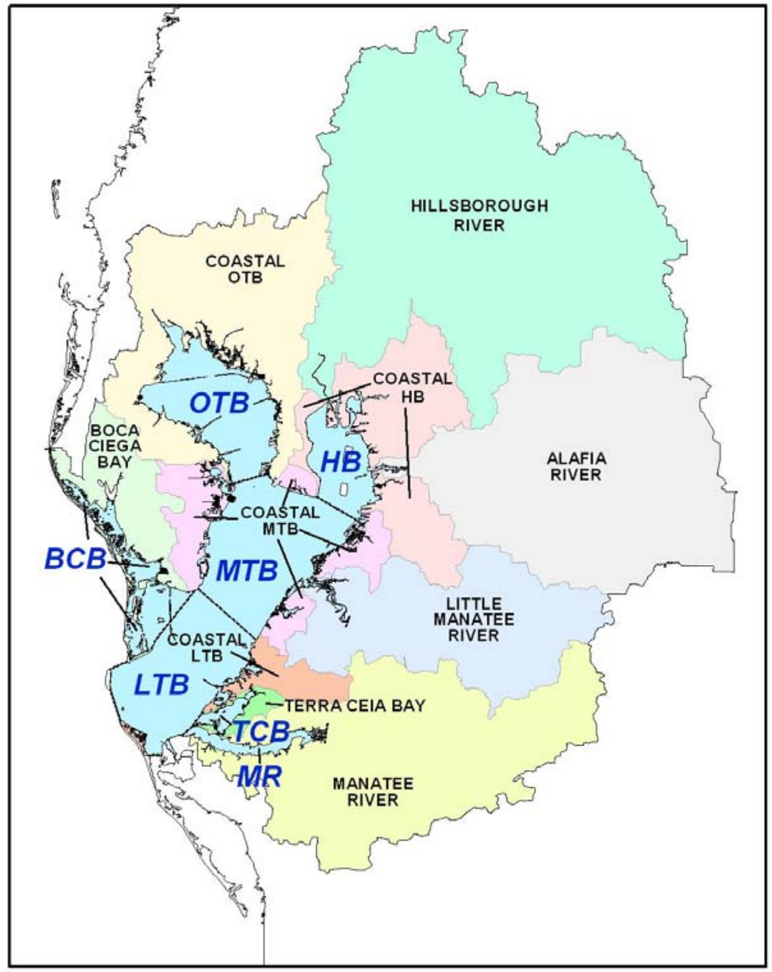


Figure 3-2. The Tampa Bay estuary with the ten major drainage basins of the watershedand the seven bay segments of Tampa Bay (OTB-Old Tampa Bay; HB-Hillsborough Bay; MTB-Middle Tampa Bay; LTB-Lower Tampa Bay; BCB-Boca Ciega Bay; TCB-Terra Ceia Bay; MR-Manatee River).

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 3-1). 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 3-1. 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 (Janicki Environmental, Inc.)

- CHAPTER HIGHLIGHTS -

☞ *Examination of salinity records from the 1960s through the 1990s 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 25 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; Taylor, 1979).

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 1960-1990 period. The results of this analysis suggest that salinity has not changed over the decadal scales examined, as shown in Figure 4-1. 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 (Janicki et al., 2001). The trend test results for surface and bottom salinity are shown in Table 4-1.

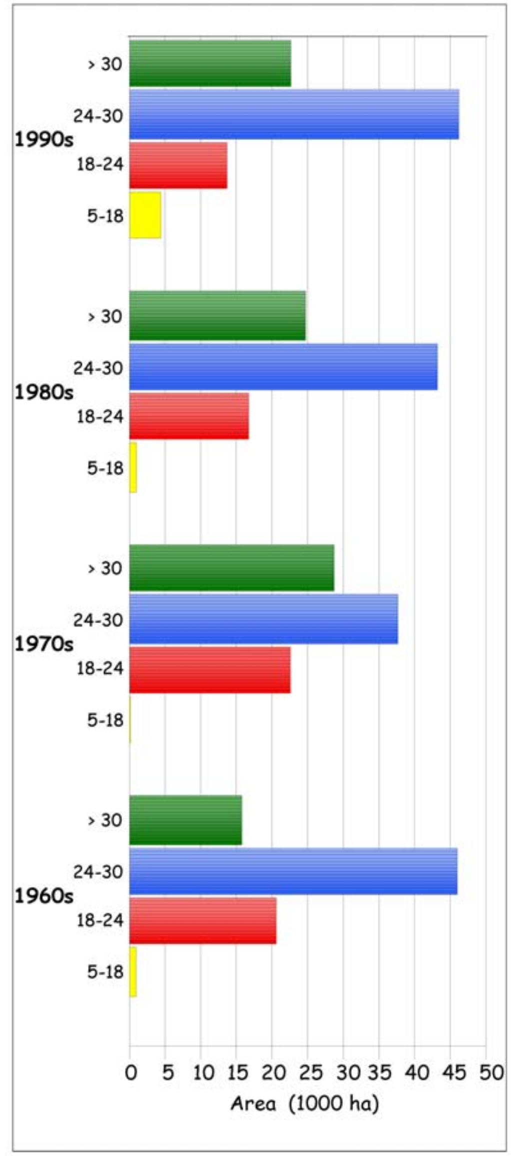


Figure 4-1. Area of salinity classes for each decade, 1960s - 1990s.

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 4-2 shows box and whisker plots of the salinity

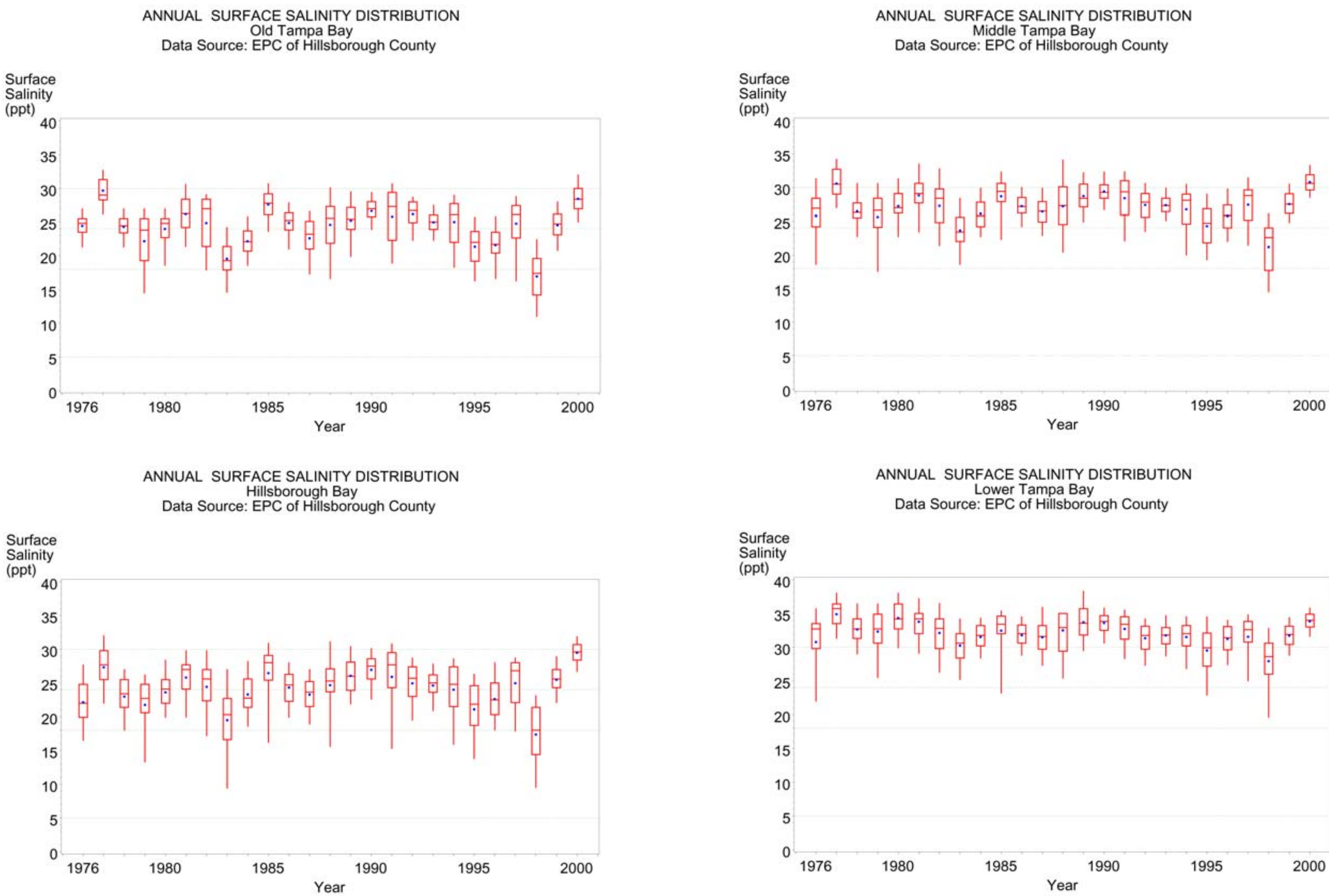


Figure 4-2. Box and whisker plots of mean annual salinity in the four mainstem segments of Tampa Bay.

data, with lines at the salinity values defining the ranges of the classes shown in Figure 4-1. Generally, it can be concluded that the long-term salinity trends in the mainstem of Tampa Bay have not been significant.

Table 4-1. 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 1976-2000 period is shown in Figure 4-3. 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 4-4. 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

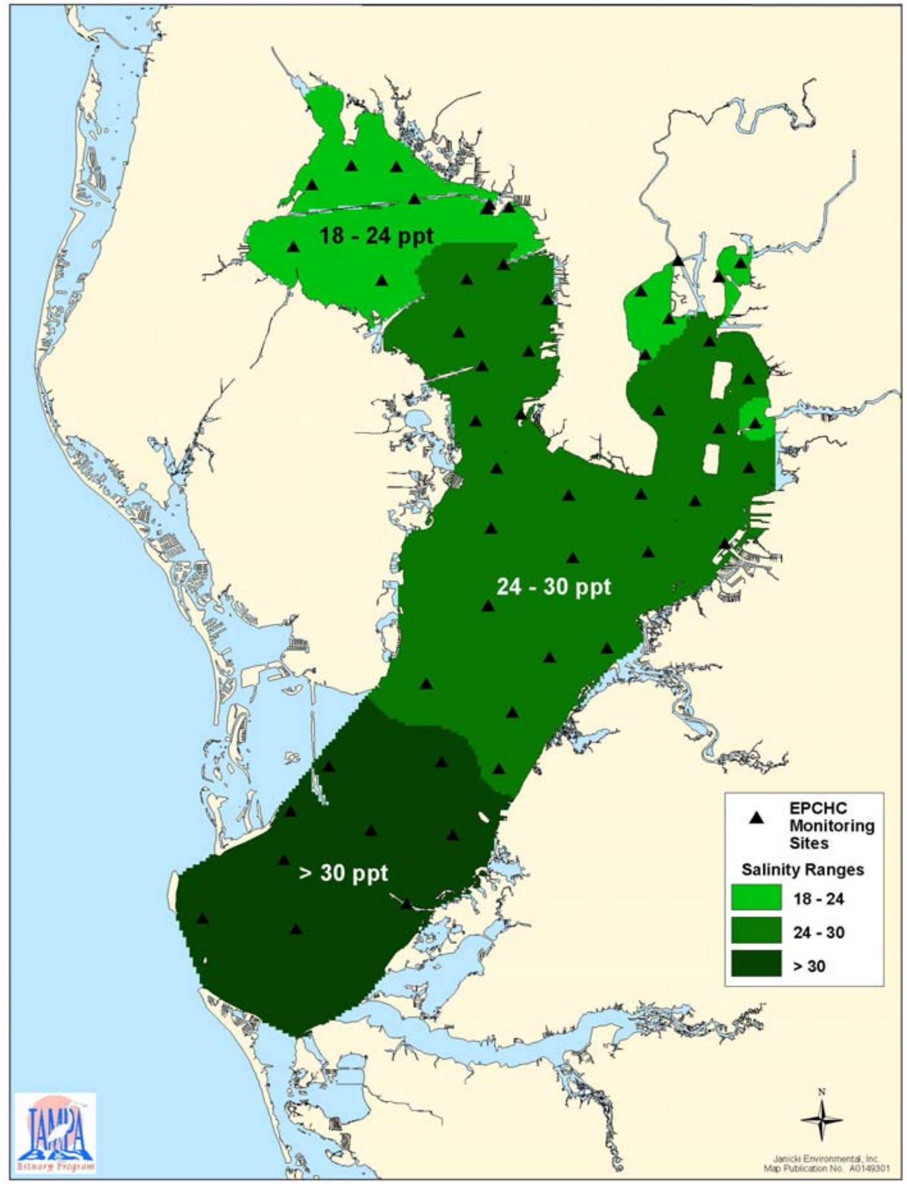


Figure 4-3. Typical distribution of mean annual surface salinity for the 1976-2000 period.

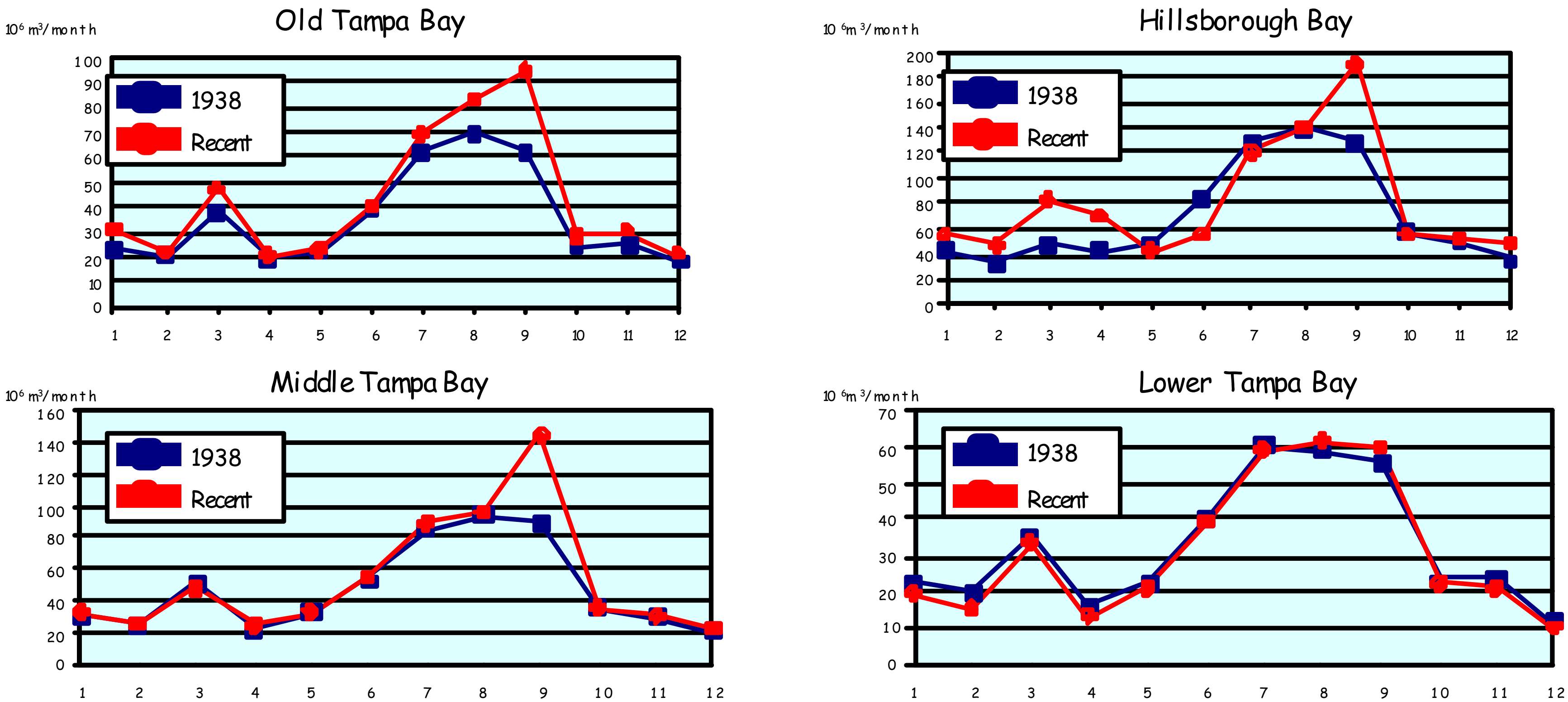


Figure 4-4. Comparison of historical and recent monthly freshwater inflows to the four mainstem segments of Tampa Bay.

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

- *CHAPTER HIGHLIGHTS* -

- *Estimates of freshwater inflow to Tampa Bay and loading of total nitrogen (TN) and total suspended solids (TSS) suggest a weak increasing trend during the period 1985-1998.*
- *The inflow and loading of TN and TSS increased substantially during the recent El Niño event in 1997 and 1998.*
- *TN loading has ranged between 5,000 and 6,500 US tons during wet years and between 3,000 and 4,000 US tons during relatively dry years.*
- *Trends of total phosphorus (TP) loading are uncertain due to a recent methodological change in the estimates of atmospheric phosphorus deposition.*
- *TSS loading reaches pronounced peaks during years with relatively high rainfall.*
- *Nonpoint sources supply the greatest portion of all estimated loads to Tampa Bay.*
- *Atmospheric deposition directly to the bay surface is currently estimated to supply 21% of the TN load to the 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

Table 5-1. Percentage contribution by each bay segment to the total Tampa Bay loading of freshwater inflow, TN, TP, and TSS. Percentages are calculated from 1995-1998 data for all parameters except TP, which is calculated from 1997-1998 data.

Bay Segment	Freshwater Inflow (percentage)	TN Loading (percentage)	TP Loading (percentage)	TSS Loading (percentage)
Old Tampa Bay	16.9	13.1	5.8	16.6
Hillsborough Bay	34.5	42.2	76.1	48.3
Middle Tampa Bay	19.3	16.3	6.2	10.0
Lower Tampa Bay	10.7	7.0	1.7	1.6
Boca Ciega Bay	5.8	5.7	1.1	10.5
Terra Ceia Bay	1.0	0.8	0.2	0.6
Manatee River	11.7	14.9	9.0	12.4

Tampa Bay segments for the 14 year period, 1985-1998. Several environmental consulting groups working under contract with the TBEP have compiled most of the data presented in this chapter.

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) and Pribble et al. (2001).

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 and in Pribble et al. (2001) for the period 1995-1998. A major modification in the method used to estimate atmospheric deposition of TP occurred in late 1996. This change substantially reduced subsequent loading estimates of TP. As a result, the long-term trend of TP loading to the bay segments and Tampa Bay as a whole is uncertain.

To provide a relatively consistent long-term record of TP loading to Tampa Bay, this author used an alternate approach to estimate annual TP loading. The method is based on the relationship between ambient Tampa Bay salinity and TP concentrations. Please see BEMR (1999; Chapter 4) for a more detailed description and discussion of this method.

RESULTS AND DISCUSSION

Estimates of freshwater inflow to Tampa Bay and the loading of TN and TSS suggest a weak increasing trend over the 14 year period 1985-1998 (Figs. 5-1, 5-2, and 5-3). In contrast, loading of TP for the same period (Fig. 5-4) shows a substantial reduction. This reduction is also evident in measured bay concentrations (see Boler, 1999). The observed reductions in bay concentrations of TP may not exclusively be caused by recent reductions in loading from external sources to the bay. Large deposits of TP may have accumulated in the bottom sediments during a documented period of high phosphorus loading prior to the 1980s. The internal loading from this source to the water column could also be decreasing as the sediments may become increasingly depleted in phosphorus over time.

The annual variation for all measured loading parameters, except TP, appears to be affected to a great extent by the annual Tampa Bay rainfall amount (Fig. 5-5). For example, the four years with the greatest amount of rainfall during the study period (1988, 1995, 1997, and 1998) also generally had the highest loading of all estimated parameters (except TP). Specifically, TSS loading reaches pronounced peaks during the years with relatively high rainfall. Further, the inflow and loading of all parameters, except TP, increased substantially during the recent high rainfall El Niño event in 1997 and 1998. In contrast, loading of TP during this event remained substantially below the loading rate for the relatively high rainfall year of 1988.

Hillsborough Bay has, by far, the greatest watershed area of all bay segments, and also receives discharges from several large point sources and the major fraction of inputs from the fertilizer facilities located near Tampa Bay. Consequently, Hillsborough Bay contributes a major portion of the total Tampa Bay loading of all parameters. During the period 1995-1998, Hillsborough Bay supplied 35% of Tampa Bay freshwater inflow, 42% of TN loading, 48% of TSS loading, and more than 70% of TP loading (Table 5-1). In contrast, Terra Ceia Bay, which is the smallest bay segment and which also has the smallest watershed area, only supplies one percent or less of any parameter to Tampa Bay. Nonpoint sources supply the greatest portion of all measured parameters to Tampa Bay (Fig. 4-6 to 4-9). During the period 1995-98, this category supplied 51% of freshwater inflow, 62% of TN loading, 98% of TSS loading, and approximately 70% of TP loading.

Atmospheric deposition to the open bay surface during the 1995-1998 period supplied substantial fractions of TN loading and freshwater inflow, 21% and 38%, respectively. Atmospheric deposition of TP, based on the most current estimates (1997-1998), only appears to supply 1% or less of the total TP input to Tampa Bay.

CONCLUSIONS

Estimates of freshwater inflow to Tampa Bay and loading of TN and TSS suggest a weak increasing trend during the period 1985-1998.

Trends of TP loading are uncertain due to a recent methodological change in the estimates of atmospheric phosphorus deposition.

Annual variability in loading of the estimated parameters (excluding TP) appears to be greatly affected by rainfall amounts.

Freshwater inflow and loading of TN and TSS increased substantially during the recent El Niño event in 1997 and 1998.

TN loading has generally ranged between 5,000 and 6,500 US tons during wet years and between 3,000 and 4,000 US tons during relatively dry years.

TSS loading reaches pronounced peaks during years with relatively high rainfall.

Nonpoint sources supply the greatest portion of all measured parameters to Tampa Bay.

Atmospheric deposition on the open bay surface currently supplies approximately 21% of the TN load to Tampa Bay.

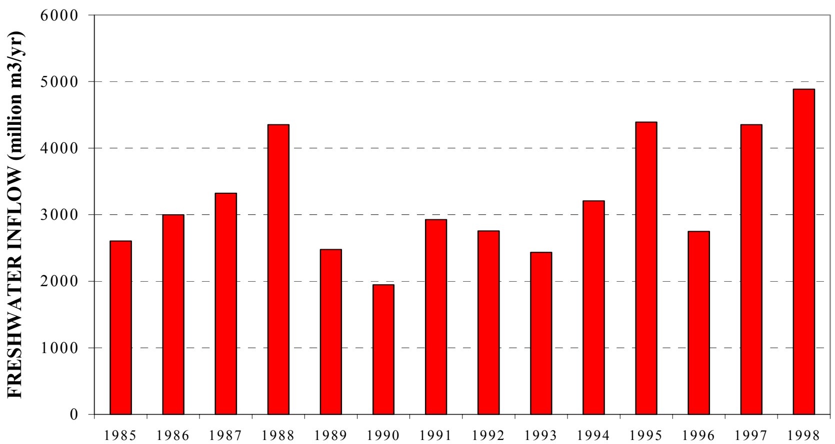

Figure 5-1. Annual freshwater inflow to Tampa Bay, 1985-1998.

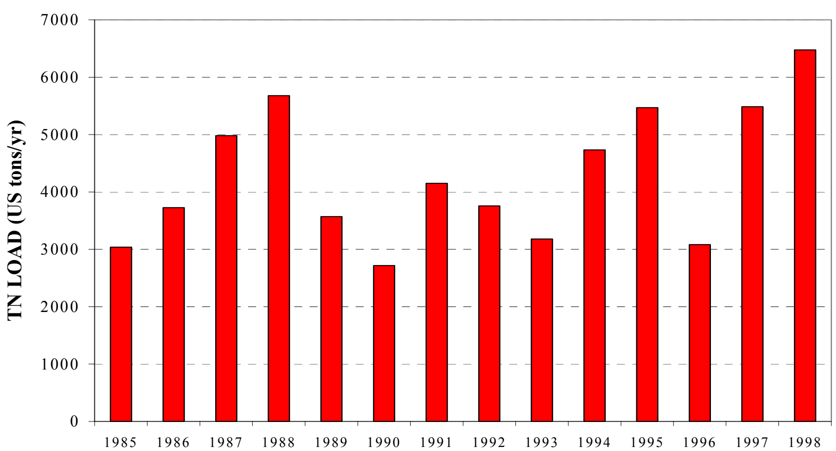

Figure 5-2. Annual TN loading to Tampa Bay, 1985-1998.

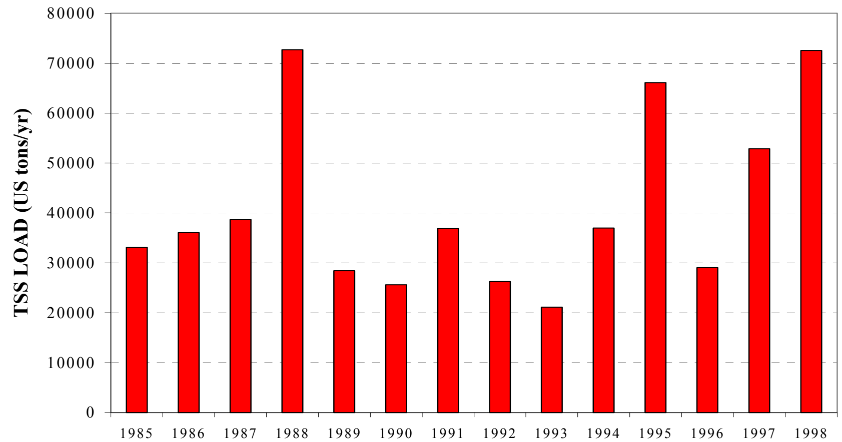

Figure 5-3. Annual TSS loading to Tampa Bay, 1985-1998.

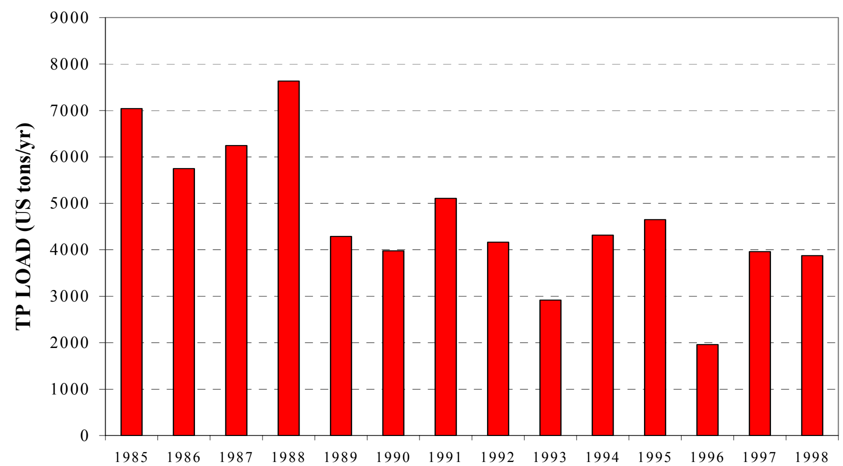

Figure 5-4. Annual TP loading to Tampa Bay, 1985-1998. Estimated from the relationship between ambient salinity and TP concentrations.

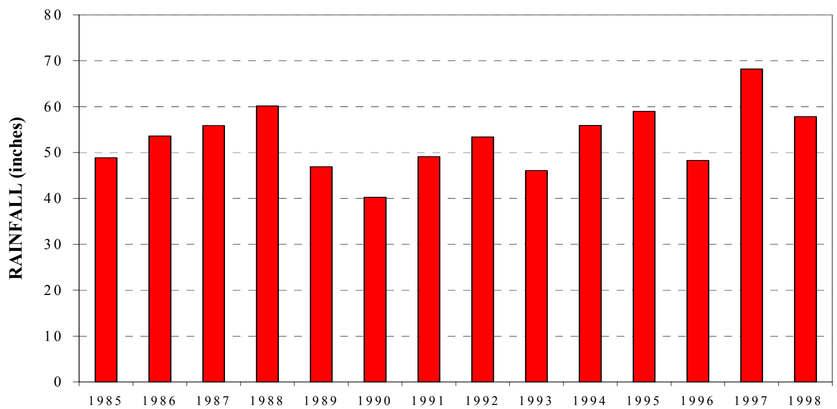

Figure 5-5. Annual Tampa Bay rainfall, 1985-1998.

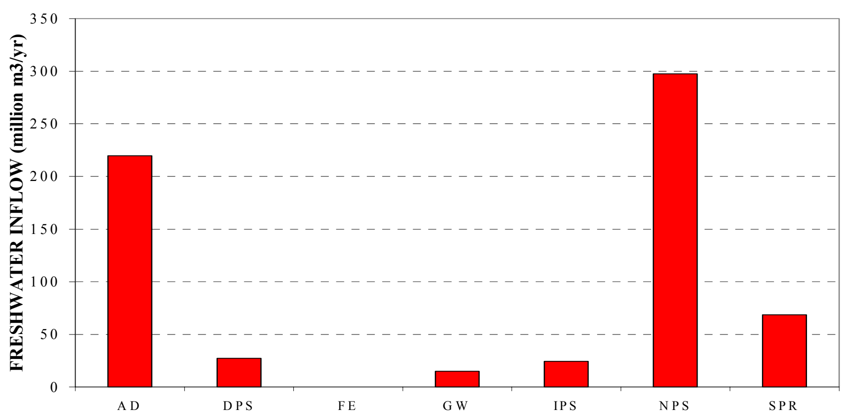

Figure 5-6. Average annual freshwater inflow from the seven major loading source categories for the period 1995-1998 (AD=Atmospheric Deposition; DPS=Domestic Point Sources; FE =Fertilizer Material Loss; GW=Groundwater; IPS=Industrial Point Sources; NPS=Nonpoint Sources; SPR=Springs).

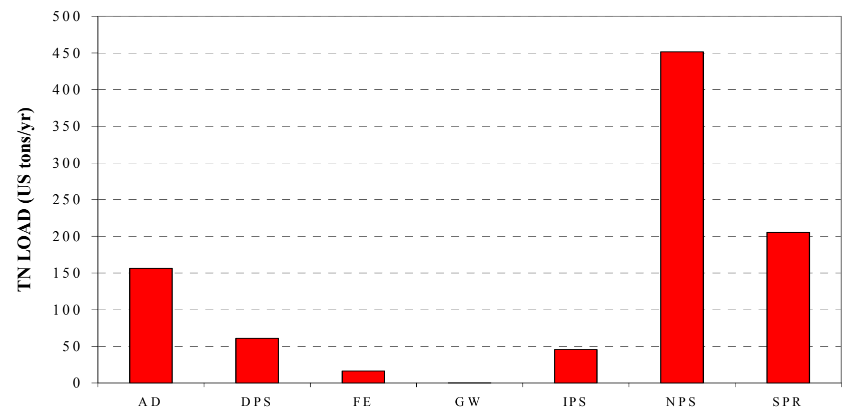

Figure 5-7. Average annual TN loading from the seven major loading source categories for the period 1995-1998 (AD=Atmospheric Deposition; DPS=Domestic Point Sources; FE=Fertilizer Material Loss; GW=Groundwater; IPS=Industrial Point Sources NPS=Nonpoint Sources; SPR=Springs).

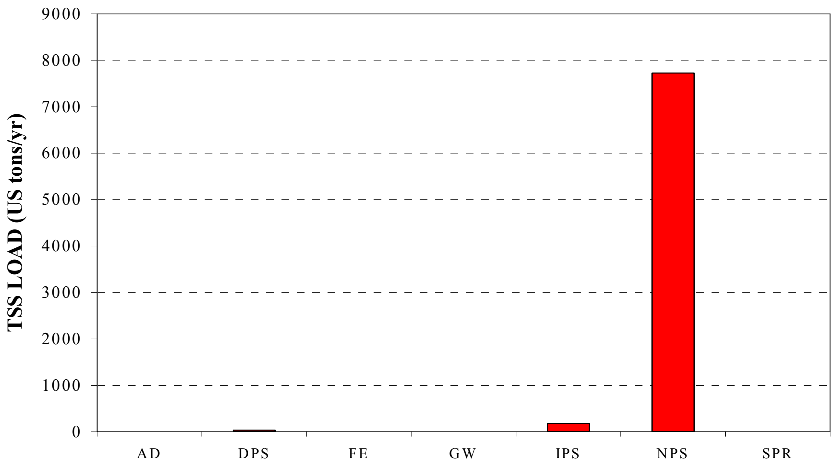

Figure 5-8. Average annual TSS loading from the seven major loading source categories for the period 1995-1998 (AD=Atmospheric Deposition; DPS=Domestic Point Sources; FE=Fertilizer Material Loss; GW=Groundwater; IPS=Industrial Point Sources; NPS=Nonpoint Sources; SPR=Springs).

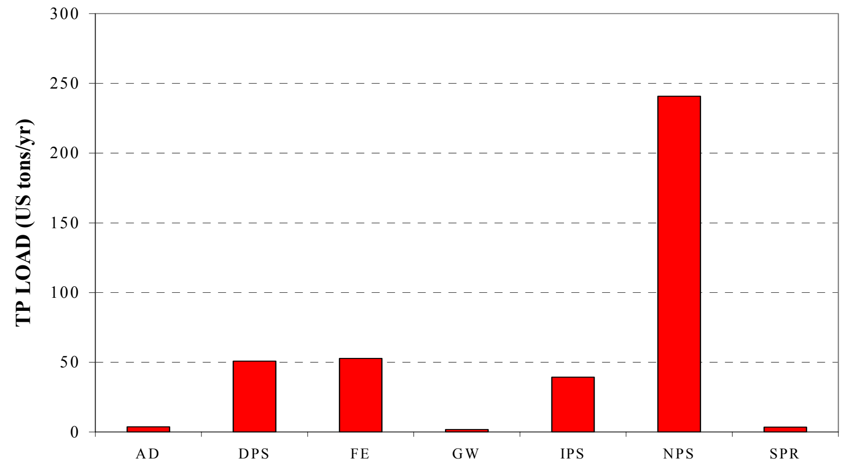

Figure 5-9. Average annual TP loading from the seven major loading source categories for the period 1995-1998. Atmospheric loading estimated from 1997-1998 data (AD=Atmospheric Deposition; DPS=Domestic Point Sources; FE =Fertilizer Material Loss; GW=Groundwater; IPS=Industrial Point Sources; NPS=Nonpoint Sources; SPR=Springs).

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-CHAPTER HIGHLIGHTS-

- *The direct atmospheric deposition rate of nitrogen to Tampa Bay is ~7.7 kg-N/ha/year (~780 metric tons/year) based on a 5-year average, with roughly equal (~1:1) average annual wet and dry deposition rates. Of this total, ammonia/ium nitrogen contributes ~4.5 kg-N/ha/year. Organic amines may constitute a significant and unaccounted for fraction of the total nitrogen deposition.*

- *Dry deposition rates of ammonia obtained from bulk deposition measurements are significantly lower than rates calculated with the inferential model.*

- *In general, air masses that spend much of their time over water before reaching Tampa Bay deliver less nitrate and ammonium nitrogen in rainfall to the bay, and are more likely to be enriched in the stable ^{15}N isotope, indicating relatively clean (non-anthropogenic) sources. Local combustion sources contribute substantially to the deposition of nitrate nitrogen to Tampa Bay, and increases in ambient air or rainfall nitrate nitrogen concentrations are associated with little or no enrichment in the stable ^{15}N isotope.*

- *Ammonia concentrations in urban and industrial Tampa averaged from 1.0 – 2.0 $\mu g/m^3$, with a peak of 16 $\mu g/m^3$ in the vicinity of Port Sutton. The relatively steep concentration gradients and low ambient air concentrations of the "hot spots" do not indicate a major impact to Tampa Bay as a whole, but do represent a potential impact to Hillsborough Bay.*

- *The direct atmospheric loading rates to Tampa Bay of mercury, copper, zinc, and iron were 22 kg (0.022 metric tons)/year, 1,900 kg (1.9 metric tons)/year, 12,000 kg (12 metric tons)/year, and 32,000 kg (32 metric tons)/year, respectively. All were higher than previously estimated by Frithsen et al. (1995).*

- *Chlordane and endosulfan direct atmospheric loading rates to Tampa Bay were ~4 kg (0.004 metric tons)/year and ~13 kg (0.13 metric tons)/year. For chlordane this was 31% of an earlier estimate by Frithsen et al. (1995). Analyses of the ambient air concentrations with local meteorology suggest that the source of chlordane is evaporation from local soils and structures surfaces.*

- *The estimated ΣPAH direct atmospheric loading rate to Tampa Bay was ~820 kg (0.82 metric tons)/year, which was high enough to indicate a significant anthropogenic contribution.*

INTRODUCTION

Urbanization has placed a significant nutrient and pollution burden on Tampa Bay and its adjacent waters (TBNEP, 1996). Nutrients and other pollutants enter the Bay from urban and agricultural runoff, direct industrial and municipal discharges to surface waters, and atmospheric deposition. This chapter reviews the history of Tampa Bay atmospheric deposition estimates and related research, and summarizes the 1999-2001 direct atmospheric deposition rate estimates for nitrogen and air toxins to Tampa Bay.

Initial nitrogen and phosphorus loading estimates to Tampa Bay revealed that atmospheric deposition directly to the bay's surface contributed about 29% of the total nitrogen load and about 31% of the total phosphorus load to the bay (Zarbock et al., 1994). Given the relative importance of these loads in comparison to the total nutrient loads to the bay, a more accurate estimate of atmospheric deposition of nitrogen and phosphorus to the bay's surface was necessary. The TBEP, Hillsborough, Pinellas, and Manatee counties, and the Florida Department of Environmental Protection (FDEP) asked that the bay be included as an EPA Great Waters Program. The Tampa Bay Atmospheric Deposition Study (TBADS), after approval by the EPA Great Waters Program, began in the spring of 1995, and resulted in dry and wet nutrient deposition data collection from August 1996 through August 2001.

TBADS and NOAA/Great Waters participants agreed on a monitoring site at the eastern end of the Gandy Bridge. Ambient air and rainfall concentration data collected from this site, in concert with meteorological data collected at a mid-bay site, were analyzed to derive the amount of nitrogen and phosphorus being directly deposited to the bay surface. These data were also utilized to estimate contributions of atmospheric deposition to storm water nutrient loadings to the bay.

The Environmental Protection Commission of Hillsborough County (EPCHC) operated and maintained the Gandy Bridge monitoring site and equipment on behalf of the TBEP for the atmospheric deposition studies; Lee Chapin operated and maintained the mid-bay meteorological station and its sensors.

From the first three years of monitoring at the Gandy Bridge monitoring site, the estimates for the direct atmospheric deposition of nitrogen to Tampa Bay were revised downward from 1000 to 760 metric tons/year, or ~24% of the 1985-1991 total nitrogen loads to the bay. For August 1996 through July 1999 the average dry: wet deposition ratio was 0.78, and ammonia gas or rainfall-dissolved ammonium contributed 58% of the total nitrogen deposition (Poor et al., 2001).

Another part of the effort to ascertain the impacts of atmospheric deposition of nutrients to Tampa Bay was an assessment of bulk deposition to the Tampa Bay watershed at seven sites (Dixon et al., 1996). Samples were analyzed for metals, nitrogen, and phosphorus at all sites over a one-year period, with samples from five of the seven sites analyzed for synthetic organics over a 12-week period. Results of the analyses showed that nitrogen loading to the bay from direct atmospheric loadings is 32% of the total nitrogen load to the bay.

This project was followed by an investigation of the relationship between bulk atmospheric deposition and storm water quality, sponsored by the Florida Department of Transportation (Dixon et al., 1998). The goals of this project were to examine spatial variability in bulk deposition and determine any relationships between bulk atmospheric deposition and storm water loadings. Samples were collected at ten sites within the bay's watershed. Sample analyses showed that ~1.5 times as much nitrogen was found in storm water than was provided by the bulk atmospheric deposition, indicating that sources other than bulk atmospheric nitrogen contributed to the storm water runoff nitrogen load.

Additionally, TBEP recently funded a study with the goal of estimating the contribution of atmospheric deposition of nitrogen to storm water loading from small urban watersheds. Utilizing two small watersheds in Tampa just east of the wet and dry deposition sampling Gandy Bridge site, storm water samples were analyzed for nitrogen. Utilizing nitrogen concentrations from rainfall events at the Gandy Bridge site and rainfall amounts from the small urban watersheds, a relationship was derived relating nitrogen in storm water to the nitrogen deposited by rainfall events. Results showed that approximately the same amount of nitrogen left the watersheds in storm water runoff as was deposited to the watersheds via rainfall from July-December 1997 (BCI and PBS&J, 1999).

Recommended by the TBADS participants and initiated in 1998 was a study funded by the Florida Department of Environmental Protection (FDEP) on the stable nitrogen isotopes in rainfall and ambient air for the purpose of classifying the natural versus anthropogenic sources of atmospherically depositing nitrogen. Florida A&M University directed the research, with the University of Virginia responsible for the laboratory analyses.

Coincident with the stable isotope study was an 18-month TBEP-funded effort by EPCHC to compare the nitrogen bulk deposition measurements with the estimates derived from separate wet deposition only plus inferential (i.e., modeled) dry deposition rates.

In May 1999, the TBEP funded the University of South Florida (USF) College of Public Health (COPH) to provide technical and administrative assistance with the analysis and interpretation of the atmospheric deposition data derived from the Gandy Bridge monitoring site and the mid-bay meteorological station. As part of this assistance, USF COPH analyzed the stable nitrogen isotope and bulk deposition data along with the nitrogen ambient air and rainwater concentrations (Poor, 2002).

At the same time and with additional funds from the USEPA Region IV, the atmospheric deposition measurements were expanded to include ambient air concentrations of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine pesticides, and both ambient air and rainfall concentrations of metals. Sediments of Tampa Bay most heavily impacted by urban or commercial activities have levels of chlorinated pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), or heavy metals that in some cases pose a significant ecological or human health risk (McConnell, et al., 1996). The earliest loading estimates suggested that for some of these toxins the atmospheric loading should not be ignored (Frithsen, et al., 1995). The air toxin measurements began in March 2000 and continued through October 2001.

Persistent, bioaccumulative or toxic metals present in the sediments of the Tampa Bay Estuary at concentrations that may pose a risk to aquatic species include arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver and zinc (Frithsen, et al., 1995; McConnell, et al., 1996).

As a consequence of the discovery of the significant ammonia component to the total atmospheric nitrogen deposition, TBADS participants recommended the deployment of passive sampling devices (PSDs) in urban and industrial Tampa to assess the fugitive ammonia emissions from ammonia and ammonium product transport, storage, processing and manufacturing. The earliest attempts to use the PSDs for measuring the relatively low ambient air concentrations met with limited success, but USF COPH continued the testing and by late 2000, with the endorsement of the TBADS participants, the TBEP funded the study. Also funded by the TBEP were further measurements of ambient air coarse particle nitrate, which is formed by the reaction of nitric acid and sea salt, to estimate the coarse particle nitrate contribution to total nitrogen atmospheric deposition.

NITROGEN DEPOSITION

Methods

Wet deposition sampling was done following the protocols developed by the National Atmospheric Deposition Program (NADP) Atmospheric Integrated Research Monitoring Network (NADP/AIRMoN). A wet bucket (Aerochemetrics, Inc.) collected daily rainfall samples, and samples of greater than 10 ml were sent to the Central Analytical Laboratory (CAL) of the Illinois State Water Survey, where the samples were analyzed by the same methods as those used by the NADP/AIRMoN program. Results are given for ammonium, chloride, sulfate, potassium, magnesium, specific conductance, orthophosphate, nitrate, sodium, calcium, and pH on rainfall samples. In addition to the rainfall samples, rainfall amounts are taken from an on-site rain gauge.

Wet deposition rates are a function of both the rainwater concentration of each analyte and the rainfall amount, as shown in Equation 1, where C_{rain} is the concentration of nitrogen in the rainfall (mg N/L), D is the depth of rainfall (mm), 0.01 is a units conversion factor, and F_{wet} is the wet flux of nitrogen (kg N/ha/day). F_{wet} was summed over each month and year to get the monthly and annual nitrogen wet deposition rates, respectively.

Equation 1. $F_{wet} = 0.01 \cdot C_{rain} \cdot D$

Dry deposition rates were calculated from the product of the ambient air concentration of the analyte C_{air} (μg/m^3), the dry deposition velocity v_d (m/s), and the integration time t (days), as shown in Equation 2, where 0.864 is the appropriate units conversion factor for a dry deposition flux F_{dry} in kg N/ha/month. F_{dry} was summed over each month and year to get the monthly and annual nitrogen dry deposition rates, respectively.

Equation 2. $F_{dry} = 0.864 \cdot C_{air} \cdot v_d \cdot t$

The ambient air concentrations of gaseous ammonia and nitric acid and particulate ammonium and nitrate were obtained from an annular denuder system (URG, Inc.). The annular denuder system (ADS) consisted of a 2.5-μm particle aerodynamic diameter cut-point PTFE®-coated cyclone inlet, two 150-mm long gas denuders, and a filter pack in series. The first of two denuders was coated with sodium carbonate to absorb nitric acid and sulfur dioxide. The second denuder was coated with citric acid to trap ammonia. A single 47-mm diameter nylon filter collected particulate nitrate, sulfate, and ammonium. The ADS was operated at a flow rate of 10 L/min for 24 hours every 6th day, coincident with the USEPA National Ambient Monitoring System schedule for particulate matter.

EPCHC technicians forwarded weekly the denuders and filter packs to Harding ESE, Inc. (Gainesville, FL), for analysis. ESE chemists extracted the denuders and filters in an aqueous solution and analyzed the extract for sulfate and nitrate by ion chromatography and for ammonium by automated colorimetry.

The NOAA buoy model and an integrated William's model were employed to calculate the gas and particle deposition velocities, respectively (Valigura, 1995; Williams, 1982). Required inputs to these models were wind speed, air temperature, water temperature and relative humidity, wind measurement height, and particle diameter. A particle diameter of 0.5 μm was assumed for nitrate, sulfate, and ammonium, consistent with observed fine particle modes for these compounds. Weather data from the mid-bay meteorological station were processed with surface weather observations from the Tampa International Airport and water temperature measurements from Clearwater Beach to obtain as complete a data set as possible of hourly over-water meteorology from August 1996 through July 2001.

From May 1999 to February 2000 at the Gandy Bridge site, the bulk nitrogen deposition samples were collected with a 12.2-cm diameter polycarbonate funnel attached to a 2 L polyethylene bottle via PTFE® tubing. The funnel and bottle combination was washed, rinsed, dried, and covered with polyethylene bags prior to and following a one-week deployment, wrapped in aluminum foil and installed at a height of 2.5 m. The EPCHC environmental laboratory analyzed the funnel rinsate and bottle rainwater for ammonia (organic plus inorganic) by the Total Kjeldahl Nitrogen (TKN) method and nitrate by ion chromatography.

From October 2001 to November 2001, the bulk deposition sampling was repeated with daily instead of weekly sample collection (Hendrix et al., 2002). In this latter study, the funnel was rinsed with 100 mL of sulfuric acid and split into two subsamples for analyses by TKN and ion chromatography (IC). Organic ammonia was calculated as the difference between TKN and IC ammonia. Samples were considered "clear" if no bugs, debris, bird droppings, feces, frogs or pollen were evident.

Bulk deposition rates were calculated from Equation 3, where C_N is the total nitrogen mass (mg N), A is the area of the funnel opening (0.0113 m^2), 0.01 is a units conversion factor, and F_{bulk} is the bulk nitrogen flux (kg N/ha/day).

Equation 3. $F_{bulk} = 0.01 \cdot C_N / A$

Isotopic ratios of nitrogen in the atmosphere may indicate the origin or history of an air mass. The ratio $\delta^{15}N$ for clean air is 0‰ and is computed from Equation 4, where R_{sa} is the isotopic ratio of the sample; R_{std} is the isotopic ratio of the standard, in this case clean air (i.e., N_2); and δ (‰) is the enrichment or depletion of the stable isotope relative to the standard.

Equation 4. $$\delta = \left(\frac{R_{sa}}{R_{std}} - 1 \right) \cdot 1000$$

For nitrogen stable isotope (^{15}N) analyses, from July 1998 to October 1999 wet-only precipitation samples were collected in a pre-cleaned stainless steel bucket daily following a rainfall. At the time of collection the samples were transferred into pre-cleaned glass bottles, which were capped with aluminum foil and lids, immediately frozen and shipped on dry ice to the University of Virginia for analysis (Earls, 2001).

Velinsky et al. (1989) describes determination of the ^{15}N composition of ammonium and nitrate. In brief, the method reduced nitrate to ammonium, and the ammonium was converted to ammonia by raising the pH of the sample aliquot, then re-trapped with acid and concentrated on a zeolite molecular sieve as ammonium. The zeolite containing the ammonium was combusted and through sequential catalytic reactions with cuprous oxide and copper was oxidized to nitrogen oxide then reduced to nitrogen gas (N_2). The nitrogen was separated at cryogenic temperatures from the accompanying combustion gases, concentrated on a molecular sieve, and analyzed with an isotope ratio mass spectrometer.

From February 1999 to November 1999, ambient air particulate samples were collected every six days for ^{15}N analyses. Air samples were integrated for 24 hours and the sampling apparatus operated with a 2.5-µm cut-point at a flow rate of 10 L/min onto pre-combusted glass fiber filters. Upon collection, the samples were immediately frozen and shipped on dry ice to the University of Virginia for analysis (Earls, 2001).

Particulate nitrogen was detected by converting the particulate nitrogen present on the filter to nitrogen (N_2) through a combustion process in an elemental analyzer. The isotopic ratios of the nitrogen gas were then determined by mass spectrometry (Velinsky, et al., 1989).

To describe the ambient ammonia concentration gradient across urban and industrial Tampa, in October 2001 more than 90 PSDs were simultaneously deployed for two weeks in an area bounded on the north by Interstates 4 and 275, including the locally famous "malfunction junction," to the east by Interstate 75, to the south by Gibsonton, and to the west by Tampa Bay. On the southern Tampa peninsula, PSDs were placed south to Bay-to-Bay Boulevard (Tate, 2002). Within the regional coverage were suburbs, an urban center, major highways, port activities, fertilizer manufacturing, wastewater treatment, coal-combustion power plants, warehousing and dairy farming. The ambient air ammonia concentrations were plotted with Surfer 7® and spatially interpolated by kriging (Tate, 2002).

Results

Annual dry, wet, and total nitrogen deposition rates are summarized in Table 6-1. Note the roughly equal amounts of nitrogen reaching the bay from wet and dry deposition. The total nitrogen deposition rates vary from 6.6 to 8.5 kg N/ha/year and are higher than the ~4 kg N/ha/year seen at more remote sites in the continental US (Sievering et al., 1996; Zeller et al., 2000), but lower than the deposition rates reported for northeastern and midwestern monitoring stations (Lawrence et al., 2000).

Presented in Figures 6-1 and 6-2 are the relative contributions to dry and wet deposition, respectively, of inorganic nitric acid/nitrate and ammonia/ammonium nitrogen. Ammonia clearly dominates dry deposition (Figure 6-1), but not wet deposition (Figure 6-2). Figure 6-3 shows the relative proportions of wet and dry deposition rates by month. Both dry and wet deposition rates show a seasonal trend, with exceptions, of higher total nitrogen deposition in the summer months.

The assumptions behind the deposition rates reported in Table 6-1 are significant. First, these rates are assumed to be representative of the entire bay but are based only on nitrogen concentration

Table 6-1. Annual nitrogen deposition rates to Tampa Bay.

Year (August-July)	Dry kg-N/ha	Wet kg-N/ha	Total kg-N/ha	Dry:Wet
1996-1997	3.6	3.4	7.0	1.1
1997-1998	4.1	4.2	8.3	1.0
1998-1999	4.1	4.2	8.2	1.0
1999-2000	4.1	4.5	8.5	0.9
2000-2001	3.4	3.2	6.6	1.1
Average	3.9	3.9	7.7	1.0

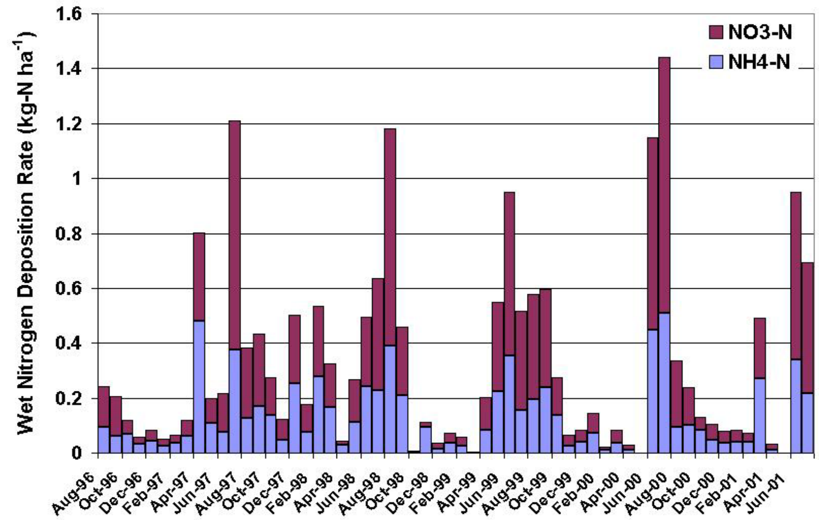

Figure 6-2. Monthly wet deposition of nitrogen to Tampa Bay, August 1996-July 2001.

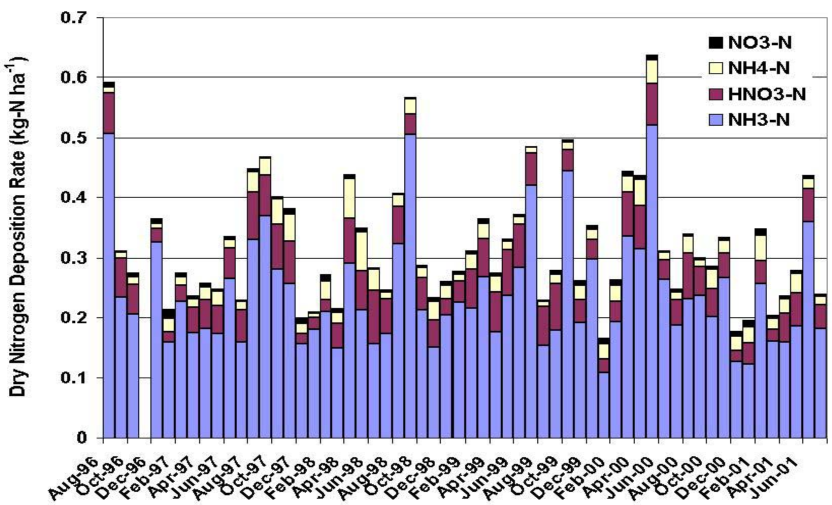

Figure 6-1. Monthly dry deposition of nitrogen to Tampa Bay, August 1996-July 2001.

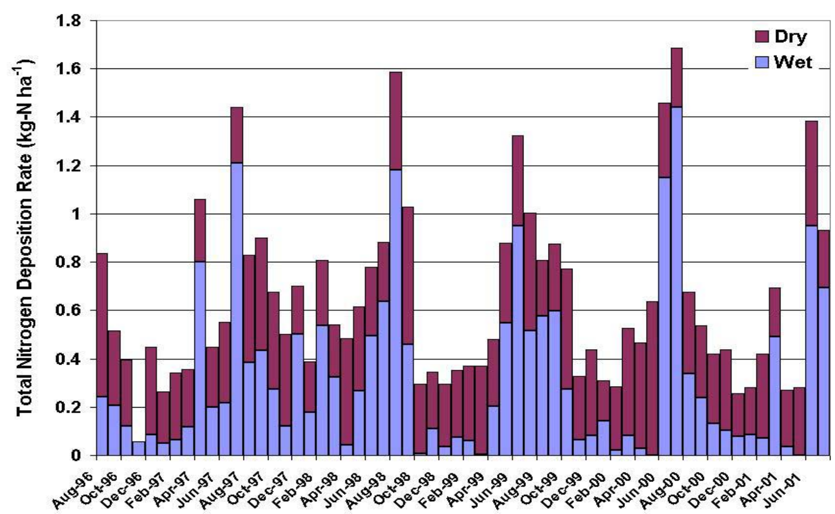

Figure 6-3. Monthly total deposition of nitrogen to Tampa Bay, August 1996-July 2001.

measurements and rainfall made at the Gandy Bridge site and the weather over Tampa Bay south of MacDill AFB. Second, the NOAA buoy model is limited to water-soluble gases and its extension to ammonia dry deposition likely overestimates by ~10% the ammonia flux (Poor, 2001). Moreover, the contribution of nitrogen oxides to the flux cannot yet be estimated with the NOAA buoy model, but likely adds another ~0.4 kg N/ha to the total, based on literature values of deposition velocities. Third, the ADS system does not capture coarse particle nitrate, the predominant nitrate mode, thus biasing the dry deposition estimates ~5% low. Finally, these estimates do not include organic forms of nitrogen.

The bulk nitrogen flux computed with weekly collocated "clear" samples using Equation 3 was 8.9 kg N/ha/year compared with a wet plus dry flux of 6.3 kg N/ha/year calculated for the same subset of sampling days using Equations 1 and 2. The difference was thought to be organic ammonia nitrogen (primary and secondary amines) and coarse particle nitrate not accounted for in the dry flux calculations presented above.

In the follow-on study by Hendrix et al. (2002) with daily measurements of TKN and IC ammonia, the bulk nitrogen flux was ~30% inorganic and ~70% organic ammonia/ium. Thus, organic amines may constitute a significant fraction of the total nitrogen deposition.

Comparing the bulk ammonia nitrogen flux for collocated "clear" samples on days with no rainfall, the bulk ammonia flux (Equation 3) was ~50% lower than the ammonia predicted by the inferential model (Equation 2), and the daily fluxes were not significantly correlated, as shown in Figure 6-4 (Hendrix et al., 2002). A plausible explanation for this result is that ammonia gas is not quantitatively trapped on the funnel surface.

Earls (2001) examined the trends and source apportionment of nitrogen in rainfall and ambient air using the stable isotope ratios of $^{15}N/^{14}N$, which were expressed as $\delta^{15}N$ according to Equation 4. Higher absolute values of $^{15}N/^{14}N$ are indicative of non-anthropogenic sources. Analyses included summary statistics and histograms of the $\delta^{15}N$ data; graphical analyses of $\delta^{15}N$ data by rainfall nitrate and ammonium and ambient air particulate nitrogen concentrations, wind direction, and air mass trajectory origin; and correlations with rainfall and ambient air pollutants.

The average isotopic ratios for rainfall and ambient air at the Gandy Bridge monitoring sites are summarized in Table 6-2, which is also organized by a wet and dry season. The results did not suggest a strong seasonal difference in isotopic ratios, but evident is a slight shift toward more enriched values during the rainy season. Strongly enriched $\delta^{15}N$ values were associated with a few isolated events such as a tropical storm.

Significant shifts in isotopic ratios were seen when data were arranged by air mass trajectory, as illustrated by Table 6-3. The name of the trajectory indicates its origin. For example, the Cuba trajectory represents an air mass that originated south of Tampa and traveled across Cuba and up the west coast of Florida.

Combustion processes including automobile combustion of gasoline that produces nitrogen oxides, which are transformed into nitric acid and nitrate, contribute little to the enrichment or depletion of $\delta^{15}N$ (Heaton, 1986). For nitrate, $\delta^{15}N$ values that approached zero were correlated with higher nitrate rainfall and ambient air particulate nitrogen concentrations, which suggest combustion sources with air mass trajectories for Atlanta, Cuba, and Tampa.

For ammonium, strongly depleted $\delta^{15}N$ values have been previously linked with ammonia volatilization from fertilizers, wastewater treatment, and animal urea, as examples (Heaton, 1986). The most depleted isotopic ratios for rainfall ammonium or ambient air particulate nitrogen were found associated with trajectories from the Bahamas and Atlanta, and from the Gulf and Bahamas, respectively (Table 6-3). The most dramatic difference is seen in the –1.0 average $\delta^{15}NH_4^+$ for a possibly cleaner air mass that arrives over Tampa Bay directly south from Cuba versus the –7.8 average $\delta^{15}NH_4^+$ for an air mass that has passed over the Miami metropolitan area and across south central Florida before reaching Tampa Bay.

To understand better the relationship between nitrogen levels in precipitation and air mass trajectory, further data analyses were done on the daily rainfall concentrations of inorganic ions for 292 samples collected from August 1996 to December 2000 at the Gandy Bridge monitoring site (Smith et al., 2002). Rainfall on days when the air mass traveled first over water (Cuba or the Gulf of Mexico) had the lowest ammonium and nitrate concentrations. The Gulf trajectories deposited the least amount of ammonium nitrogen, and the Cuba trajectories the least amount of nitrate nitrogen, to Tampa Bay. Highest rainwater concentrations and fluxes of nitrate nitrogen occurred when an air mass had stagnated over Tampa Bay, but highest rainwater concentrations and fluxes of ammonium nitrogen came from the direction of Cape Canaveral and the Bahamas. These rainfall data were re-analyzed by chemical composition for further insight as to the nature of the air mass (Smith et al., 2002). The lowest ammonia and nitrate rainfall concentrations and fluxes were associated with a marine air mass (low [Ca]: [Na]). The highest nitrate rainfall concentrations and fluxes were associated with local combustion (high [SO_4^{2-}] and [H^+]). Both local and aged combustion (high [NH_4^+]: [SO_4^{2-}] ratio) yielded the highest ammonium rainfall concentrations, but the highest ammonium flux was for aged combustion. These results are relatively consistent with the air mass trajectory classifications.

Adjacent to Hillsborough Bay are several significant fugitive ammonia emission sources, as shown in Table 6-4, and their impact on local air quality was largely unknown. Typical ambient air concentrations of ammonia measured at ground level are ~0.1 to 4 µg/m^3 (ATSDR, 2002; Sutton, et al., 1994), in agreement with this study, but concentrations over animal feedlots and freshly fertilized fields may exceed 100 µg/m^3.

For most of the passive sampling device coverage, 2-week averaged ammonia concentrations were at background concentrations of 1-2 µg/m^3, with a peak of 16 µg/m^3 next to Port Sutton Road (Figure 6-5). The relatively steep concentration gradients and low ambient air concentrations of these "hot spots" do not indicate a major impact to Tampa Bay as a whole, but represent a potential impact to Hillsborough Bay. The local impact of the ammonia plumes on Hillsborough Bay may be mitigated by atmospheric dispersion and by the bi-directional flux of ammonia across the air/water interface.

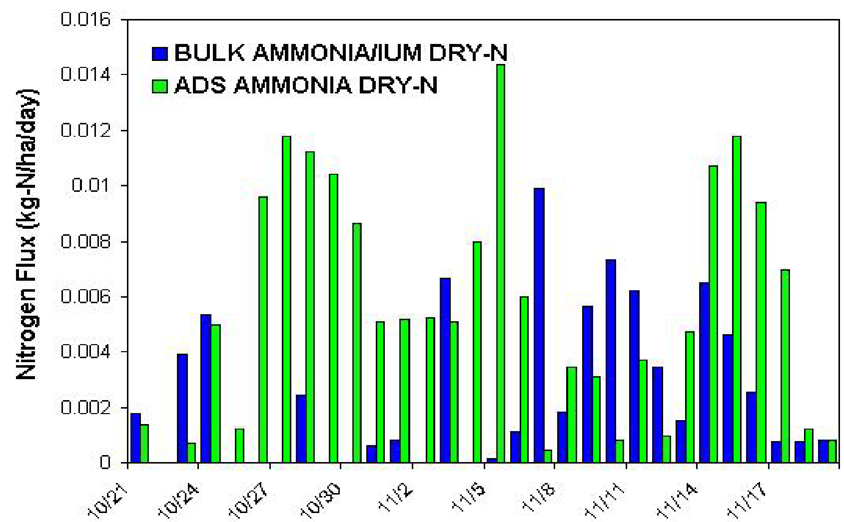

Figure 6-4. Daily dry ammonia/ium fluxes estimated from bulk deposition measurements and from inferential modeling based on ambient air concentrations obtained from the ADS, October 2001 to November 2001 (Hendrix et al., 2002).

Table 6-2. Statistics for precipitation (rain) and ambient air (dry) $\delta^{15}NH_4^+$, $\delta^{15}NO_3^-$ and Total $\delta^{15}N$ for complete datasets and by wet and dry seasons, reported in ‰, n = number of samples in each category. Dry season was defined as October through May and wet season as June through September.

	Mean	Std Dev
Rain Data (n=88)		
$^{15}NH_4^+$	-4.9	4.2
$^{15}NO_3^-$	-1.8	3.8
Dry Season (n=23)		
$^{15}NH_4^+$	-5.9	3.0
$^{15}NO_3^-$	-3.1	3.8
Wet Season (n=65)		
$^{15}NH_4^+$	-4.6	4.6
$^{15}NO_3^-$	-1.4	3.7
Ambient Air Data (n=47)	-0.5	3.0
Dry Season ^{15}N (n=18)	-0.8	2.7
Wet Season ^{15}N (n=29)	-0.1	3.5

Table 6-3. Statistics for precipitation $\delta^{15}NH_4^+$ and $\delta^{15}NO_3^-$ for each trajectory class, reported in ‰, n = number of samples in each category.

Trajectory (Rain)	Avg. $\delta^{15}NH_4^+$	Avg. $\delta^{15}NO_3^-$	Trajectory (Dry)	Avg. $\delta^{15}N$
Cuba (n=15)	-1.0	0.1	*Atlanta (n=5)*	0.7
Gulf (n=13)	-3.5	-1.5	*Cuba (n=4)*	0.6
Tampa (n=12)	-4.5	-0.9	*Tampa (n=4)*	0.6
Panhandle (n=10)	-5.2	-3.1	*Cape (n=13)*	-0.6
Cape (n=16)	-6.1	-3.5	*Panhandle (n=5)*	-0.9
Atlanta (n=3)	-6.3	-0.1	*Bahamas (n=7)*	-1.0
Bahamas (n=19)	-7.8	-2.3	*Gulf (n=9)*	-1.4

Table 6-4. Inventoried ammonia emission sources near Hillsborough Bay (TRI, 2001; CMU 2001).

Map Number	Name	Emissions 1000 kg (metric tons) yr^{-1}
1	Nitram	160
2	Howard F. Curren Waste Water Treatment Plant	150
3	Cargill Fertilizer-Riverview Operations	50
4	IMC AGRICO – Port Sutton Terminal	17
5	Farmland Hydro L P – Ammonia Terminal	17
6	AMERICOLD - Tampa	14
7	CF Industries – Ammonia Terminal	13
8	Reddy Ice - Tampa	3.9
9	Coca Cola Bottling - Tampa	3.5
10	Trademark Nitrogen	2.0
11	Harborside Refrigerator Services	1.9
12	AMERICOLD - Port	0.91
13	UNIROYAL Optoelectronics	0.68
14	Rapid Blueprint	0.43

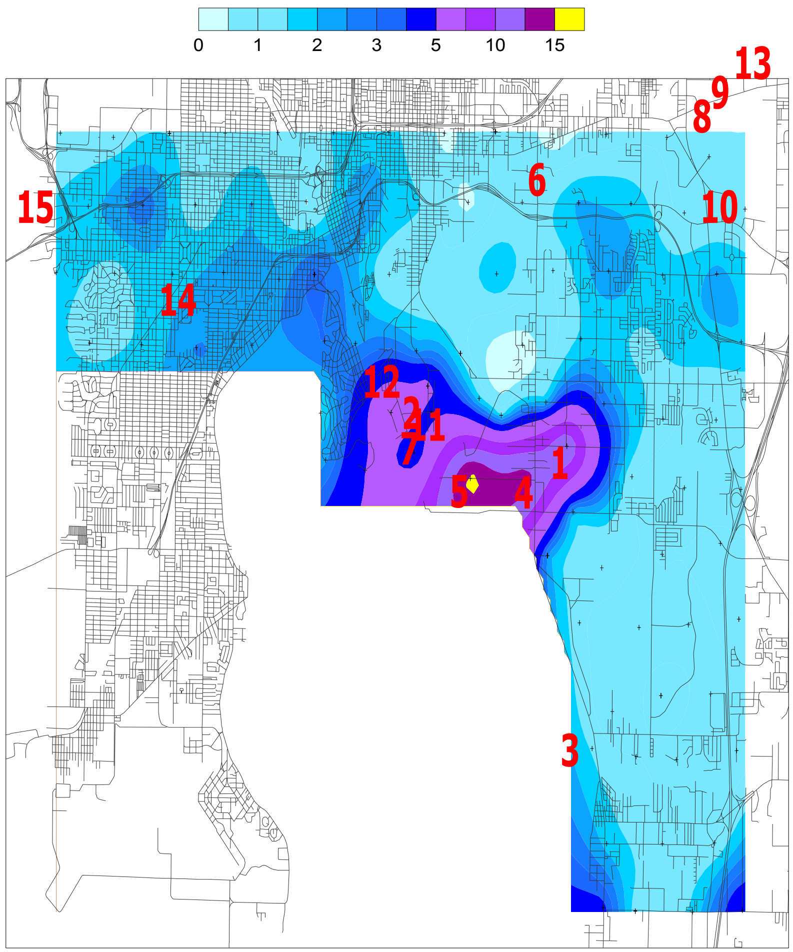

Figure 6-5. Two-week averaged ammonia concentration gradient across urban Tampa, October 2001 (Tate, 2002). The numbers indicate inventoried ammonia emission sources, as described in Table 4. Units for the color scale are μg/m^3.

METALS DEPOSITION

Methods

Ambient air fine (<2.5 μm in diameter) and coarse (>2.5 μm and <10 μm in diameter) particle samples were obtained with a dichotomous sequential air sampler (Rupprecht & Patashnick, Inc., Model 2025 Partisol® - Plus), which has been operating on a daily schedule at the Gandy Bridge monitoring site since January 2000. Samples were collected for 24 hours on 47-mm PTFE® filters at a total flow rate of 16.7 L/min. Filters were pre- and post-weighed in Tallahassee at the Florida Department of Environmental Protection (FDEP) laboratory in accordance with 40CFR50 requirements. For more details on the storage, handling, data analyses and uncertainties for the particulate matter measurements, refer to Poor et al., 2002.

Forty-five filters plus laboratory and field blanks, one for every 6th day of the measurement period from January 2000 to September 2000, were selected for x-ray flourescence (XRF) analyses at the EPA National Environmental Research Laboratory in Research Triangle Park, North Carolina. XRF spectrometry (Kevex) can quantify elements for atomic numbers 11-82 (sodium through lead) and was calibrated with NIST special reference materials. XRF results were corrected for blank background, attenuation, and interferences.

From March 2000 to March 2001, a wet-only precipitation collector (MIC, Inc.), re-engineered to funnel rainfall into four separate bottles, captured rainfall at the Gandy Bridge site for the purpose of trace metal and mercury analyses. Pre-cleaned funnels and 1 L bottles were checked daily for rainfall. If present, rainfall was decanted into pre-cleaned 250 mL bottles, immediately chilled, and returned on ice to the University of Michigan Air Quality Laboratory for analyses. After either a rainfall or one week with no rainfall, funnels and bottles were also returned to the University of Michigan for re-cleaning. A more detailed description of the modified MIC collector, the funnel and bottle design and materials, the pre- and post-cleaning and handling procedures can be found in Landis and Keeler (1997).

Trace metal analyses were by inductively coupled plasma mass spectrometry (Perkin Elmer ELAN 5000 A) and mercury analyses by cold vapor atomic fluorescence spectrophotometry (Brooks Rand), also at the University of Michigan Air Quality Laboratory. Landis and Keeler (1997) describe the laboratory techniques, method detection levels, and quality assurance and control for these analyses.

To calculate the average ambient air concentration of each metal, a concentration at or above the uncertainty was averaged as reported, and a concentration below the uncertainty was averaged as zero. Using 2000 over-water meteorological data, average deposition velocities of 0.00008 m/s and 0.0005 m/s were computed with the modified Williams model for fine and coarse particles, assuming that the aerodynamic diameters were 0.5 μm and 5 μm, respectively. Dry deposition rates $F_{metal\text{-}dry}$ (kg/year) for Tampa Bay were obtained from Equation 5, where $C_{metal\text{-}air}$ (ng/m^3) was the average ambient air concentration of the metal, v_{davg} (m/s) was the average deposition velocity and 31,536 was the appropriate units conversion factor for the annual dryfall loading of metals to the surface of Tampa Bay.

Equation 5. $F_{metal\text{-}dry} = 31{,}536 \cdot C_{metal\text{-}air} \cdot v_{davg}$

The wet deposition rates for each metal $F_{metal\text{-}wet}$ (kg/day) were determined as shown in Equation 6, where $C_{metal\text{-}rain}$ is the concentration of the metal in the rainfall (μg/L), D is the depth of rainfall (mm), and 1.0 is a units conversion factor. $F_{metal\text{-}wet}$ for every day of rainfall was summed over the year to get the annual rainfall loading of metals to the surface of Tampa Bay.

Equation 6. $F_{metal\text{-}wet} = 1.0 \cdot C_{metal\text{-}rain} \cdot D$

Results

Frithsen et al. (1995) used the geometric mean of Florida rainfall concentration data reported in literature to estimate the direct deposition of toxic metals from the atmosphere to the Tampa Bay Estuary. They computed the total atmospheric deposition including an indirect loading term by assuming that 10% of the contaminant mass deposited to the watershed found its way into the estuary. Combined with estuary loading estimates from point source discharges, urban runoff, and groundwater infiltration, their results indicated that total atmospheric deposition is a major contributor of cadmium (46%), chromium (13%), copper (18%), iron (11%), and lead (12%), and a minor contributor of arsenic (7%), zinc (4%), and mercury (1%) to the *total* annual loading of these metals to the bay.

A comparison of the 1995 (Frithsen et al., 1995) and 2000 direct loading rates to the Tampa Bay estuary of arsenic, cadmium, chromium, iron, mercury, nickel, copper, lead, silver, and zinc are presented in Figure 6-6. For arsenic, cadmium, chromium, nickel, and lead, the 2000 direct atmospheric loading rates were well below the 1995 estimates; however, the loading rates for copper, mercury, zinc, and iron were significantly above the previous estimates.

If the direct plus indirect atmospheric deposition portion of the 1995 loading rates are re-done to reflect the revised 2000 loading rates, then arsenic, chromium, lead, and mercury contributions dropped to less than 5%; cadmium and zinc change to ~10%, copper to ~20%, and iron to ~40% of the *total* loading from all point and non-point sources. No total loading rates were available for nickel and silver.

The presence of copper at elevated concentrations in the sediments of Tampa Bay and its association with toxic sediments based on bioassays (McConnell et al., 1996; Long and Greening, 1999), its prevalence in ambient air and rainwater, and its relatively high direct deposition to Tampa Bay are a “red flag” for continued accumulation of this toxin in the estuary and perhaps the need to identify a critical loading threshold.

According to the 2000 Toxics Release Inventory (TRI, 2002) the three largest stationary sources were two ship repair facilities and one steel company in close proximity to Tampa Bay, with combined air emissions of 30 metric tons/year and 80 metric tons/year of copper and zinc, respectively. Municipal solid waste incinerators also emit significant quantities of copper and zinc; however, the Toxics Release Inventory did not provide these emissions for the three incinerators in the Tampa Bay region.

Iron has as its sources of ambient air particles re-suspended soils or road dust, and high-temperature combustion of coal and oil. Iron can be transported across the Atlantic Ocean from the Sahara Desert at concentrations high enough to produce a visible reddish haze in the Tampa Bay area. Although iron is not usually considered a toxic metal, it may be a limiting nutrient in stimulating harmful algal blooms such as red tide (Walsh and Steidinger, 2001).

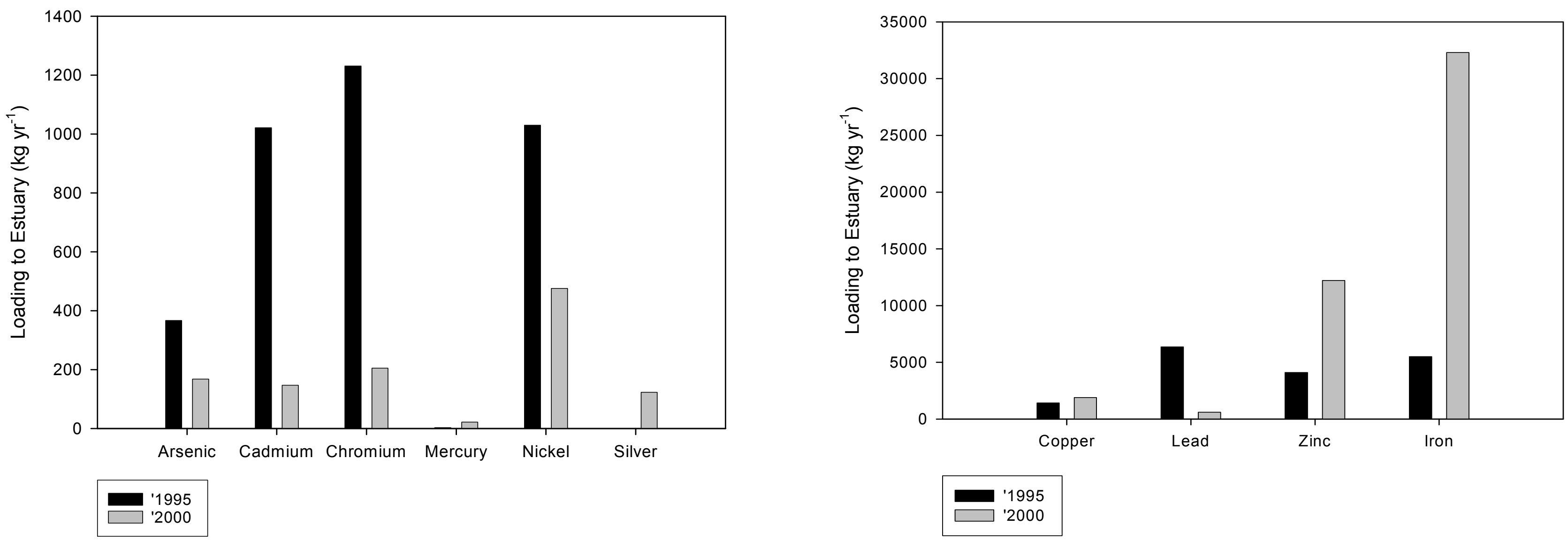

Figure 6-6. A comparison of the 1995 (Frithsen et al.,1995) and direct atmospheric loading of toxic metals to the Tampa Bay Estuary.

DEPOSITION OF PCBS, PAHS AND ORGANOCHLORINE PESTICIDES

Methods

From March through October, 2001, ambient air samples of organochlorine pesticides and PAHs were collected at the Gandy Bridge site with a high volume sampler (Tisch Environmental, Inc.) operated at a flow rate of 225 L min^{-1} for 24 hours every 6^{th} day, on a schedule coincident with the NAMS schedule for PM_{10}. Identical to the USEPA Compendium Method TO-4A (1999) sampler, the sampler featured a total suspended particulate (TSP) inlet, and a 10-cm diameter quartz filter followed by a 6-cm x 10-cm piece of polyurethane foam (PUF). The sampler was positioned on top of a monitoring trailer and the sampler inlet height was ~4 m.

Daily $PM_{2.5}$ and $PM_{10\text{-}2.5}$ concentrations were available from a sequential dichotomous sampler also located at the Gandy Bridge site (Poor, et al., 2002). Daily surface weather observations from the National Weather Service Station at Tampa International Airport, ~10 km due north of the Gandy Bridge site, were obtained from the National Climatic Data Center website.

The pre-baked quartz filters (Whatman, Inc.) in aluminum foil within a sealed glass jar and the pre-cleaned PUFs (Supleco, Inc.) sealed in a glass jar within an aluminum canister were transported each week as needed in a cooler on blue ice from and to the Florida Department of Environmental Protection (FDEP) laboratory in Tallahassee and the EPCHC in Tampa, Florida. Prior to installation in and after removal from the air sampler, the quartz filters and PUFs were stored in a dark freezer at $4^{o}C$.

For each day of sampling, the FDEP Organics Laboratory extracted the PCBs, PAHs, and organochlorine pesticides from the *combined* filter and PUF media, and analyzed the extracts with gas chromatography and either a mass spectrometer (PAHs) or an electron capture device (PCBs, organochlorine pesticides). Testing was done for 17 PCB congeners, 20 pesticides, and 16 PAHs. Refer to the EPA Method TO-13A (1999) and Poor (2002) for the specifics on the analytical methods. Exceptions to the method included a longer holding time (40 days) for the frozen sample extracts and the extraction of the filters and PUFs with 100% acetone.

Average ambient air concentrations were calculated for those organic air toxins with at least one concentration above the analytical lower detection level (LDL). Atmospheric deposition rates, however, were calculated only for those contaminants whose concentrations were above the LDL in 75% or more of the samples. For ambient air concentrations and atmospheric deposition rates, concentrations below the LDL were estimated as one-half of the LDL.

The assumptions, input data, and equations for estimating the deposition rates of toxic organic compounds are given in Poor (2002). The general approach was to predict from ambient concentrations of organic toxins and from local meteorology both their wet and dry atmospheric loading to Tampa Bay. The model algorithms, which were adopted from current literature, predict based on the air temperature, wind speed, and the chemical properties of individual compounds the partitioning of these compounds between gas and particle phases, and their transfer between air and seawater or rainfall.

Results

No PCBs had ambient air concentrations above the analytical method LDL. Of the pesticides monitored, only chlordane and endosulfan had detectable concentrations in more than 50% of the samples. The estimated direct deposition rate of chlordane from the atmosphere to Tampa Bay is low at ~4 kg yr^{-1}, which is less than 50% of the 1995 estimate of 13 kg yr^{-1} (Table 6-5). Moreover, the source of chlordane to the atmosphere is most likely the re-volatilization of chlordane from soil and structures surfaces, a source that should diminish with time. The inferred sources of the chlordane, however, are relatively strong regional reservoirs. Thus, urban and agricultural runoff of chlordane may still pose a threat to the health of the bay.

Endosulfan most likely has as its sources both local and statewide application to fruit and vegetable crops. The atmospheric deposition rate to Tampa Bay was relatively low at ~13 kg yr^{-1} (Table 6-5). In the more rural southeastern coast of Tampa Bay, however, fruit and vegetable farming is still important and endosulfan use may have a more local impact on the estuary.

The total direct atmospheric loading of PAHs to Tampa Bay was ~820 tons/year. Ambient air concentrations of the PAHs were generally above the levels seen at more remote locations but not as high as those found in larger cities (Poor, 2002).

According to Dickhut, et al. (2000), motor vehicles and coal combustion accounted for 53% and 47%, respectively, of the PAHs that deposited to the surface of the Chesapeake Bay. In Chicago, the atmospheric apportionment of PAHs was 48% coal combustion, 26% natural gas, 14% coke ovens (steel production), and 9% vehicle emissions (Simcik, et al., 1999). Too few data for the higher molecular weight species, and apparent biases in the naphthalene and anthracene concentrations, hampered the unambiguous assignment of PAHs to source categories. However, the prevalence of anthracene, phenanthrene, fluoranthene, and pyrene suggested coal and oil combustion as a significant source (Simcik, et al., 1999).

CONCLUSIONS

The direct atmospheric deposition rate of nitrogen to Tampa Bay is ~7.7 kg-N/ha/year (~780 metric tons/year) based on a 5-year average from August 1996 through July 2001, with roughly equal (~1:1) average annual wet and dry deposition rates. Ammonia/ium nitrogen contributes ~60% and nitric acid/nitrate ~40% to this atmospheric deposition.

This estimate does not yet include coarse particle nitrogen and the relatively insoluble gaseous species of nitrogen oxides, nor does it account for bi-directional exchanges of ammonia and nitrogen oxide at the Bay surface, which are likely offsetting adjustments to the current estimate. This estimate does not yet include the deposition of organic nitrogen, which is present in the atmosphere as organic amines and nitrates, and preliminary measurements suggest that the magnitude of the organic nitrogen flux may be significant.

The preliminary estimates Frithsen et al. (1995) of the direct atmospheric deposition of metals, PCBs, and pesticides were only lower than the current estimates for copper, zinc, and iron. The copper, zinc and iron deposition rates are high enough to be an environmental health concern for Tampa Bay. The total PAH flux to Tampa Bay was ~820 kg/year, which represents a modest anthropogenic input based on comparisons with other bays.

Table 6-5. Estimated total direct atmospheric loading (kg yr^{-1}) of pesticides and PAHs to the Tampa Bay Estuary. These estimates were made with the assumption that there were no emissions of pesticides and PAHs from the bay water to the air.

	Dry Deposition		Wet Deposition		Total
	Gas	Particle	Gas	Particle	Deposition
Chlordane	4	<<1	0.1	0.3	4
Endosulfan	12	<<1	0.6	0.7	13
Napthalene	7	0	0	0	7
Fluorene	17	0	0	2	19
Anthracene	30	0	0	0	30
Phenanthrene	385	0	3	2	390
Fluoranthene	229	1	6	15	251
Pyrene	105	1	2	14	121
ΣPAH	773	2	11	33	818

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- CHAPTER HIGHLIGHTS -

- *The large water quality improvements realized in the early to mid 1980s (water clarity, nutrients, chlorophyll-a) have been maintained through 2001.*
- *All four major segments of Tampa Bay have shown long-term improvement in chlorophyll-a concentrations.*
- *Dissolved oxygen conditions have maintained their improved level through 2001 compared to conditions observed in the early 1980s.*
- *Hillsborough Bay continues to have the greatest percentage of samples not meeting State water quality standards for dissolved oxygen.*
- *Long-term salinity records show no trends in most segments of the bay, with only Lower Tampa Bay showing a significant, though slight, decrease in salinity. Changes in salinity are of great importance as desalination begins and freshwater withdrawals increase in the bay area*

INTRODUCTION

The water quality of Tampa Bay is of utmost importance 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. In terms of economics, many commercial and recreational fish are dependent on the quality of the bay's water for survival. Furthermore, users of the bay want clean water for safe swimming and boating, as well as for its aesthetic benefits.

The periodic assessment of water quality can provide an early warning system of degraded water quality before conditions become critically degraded and key resources or uses of the bay are negatively impacted. Since no single measurement alone can adequately determine water quality, it is assessed through the measurement of several key indicators (or parameters). Tampa Bay's water quality is primarily monitored by local county and municipal programs.

This chapter first identifies and describes the importance of water quality indicators measured in Tampa Bay. Later in the chapter, the temporal and spatial variations of these key water quality indicators, as determined by the local government monitoring programs, are reviewed and discussed.

WATER QUALITY INDICATORS

The water quality indicators reviewed include physical parameters (water temperature and salinity), water clarity parameters (Secchi disk depth and turbidity), dissolved oxygen concentration, nutrients (total phosphorus and total nitrogen), and phytoplankton biomass as estimated by chlorophyll-*a* concentration. Each indicator is briefly addressed in the following.

Temperature

Temperature changes can cause great variation in the properties of seawater. Temperature affects the solubility of both solids and gases in seawater. As water temperatures increase, a greater amount of solids, such as salts, and conversely a smaller quantity of gases, such as dissolved oxygen, can be dissolved in a given volume of water. Water temperature is affected by radiant energy, air temperature, heat absorbance and heat loss properties of a water mass, and the degree of mixing and flushing of a water mass. Other factors that may affect water temperatures include water column depth and point source inputs from power plants and wastewater treatment plants.

Temperature changes also greatly affect the living organisms that seawater supports. Most animals (the "cold blooded forms") and virtually all plants lack the ability to regulate their body temperature. Consequently, their body temperatures are largely controlled by water temperature. For example, the metabolic rate of many "cold blooded" animals is roughly doubled by a 10°C temperature increase.

Salinity

The total amount of dissolved solids (primarily salts) in seawater is referred to as salinity, which is measured in parts per thousand (ppt) or practical salinity units (psu). The salt content in estuarine waters provides the chemical substances necessary for the growth and maintenance of plant and animal tissue. The distribution of living organisms inhabiting estuarine waters is often closely related to the salinity distribution of the estuary. The average ocean salinity is 35 psu, while the salinity of freshwater is 0 psu. Estuarine salinities, including those in Tampa Bay, range between values found in oceanic and freshwater environments.

Salinity is altered by processes that add or remove salts or water from the estuary. The primary mechanisms of salt and water addition and removal are evaporation, tidal exchange, rainfall, and freshwater inputs from tributaries and point sources such as wastewater treatment plants. The distribution of salinity in Tampa Bay, therefore, is affected by these primary mechanisms and the hydrodynamic characteristics of the bay itself that control the circulation of water throughout the estuarine system. Salinity distribution, at least on a localized level, could also be affected by the discharge of saline "concentrate" to Tampa Bay from a desalination plant currently being planned in Tampa Bay, and/or by increased freshwater withdrawals from our rivers.

Water Clarity

The degree of transparency of water, or water clarity, is one of its most important attributes. Water transparency allows the penetration of light, which supports life through the photosynthetic process. The degree of water transparency has a direct impact on seagrass bed growth and distribution in Tampa Bay. Water transparency also allows organisms with visual organs to see in order to search for food and shelter. Water transparency can be affected by water color, suspended organic and inorganic matter in the water column, and dissolved substances. Two indicators of water clarity reviewed in this chapter are Secchi disk depth and turbidity.

A simple method to determine the amount of light penetration in the water column is with a Secchi disk. A Secchi disk 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 until it disappears from sight. This depth of disappearance is called the depth of visibility or Secchi disk depth.

Turbidity is the optical property of water which is related to the amount of light scattered and absorbed in the water column. The amount and size distribution of suspended particles, such as plankton, organic debris, silt, and clay, can greatly affect the degree of turbidity measured in the water column. In the data collected for this review, turbidity was measured as Nephelometric Turbidity Units (NTU) using a nephelometer.

Dissolved Oxygen

Dissolved oxygen in the form of O_2 in estuarine water is necessary for the survival of most organisms with the exception of some species of anaerobic microorganisms. The abundance or lack of O_2 in water strongly influences the distribution of marine life. The transfer of oxygen from the atmosphere to the water at the water surface, the production of oxygen from marine plants by photosynthesis, and the introduction of oxygenated waters from landward (e.g., tributaries) or seaward (e.g., Gulf of Mexico) sources are the only methods of adding oxygen into estuarine waters. In estuaries, low bottom water dissolved oxygen concentrations (e.g., < 2.0 mg/L) may cause stress or death to marine animals. Low dissolved oxygen conditions in bottom waters of an estuary may often result from eutrophication, the over-enrichment of aquatic systems by excess inputs of nutrients. Eutrophic conditions that cause an accumulation of planktonic algae near the surface of the water may also result in elevated dissolved oxygen concentration in surface waters from photosynthetic activity by the algae. In addition to low dissolved oxygen in bottom waters, and high dissolved oxygen in surface waters, eutrophic conditions may also cause fish kills and benthic fauna mortality if widespread dissolved oxygen depletion in bottom waters occurs.

Nutrients

Phosphorus and nitrogen, commonly found in fertilizers, are important elements needed to support the growth of marine plants. These two nutrients, and their various chemical forms, are generally of greatest concern in marine systems. The amount of nitrogen relative to phosphorus that is available to marine plants, including marine algae, is related to the potential productivity of marine plants in the estuary. Since marine plants are at the base of the "food chain," nutrients play a vital role in the overall health and production that occurs in estuaries. An excessive supply of these nutrients, in appropriate forms for uptake by marine plants, may result in eutrophic conditions. Eutrophic conditions are exemplified by an ecological imbalance resulting in large concentrations of algae, poor water clarity, and low bottom water dissolved oxygen conditions. Low dissolved oxygen levels, as previously discussed, can result in fish kills and other undesirable effects.

Phytoplankton Biomass

Water column chlorophyll-*a* concentrations are an indirect measure of the quantity or biomass of planktonic algae present in a body of water. Planktonic algae or phytoplankton are typically single celled organisms that live suspended in the water column. Their life cycles can respond quickly to changes in environmental conditions, such as changes in dissolved nutrient concentrations, available light, and water temperatures. Phytoplankton are one of several major forms of plants that exist in Tampa Bay and in all estuaries. Other major estuarine plant types include submerged seagrass, macro-algae, and benthic micro-algae such as epiphytic algae that often attach to seagrass blades. These different plants can be viewed as being in competition with each other for required resources of light and nutrients. Eutrophic conditions brought about by excessive nutrient loadings into a system are often manifested in high phytoplankton and macro-algal biomass. High algal biomass can greatly reduce water clarity, which in turn often limits the growth and distribution of seagrass beds and can degrade the aesthetic quality of a body of water.

In 1989, the Tampa Bay Regional Planning Council's Agency on Bay Management, in recognition of the importance of chlorophyll-*a* as an indicator of water quality, established annual average chlorophyll-*a* target concentrations for four major segments of Tampa Bay. In 1996, modified chlorophyll-*a* targets were calculated from TBEP model predictions relating chlorophyll-*a*, water column light transparency, and seagrass depth distribution. These modified target concentrations are listed below.

Old Tampa Bay (OTB)	8.5 µg/l
Hillsborough Bay (HB)	13.2 µg/l
Middle Tampa Bay (MTB)	7.4 µg/l
Lower Tampa Bay (LTB)	4.6 µg/l

DATASETS REPORTED

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

EPC has been monitoring water quality monthly since the early 1970s at more than 50 stations throughout the Tampa Bay estuary, with most of the stations located within the OTB, HB, MTB, and LTB segments.

PCDEM has been monitoring water quality monthly in Boca Ciega Bay (BCB) since 1991. Water quality results reported were from about ten (depending on year) randomly selected sites within the defined TBEP boundaries of BCB.

Manatee County 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 one time every three month period.

The geographical boundaries sampled by Manatee County 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. For this report, the NMC segment is compared to the other five segments of the bay.

Finally, the Bay Study Group of the City of Tampa (COT) has been monitoring water quality at several stations in HB and one station in MTB since the late 1970s. The figures and data summaries following do not incorporate COT data.

Most of the data reviewed were collected on a monthly basis, but data collected in NMC were collected quarterly. Data from more than 110 sites were used in this review, although about twice as many sites were actually monitored by the four programs.

Long-term (1974-2001) and recent (1997-2001) mean annual water quality data were examined. Long-term records were reviewed from data collected by the EPC. Recent mean annual data were available for all six bay segments. The recent data sets depict existing conditions in Tampa Bay and contain pooled data for each segment from the EPC program plus data from other monitoring programs.

TEMPERATURE AND SALINITY

Temperature

Mean annual water temperatures among the four major bay segments from 1974 through 2001 varied from about 21°C to about 26°C, depending upon the year (Figure 7-1). The variability of mean annual temperatures among the four major bay segments during any given year typically was very small; only a few exceptions occurred in the more shallow bay segments (OTB and HB).

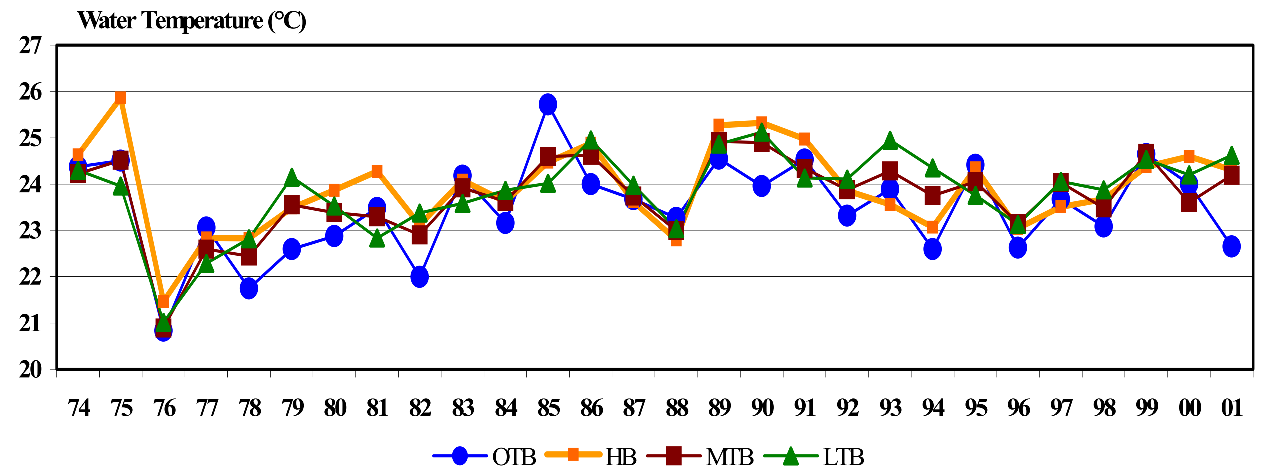

Figure 7-1. Mean annual water temperatures in Tampa Bay.

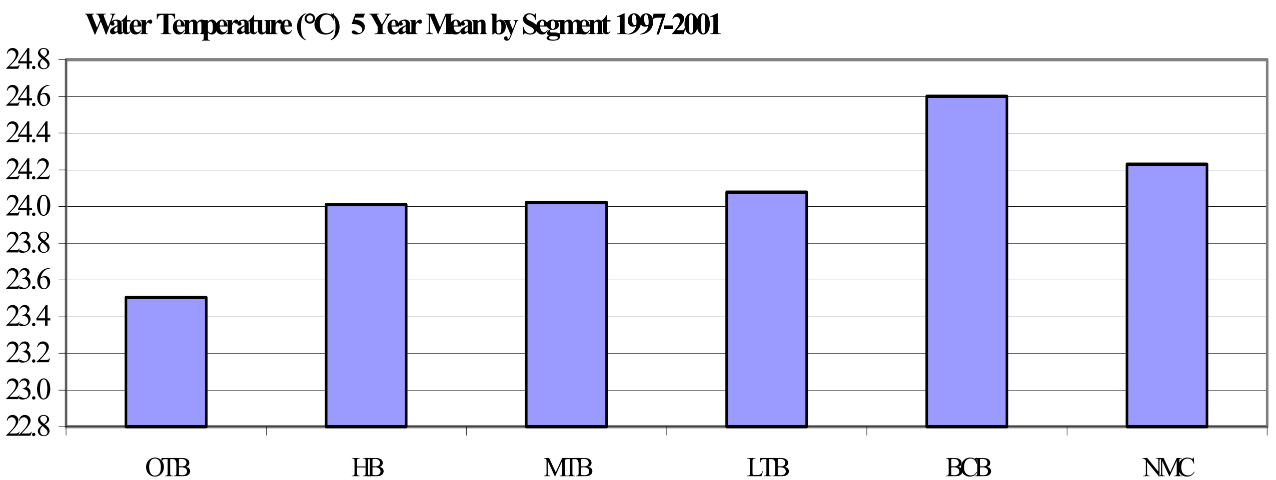

Figure 7-2. Mean annual temperatures in Tampa Bay during 1997-2001.

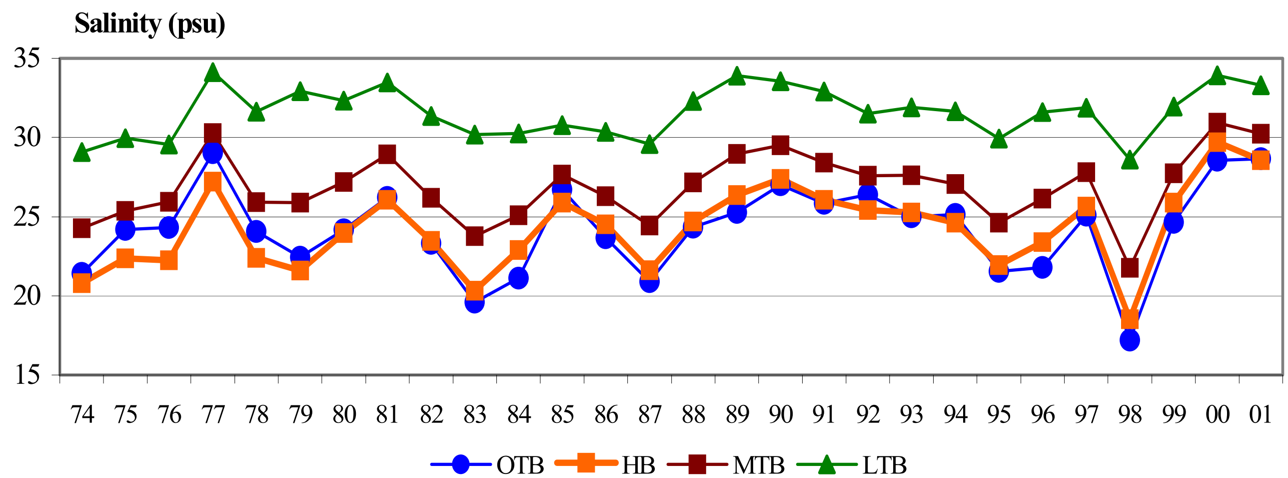

Figure 7-3. Mean annual salinities in Tampa Bay.

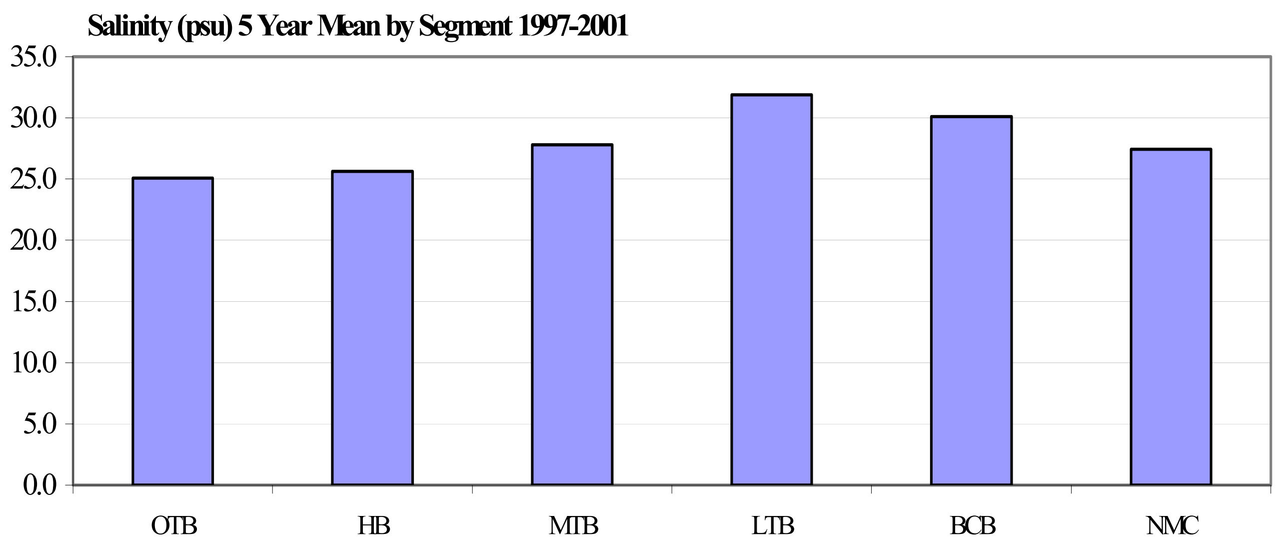

Figure 7-4. Mean annual salinities in Tampa Bay during 1997-2001.

Mean annual water temperatures among bay segments for the 5-year period from 1997 through 2001 are compared in Figure 7-2. Mean annual temperatures ranged from an average low of 23.5°C in Old Tampa Bay to a high of 24.6°C in BCB.

Salinity

Mean annual salinities for the four major bay segments from 1974 through 2001 ranged from a low of about 17 psu in OTB in 1998 to a high of nearly 34 psu in LTB in 2000 (Figure 7-3). During any given year, salinities among bay segments typically varied from 5 to 10 psu from the bay segment with the lowest mean salinity to the bay segment with the highest mean salinity. Lowest salinities occurred in either HB or OTB (20 to 27 psu), intermediate salinities occurred in MTB (24 to 31 psu), and highest salinities were recorded in LTB (29 to nearly 35 psu). The long-term time series by bay segment show a pattern of peaks (and troughs) about 4 or 5 years apart and are related to rainfall. These salinity oscillations may be related to changes in freshwater loads and/or changes in tidal prism; however, confirmation of such relationships has not occurred.

Five-year mean annual salinities among all six bay segments are shown in Figure 7-4. Overall highest mean annual salinity occurred in LTB and lowest salinity occurred in OTB. Previous work performed by the TBEP involving statistical trend tests of salinity variations has shown that no significant trends exist in any of the mainstem segments of Tampa Bay, except for a slight but statistically significant declining trend in LTB.

LONG-TERM DATA BY BAY SEGMENT

Long-term time series of water quality data collected by the EPC from 1974 through 2001 are examined for the four major bay segments of Tampa Bay in Figures 7-5 to 7-10. Water quality indicators examined for each bay segment include water clarity (Secchi disk depth, turbidity), dissolved oxygen, nutrients (total phosphorus, total nitrogen), and phytoplankton biomass (chlorophyll-*a*). The methodology for measuring nitrogen produced unreliable results until 1981; thus no total nitrogen concentrations prior to 1981 are shown.

Old Tampa Bay

Mean annual values of water quality indicators measured from OTB are plotted in Figures 7-5 to 7-10. These figures only include data collected by EPC for the four major segments of the bay. The comparison of water quality conditions among bay segments will be emphasized in a subsequent section of this chapter.

Water clarity was reviewed with respect to Secchi disk depths and turbidity. Water clarity in OTB as measured by mean annual Secchi disk depth was about 1.75 m in 1974, declined to about 0.75 m in 1979, and has leveled off at about 1.5 m since 1985 (Figure 7-5). Turbidity shows a somewhat different response over time, with most annual values, except those from 1989-1993, ranging between 3 and 5 NTU. Turbidities steadily declined from 1991 through 2000 but jumped up in 2001 (Figure 7-6).

Mean annual dissolved oxygen concentrations in OTB fluctuated around 7 mg/L from 1974 through 1982, then dropped to values ranging from about 6 mg/L to 7 mg/L since 1983 (Figure 7-7). The implications of this drop in dissolved oxygen concentration are discussed later.

Mean annual total phosphorus and total nitrogen concentrations were examined to assess ambient nutrient trends. Total phosphorus concentrations have shown a nearly steady decline during the last 27 years, from about 1.2 mg/L in 1974 to about 0.2 mg/L by 2001 (Figure 7-8). Mean annual total nitrogen concentrations have varied from about 0.65 mg/L to about 1.1 mg/L since 1981, when reliable data were first available (Figure 7-9). Total nitrogen values peaked in 1984, 1987, 1994, and 2000. The lowest concentration of about 0.55 mg/L was recorded in 1990. Since the 1994 peak of 1 mg/L, concentrations have dropped each year until elevated values were measured in 2000.

Phytoplankton biomass, as estimated by chlorophyll-*a*, ranged between about 7 µg/L and 18 µg/L from 1974 to 1983, then dropped to values averaging less than 10 µg/L most years since 1984 (Figure 7-10). The chlorophyll-*a* not-to-exceed target of 10.0 µg/L has been achieved all but two years (1995 and 1998) since 1987 according to data collected exclusively from EPC sites.

The water quality indicators, Secchi disk depth, dissolved oxygen, total phosphorus, and chlorophyll-*a* concentration, showed improving conditions in OTB between current conditions and those measured beginning in the late 1970s to early 1980s. Improving conditions in light transparency began in 1980, a lower range of dissolved oxygen concentrations occurred after 1982, a large drop in total phosphorus concentrations occurred after 1978, and phytoplankton biomass dropped to lower levels after 1983.

Dissolved oxygen was measured at surface, middle, and bottom depths at each station. The mean of these three measurements was plotted for each year in Figure 7-7. The higher surface water dissolved oxygen concentrations observed from 1974 through 1982 compared to the period 1983 to 2001 are likely reflective of the higher levels of phytoplankton biomass present during the earlier period (Figure 7-10). Surface dissolved oxygen concentrations prior to 1983 were very high and often reached supersaturation levels at some locations. Greater phytoplankton biomass in the water column prior to 1983 may have caused the higher amounts of oxygen produced during daylight hours, the time period in which sampling occurred. Since photosynthetic activity by phytoplankton result in the production of oxygen, higher levels of phytoplankton biomass often produce greater amounts of oxygen. Prior to 1983, the mean surface dissolved oxygen concentration baywide was 7.7 mg/L. As water quality conditions improved during the 1980s, phytoplankton biomass declined, and likewise the amount of oxygen generated during the day by phytoplankton declined, resulting in lower water column dissolved oxygen concentrations.

Hillsborough Bay

Hillsborough Bay has often been considered the most impacted segment of Tampa Bay as it has received the highest nutrient loads and has the greatest amount of industrial activity relative to other Tampa Bay segments. Mean annual values of water quality indicators measured from HB are also plotted in Figures 7-5 to 7-10.

Water clarity as measured by Secchi disk depths was poorest during the late 1970s (about 0.6 m), but has improved considerably since that time to values between 1.0 m and 1.5 m through 2001 (Figure 7-5). Turbidity values (Figure 7-6) show interannual fluctuations ranging from 4 NTU (1980) to 10 NTU (1992). A general decline in turbidity since 1992 has occurred. Prior to 1992, most mean annual turbidity values in HB were higher than in other bay segments. Since 1992, HB turbidities have fallen to within a range consistent with those in the other bay segments.

Long-term variations in dissolved oxygen concentration in HB are similar to those described for OTB, with consistently lower concentrations (5.7-6.5 mg/L) occurring after 1981 (Figure 7-7). The high pre-1982 phytoplankton biomass observed in HB (Figure 7-10) was probably associated with high rates of photosynthetic activity resulting in elevated dissolved oxygen levels. Mean annual dissolved oxygen values in HB, calculated from surface, middle, and bottom daytime measurements, were typically lower than in other bay segments after 1981. The sharp drop in HB phytoplankton biomass levels after 1981-1982 coincided with a marked reduction in mean annual water column dissolved oxygen levels.

Long-term variations in HB nutrient concentrations were similar to those seen in OTB. Since 1974, total phosphorus values have declined from 2 mg/L to about 0.25 mg/L in 2001 (Figure 7-8). Total nitrogen values were greatest from 1981 through 1984, in 1987, 1994 and in 2000 (Figure 7-9).

HB has shown considerable improvement in chlorophyll-*a* concentrations. Mean annual chlorophyll-*a* values were greatest from 1974 through 1983, ranging from about 22 µg/L to 33 µg/L (Figure 7-10). After 1983, concentrations have remained much lower, ranging from about 10 to 20 µg/L from 1984 through 2001, with most annual mean concentrations near or below the established target of 13.2 µg/L after 1986. Since 1984, the greatest exceedances of the target concentration occurred in 1994 (18.0 µg/L), 1995 (19.6 µg/L) and 1998 (20.7µg/L).

As was the case with OTB, the water quality indicators of Secchi disk depth, dissolved oxygen, total phosphorus, and chlorophyll-*a* concentration in HB generally reflected improving conditions since the early 1980s.

Middle Tampa Bay and Lower Tampa Bay

Mean annual values of water quality indicators for MTB and LTB are also plotted in Figures 7-5 to 7-10. The long-term water quality variations in MTB and LTB are very similar to those in OTB for all parameters plotted.

Water clarity was generally better in MTB and LTB (higher Secchi disk depths and lower turbidity values) compared to OTB and HB. Secchi disk depths were lowest in 1979 (about 1.2 m in MTB, 1.75 m in LTB), peaked in 1986-87, and have slowly declined through 2001 (Figure 7-5). Turbidity in MTB and LTB increased from 1986 through 1992, followed by a decline through 2001 (Figure 7-6).

Long-term variations in dissolved oxygen concentrations were similar in MTB and LTB compared to other segments. Mean annual dissolved oxygen concentrations in MTB and LTB dropped sharply from values ranging from about

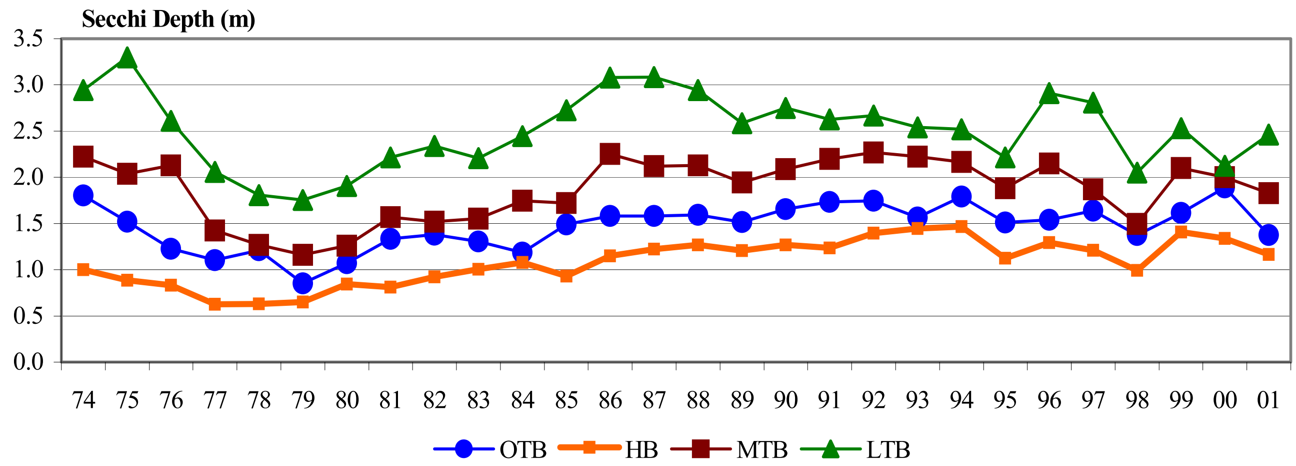

Figure 7-5. Mean annual Secchi disk depths in Tampa Bay.

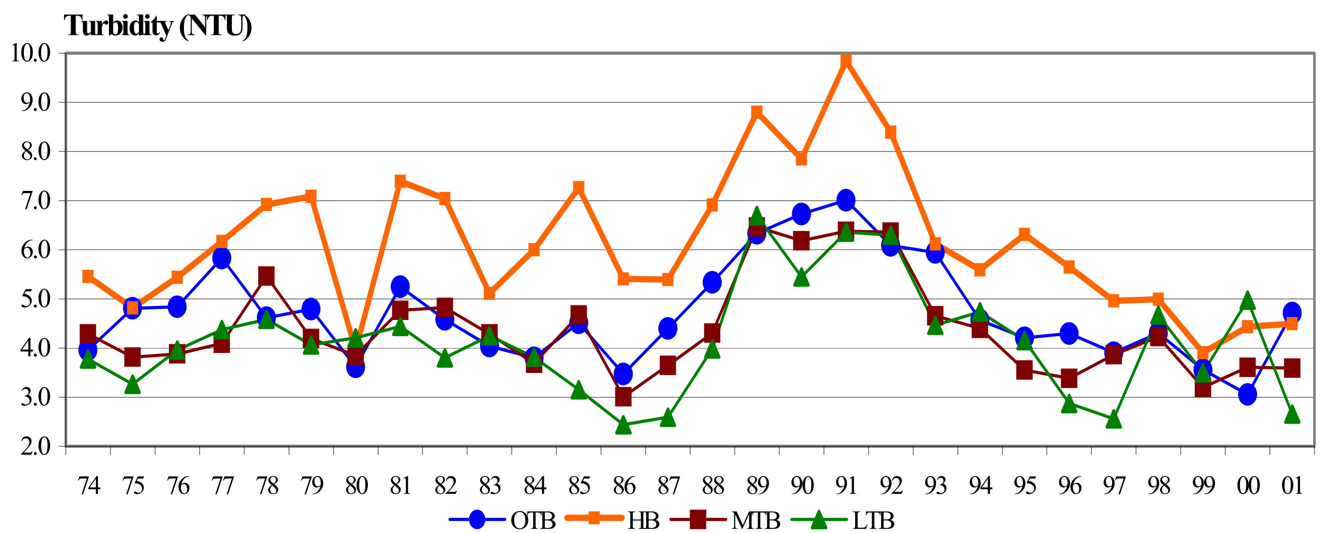

Figure 7-6. Mean annual turbidity values in Tampa Bay.

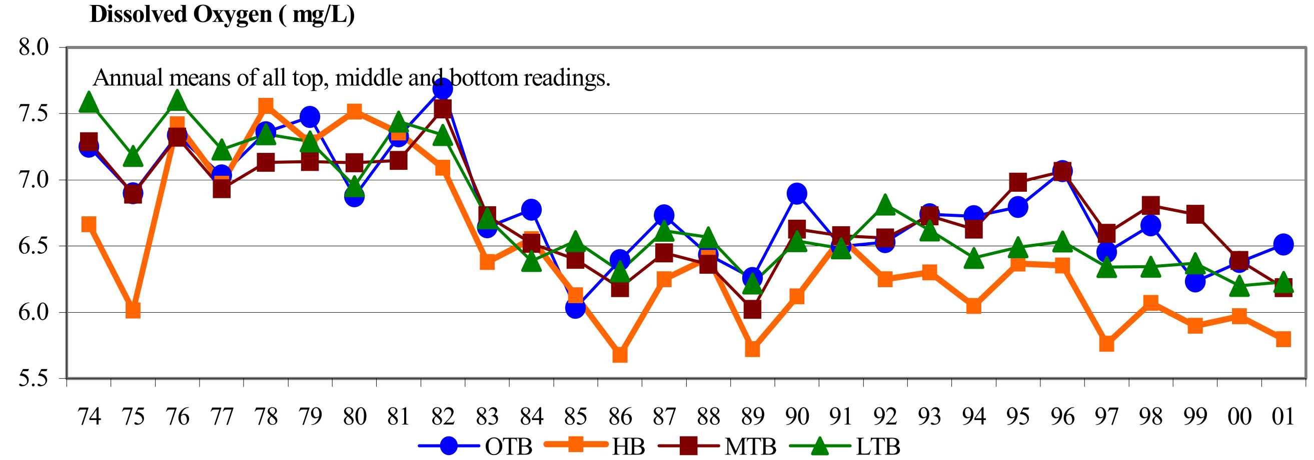

Figure 7-7. Mean annual dissolved oxygen concentrations in Tampa Bay.

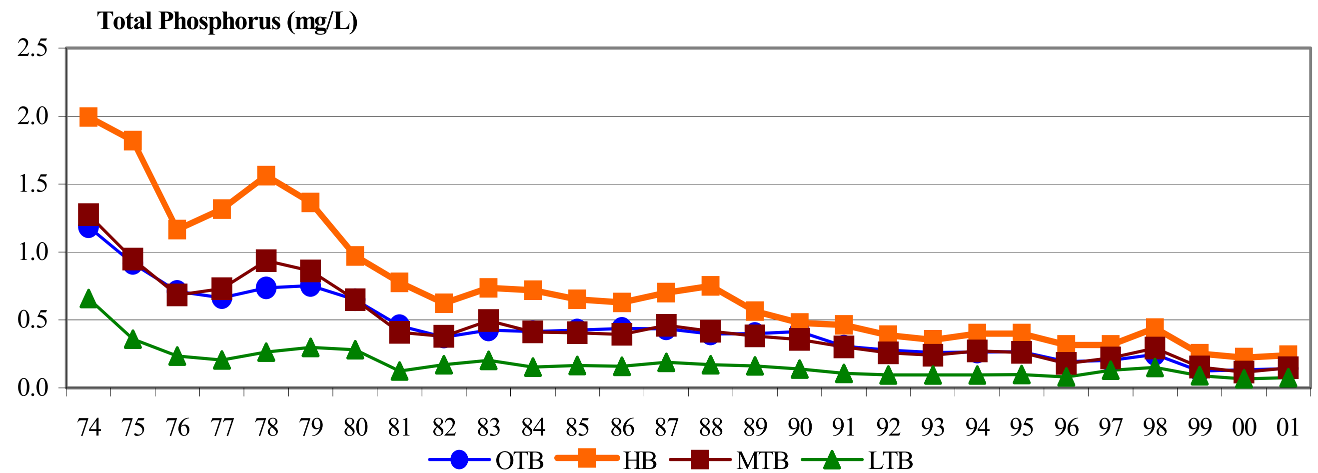

Figure 7-8. Mean annual total phosphorus concentrations in Tampa Bay.

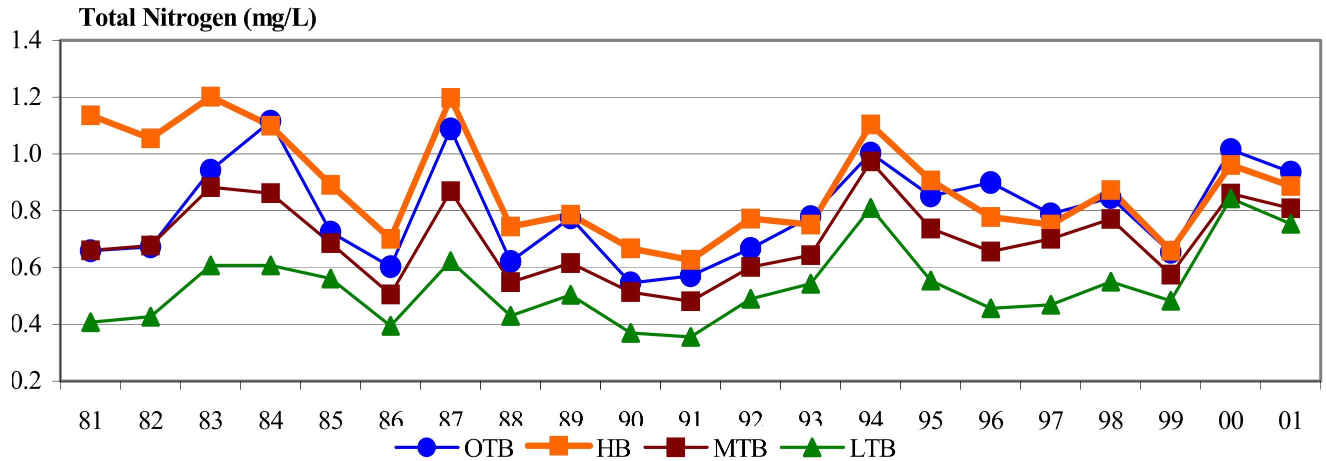

Figure 7-9. Mean annual total nitrogen concentrations in Tampa Bay.

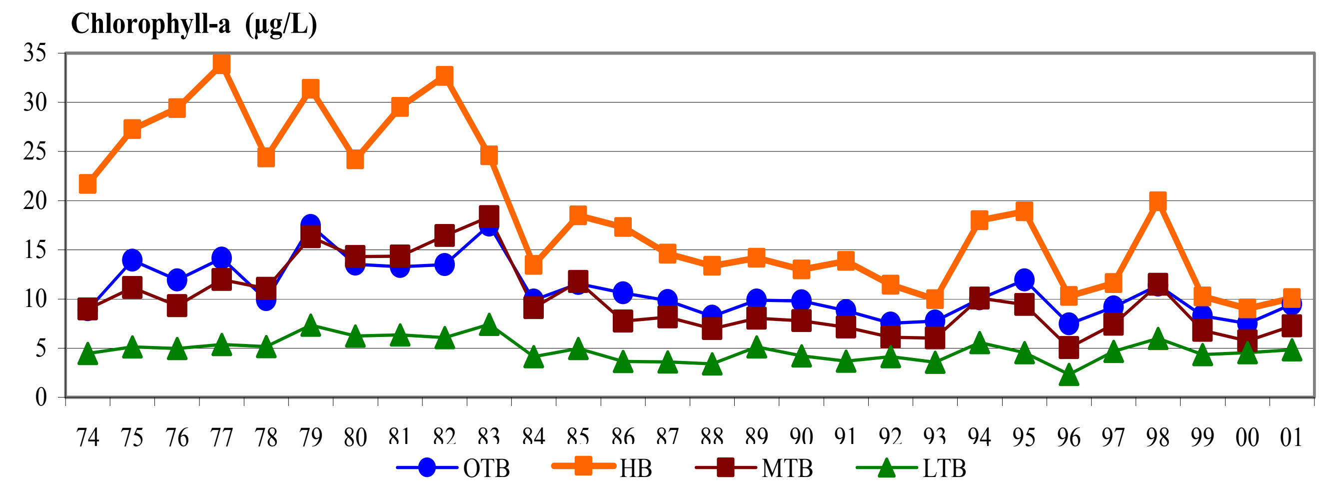

Figure 7-10. Mean annual chlorophyll-*a* concentrations in Tampa Bay.

6.8 to 7.6 mg/L through 1982 to values ranging from about 6 to 7 mg/L after 1982 (Figure 7-7).

Nutrient concentrations were somewhat lower in MTB and LTB relative to OTB and HB. Long-term total phosphorus concentrations showed a decline from a high of 1.3 mg/L in MTB and 0.7 mg/L in LTB in 1974, to a low of 0.15 mg/L in MTB and 0.10 mg/L in LTB during 2001 (Figure 7-8). Total nitrogen concentrations in MTB and LTB followed those found in OTB, but were slightly lower. Since 1981, mean annual total nitrogen concentrations in MTB and LTB have ranged from 0.35 mg/L to 0.97 mg/L (Figure 7-9).

Chlorophyll-*a* variations in MTB and LTB (Figure 7-10) are also similar to those observed in OTB. Values in MTB dropped from about 18 µg/L in 1983 to about 9 µg/L in 1984, and have varied between 5 and 12 µg/L since 1984. Mean annual MTB chlorophyll-*a* values were at or lower than the target concentration of 8 µg/L most years since 1986. Values in LTB dropped from about 7.5 µg/L in 1983 to about 2.3 µg/L in 1996. Since 1984, LTB chlorophyll-*a* concentrations have varied between about 2.3 and 6.0 µg/L, concentrations that are generally consistent with the established target of 4.6 µg/L.

COMPARISON OF BAY SEGMENTS

Long-term Time Series

In general, Tampa Bay water quality conditions during any given year since 1974 improved as distance to the Gulf of Mexico decreased; thus LTB had better water quality than MTB, which in turn had better water quality than OTB. HB, being the most impacted segment, typically had the poorest water quality as best depicted in Secchi disk depth, total phosphorus concentrations, and chlorophyll-*a* values.

The time of poorest water quality during the period of record (1974-2001) occurred during the late 1970s and early 1980s. As expected, water quality degradation was most pronounced in HB during this period when mean annual Secchi disk depths were often less than 0.7 m, compared to values often exceeding 1 m in OTB and MTB (Figure 7-5). Also, mean annual chlorophyll-*a* concentrations in HB during that time period ranged from about 25 µg/L to more than 32 µg/L, about twice the concentrations found in OTB and MTB (Figure 7-10).

The improvements in water quality after this period are primarily attributed to decreased point source loadings from wastewater treatment plants, and in particular, the conversion of the City of Tampa's Hookers Point wastewater treatment plant (now known as the Howard F. Curren wastewater treatment plant) from primary to advanced treatment between 1979 and 1980. The relatively sharp decrease in total phosphorus concentrations from 1978 to the present represents fertilizer production/shipping improvements (improved housekeeping and less spillage of product), phosphate removal from detergents, better stormwater management, and better phosphate removal by sewage treatment facilities. Since phosphorus is not considered limiting to phytoplankton growth in most areas of Tampa Bay, the decline in phosphorus levels should not have directly affected the eutrophic state or existing water quality conditions in Tampa Bay. The decline in the amount of fertilizer product shipped and handled in and adjacent to Tampa Bay, which included nitrogen as well as phosphorus containing fertilizers, may have reduced nitrogen loads into Tampa Bay, thus contributing to improved water quality conditions.

Unfortunately, nitrogen loading measurements into Tampa Bay were not performed during this period of changing conditions. It should also be recognized that, since nitrogen is a very reactive element, the amount of nitrogen loading to Tampa Bay in a given year is not necessarily reflected in total nitrogen concentrations measured in the water column. Furthermore, mean annual total nitrogen concentrations are not necessarily related to the water quality and/or eutrophic state of the estuary.

Since the early 1980s, all segments of Tampa Bay have shown considerable improvement in water quality. Assuming that Secchi disk depths and chlorophyll-*a* values most directly reflect perceived water quality conditions in Tampa Bay, these two parameters have shown continued good water clarity and relatively low phytoplankton biomass since the mid 1980s.

Existing (1997-2001) Conditions

Mean annual values of water quality indicators measured in 1997 through 2001 were examined (Figures 7-11 through 7-16) to compare the existing conditions among all Tampa Bay segments including NMC (see discussion below). Available data from the three county monitoring programs were used in these comparisons.

Water clarity as depicted by mean annual Secchi disk depths was greatest in LTB and NMC, followed in order of decreasing water clarity by: MTB, OTB, and HB and BCB (Figure 7-11). In summary, LTB and NMC had the best water clarity, OTB and MTB had intermediate water

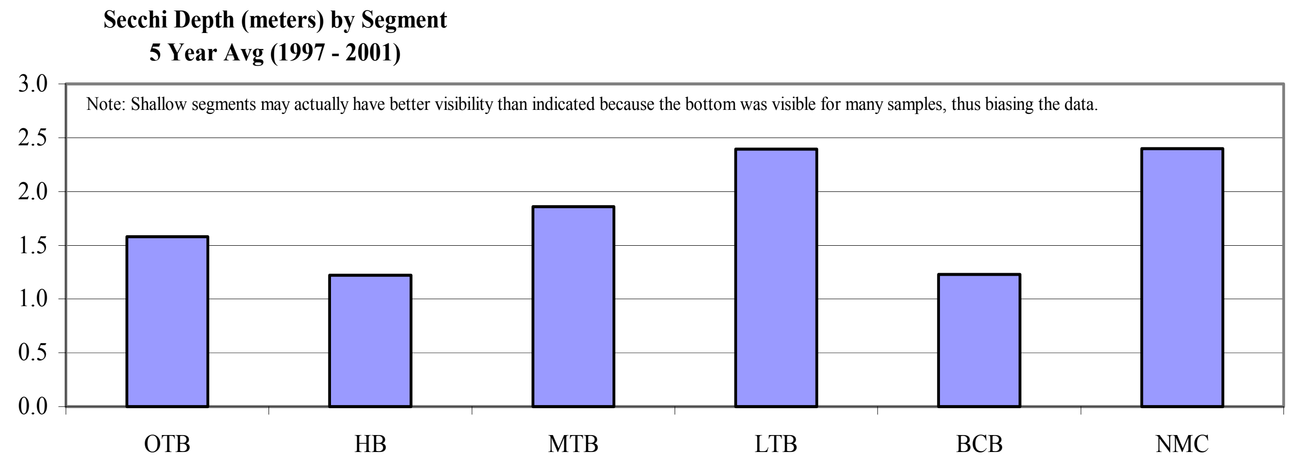

Figure 7-11. Mean annual Secchi disk depths in Tampa Bay, 1997-2001.

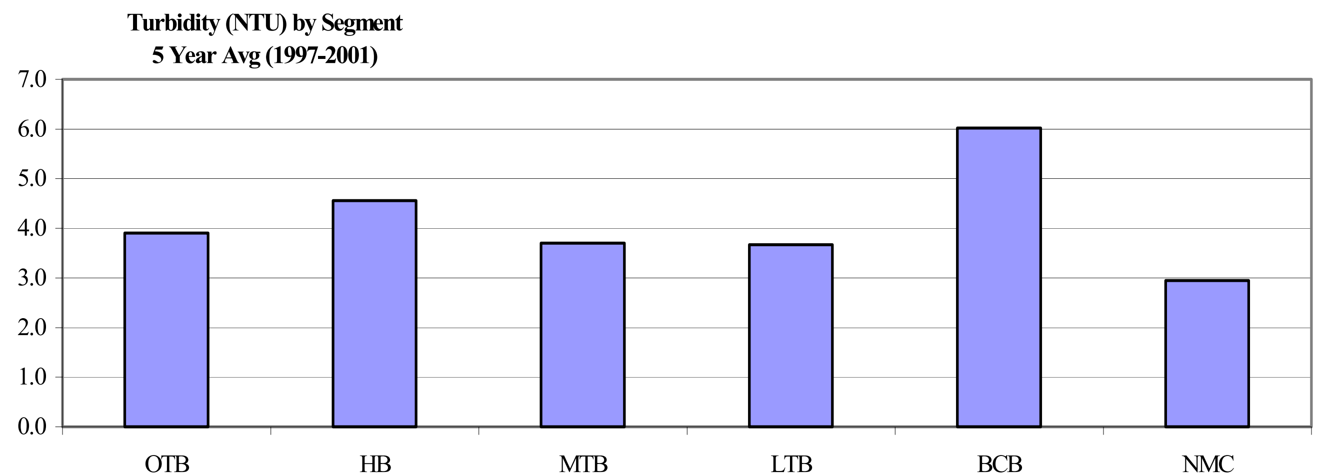

Figure 7-12. Mean annual turbidity values in Tampa Bay, 1997-2001.

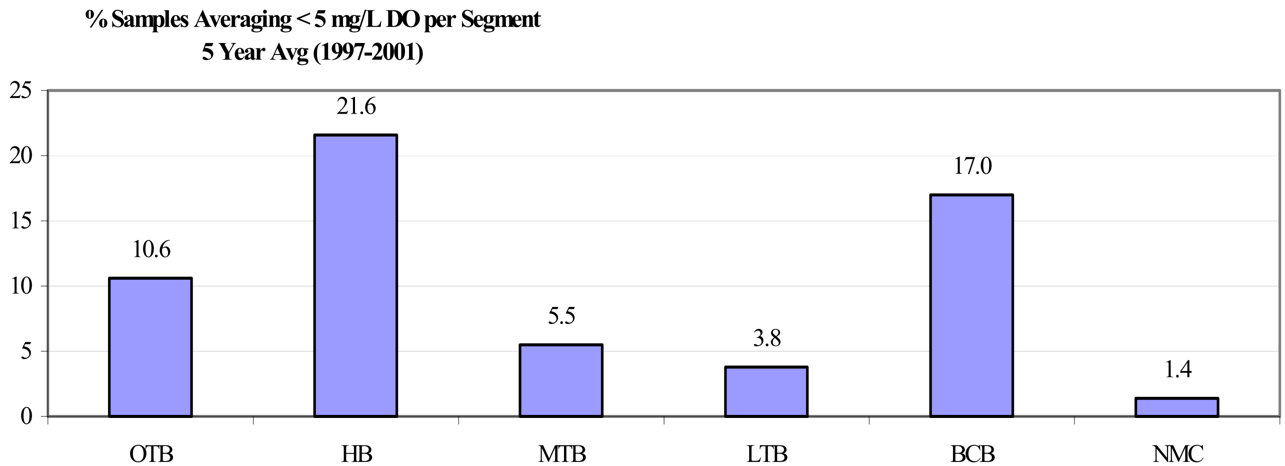

Figure 7-13. Comparison of measured dissolved oxygen concentrations to State water quality standard during 1997-2001: <5 mg/l.

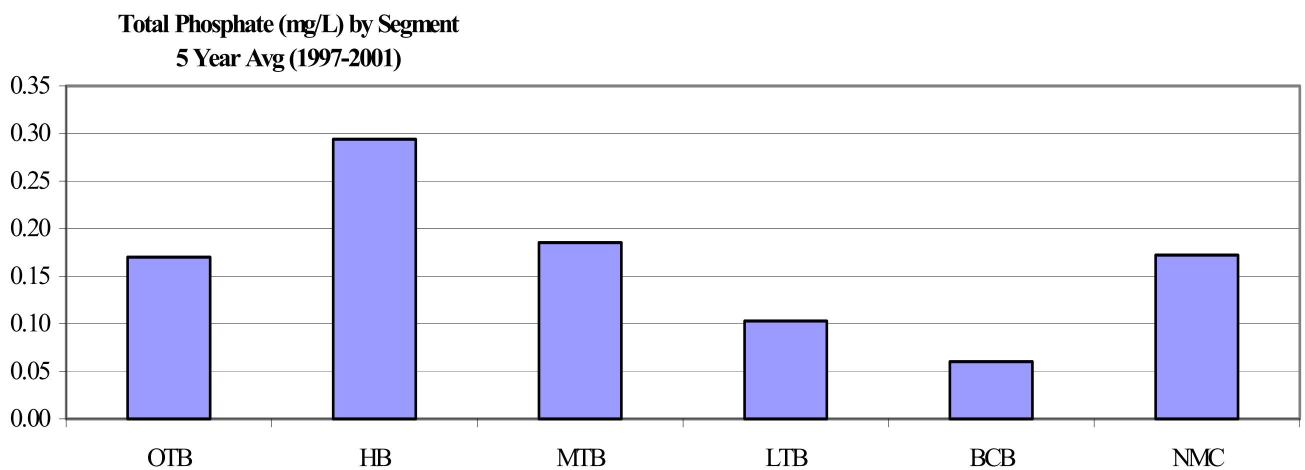

Figure 7-14. Mean annual total phosphorus concentrations in Tampa Bay, 1997-2001.

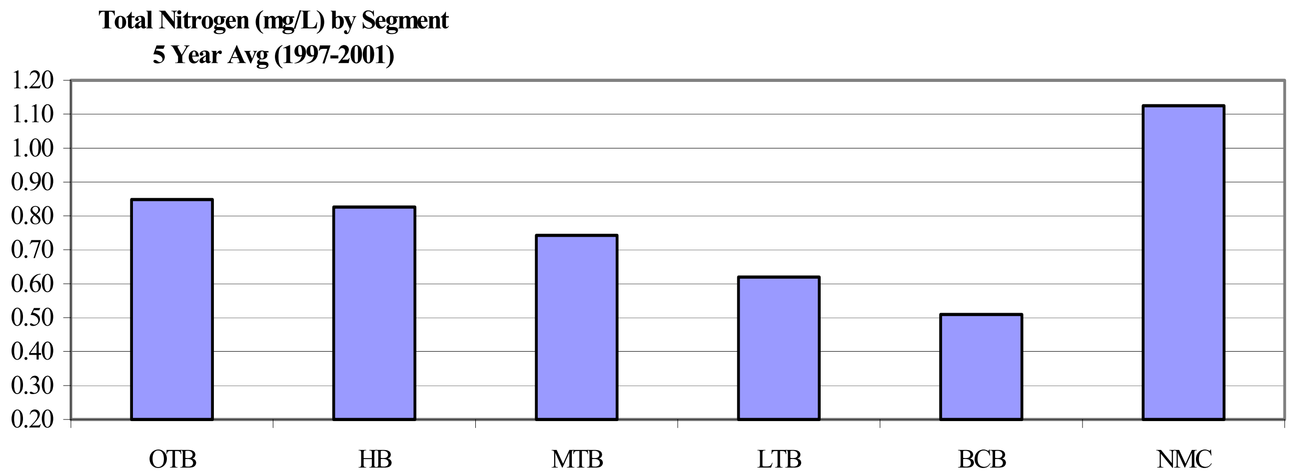

Figure 7-15. Mean annual total nitrogen concentrations in Tampa Bay, 1997-2001.

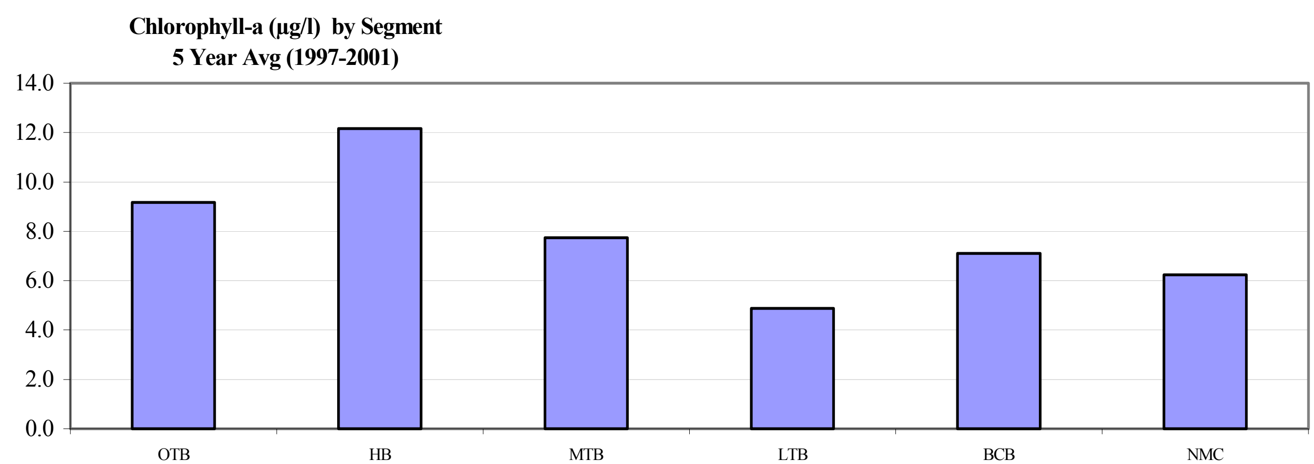

Figure 7-16. Mean annual chlorophyll-*a* concentrations in Tampa Bay, 1997-2001.

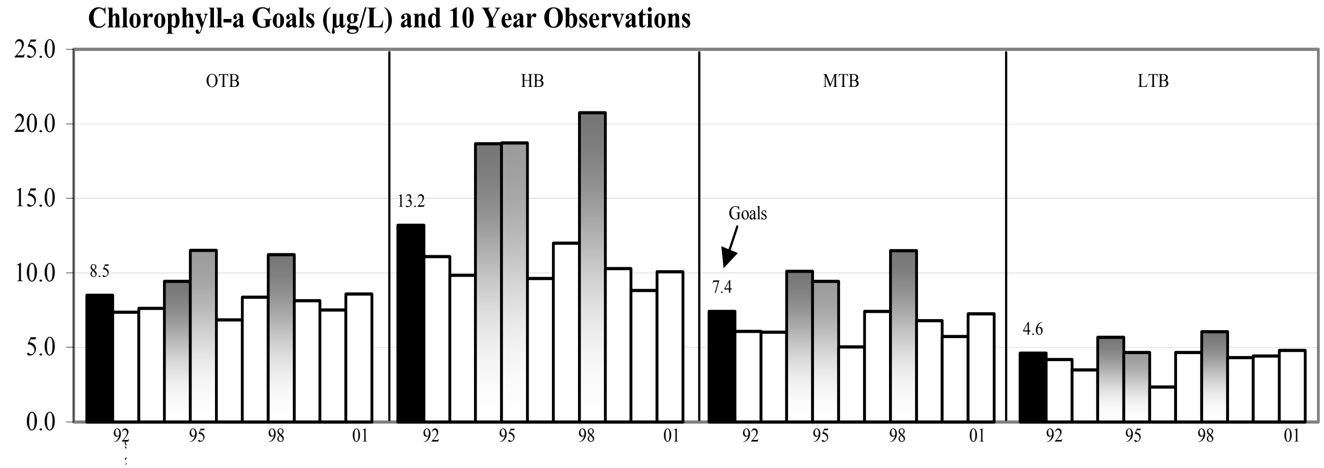

Figure 7-17. Comparison of chlorophyll-*a* concentrations in each segment to segment-specific targets, 1992-2001.

clarity, while BCB and HB had the poorest water clarity of segments examined in Tampa Bay.

Five-year mean annual turbidity values were relatively low for most bay segments, ranging from 2.9 to 4.6 NTU in the mainstem of the bay. BCB has the highest average turbidity (6 NTU) and NMC the lowest (2.9 NTU) (Figure 7-12). Rather than comparing mean annual dissolved oxygen concentrations among segments, it was deemed more useful to compare dissolved oxygen concentrations to State water quality standards. All open water areas within the seven bay segments of Tampa Bay have been designated either Class II or Class III waters by the State of Florida. State Class II and Class III surface water quality standards for dissolved oxygen are the same and encompass the following two criteria:

1. average dissolved oxygen concentration over a 24-hour period shall not be less than 5.0 mg/L; and
2. instantaneous measurements of dissolved oxygen concentration shall not be less than 4.0 mg/L.

To evaluate the 5 mg/L criteria for each year, mean annual dissolved oxygen concentrations were calculated for each site over a five year period (1997-2001). The percentage of all samples within each segment not meeting the 5 mg/L criterion were calculated and are graphically depicted in Figure 7-13. The 4 mg/L criterion was not evaluated.

Considering all six bay segments, HB had the greatest percentage of samples (21.6%) that fell below the 5 mg/L State water quality standard for dissolved oxygen (Figure 7-13). BCB had the next greatest percentage (17.0%) of samples not meeting State standards.

Mean annual total phosphorus concentrations were highest near major tributaries, and tended to decrease as distance from tributaries increased (Figure 7-14). HB had the greatest total phosphorus concentration over the five-year period (1997-2001). BCB had the lowest value.

Five-year mean annual total nitrogen values for all six segments ranged between about 0.5 and 1.1 mg/L (Figure 7-15). NMC had the highest concentration and BCB the lowest.

Five-year mean annual chlorophyll-*a* concentrations from 1997 through 2001 (Figure 7-16) ranged from a low of 4.9 µg/L in LTB to a high of 12.2 µg/L for HB.

CONCLUDING REMARKS

The restoration and protection of seagrasses is a major goal of the TBEP. Seagrasses need sufficient light to grow and the growth and areal expansion of seagrass meadows have been strongly linked to water clarity. Chlorophyll-*a* concentration has been shown to be the most important water column light attenuating factor in the four mainstem segments of Tampa Bay.

The data summarized herein show that light attenuation in BCB may not be as strongly influenced by chlorophyll-*a* compared to the mainstem segments. In BCB, the five-year mean annual water quality values showed that

1) Secchi depths were the lowest of all segments,

2) turbidity was the greatest of all segments, and

3) chlorophyll-*a* was relatively low (7.1 µg/L).

These results suggest that factors other than chlorophyll-*a*, such as suspended sediments, may attenuate a larger proportion of available light relative to what is occurring in other Tampa Bay segments.

Based on mean annual chlorophyll-*a* concentrations, water quality in the Tampa Bay estuary has continued to meet TBEP targets for chlorophyll through a ten-year period from 1992 through 2001. In Figure 7-17, mean annual chlorophyll-*a* concentrations are compared to chlorophyll-*a* targets by segment. Mean annual chlorophyll-a concentrations exceeded established TBEP chlorophyll-*a* targets during three years in each of the four mainstem segments. All of the exceedances occurred during the same three years, 1994, 1994, and 1998. Recent water clarity observations indicate that Tampa Bay is "holding the line" with respect to water quality, and large water quality improvements realized in the early 1980s have been maintained through 2001.

R. McConnell (Tampa Bay Water)

- CHAPTER HIGHLIGHTS -

- *A Hydrobiological Monitoring Program (HBMP) was designed and implemented as required by permits for some elements of Tampa Bay Water's Master Water Plan.*
- *The HBMP includes monitoring in the Lower Hillsborough River, Lower Palm River/ Tampa Bypass Canal, Alafia River, and Hillsborough Bay.*
- *Overall HBMP goals are to ensure that once river withdrawals begin, flows do not deviate from the normal rate and range of fluctuation to the extent that water quality, vegetation, animal populations, salinity patterns, or recreational/aesthetic qualities are adversely impacted.*
- *Data collected during WY 2001 help define natural conditions and characterize differences between reporting units. A synopsis of the data collected with respect to hydrology, water quality, benthos, plankton, fish, birds, and vegetation/habitat is provided.*

INTRODUCTION

This chapter provides an overview of Tampa Bay Water's surface water projects and development/implementation of the associated Hydrobiological Monitoring Program. A synopsis of Water Year 2001 results is included to illustrate some of the parameters and evaluation methods included in the program.

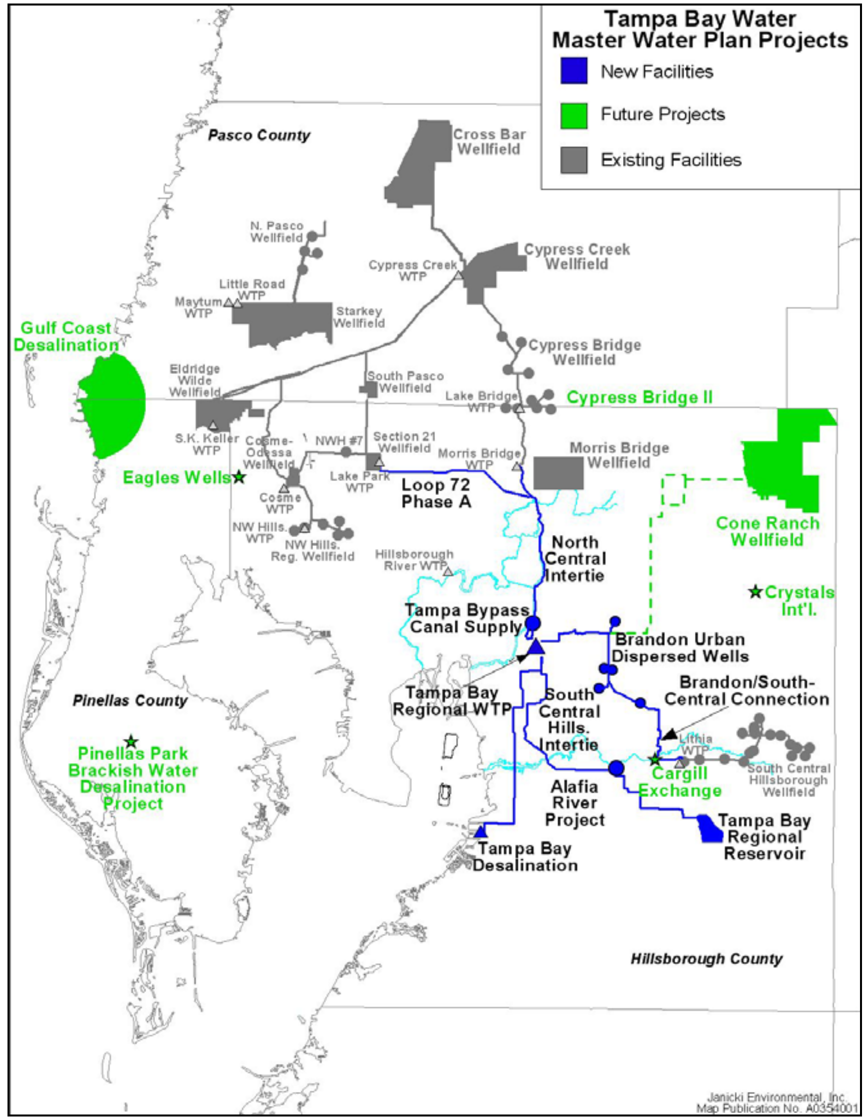

Figure 8-1. Tampa Bay Water's Master Water Plan.projects.

After decades of increasing groundwater use in the Tampa Bay region, environmental impacts (e.g., lowered lake levels and wetland stress) have become a significant concern in some areas. In addition to water conservation measures, new water supply sources must be developed to relieve environmental stress around regional groundwater facilities and meet increasing water demand for an ever-growing population. New supply sources currently being developed as alternatives to groundwater pumping include surface water withdrawals and desalination.

Tampa Bay Water, the regional water supply authority in the Tampa Bay Region supplying potable water to Hillsborough, Pasco, and Pinellas counties, and the cities of New Port Richey, St. Petersburg, and Tampa, has adopted a Master Water Plan (see Figure 8-1) that includes the Tampa Bypass Canal, the Hillsborough River, and the Alafia River as significant sources of additional water supply. All three tributaries discharge to Hillsborough Bay, a major segment of the Tampa Bay estuarine system.

Environmental concerns related to these planned withdrawals reflect the natural areas and recreational/aesthetic values provided by these waterbodies, as well as their contribution to the Tampa Bay ecosystem.

The Tampa Bypass Canal/Hillsborough River and the Alafia River projects are part of an integrated system referred to as the Enhanced Surface Water System (ESWS) that also includes the new Tampa Bay Regional Reservoir. The ESWS is designed to manage and optimize withdrawals, conveyance, and storage of surface water supply. Construction

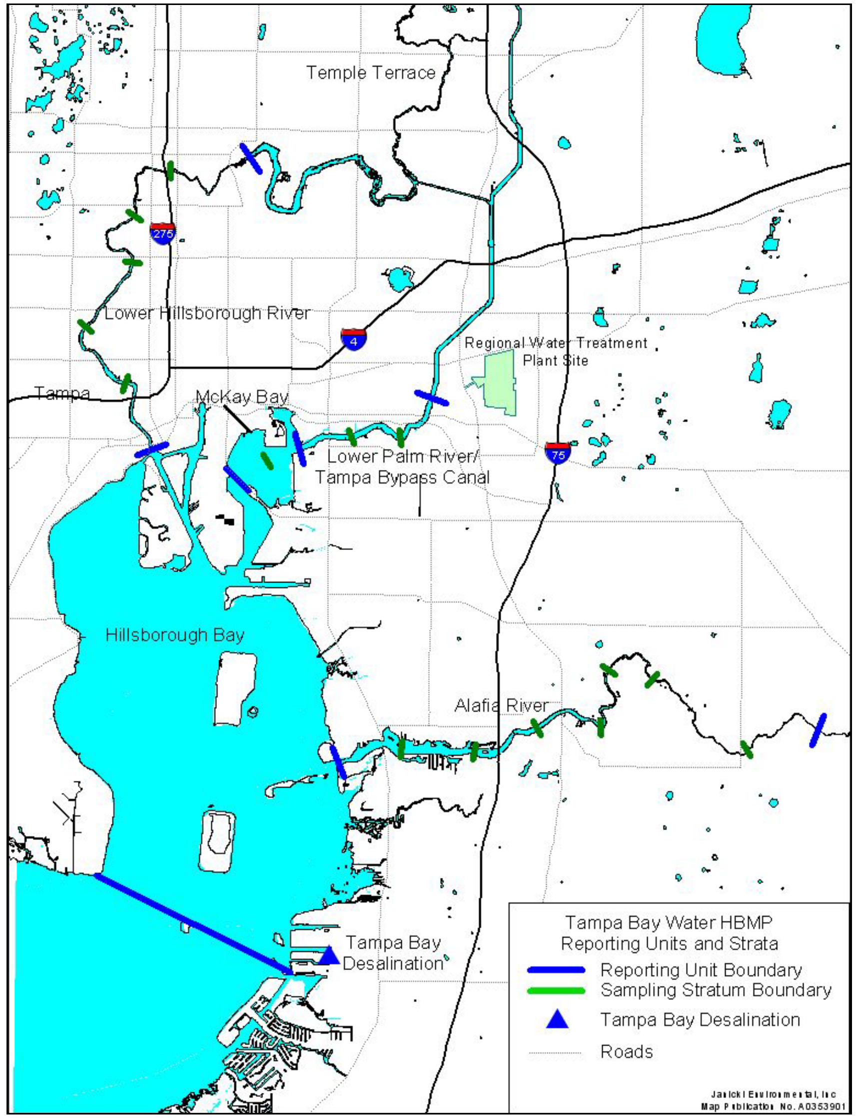

Figure 8-2. Tampa Bay Water HBMP study area.

activities for these projects will be completed in 2002 at which time they will become part of the regional supply system.

Withdrawal schedules for these new sources were developed to minimize hydrological and ecological impacts to the riverine systems, and to ensure that flows remain within the range of natural variability. The permitted withdrawal schedules for both the Tampa Bypass Canal/ Hillsborough River and Alafia River projects vary with available flows (i.e., withdrawals increase with increasing flows up to a permitted maximum, no withdrawals below a designated low flow). In the near future when water cannot be withdrawn from the rivers during the dry season, the new Regional Reservoir will be used for supply (anticipated completion 2005).

Water Use Permits for the surface water projects required the development of a Hydrobiological Monitoring Program (HBMP). Due to similar project development schedules, close proximity, and the integrated nature of the two projects, a single unified HBMP was developed to address permit requirements for both projects.

The HBMP was implemented in spring 2000 so that baseline data could be collected prior to initiation of new surface water withdrawals (expected to begin in fall 2002). Reporting includes quarterly and annual data reports, as well as detailed interpretative reports to be produced in Years 3 and 5 (2003 and 2005).

The annual implementation cost of the HBMP is approximately $950,000. The detailed HBMP design document, quality control documents, and data reports are available through the project website linked to http://www.tampabaywater.org.

DEVELOPMENT OF THE HBMP

To maximize stakeholder participation and the use of available technical resources, a consensus-based focus group, consisting of consultant and university experts, representatives of federal, state, and local environmental agencies, and various environmental organizations was established to help design the HBMP; members of this group will convene annually to evaluate monitoring data.

The focus group anticipated that any potential withdrawal impacts will first be manifested in the rivers and upper bay segments. For this reason, four geographic areas of concern, or reporting units, were defined: the lower Hillsborough River, lower Alafia River, lower Palm River, and McKay Bay (see Figure 8-2). Hillsborough Bay was also included as a secondary reporting unit: monitoring relies on data collected by the Environmental Protection Commission of Hillsborough County (EPCHC), the Southwest Florida Water Management District (SWFWMD), the Florida Fish and Wildlife Conservation Commission's Florida Marine Research Institute (FMRI) in St. Petersburg, the City of Tampa Bay Study Group, and others.

Overall HBMP goals are to ensure that once withdrawals begin, flows do not deviate from the normal rate and range of fluctuation to the extent that water quality, vegetation, animal populations, salinity patterns, or recreational/aesthetic qualities are adversely impacted. Important HBMP objectives are to:

- document existing conditions,
- enable the detection of changes,
- determine if changes are attributable to flow reduction and withdrawals,
- determine whether the detected changes constitute unacceptable adverse impacts, and
- recommend appropriate actions or operational changes to mitigate any unacceptable adverse impacts.

The HBMP uses a stratified-random sampling design where the reporting units are divided into segments or spatial strata (see Figure 8-2). Specific sampling locations are then randomly selected from a list of potential sites within that reporting unit, apportioned across each stratum. The stratified-random design allows for the statistical characterization of an entire segment of a river or embayment rather than the characterization of a single location as with a fixed station design. Some fixed water quality and vegetation stations were also included to address special monitoring needs.

The design also accounts for key within-year sources of temporal variation by collecting an adequate sample size for drawing inferences for each reporting unit on a quarterly basis, and ensuring that statistically valid inferences can be made between wet and dry season rainfall conditions.

The HBMP defines monitoring program elements, objectives, and parameters (see Table 8-1). Elements include hydrology/ water quality, biota, and habitat/vegetation; critical indicators were identified for each reporting unit and element (see Table 8-2).

The TBC/Hillsborough River Project

The Palm River once drained lands between the Hillsborough River and Alafia River watersheds, and discharged into McKay Bay, a small embayment in northeast Hillsborough Bay. The Tampa Bypass Canal (TBC) was created during the 1960s, when the Palm River was completely channelized, deepened, and impounded. Completed in 1970, the purpose for this alteration was to control flooding by intercepting and diverting high flows from the upper Hillsborough River around the urban areas of the City of Tampa. During construction, the confining layer of the artesian Floridan aquifer was breached, and it is estimated that 20 to 40 million gallons per day (MGD) of groundwater currently discharges to the TBC.

Although the TBC still discharges to McKay Bay (from 1977-1996 mean annual discharge at S-160 was 79 MGD), the natural hydrology and ecology of the historic Palm River have been substantially altered. Today, the TBC is tidally influenced up to flood control structure S-160, the most downstream control structure in the canal system, but virtually no natural riparian wetland communities exist along this segment.

Table 8-1. Summary of HBMP monitoring elements, objectives, and parameters.

HBMP Element	Objective(s)	Parameters
Hydrology/Water Quality	Estimate daily freshwater flows, withdrawals, and water levels. Evaluate trends/changes in salinity regimes and relationships between water quality parameters and flow.	Monthly: Hydrolab casts or grab samples: salinity, conductivity, temperature, DO, Secchi disk depth, chlorophyll-a, TOC, DOC, TSS, color. Daily: rainfall, flow measurements.
		Continuous recording hydrographic instruments at six fixed stations: water level, conductivity, temperature and DO.
Benthic Invertebrates	Evaluate changes in species composition, abundance and/or distribution.	Monthly sampling of epifauna, infauna, grain size and organic matter in freshwater and estuarine strata. More intense sampling in wet season and most likely potential impact areas.
Zooplankton and Larval Fishes	Evaluate changes in species composition, abundance and/or distribution.	Monthly oblique tow data are collected by the University of South Florida.
Adult and Juvenile Fishes	Evaluate changes in species composition, abundance and/or distribution.	Monthly trawl and seine data are collected by the Florida Marine Research Institute.
Water Dependent Birds	Evaluate changes in abundance and richness over time, and any correlation with changes in water quality or other biological indicators.	Bimonthly surveys are conducted at three locations: Alafia Banks, ponds near the mouth of the Palm River, and upper McKay Bay.
Habitat/Vegetation Indicators	Estimate areal extent, relative abundance, and upstream/downstream shifts of vegetative communities.	Annual linear shoreline and wetland polygon mapping, annual emergent and submerged aquatic vegetation survey by strata and fixed stations in the Alafia River.

Located approximately 17 km upstream of the Hillsborough River's confluence with Hillsborough Bay, the Hillsborough River Dam has altered the natural hydrology of this tidal river for more than a century. Unlike the majority of municipalities in the Tampa Bay region, the City of Tampa has relied upon surface water withdrawals from the impounded Hillsborough River Reservoir to meet its water supply needs since the late 1800s. The Harney Canal, an interconnection between the Hillsborough River Reservoir and the TBC, was completed during the late 1970s. The City of Tampa is currently permitted to divert water from the Harney Canal into the reservoir to augment water supplies during low flow periods.

The historic mean annual discharge for the Hillsborough River was 1.53×10^{11} gallons (Lewis and Estevez, 1988), or about 419 MGD. Although substantially altered from its natural condition, this river constitutes the greatest single source of freshwater inflow to Tampa Bay. Mean annual discharge at the Dam from 1977 to 1996 was approximately 148 MGD. In addition to alterations in flow, the lower tidal segment of the Hillsborough River is heavily urbanized, and the vast majority of the shoreline has been hardened.

The TBC/Hillsborough River withdrawal project involves diversion of a percentage of high flows from the Hillsborough River through an existing flood control structure (S-161 located in the Harney Canal) into the TBC. Diverted river water, as well as flow originating from the TBC, will be withdrawn at a single pumping facility located on the east side of the TBC adjacent to structure S-162. The pump station will deliver water to the Tampa Bay Regional Water Treatment Plant and a re-pump station, located at the water treatment plant, will deliver excess capacity to the Tampa Bay Regional Reservoir (estimated completion in 2005).

The permitted withdrawal and diversion schedules for both the TBC and the Hillsborough River vary with available flows. Withdrawals increase with increasing flows up to a permitted maximum, and no water can be withdrawn below an established low flow limit at both points of discharge to tidal waters. The maintenance of a minimum flow and level (MFL) in surface waters is required under Florida law to ensure that aquatic ecosystems and recreational uses are not adversely affected by withdrawals.

Table 8-2. HBMP elements and critical indicators by reporting unit.

HBMP Element	Critical Indicators	AR	PR	MB	HR	HB
Hydrology/Water Quality	Freshwater Withdrawals	X	X		X	
	Streamflow	X	X		X	
	Water Level	X	X	X	X	
	Salinity	X	X	X	X	X
	Conductivity	X	X	X	X	
	Temperature	X	X	X	X	X
	Dissolved Oxygen	X	X	X	X	X
	Secchi Disk Depth	X	X	X	X	X
	Chlorophyll-a	X	X	X	X	X
	Color	X	X	X		X
	Total Organic Carbon	X	X	X		
	Dissolved Organic Carbon	X	X	X		
	Total Suspended Solids	X				X
Biota	Benthic Macroinvertebrate Infauna	X	X	X	X	X
	Benthic Macroinvertebrate Epifauna	X	X	X	X	X
	Ichthyoplankton and Zooplankton	X	X	X	X	
	Adult and Juvenile Fishes	X	X	X	X	X
	Water-Dependent Birds	X	X	X		
Vegetation/Habitat	Emergent Aquatic Vegetation	X	X	X	X	
	Submerged Aquatic Vegetation	X				
	Sediment Grain Size	X	X	X	X	
	Sediment Organic Matter	X	X	X	X	

Note: AR - Alafia River, PR - Palm River, MB - McKay Bay, HR - Hillsborough River; HB - Hillsborough Bay (secondary reporting unit)

The Hillsborough River withdrawal schedule allows for diversion of proportionately greater volumes of the high flows that occur during periods of heavy rainfall, between 65 and 647 MGD, but limits or prevents withdrawals during low flows. Diversions from the Hillsborough River would not begin until flow is more than five times the current MFL (10 cubic feet/sec (cfs) at the Tampa Dam). The TBC withdrawal schedule begins at 11 cfs (the current MFL for this system is 0 cfs at S-160) and allows for the withdrawals of 80% of the flow between 7 and 81 MGD.

The Alafia River Project

The Alafia River is the second most important tributary to Tampa Bay in terms of freshwater inflow, with an historic mean annual discharge of 1.12×10^{11} gallons (Lewis and Estevez, 1988), or about 307 MGD. The river originates in Polk County to the east and discharges into southeastern Hillsborough Bay. The river is tidally influenced approximately 16 kilometers (km) upstream of its mouth. Rural and undeveloped land uses exist in much of the Alafia watershed, and the natural hydrology and ecology of the Alafia River have been largely maintained. The upper watershed, however, has been affected by phosphate mining, and some of the upper branches are partially impounded.

The Alafia River project involves the withdrawal of seasonally available surface water from the river for regional public supply use. The withdrawal location is the south side of the Alafia River at Bell Shoals Road, approximately 18 km upstream from the mouth of the river on Hillsborough Bay.

The withdrawal schedule for the Alafia River project was developed to minimize hydrologic and ecological impacts to this riverine system by not withdrawing water during low flow periods, and to ensure that flows remain within the range of natural variability. Proposed withdrawals will only occur when the river flow at Bell Shoals is at 80 MGD or greater, at which time only 10 percent of the flow will be withdrawn. From 1977-1996, mean annual discharge at this location was approximately 214 MGD. The minimum flow threshold of 80 MGD corresponds to the 80th percentile (flow rate exceeded 80 percent of the time during an average year). The permitted maximum withdrawal is 52 MGD.

HBMP IMPLEMENTATION

The HBMP was implemented in the spring of 2000 so that additional baseline water quality and biological data could be collected prior to initiation of new surface water withdrawals. The first year of data collection, Water Year (WY) 2000, included Quarters 3 (April 2000-June 2000) and 4 (July 2000–September 2000). The second year, WY 2001 (October 2000–September 2001), included a full year of data collection. Withdrawals are scheduled to begin in fall 2002; about two years of pre-operational data will be collected and used in conjunction with historical data to determine baseline conditions.

Detailed information on the methods used for all HBMP sampling and analysis activities is provided in the Tampa Bypass Canal/Alafia River Water Supply Projects Hydrobiological Monitoring Program Design Report (PBS&J, 2000) and the Tampa Bypass Canal/Alafia River Water Supply Projects Hydrobiological Monitoring Program Quality Assurance and Quality Control Plan, Version 1.1 (PBS&J, 2002b).

HBMP data are stored in an ACCESS® database currently maintained by PBS&J. Data collected at each site are entered into a series of linked database tables that include results, qualifiers, field observations, variable definitions, taxonomy, and other information. Hydrolab data (collected during water quality, benthos, birds, fish, and plankton sampling) and rainfall and flow data are also included in the database.

Synopsis for Water Year 2001

The information provided below is excerpted and condensed from the WY 2001 Annual Data Report (PBS&J 2002): see this report for more information.

Monitoring highlights from WY 2001 are provided in this chapter, including some comparisons between reporting units to illustrate general differences between the systems. Selected results are to illustrate some important HBMP parameters. It should be noted that it is not an objective of the HBMP to compare conditions between spatial reporting units, but to characterize conditions and detect changes within individual spatial reporting units. In addition, data collected during WY 2001 represent hydrobiological conditions during a period of regional drought. Nevertheless, these data help define natural conditions and characterize differences between reporting units.

For various HBMP biological elements, statistical measures evaluated may include the total number of organisms, total number of taxa, center of abundance (COA), center of frequency (COF), abundance-weighted salinity (AWS), and frequency-weighted salinity (FWS). For the linear riverine reporting units that are divided into spatial strata along a gradient, COA/COF and AWS/FWS statistics are used to evaluate biological effects of changes in freshwater flows and salinity by describing the average position of occurrence for a given taxon over the sampling time period. See the WY 2001 Annual Data Report (PBS&J 2002a) for more information.

Hydrology

The objectives of this monitoring element for all three river systems are to: monitor water levels, estimate daily freshwater inflows, and monitor daily total freshwater withdrawals.

HBMP hydrologic and rainfall measurements are obtained from rain gage and stream stage/flow recording stations maintained by outside agencies including the U.S. Geological Survey (USGS) and the SWFWMD, and water level and quality recording stations installed specifically for the HBMP. HBMP continuous recorders were installed in the early part of WY 2001; these stations measure conductivity/salinity at all locations, and stage and dissolved oxygen at select locations.

In WY 2001, continuation of an extensive regional drought exerted a strong influence on rainfall and corresponding river flows throughout southwest Florida. Although data collection during extreme drought conditions has allowed documentation of low flow conditions, withdrawals would not have occurred under these conditions. Data collected during more typical rain/flow patterns will also be used to define baseline conditions.

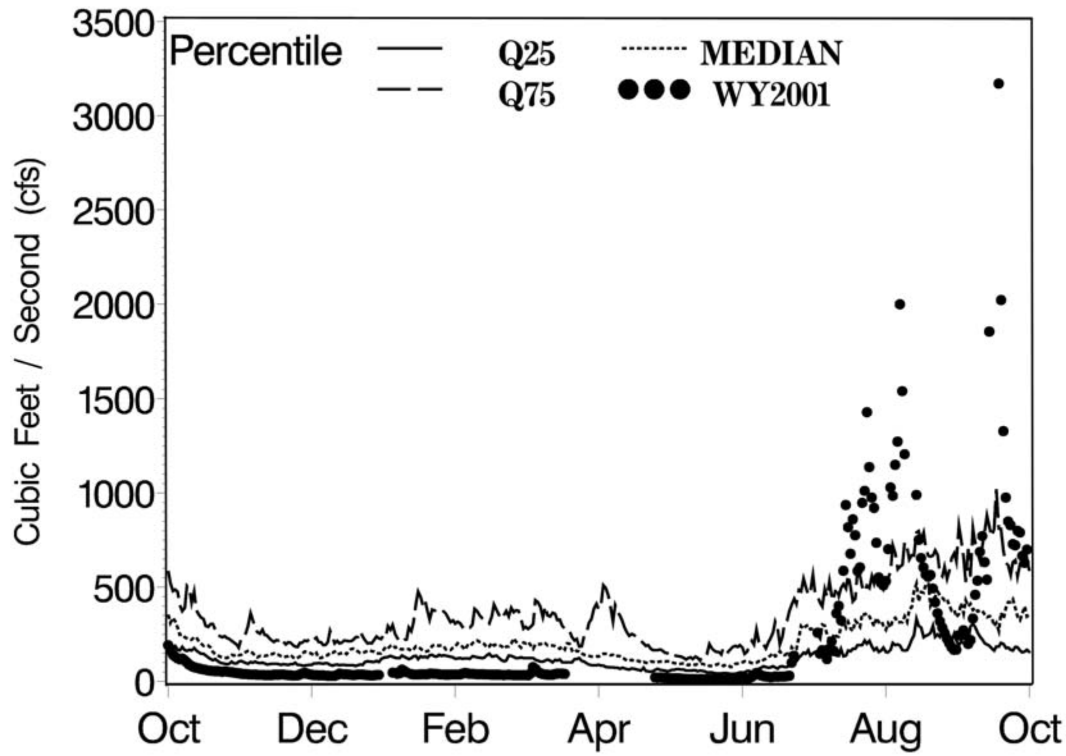

Figure 8-3. Alafia River flow (cfs) at Bell Shoals (estimated) during water year.

Cumulative rainfall deficits within both the Alafia and Hillsborough River watersheds were approximately 10 inches during the first eight months of WY 2001. When combined with the preceding year (WY 2000), this resulted in collective rainfall deficits in excess of 20 inches going into the 2001 summer wet season.

Subsequent to this extended dry period, summer 2001 rainfall in both the Alafia and Hillsborough watersheds exceeded recent historic long-term averages. The wet season rainfall, however, was not sufficient to allow groundwater levels and basin surface water discharges to reach normal levels.

Alafia River flows at Bell Shoals (estimated from the Lithia gage) during WY 2001 in relation to the statistical distributions of long-term historical flows (see Figure 8-3) indicate the response of river flows to the very dry conditions that characterized the period extending from October 2000 through June 2001.

For the TBC/Palm River, flows at the structure S-160 gage were well below normal throughout most of WY 2001 (see Figure 8-4); zero flow was recorded at S-160 from mid-November 2000 through June 2001.

Similarly, freshwater flows at the Hillsborough River Dam (see Figure 8-5) were limited to 0.2 cfs throughout the majority of the reporting period, with the only significant flows in August and September 2001.

Water Quality

The objectives for HBMP ambient water quality monitoring elements are to estimate the spatial and temporal distribution and variance of surface water quality indicators within each of the reporting units. Since HBMP elements were designed to address specific characteristics within individual reporting units, different suites of water quality parameters are measured within each unit (see Table 8-2); in addition to salinity, only dissolved oxygen (DO) and chlorophyll-*a* are measured in all units.

As salinity is directly linked to withdrawals and potential biological effects, this is a key indicator for all reporting units. Due to space limitations, only results for bottom salinity and bottom DO, another critical indicator, are presented here. See the WY 2001 Annual Data Report (PBS&J 2002) for complete results.

Water quality samples and measurements are taken once a month in each of the four primary reporting units. Grab samples are typically collected during a two- to three-day period. Hydrolab casts or profiles are performed at each station. Salinity data are also collected at 15-minute intervals at HBMP continuous recorder stations.

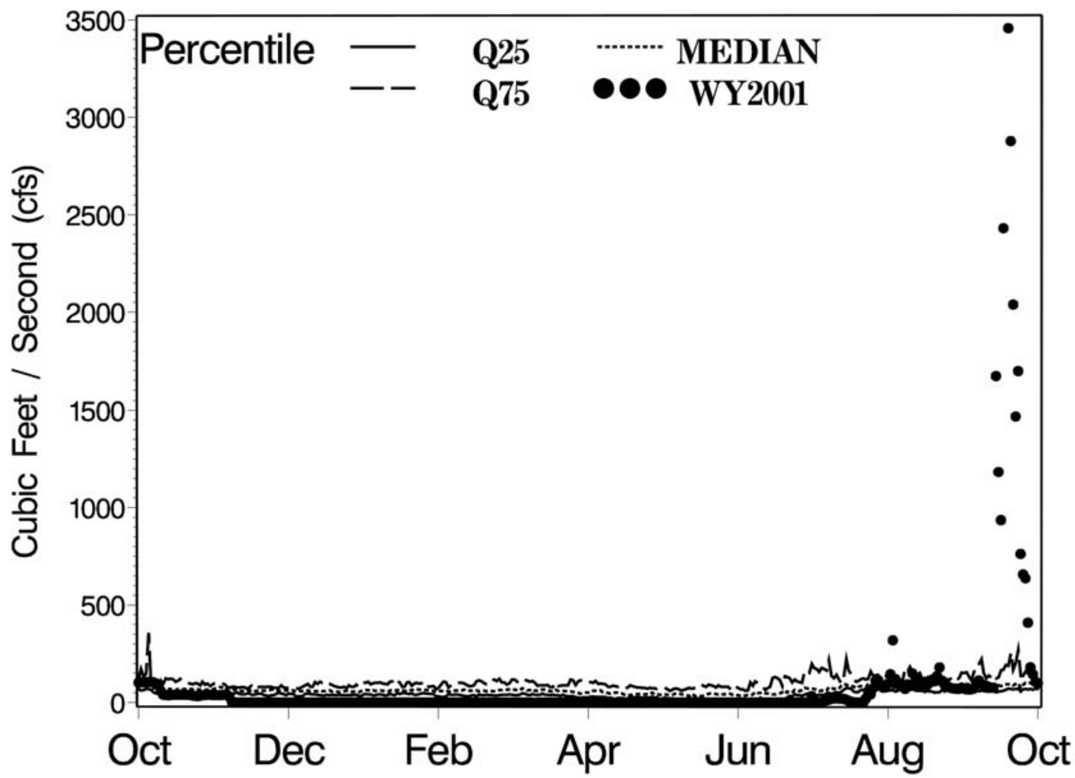

Figure 8-4. Palm River flow (cfs) at S-160 during water year.

Box and whisker plots are provided here to summarize statistical distributions of data for WY 2001: the median (50th percentile) is indicated by a horizontal line within the box; the 25th and 75th percentiles, respectively, form the bottom and top of the box; the whiskers are lines that extend from the 25th percentile to the 10th and 75th percentile to the 90th; and extreme values (outside the 10th and 90th percentiles) are represented by dots at the ends of the whiskers. In addition, data from nearby EPCHC "fixed" Hillsborough Bay sampling sites (stations 8, 55, 71 and 73) are presented for comparison to ambient characteristics outside the rivers.

For the Alafia River (see Figure 8-6), bottom salinities were generally higher than the corresponding surface measurements and exhibited similar overall spatial and seasonal patterns. During the summer wet season, very low bottom salinities were observed downstream to approximately river km (Rkm) 4. It should be noted that during much of WY 2001, elevated bottom salinities extended upstream beyond Rkm 16. This was almost two kilometers further upstream than high salinity waters extended during the preceding year.

For the TBC/Palm River (see Figure 8-7), bottom salinities were higher during Quarter 4 than corresponding surface measurements. Bottom salinities were both higher and exhibited far less seasonal variation in the deep sub-strata, when compared to bottom salinities measured in shallow sub-strata. Overall, bottom salinities in the three Palm River deep sub-strata exhibited spatial and seasonal variation very similar to nearby EPCHC Hillsborough Bay locations.

For the Hillsborough River (see Figure 8-8), bottom salinities were often higher than corresponding surface measurements. During the very dry Quarter 3, near-bottom salinities were as high as 18 ppt at the most upstream stratum (HR6) near the Tampa Dam. However, during Quarter 4, bottom salinities less than 5 ppt were observed extending downstream to near Rkm 4.

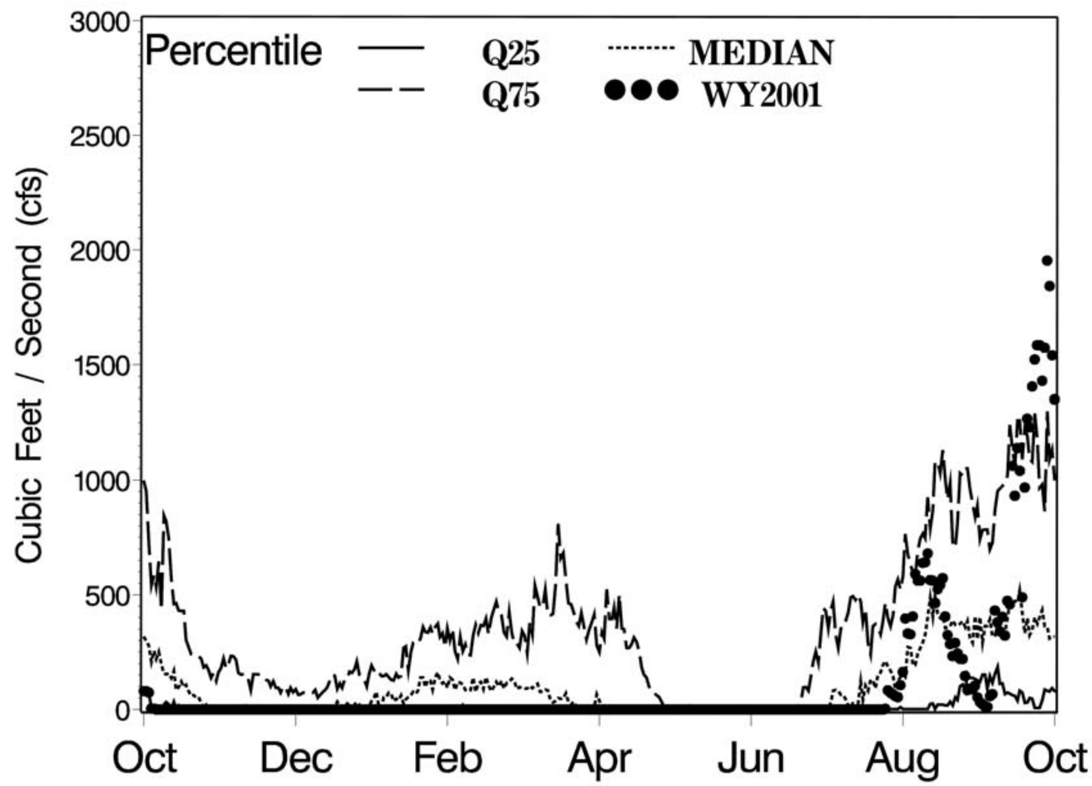

Figure 8-5. Hillsborough River flow (cfs) at Tampa Dam during water year.

Primarily due to density stratification effects that are affected by changes in freshwater flows, DO is another critical HBMP indicator. No estuarine standard has been established by the State of Florida, but the State of Florida marine standard for Class 3 waters (4.0 mg/L) can be used for comparison. It should be noted that portions of many natural systems do not meet this standard throughout the year. A higher standard (5.0 mg/L) has been established for freshwater systems.

For WY 2001, annual average surface concentrations exceeded the standard for Class III estuarine waters of 4.0 mg/L in all the reporting units. However, concentrations below this standard were occasionally observed at the surface in all three reporting units.

Yearly average bottom DO concentrations were below 4.0 mg/L in:

1) stratum AR6 in the Alafia River;
2) all three strata in the Palm River; and
3) strata HR4 through HR6 in the Hillsborough River.

In addition, DO below this standard was frequently observed in the near-bottom waters in all three river reporting units, and occasionally in Hillsborough Bay.

For the Alafia River (see Figure 8-9), bottom DO concentrations were generally above 4.0 mg/L in most upstream Alafia River strata, although from the river's mouth upstream to around Rkm 14, bottom DO was often well below this standard. Not surprisingly, lower bottom DO was observed during Quarter 4 in downstream strata corresponding to both increased stratification and higher water temperatures; in contrast, increased flows and the lack of stratification in the upstream strata resulted in slightly higher bottom DO during this period. The highest near-bottom DO was observed during Quarter 2. Elevated DO measurements in the middle of this reporting unit (AR3 and AR4) reflected seasonal occurrences of high phytoplankton biomass.

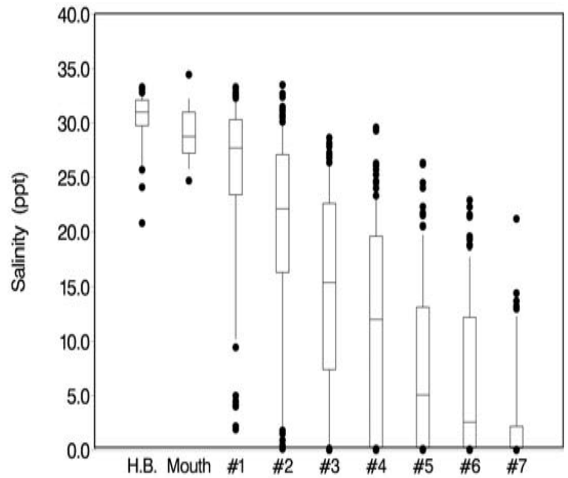

Figure 8-6. Box and whisker plot of bottom salinity along the Alafia River (AR1-AR7) and Hillsborough Bay.

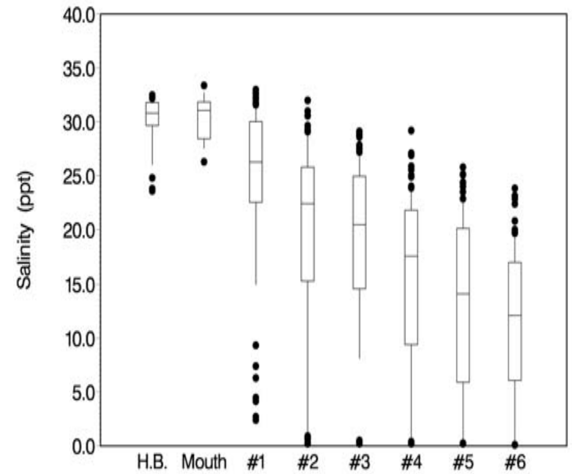

Figure 8-8. Box and whisker plot of bottom salinity along the Hillsborough River (HR1-HR6) and Hillsborough Bay.

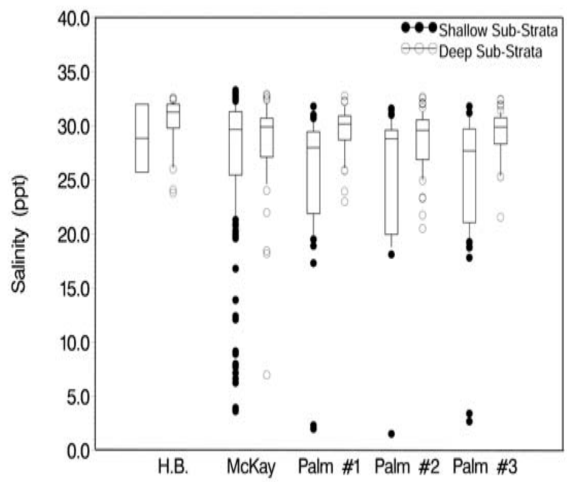

Figure 8-7. Box and whisker plot of bottom salinity along McKay Bay/Palm River (PR1-PR3) and Hillsborough Bay.

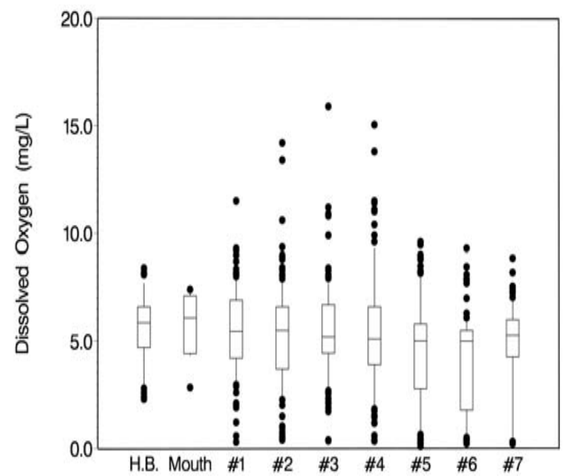

Figure 8-9. Box and whisker plot of bottom dissolved oxygen along the Alafia River (AR1-AR7) and Hillsborough Bay.

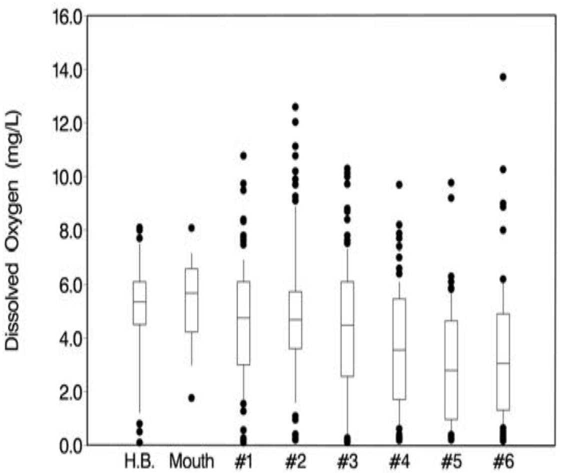

Figure 8-10. Box and whisker plot of bottom dissolved oxygen along McKay Bay/Palm River (PR1-PR3) and Hillsborough Bay.

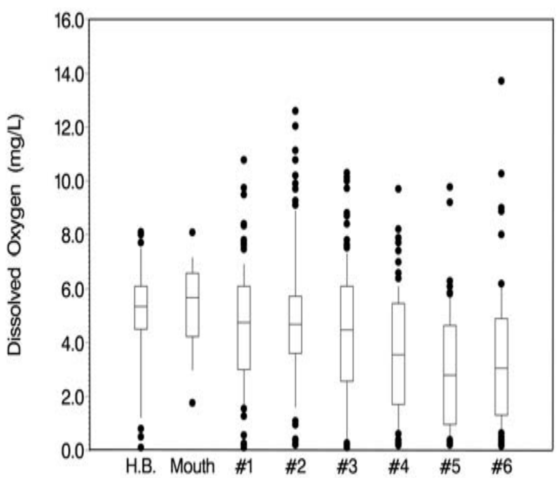

Figure 8-11. Box and whisker plot of bottom dissolved oxygen along the Hillsborough River (HR1-HR6) and Hillsborough Bay.

For the TBC/Palm River system (see Figure 8-10), bottom DO was generally above 4.0 mg/L in the shallow sub-strata of McKay Bay and the first two Palm River strata. Bottom DO in the deep sub-strata in McKay Bay, and all three Palm River strata, was often well below 4.0 mg/L. In all of the Palm River deep strata, bottom DO averaged less than 4.0 mg/L and 1.0 mg/L during Quarters 3 and 4, respectively. In this system, occurrences of very low DO were far more frequent during Quarter 4, resulting from increased freshwater inflows and resultant stratification.

For the Hillsborough River (see Figure 8-11), bottom DO was generally lower than corresponding surface measurements, and a large portion of measurements within the six strata were below 4.0 mg/L. By comparison, bottom DO was usually above this standard at EPCHC Hillsborough Bay sites and the HBMP river mouth station. During the first three quarters of WY 2001, there was a general pattern of declining near-bottom DO progressing upstream. However, the lowest DO measurements (less than 0.5 mg/L) were observed in the most downstream strata (HR1-3) during Quarter 4 periods of highest freshwater flow.

Benthos

Primary objectives for this monitoring element are to document existing conditions and relationships between freshwater inflows and benthic invertebrate abundance, composition and distribution.

Benthic macroinvertebrate samples are collected once a month in each of the four reporting units using a 0.04 m^2, Young-modified VanVeen grab-sampler. Sampling is typically conducted over a three- to four-day period. Hydrolab profiles and Secchi depth measurements are also collected at each station. Sediment samples are taken in conjunction with benthos samples in order to characterize substrate; these samples are analyzed for percent fines and organic content. Sampling intensity (number of samples and/or frequency of events depending on reporting unit) is higher during the summer wet season. In accordance with the HBMP sampling design, some benthic samples are archived for future analysis if needed (see PBS&J 2002a).

Indicators used to evaluate potential biological effects of changes in freshwater flows include number of organisms, number of taxa, and two statistics that describe the average position of occurrence for a given taxon over the sampling time period: the center of abundance (COA) and center of frequency (COF). More detailed HBMP interpretative reports for Years 3 (July 2003) and 5 (July 2005) will include additional metrics and analyses.

For example, numbers of organisms and taxa in the Alafia River, McKay Bay, and the Palm River during WY 2001 (Figures 8-12 and 8-13) illustrate differences within and between these systems.

In Quarters 1 and 4, and overall, McKay Bay had by far the greatest density of benthic organisms and number of taxa per sample. By comparison, the density of benthic organisms in the Palm River was one to two orders of magnitude less, with deep strata samples often having few or no organisms.

In Quarters 2 and 3, the highest densities were observed in the Alafia River, with average densities in lower strata similar to those observed in McKay Bay. The density of benthic organisms in the Palm River during this period was again low; densities in the Hillsborough River were greater than in the Palm River system, and less than in the Alafia River. The lowest densities of organisms were observed in samples from the upper Alafia River strata (see summary in Figure 8-14).

For the Alafia River, the most frequent and/or numerous benthic organisms collected were amphipods (*Ampelisca cf. abdita* and *Grandidierella bonnieroides),* bivalves (*Mulinia lateralis* and *Mytilopsis leucophaeta*), a polychaete (*Streblospio benedict)*, and a brachiopod (*Glottidea pyramidata).* Amphipods accounted for over 50% of the individuals collected.

For the Hillsborough River, the most numerous benthic organisms were amphipods (*A. abdita* and *G. bonnieroides)* and polychaetes (*Steninonereis martini*, *Laeonereis culveri*, *S. benedicti*, *Capitella capitata*, and *Monticellina dorsobranchialis)*. The average number of organisms and taxa per sample was highest in HR2 and HR3, and HR1 and HR2, respectively. The average number of organisms and taxa per sample was lowest in HR5 and HR6.

For the TBC/Palm River, the most numerous benthic organisms were amphipods (*A. abdita*, *A.. holmesi*, and *Melita nitida complex),* bivalves (*M. lateralis* and *Mactra fragilis)*, and a polychaete (*S. benedicti).*

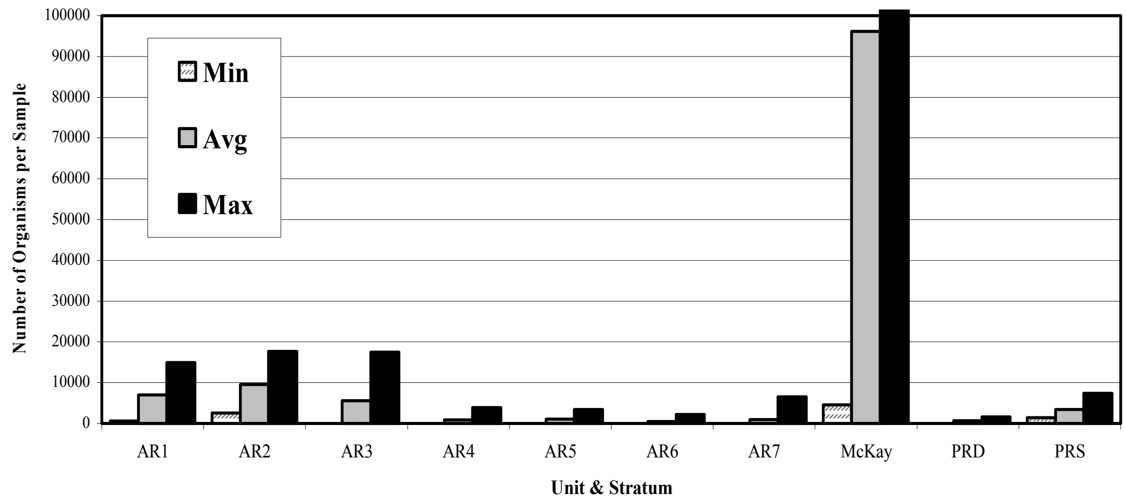

Figure 8-12. Number of organisms per sample in three reporting units during WY 2001 (PRD – Palm River Deep; PRS – Palm River Shallow).

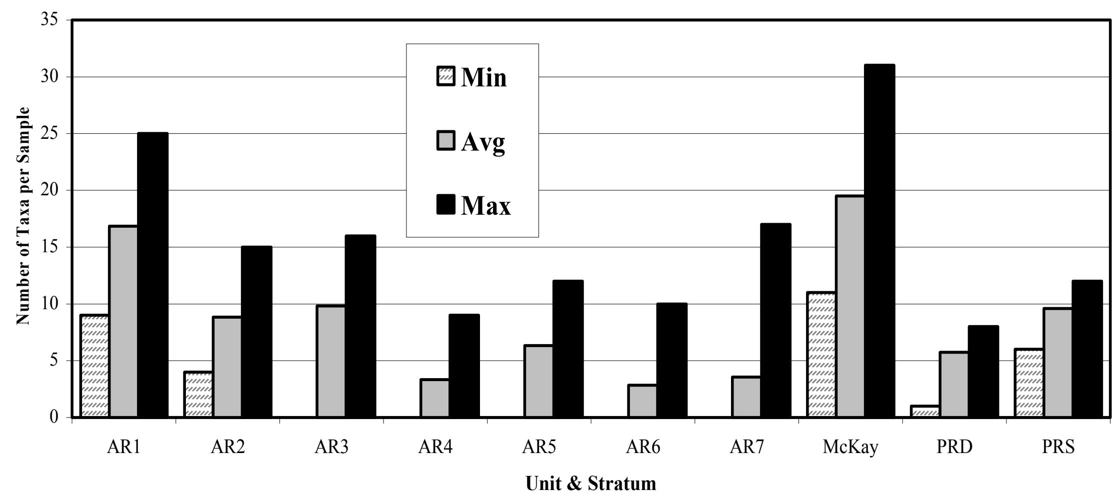

Figure 8-13. Number of taxa per sample in three reporting units during WY 2001 (PRD – Palm River Deep; PRS – Palm River Shallow).

For McKay Bay, the five most numerous taxa included amphipods (*Corophium* sp., *A. abdita*, *A. holmesi*, *G. bonnieroides),* and a polychaete (*S. benedicti)*. These species accounted for 69% of all organisms collected. Other abundant species included the amphipods *Acuminodeutopus naglei* and *Hargeria repax*. The taxa that occurred in the most samples were the polychaetes *Glycinde solitaria*, *Paraprionospio pinnata*, and *Podarkeopsis levifuscina*; the amphipod *A. holmesi*; and *Nemertea* sp.

Many of the most abundant organisms were also those that exhibited the greatest change across quarters; this pattern could simply reflect clumped distributions of the species. The species showing the smallest change in AWS and FWS across quarters were generally restricted to low salinities or fresh water; insects were frequently in this category.

In WY 2001, several samples collected in the upstream strata of both the Alafia and Hillsborough rivers contained no organisms. This likely reflected substrate conditions where only a thin veneer of unconsolidated sediment or detritus was present overlying lime rock. This condition was not observed in either the Palm River or McKay Bay.

For percent fines, the highest annual averages in both the Alafia and Hillsborough river systems occurred in Strata 3 through 5. This pattern may result from the flocculation of fine materials that typically occurs when freshwater mixes with saltwater. Similarly, very high levels of fine sediments characterized the deep sediments in the first two strata of the Palm River. The highest

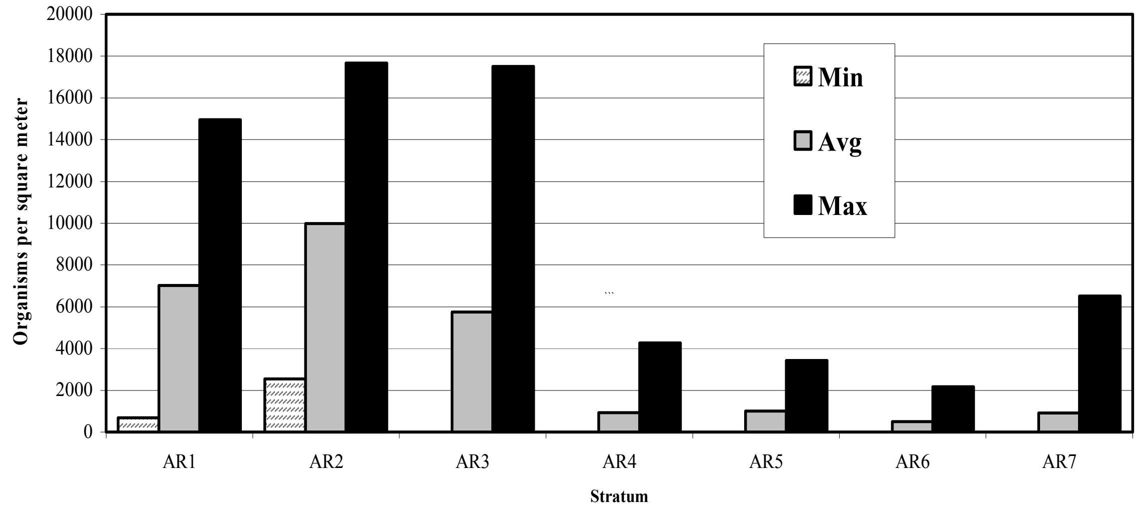

Figure 8-14. Number of benthic macroinvertebrates/m^2 in the Alafia River during WY 2001.

percent organic content was found in the Alafia system in AR4 (which coincides with the observed area of high phytoplankton biomass) and the middle strata in the Hillsborough River.

Plankton

The primary objective of this HBMP element is to develop comprehensive, long-term measurements of ichthyoplankton and invertebrate zooplankton species composition, abundance, and distribution within each of the HBMP reporting units. This work is being conducted by Dr. Ernst Peebles and his research staff at the University of South Florida. Information in this section was excerpted from the WY 2001 Annual report and the HBMP QA/QC Plan (PBS&J 2002 a,b).

Distribution patterns for ichthyoplankton (fish eggs, larvae, and small juveniles) reflect local fish spawning activity and also the ingression of larvae and juveniles into inshore nursery habitats from more distant spawning locations. Ingression may result from passive transport, active migration, or a combination of these processes. Freshwater inflows influence spawning activity, larval transport mechanisms, and the distribution of larvae and juveniles within estuarine nursery habitats. Some fish species prefer structured, stationary habitats (e.g., mangrove roots, seagrasses, marsh edges) and exhibit relatively small distributional responses to inflow variation, whereas others, particularly those that occupy unstructured channel areas, shift position readily as inflows vary.

With the exception of the egg stage, ichthyoplankton are fairly motile and can actively seek water masses that provide conditions more conducive to survival (e.g., salinity ranges, algal blooms). Salinity is considered to be a major environmental factor determining the spatial distribution of ichthyoplankton, and for the more advanced life stages (e.g., postflexion larvae, juveniles, etc.), the AWS can generally be viewed as an optimal salinity range for a given taxa.

Although salinity is an important environmental factor determining spatial distribution, invertebrate zooplankton are generally less motile than ichthyoplankton and are less able to actively seek optimal conditions (e.g., salinity ranges that are physiologically beneficial or that concentrate preferred prey items). Rather, the reproductive cycles of zooplankters tend to be on much shorter timescales than ichthyoplankters, allowing a population to maintain a position within an optimal salinity regime through rapid reproduction.

HBMP plankton collections are made monthly in each reporting unit. Dates of sampling are chosen to correspond with the occurrence of night-time flood tides. The sampled locations within each reporting unit were selected using a one-time stratified-random approach. Large numbers of invertebrate zooplankton are also collected during ichthyoplankton monitoring.

Diet studies have shown that many of these organisms serve as important prey for the young fishes that occupy estuarine nursery habitats. The distributions and numbers of these prey groups may also change in response to freshwater inflow variation. Distributional shifts, in turn, may cause prey to be centered upstream or downstream of the fishes' preferred habitat, particularly with species that are strongly associated with stationary habitats. USF researchers are using HBMP plankton and fish data (see next section) with regression models to estimate the spatial overlap between predator and prey as a function of either freshwater inflow or surrogate parameters such as isohaline position.

For WY 2001, a comparison of overall ichthyoplankton and zooplankton richness and abundance (see Figure 8-15) shows that:

- Ichthyoplankton species richness was similar in the Alafia and Hillsborough Rivers, and lower in the Palm River/McKay Bay unit (combined for simplicity, although richness and abundance were much higher in McKay Bay);

- Zooplankton species richness was similar in the Hillsborough River and Palm River/McKay Bay units, and slightly higher in the Alafia River; and

- Ichthyoplankton- and zooplankton abundance were highest in the Palm River/McKay Bay unit and lowest in the Hillsborough River, with the Alafia River in between.

In general, greater seasonal downstream shifts in COA were observed for the most abundant planktonic organisms in the Alafia River reporting unit during Quarter 4 compared to the Hillsborough River and Palm River/McKay Bay reporting units even though freshwater flow in all three reporting units increased substantially in Quarter 4. Results are summarized briefly below for the Alafia River only due to space limitations; see the WY 2001 Annual Data Report for additional information.

For the Alafia River in WY 2001, the ten most abundant ichthyoplankton taxa included species in the family Engraulidae (anchovies), Gobiidae (gobies), and Clupeidae (herrings and menhaden). Percomorph fish eggs (primarily of the family Sciaenidae (drum)) were also abundant. These taxa were also among the most frequently collected.

AWS values for the ten most frequently collected ichthyoplankton taxa were greater than 20 ppt., with the exception of *Anchoa mitchilli* juveniles and adults (17.1 ppt and 13.3 ppt, respectively). The five most frequently collected ichthyoplankton taxa all showed a downstream displacement in COA during Quarter 4 (see Figure 8-16). This shift in COA was likely due to increased freshwater flow resulting in downstream advective transport, and/or a downstream shift in isohalines combined with ichthyoplankton motility to maintain a desired salinity range.

Zooplankton collected in the Alafia River in WY 2001 were represented by a wide variety of taxa, with crustaceans (primarily decapod zoeae) being most abundant. AWS values for the ten most frequently collected zooplankton taxa were greater than 20 ppt. Four out of the five most abundant zooplankton taxa showed a downstream displacement in COA during Quarter 4 (see Figure 8-17). This shift in COA was most likely due to downstream advective transport resulting from the substantial increase in flow during Quarter 4.

Fish

The primary objective of this HBMP element is to develop comprehensive, long-term measurements of species composition, abundance, and distribution of adult and juvenile fishes within each of the reporting units. This work is being conducted by the Fisheries Independent Monitoring section of the FMRI under the direction of T. MacDonald.

Sampling is conducted on a monthly basis on randomly selected dates; data are reported on a quarterly basis. Each of the rivers has been subdivided into relatively equal length strata, ensuring that the entire salinity gradient is sampled each month. An octagonal grid system was used to stratify sampling sites for McKay Bay. Within each stratum, two 21-m seines and one 6.1-m otter trawl samples are collected.

Most of the animals traditionally sampled by the FMRI's Fisheries Independent Monitoring Program (FIMP) are included in this effort: all fishes, blue crabs, stone crabs, horseshoe crabs, and penaeid shrimp. Fish data are collected using two different types of gear: seine nets and trawl nets. Seine nets are deployed by hand in shallow areas, typically along a shoreline, and tend to collect primarily juvenile and adults of smaller species. Trawl nets are deployed from a boat in deeper areas, typically in channels and deeper open water, and tend to collect adults of larger species. Between the two gear types, the entire ichthyofauna in a given area can be sampled across various size classes and habitat types. Hydrolab profile and Secchi depth measurements are also performed at each station.

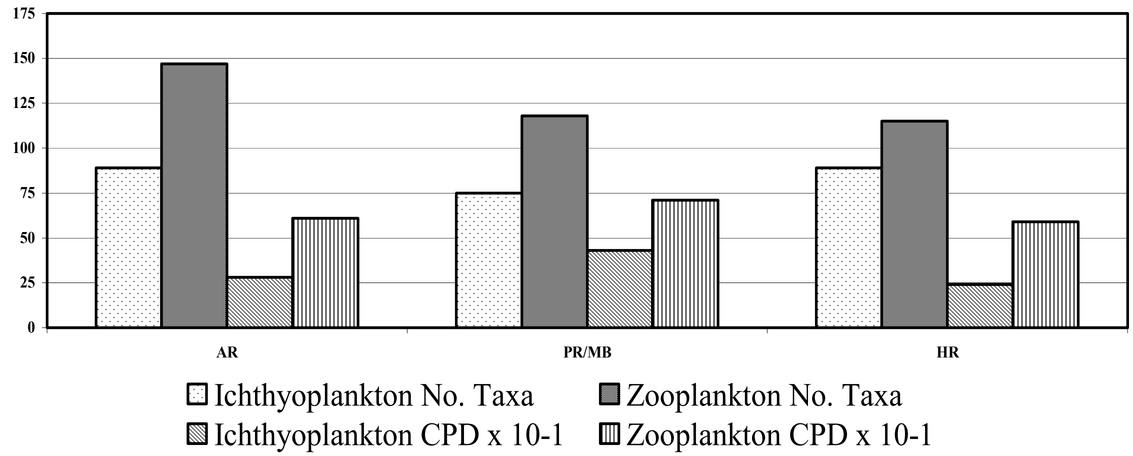

Figure 8-15. Plankton species richness and abundance.

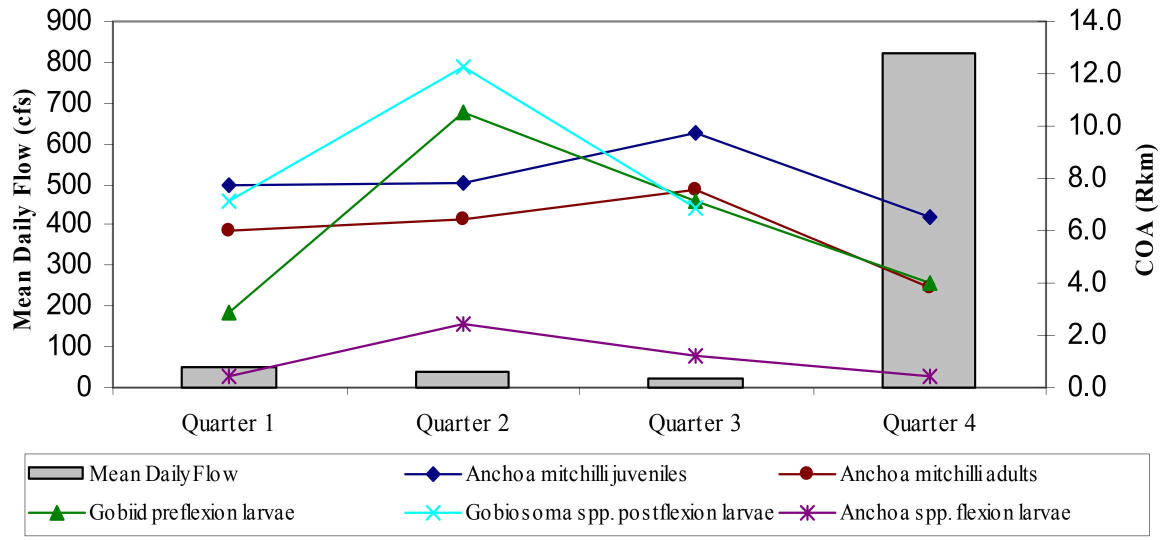

Figure 8-16. Quarterly change in ichthyoplankton COA in the Alafia River.

Most estuarine-dependent fishes found along the coasts of the Gulf of Mexico and South Atlantic exhibit a catadromous life history pattern. As juvenile fishes are very motile and far less likely than plankton to be transported downstream by advective processes, and also actively seek habitat types (e.g., bottom type and vegetative cover) and preferred food sources (e.g., zooplankton and benthic invertebrates), shifts in COA may reflect more of a behavioral response that direct response to environmental factors. In other words, the distribution of juvenile fishes along a salinity gradient is typically determined more by the distribution of prey than by salinity itself. As juveniles mature into adults, their distribution tends to shift towards deep water areas with higher salinity.

A comparison of the species richness (e.g., total number of taxa collected) and abundance (e.g., total number of organisms collected per deployment) for WY 2001 data collected by seine and trawl (see Figure 8-18) shows both seine and trawl species richness greatest in the Alafia River, and least in the Hillsborough River, with the combined Palm River/McKay Bay reporting unit falling in between. Species richness and abundance for both seine and trawl fish were much greater in the McKay Bay reporting unit than in the TBC/Palm River reporting unit

For seine fish abundance, the combined Palm River/McKay Bay and Hillsborough River reporting units were comparable. The Alafia River showed less seine fish abundance, an unexpected observation given the increased riparian habitat in this system.

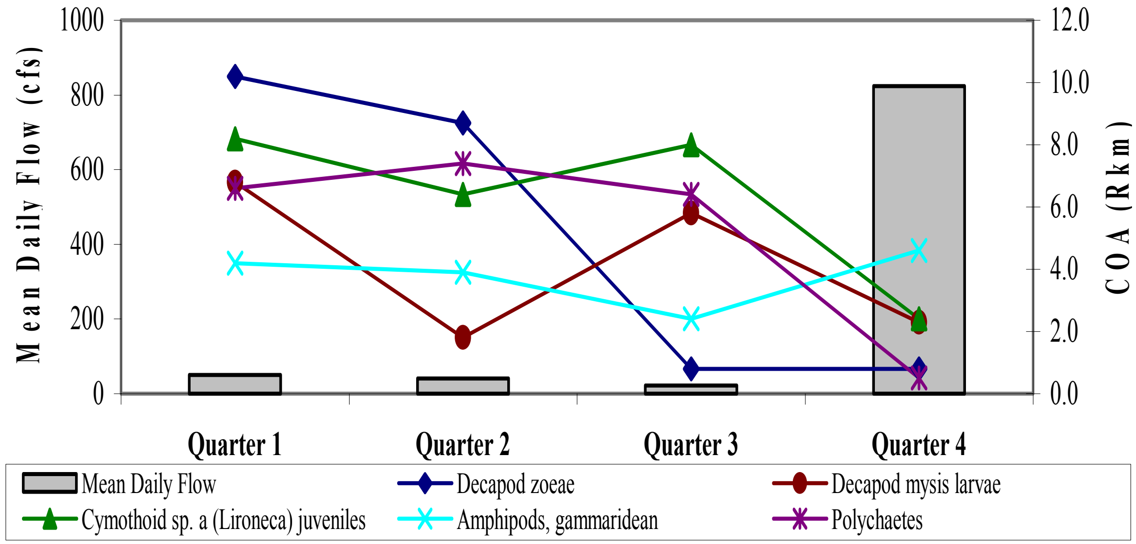

Figure 8-17. Quarterly change in zooplankton COA in the Alafia River.

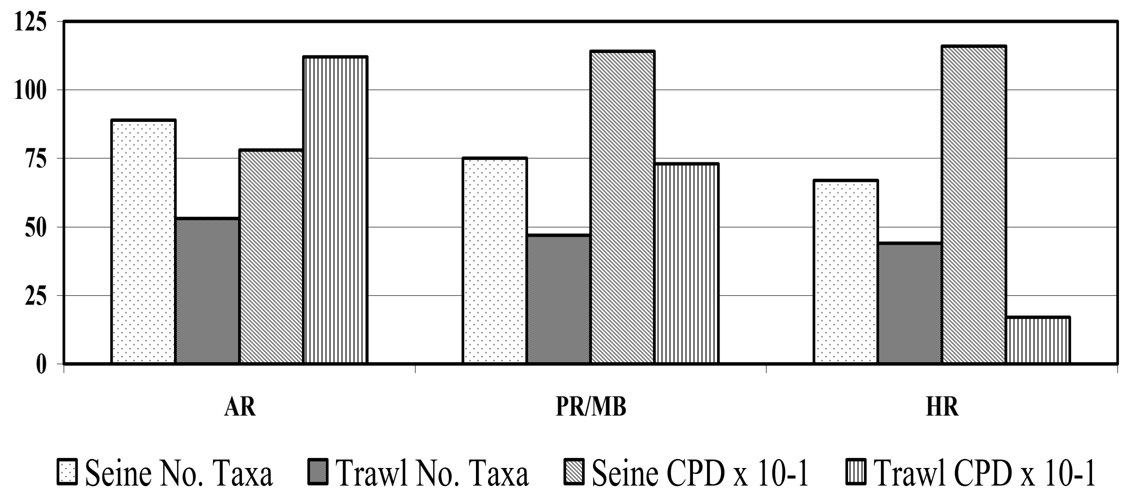

Figure 8-18. Fish species richness and abundance.

Trawl fish abundance was greatest in the Alafia River, and least in the Hillsborough River, with the combined Palm River/McKay Bay reporting unit falling in between. The seine abundance results and inconsistency with trawl data may be an artifact of sampling technique and/or random site selection for this particular year.

The most frequently collected and most abundant fish taxa in all reporting units were various life stages of the genus *Anchoa*, with the ubiquitous bay anchovy (*Anchoa mitchilli*) being the predominant species. A simple AWS comparison was performed to determine if various life stages of *A. mitchilli* were differentially utilizing habitats within reporting units. Based on this comparison, *A. mitchilli* postlarvae were most common at higher salinities and juveniles and adults were found at progressively lower salinities in both the combined Palm River/McKay Bay unit and the Hillsborough River, juveniles were found to be more abundant at lower salinities than adults in the Alafia River, and AWS for all life stages of *A. mitchilli* were highest in the combined Palm River/McKay Bay unit.

For the Alafia River in WY 2001, the most abundant ichthyofaunal taxa were *A. mitchilli, Menidia* spp. (silversides), followed by a crustacean *Palaeomonetes pugio* (grass shrimp). Other bony fishes included the sciaenid *Leiostomus xanthurus* (spot) and the sparid *Lagodon rhomboids* (pinfish). The most frequently collected species included *Menidia* spp., the gobiid *Microgobius gulosus* (clown goby), *A. mitchilli*, *P. pugio*, and the cyprinodontid *Lucania parva* (rainwater killifish).

AWS for the ten most frequent seine fish taxa collected in the Alafia River ranged from about 10 ppt to 22 ppt. The soleid *Trinectes maculatus* (hogchoker) exhibited the greatest affinity for oligohaline conditions with an AWS of 9.9 ppt. Changes in COA for seine fish species (See Figure 8-19) show a Quarter 4 downstream shift for three of the five most abundant seine fish taxa (*Menidia* spp., *Microgobious gulosus,* and *Palaeomonetes pugio*). In contrast, *A. mitchilli* and *L. parva* exhibited an upstream COA shift during this same period.

For WY 2001, the most abundant trawl fish species in the Alafia River were *A. mitchilli* and *L. xanthurus.* Unlike the seine samples, however, other abundant species included the scaenid *Cynoscion arenarious* (sand seatrout), *L. rhomboides* and *T. maculates*s. Additional abundant taxa included adult blue crabs (*Callinectes sapidus*) and pink shrimp (*Farfantepenaeus duorarum*).

AWS for the ten most frequently collected trawl fish species ranged from about 13 ppt to 30 ppt, which is notably higher than the salinity range observed for the most abundant juvenile fishes collected by seine net.

Changes in COA for trawl fish species (see Figure 8-20) show that none of the five most abundant trawl taxa showed a Quarter 4 downstream displacement in response to higher flows, whereas two taxa (*C. arenarius* and *C. sapidus*) showed a slight upstream shift during this period. This reflects the increased ability of adult fishes to swim against advective currents and control their horizontal distribution. As such, their distribution is likely determined more by the location of a preferred habitat or prey rather than by a physiological need to maintain their distribution within a certain salinity range.

Birds

HBMP bird surveys are conducted for water-dependent bird species in three areas: 1) the Alafia Banks; 2) "the Ponds" adjacent to the Palm River; and 3) the northeastern arm of McKay Bay. These areas have rough geographic correspondence to the respective reporting units, but none are located within a reporting unit.

Surveys are conducted at extreme high and low tides (as dictated by time of day), on four mornings and two afternoons every other month (six times per year). Point surveys are conducted from four stations at the Alafia Banks, four stations at the Ponds, and two stations at upper McKay Bay.

In WY 2001, 5,319 birds were recorded from the Alafia Banks, representing 49 different bird taxa; 502 birds representing 30 different taxa were observed at the Palm River ponds; and 4,262 individual birds representing 42 different taxa were observed at the north McKay Bay mudflats.

Vegetation/Habitat

The HBMP vegetation monitoring element includes:

- aerial photograph interpretation to estimate total cover of vegetation types

- shoreline surveys to estimate areal extent and upstream/downstream limits of emergent aquatic vegetation communities, and
- quantitative techniques (e.g., plots) to estimate species composition and abundance of emergent/submerged aquatic vegetation within marine to brackish and brackish to freshwater transition zones (Alafia River only).

Additional monitoring activities for the habitat element include evaluation of substrate in all reporting units (summarized in the benthos section above) and interstitial salinities in the Alafia River only (see PBSJ 2002a).

Vegetation mapping and monitoring are performed in the late summer and fall of each year (September through December). Vegetation is mapped in four reporting units: 1) the Alafia River; 2) McKay Bay; 3) the Palm River/TBC; and 4) the Hillsborough River. Vegetation cover and species composition is monitored at fixed stations on the Alafia River.

The Alafia River and McKay Bay reporting units have the largest areas of emergent vegetation at 400 and 551 hectares (ha) respectively. The largest single vegetation association within these two units and the Palm River is mangrove swamp. The Alafia River has 148 ha, McKay Bay has 491 ha, and the Palm River has 63 ha of mangrove swamp. The Alafia also has 126 ha of needlerush monocultures, and about 200 ha combined for needlerush monocultures and mixed stands of needlerush, leather fern, small mangroves, and/or cattails. Cattails comprise the largest vegetation association by area along the Hillsborough River.

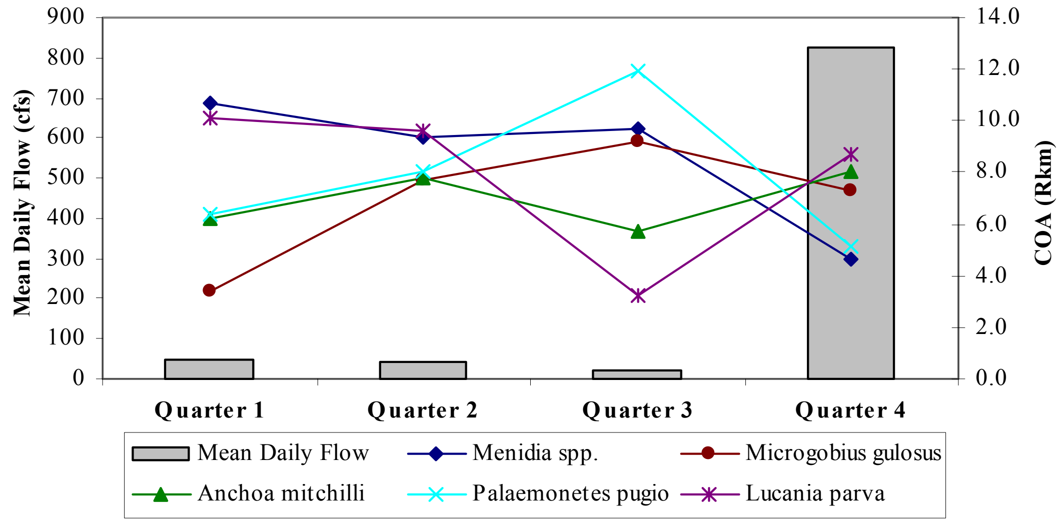

Figure 8-19. Quarterly change in seine fish COA in the Alafia River.

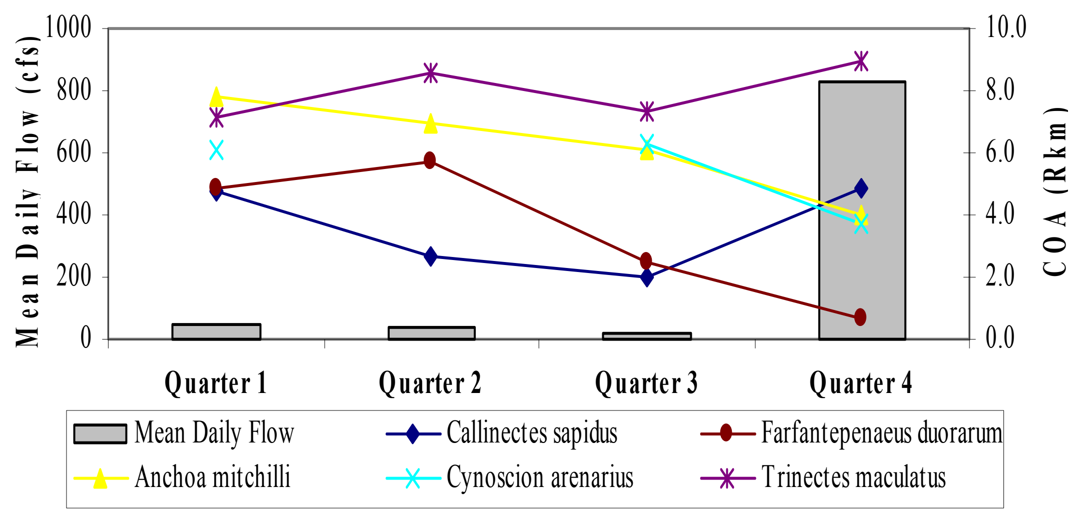

Figure 8-20. Quarterly change in trawl fish COA in the Alafia River.

The relatively small total areas of emergent vegetation on the Hillsborough River reflect both the river's hardened and urbanized shoreline in general, and particularly its urbanized shoreline near the mouth. The largest areas of vegetation on the Alafia and Palm Rivers are located near the mouths of these rivers. The mouth of the Hillsborough River is urbanized with extensive sea walls. As such, the Hillsborough River lacks the extensive mangrove swamps and needlerush marshes that are present along the Alafia River.

FUTURE ACTIVITIES

The HBMP will continue for the duration of the water use permits for the associated surface water withdrawal projects. More detailed evaluation to further understanding of hydrologic and biologic conditions in each of the surface water systems will be performed as the HBMP database expands. The first interpretative report covering data through September 2002 will be completed in mid-2003. As initiation of withdrawals is scheduled for late 2002, this report will cover pre-operational baseline conditions. The second interpretative report covering pre- and post-operational conditions through September 2004 will be completed in mid-2005.

The HBMP is important not only because it helps to ensure that these withdrawal projects will not have significant adverse impacts, but also because the comprehensive nature of the program contributes to an understanding of the importance of freshwater inflows and effects associated with changes to flow regimes. HBMP data are also being used for minimum flow and level (MFL) studies being conducted by the SWFWMD and research investigations conducted by USF. Data will also be used in conjunction with ambient monitoring efforts by other local agencies, and will likely be used for evaluations of other system stressors such as total maximum daily loads (TMDLs).

Another Master Water Plan project, the Tampa Bay Seawater Desalination facility, is expected to be operational in early 2003. This reverse osmosis (RO) facility is located adjacent to the TECO Big Bend facility, and will withdraw a portion of the power plant cooling water for treatment and potable use. The withdrawal of cooling water for RO treatment results in a concentrate (concentrated minerals naturally occurring in Hillsborough Bay water) that is then re-diluted with cooling water prior to discharge. Monitoring activities required under the NPDES discharge permit issued by the Florida Department of Environmental Protection (FDEP) for this project include collection of water quality and benthic invertebrate samples, and evaluation of seagrass, fish, and marine mammal data currently collected by other agencies. These and other Hillsborough Bay monitoring activities will be coordinated and integrated with the HBMP where possible.

The water use permits also require incorporation of withdrawals into Tampa Bay Water's Optimized Regional Operations Plan (OROP). The OROP system was originally developed to manage groundwater withdrawals, and incorporates predictive and optimization models to maximize production and raw water quality while minimizing environmental impacts. For the surface water projects, although water use permit conditions specify withdrawal rates that vary with available flows, the inclusion of specific indicators as OROP constraints (i.e., salinity change) was recommended during development of the HBMP. In WY 2001, historical water quality data and biological data were evaluated for initial identification of OROP salinity monitoring sites.

In addition to the above, studies currently being conducted by the SWFWMD and USF are examining relationships between freshwater inflows and water quality and biological conditions, and improvements to predictive models based on monitoring results. The findings of these studies will be incorporated in future evaluations of potential changes and refinement of the HBMP.

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David A. Tomasko (Southwest Florida Water Management District)

-CHAPTER HIGHLIGHTS-

- *In Tampa Bay, recent increases in seagrass coverage have been linked to improved water quality. Improvements in water quality are due mostly to reductions in phytoplankton levels, which, in turn, have been linked to reductions in anthropogenic nitrogen loads.*

- *Seagrass mapping efforts have played an important role in gauging the success, or lack thereof, toward maintaining and expanding on improvements to water quality in Tampa Bay and other estuaries.*

- *In 1950, it was estimated that seagrass meadows covered 40,400 acres of bay bottom. By 1982, that number had dropped to 21,653 acres. From 1982 to 1996, acreage increased to 26,916 acres. From 1988 to 1996, the average rate of increase was 454 acres per year, from 23,285 to 26,916. From 1996 to 1999, an 8 percent decline occurred, down to 24,841 acres. Seagrass coverage in Tampa Bay in 1999 was 61 percent of that of 1950.*

INTRODUCTION

In Tampa Bay, recent increases in seagrass coverage have been linked to improved water quality. Improvements in water quality are due mostly to reductions in phytoplankton levels, which, 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 mapping efforts have played an important role in gauging the success, or lack thereof, toward maintaining and expanding on improvements to water quality in Tampa Bay and other estuaries. For the past several years, these mapping efforts have been conducted on a roughly biennial basis by the Southwest Florida Water Management District (District).

To conduct these seagrass mapping efforts, the District puts out a Request for Proposals for consultants to conduct aerial photography, groundtruthing, photointerpretation, and GIS-based analysis. In 1999, the successful respondent was Agra-Baymont, Inc. A post map-production classification accuracy assessment (described below) is conducted by District staff.

MATERIALS AND METHODS

Seagrass maps have been produced for the District for the years 1988, 1990, 1992, 1994, and 1996. Previous efforts have been conducted for the years of 1950 (Tampa Bay Regional Planning Council, 1986) and 1982 (Haddad, 1989). For the years 1988, 1990, 1992, 1994, 1996, and 1999, seagrass maps are produced through a multiple step process. First, aerial photography is obtained, usually in the late fall to early winter. This time of year is associated with both good water clarity and relatively high seagrass biomass. Photography is true color at a scale of 1:24,000. On the day that photography is to be obtained, Secchi disk depths must be at least two meters for each estuary flown, wave height must be less than two feet, and wind speed must be less than 10 miles an hour. Other restrictions include sun angle, which must be greater than 35%, and cloud cover and/or haze must not interfere with the quality of the photography.

Second, photointerpretation efforts are conducted in the field, to allow for the successful evaluation of distinct photographic signatures. Seagrass signatures are divided into two classes: continuous coverage (<25% unvegetated bottom visible within a polygon) and patchy coverage (>25% unvegetated bottom visible within a polygon), with a minimum mapping unit of 0.5 acres.

Third, polygons are integrated into an ARC/Info program. For past efforts, individual polygons were delineated on mylar overlays, cartographically transferred using a Zoom Transfer Scope to USGS quadrangles, and then digitally transferred to an ARC/Info data base for further characterization. These techniques allowed for the seagrass maps to meet USGS National Map Accuracy Standards for 1:24,000 scale maps. For 1999 seagrass maps, a 1:12,000 National Map Accuracy Standard was met. While photography remained at a scale of 1:24,000, the higher positional accuracy standard required the use of tighter ground control and more sophisticated mapping techniques. Analytical stereo plotters were used for photointerpretation, as opposed to stereoscopes. This technique allowed for the production of a georeferenced digital file of the photointerpreted images, without the need for additional photo-to-map transfer.

Fourth, hard copy plots were made of photointerpreted seagrass coverage, and sixty (60) randomly chosen points were identified for a post map-production classification accuracy assessment. A hand-held Global Positioning System was used, along with the map and the latitude and longitude of the randomly located stations, to develop an unbiased determination of the map's classification accuracy. A 90% classification accuracy standard is required in the

Table 9-1. Acreage totals of seagrass coverage in Tampa Bay. For this table, HB = Hillsborough Bay, OTB = Old Tampa Bay, MTB = Middle Tampa Bay, LTB = Lower Tampa Bay, BCB = Boca Ciega Bay, TCB = Terra Ceia Bay and MR = Manatee River.

	1950	1982	1988	1990	1992	1994	1996	1999
HB	2,300	0	7	47	46	147	193	192
OTB	10700	5943	5006	5561	5877	5911	5763	4395
MTB	9600	4042	5205	5307	5270	5775	5541	5639
LTB	6100	5016	5515	6143	6242	6205	6381	5847
BCB	10800	5770	6258	6805	6952	7116	7699	7464
TCB	700	751	947	1000	1003	999	973	929
MR	200	131	347	363	363	365	366	375
TOTAL	40400	21653	23285	25225	25753	26519	26916	24841

consultant’s contract, and a 96% accuracy was achieved for 1999 efforts (i.e., 53 of 55 stations that could be visited were accurately described).

RESULTS

In 1950, it was estimated that seagrass meadows covered 40,400 acres of bay bottom. By 1982, that number had dropped to 21,653 acres. From 1982 to 1996, acreage increased by 5,262 acres, up to 26,916 acres. The average rate of increase between 1982 and 1996 was 376 acres per year. From 1988 to 1996, the average rate of increase was 454 acres per year, from 23,285 to 26,916. From 1996 to 1999, a decrease in coverage of 2,074 acres was found (8 percent decline), down to 24,841 acres. Seagrass coverage in Tampa Bay in 1999 was 61 percent of 1950 estimates.

Trends in seagrass coverage varied among different bay segments. Employing the segmentation scheme used by the Tampa Bay Estuary Program (first proposed by Lewis and Whitman, 1985) the bay can be divided into seven segments. Based on this segmentation scheme, various patterns of seagrass coverage can be detected. In Hillsborough Bay, seagrass coverage is estimated to have dropped from 2,300 acres in 1950 to a complete absence in 1982. However, these acreage estimates do not include coverage associated with meadows of *Ruppia maritima*, whose abundance is rather ephemeral in much of the bay (Roger Johansson, personal communication). Also, acreage estimates conducted in Hillsborough Bay by the City of Tampa's Bay Study Group are probably more accurate than District estimates, as they are from a finer scale assessment, made possible by the smaller area of interest. In 1999, coverage was estimated at 192 acres, a rate of increase of 11 acres per year between 1982 and 1999. Seagrass coverage in Hillsborough Bay in 1999 was 8 percent of 1950 estimates, and less than 1 percent of present bay-wide coverage estimates.

In Old Tampa Bay, seagrass coverage declined from an estimated 10,700 acres in 1950 to 5,006 acres in 1988. Over 1988-1994, acreage increased at a rate of 151 acres per year, to 5,911 acres. From 1994 to 1996, acreage decreased to 5,763 (74 acre per year decline). From 1996 to 1999, acreage decreased to 4,395, a rate of decline of 456 acres per year. Seagrass coverage in Old Tampa Bay in 1999 is 41 percent of 1950 estimates, and 18 percent of present bay-wide coverage estimates.

In Middle Tampa Bay, seagrass coverage declined from 9,600 acres in 1950 to 4,042 acres in 1982. From 1982 to 1999, seagrass coverage increased by 1,597 acres, a 40 percent increase. Seagrass coverage in Middle Tampa Bay in 1999 is 59 percent of 1950 estimates, and 23 percent of present bay-wide coverage estimates.

In Lower Tampa Bay, seagrass coverage in 1950 is estimated at 6,100 acres. In 1999, seagrass coverage in Lower Tampa Bay is estimated at 5,847 acres, or 96 percent of 1950 estimates. Seagrass coverage in Lower Tampa Bay in 1999 is 24 percent of present bay-wide coverage estimates.

In Boca Ciega Bay, seagrass coverage declined from an estimated 10,800 acres in 1950 to 5,770 acres in 1982. From 1982 to 1999, seagrass coverage increased at a rate of 100 acres per year, to a total of 7,464 acres. Seagrass coverage in Boca Ciega Bay in 1999 was 69 percent of 1950 estimates, and 30 percent of present bay-wide coverage estimates.

In Terra Ceia Bay, seagrass coverage remained similar between 1950 and 1982 (700 and 751 acres, respectively). However, 1988 coverage was estimated to be 947 acres, a 26 percent increase from 1982. In 1999, seagrass coverage in Terra Ceia Bay was estimated at 929 acres, or 33 percent higher than in 1950, and 4 percent of present bay-wide coverage estimates.

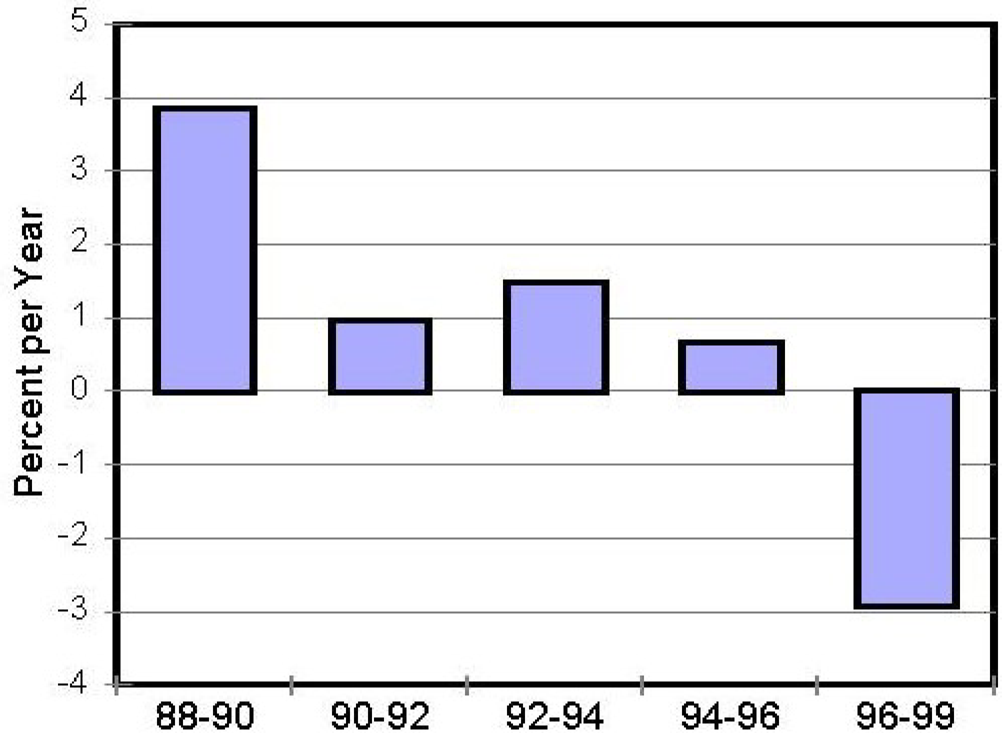

Figure 9-1 Rate of change (positive = increase, negative = decrease) in seagrass acreage in Tampa Bay. Values are percent change per year between actual dates of photography for individual mapping events.

In the Manatee River, seagrass coverage declined between 1950 and 1982 (200 and 131 acres, respectively). However, 1988 seagrass coverage was estimated to be 347 acres, a 165 percent increase from 1982. In 1999, seagrass coverage in the Manatee River was estimated at 375 acres, or 88 percent higher than in 1950, and approximately 2 percent of present bay-wide coverage estimates.

DISCUSSION

Tampa Bay's seagrass coverage has been previously 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). However, the 1996 to 1999 seagrass mapping effort appears to have documented an unexpected decline in bay-wide coverage of 2,074 acres, an 8 percent decrease. While most bay segments exhibit patterns of periods of losses and gains of seagrass coverage over time, Old Tampa Bay is the only bay segment that appears to have less seagrass coverage at present than at any previous time period during 1950 to 1999 (Table 9-1). From 1988 to 1999, annual rainfall measured at Tampa International Airport averaged 46 inches (District rainfall data). During 1997, annual rainfall was 68 inches. Total rainfall at this same site was 55 inches in 1998. These two years, with rainfall amounts 48 and 20 percent higher than the 1988 to 1999 average, correspond to the 1997 to 1998 El Niño event, which caused substantial flooding in Southwest Florida. It is likely that the 1997 to 1998 El Niño event caused seagrass coverage declines in Tampa Bay, due to the significant increases in nutrient and suspended solids loads that accompanied this event. However, the 24 percent decrease in coverage in Old Tampa Bay between 1996 and 1999, coupled with the prior decrease between 1994 and 1996, suggests a more serious condition could exist in this part of the bay.

Over the past few years, the rapid rate of increase in seagrass coverage seen in earlier times has moderated. While seagrass acreage increased at nearly four percent per year in the late 1980s, more recent times have been associated with increases of less than two percent per year (Figure 9-1). When this trend is considered in combination with the recent decrease in coverage between 1996 and 1999, it appears that seagrass acreage is not presently recovering at the same rate as twenty years ago. 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.

ACKNOWLEDGMENTS

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Walt Avery (City of Tampa, Bay Study Group)

-CHAPTER HIGHLIGHTS-

- *A multi-agency consortium, under the auspices of the TBEP, has been monitoring seagrass composition and abundance from 1998 to present along more than 60 transects in Tampa Bay.*
- *In Old Tampa Bay, only small changes in abundance were observed along the transects, in contrast to aerial observation results, leading to relocating transects in this segment.*
- *In Hillsborough Bay, seagrass coverage increased from about 56 ha in 1997 to nearly 86 ha in 2001.*
- *In Middle Tampa Bay, there has been some thinning and loss of the seaward seagrass edge near Wolf Branch.*
- *There appears to be a slight decrease in T. testudinum abundance in southeastern Lower Tampa Bay.*

INTRODUCTION

The state of Tampa Bay's seagrass meadows has become an important issue in the past three decades as scientists and environmental managers have worked to reverse the detrimental effect of eutrophication upon this important habitat within the estuarine ecosystem. Seagrass coverage in Tampa Bay declined from about 16,000 ha in 1950 to near 8800 ha 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.

As seagrass began to recover in the 1980s, the City of Tampa (COT) and the Southwest Florida Water Management District (SWFWMD) Surface Water Improvement Management Program (SWIM) initiated seagrass monitoring programs. The COT has used aerial photography combined with intensive groundtruthing to document changes in the seagrass community of Hillsborough Bay. Similarly, SWIM has used aerial photography coupled with quality assurance field checks to follow spatial changes in seagrass distribution for Tampa Bay.

In 1997, the TBEP coordinated the creation of a baywide 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.

This paper presents a general overview of the Tampa Bay Interagency Seagrass Monitoring Program and some preliminary results concerning seagrass distribution within Tampa Bay. Therefore, many data collected during the course of the program are not discussed within this report. A more in-depth discussion of methods, results, and trends for the 1997-2000 period is presented in a treatise entitled *Tampa Bay Interagency Seagrass Monitoring Program: Seagrass Species Distribution and Coverage Along Fixed Transects 1997-2000*, available through the TBEP. Further, results of seagrass species composition and abundance for each transect during the 1997-2001 monitoring period may be obtained from the TBEP. Finally, an in-depth discussion of seagrass trends in Hillsborough Bay since 1986 is presented in the COT 2001 annual report entitled *Seagrass and Caulerpa Monitoring in Hillsborough Bay: Thirteenth Annual Report*.

METHODS

Field and Laboratory

In 1997, 30 fixed seagrass monitoring transects were selected from randomly placed Tampa Bay transects that had previously been used by SWIM to groundtruth aerial photographic surveys. An additional 27 fixed transects were placed in a nonrandom manner in other areas of interest within Tampa Bay. In 2000, two transects in Middle Tampa Bay and three transects in Lower

Tampa Bay were added. Also in 2000, one transect in Lower Tampa Bay was not monitored due to the impending expansion at Port Manatee. Finally, in Old Tampa Bay five randomly selected transects were deleted in 2001 due to the paucity of data generated from these transects. They were replaced with five transects traversing selected areas of existing seagrass meadows or potential zones for seagrass development.

Generally, the fixed transects start at the shoreline and traverse the study area on a line most often perpendicular to the shoreline. Most transects end at a water depth that approximates the adopted TBEP seagrass target depth for the respective bay subsection. The target depths range from 1.0 m to 2.5 m. The length of the transects range from 40 m to 2700 m. PVC poles mark the starting point, each 100 m mark (where applicable), and the terminus of each transect. Transect monitoring occurs every fall to coincide with vertical aerial photography

Seagrass species composition and abundance are determined by a diver using a meter square frame placed on the bottom along the transect line at every 25 m in Old Tampa Bay, Hillsborough Bay, and Middle Tampa Bay, and at every 50 m in Boca Ciega Bay and Lower Tampa Bay (including Terra Ceia Bay). The abundance of each seagrass species within the frame is estimated using the Braun-Blanquet rating system. This rating allows for a rapid assessment of percent coverage of each seagrass species and the result is assigned to one of seven classes of coverage. Other data collected at each meter square placement include:

1) time,
2) water depth (not corrected for tidal stage nor related to a fixed elevation datum),
3) a rating of sediment composition (oyster bar, shell, sand, muddy sand, mud),
4) a rating of seagrass epiphyte load (clean, light, moderate, heavy),
5) a rating of seagrass appearance (excellent, good, fair, poor), and
6) a rating of attached and drift macro-algae abundance.

Seagrass short shoot density and canopy height measurements for each species are taken at various points along the transect. In addition, hydrographic and photosynthetic active radiation (PAR) measurements are recorded at the middle of the meadow, at the deep edge of the meadow, and at the two meter water column depth. Water samples are collected from mid-depth at the time of hydrographic and PAR measurements and are placed on ice until analysis of chlorophyll-*a* and turbidity can be performed in the laboratory.

It should be noted that this document mainly discusses the composition of seagrass species within each bay segment during 2001. Also included are a summary of trends in areal coverage and major changes in species composition observed during the course of the monitoring program. All information collected during the monitoring program, including parameters listed above but not presented in this report, may be obtained through the TBEP.

Training of Participating Agency Personnel

During the initial development of the seagrass transect monitoring program, concerns were raised about the need to collect comparable data between the participating agencies. To address this concern, a training class was scheduled several weeks prior to the start of each annual monitoring effort to train personnel in field sampling procedures and protocols.

RESULTS AND DISCUSSION

Detailed figures illustrating seagrass abundance and coverage trends along the 62 established seagrass monitoring transects within Tampa Bay are not included in this report and may be obtained from the TBEP office. However, one detailed figure is included here to illustrate increased seagrass coverage along one transect in southeast Hillsborough Bay.

Old Tampa Bay

Of the twelve transects monitored in Old Tampa Bay during 2001 (Figure 10-1), only S1T1, S1T3, S1T5, S1T6, S1T8, and S1T9 have data that encompass the four-year data set generated from the onset of the program. Transect S1T4 was established in 1999, while monitoring of transects S1T13, S1T14, S1T15, S1T16, and S1T17 commenced in 2001.

All five seagrass species found in Tampa Bay were found in Old Tampa Bay during 2001 (Table 10-1). Generally, *Halodule wrightii* (shoal grass) has been the dominant species found along each transect. However, *Thalassia testudinum* (turtle grass) and *Syringodium filiforme* (manatee grass) have comprised a substantial portion of the seagrass composition along the eastern shoreline and the western shoreline south of Gandy Bridge. Sparse *Ruppia maritima* (widgeon grass) and *Halophila engelmanni* (star grass) have been documented in northeast and northwest Old Tampa Bay, respectively.

Only minor changes in species composition and distribution have been noted in Old Tampa Bay during the course of the study. In contrast, SWIM reported large losses of Old Tampa Bay seagrass coverage during the 1996-1999 period (Dave Tomasko, personal communication). This dichotomy may serve to illustrate the ineffectiveness of the five transects deleted in 2001. In a 2001 meeting of the Tampa Bay Seagrass Working Group to discuss transect relocation in Old Tampa Bay, it was agreed that data from the new site transect selections would have reflected this loss of coverage.

Figure 10-1. Locations of seagrass transects in Old Tampa Bay.

Table 10-1. Percent occurrence of meter square placements for each seagrass species present along each Old Tampa Bay transect during 2001. 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*

Transect #	L	N	% Bare	% He	% Hw	% Rm	% Sf	% Tt
S1T1	450	24	25	0	71	0	4	0
S1T3	400	33	42	6	52	0	0	0
S1T4	860	47	74	0	26	0	0	0
S1T5	460	32	9	0	53	3	9	25
S1T6	400	19	16	0	21	0	11	58
S1T8	180	20	60	0	5	0	30	15
S1T9	700	30	23	0	50	0	17	3
S1T13	1100	45	31	0	69	0	0	0
S1T14	660	28	14	0	39	0	39	18
S1T15	630	29	21	0	38	0	28	24
S1T16	1000	46	33	0	46	0	11	15
S1T17	2700	122	75	0	19	0	7	0

Hillsborough Bay

Eleven transects have been monitored in Hillsborough Bay since 1997 (Figure 10-2). *H. wrightii* has been the dominant species where seagrass coverage was present (Table 10-2). Also, *R. maritima* has persisted along the northeastern shoreline and has been noted periodically in most areas of Hillsborough Bay.

Hillsborough Bay seagrass coverage increased over 50 percent from about 56 ha in 1997 to nearly 86 ha in 2001, largely due to rapid *H. wrightii* recolonization around southeastern Interbay Peninsula (Figure 10-3). However, there has been little coverage change in other areas of Hillsborough Bay since 1997.

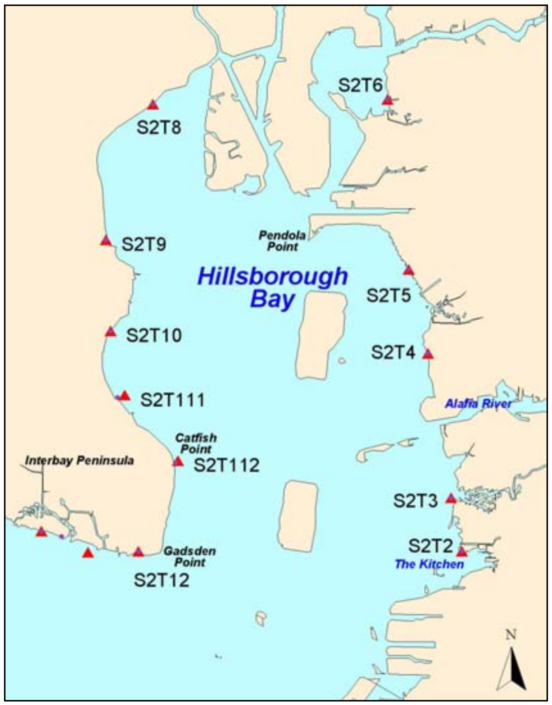

Figure 10-2. Locations of seagrass transects in Hillsborough Bay.

Table 10-2. Percent occurrence of meter square placements for each seagrass species present along each Hillsborough Bay transect during 2001. 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*

Transect #	L	N	% Bare	% He	% Hw	% Rm	% Sf	% Tt
S2T2	1375	69	55	0	45	0	0	0
S2T3	900	52	79	0	21	0	0	0
S2T4	400	17	100	0	0	0	0	0
S2T5	700	37	78	0	19	3	0	0
S2T6	400	18	100	0	0	0	0	0
S2T8	200	9	100	0	0	0	0	0
S2T9	400	24	71	0	29	0	0	0
S2T10	350	21	33	0	67	0	0	0
S2T111	500	34	74	0	26	0	0	0
S2T112	550	30	57	0	43	0	0	0
S2T12	800	40	20	0	80	0	0	0
S2T2	1375	69	55	0	45	0	0	0

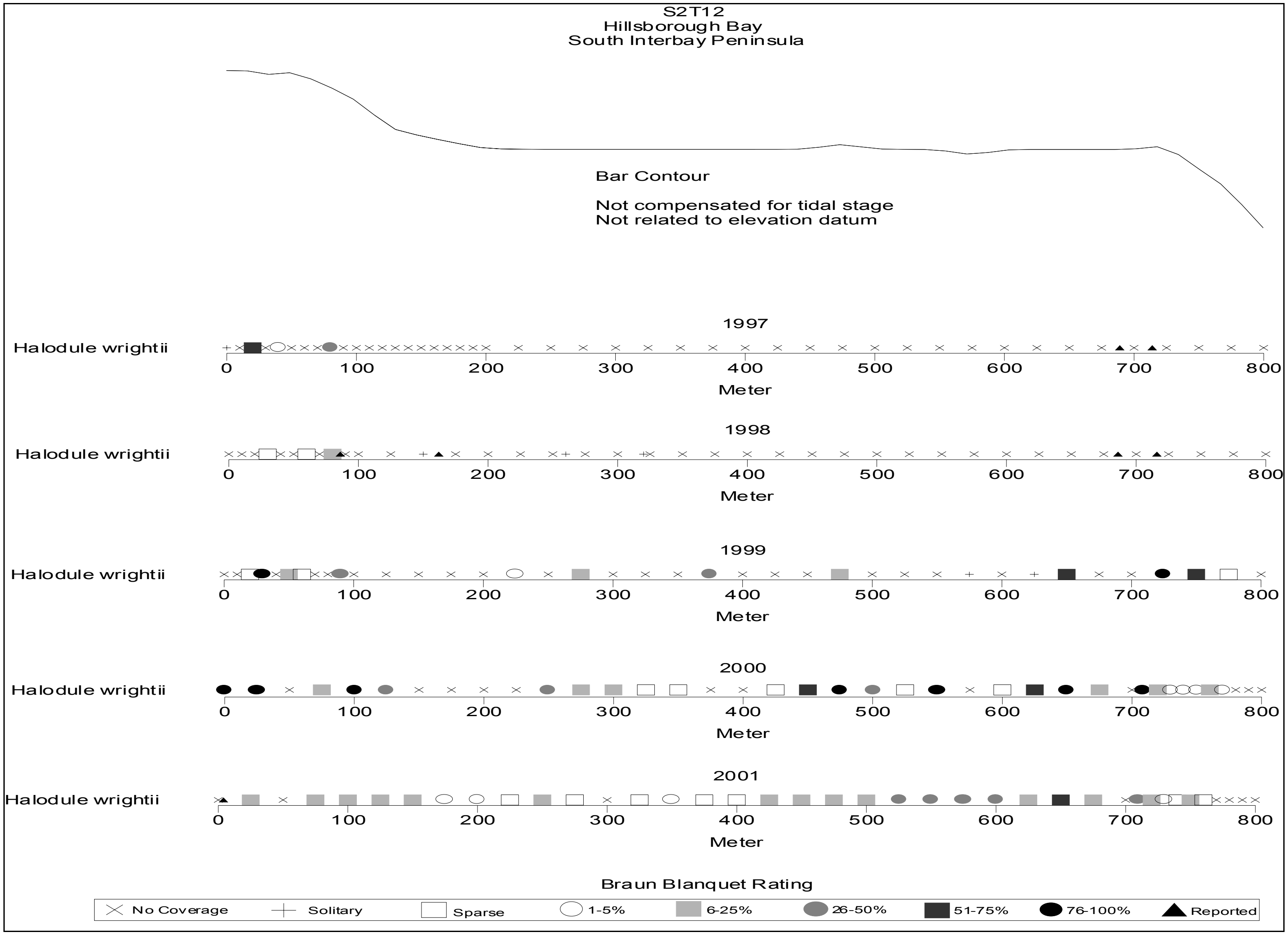

Figure 10-3. Distribution and abundance of *Halodule wrightii* along Transect S2T12 from 1997-2001. Braun Blanquet ratings indicate percent coverage of each seagrass species assessed within each meter square site. Meter squares are placed at 10 m or 25 m intervals. The depth measured at every meter square placement generates the bar contour.

Middle Tampa Bay

Thirteen transects have been established in Middle Tampa Bay (Figure 10-4). Two transects, S3T12 and S3T14, have been monitored since 1997. Two additional transects, S3T10 and S3T11, were established in 2000.

Four seagrass species, *H. wrightii*, *R. maritima*, *S. filiforme*, and *T. testudinum* were documented in Middle Tampa Bay during 2001 (Table 10-3). *H. wrightii* has been the dominant species in the northeast quadrant of Middle Tampa Bay. Typically, seagrass composition south of the Little Manatee River and along the western side of Middle Tampa Bay has been comprised of *H. wrightii*, *S. filiforme*, and *T. testudinum*.

In general, there has been little variation in seagrass species composition and abundance in Middle Tampa Bay. During the course of the monitoring, the only notable change has been the apparent thinning and loss of the seaward edge of *H. wrightii* coverage near Wolf Branch (transect S3T13). The edge of this meadow has retreated nearly 40 m since 1998.

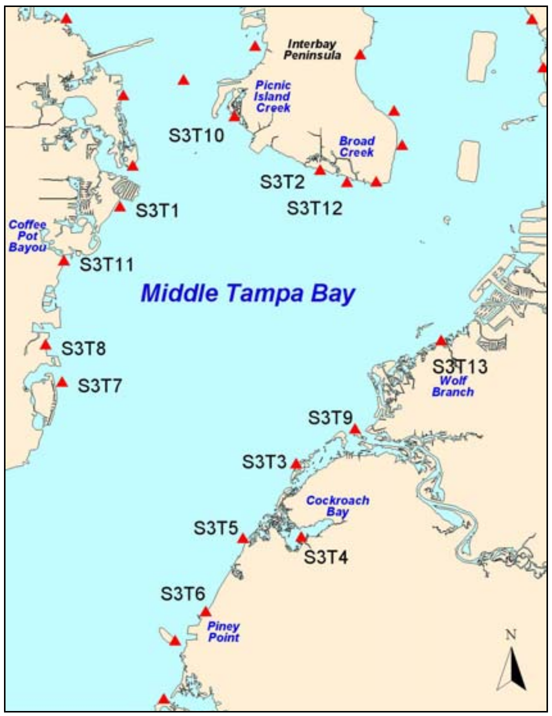

Figure 10-4. Locations of seagrass transects in Middle Tampa Bay.

Table 10-3. Percent occurrence of meter square placements for each seagrass species present along each Middle Tampa Bay transect during 2001. 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*.

Transect #	L	N	% Bare	% He	% Hw	% Rm	% Sf	% Tt
S3T1	700	62	48	0	31	0	29	10
S3T2	860	52	44	0	56	0	0	0
S3T3	350	18	28	0	50	0	11	44
S3T4	250	12	25	0	75	0	0	17
S3T5	675	33	45	0	21	0	24	18
S3T6	310	15	33	0	40	0	20	7
S3T7	300	51	43	0	24	0	29	16
S3T8	450	32	41	0	25	0	3	13
S3T9	445	20	30	0	70	0	0	0
S3T10	1000	47	72	0	21	0	0	9
S3T11	1000	44	34	0	27	0	41	18
S3T12	1000	48	31	0	69	0	0	0
S3T13	1200	55	73	0	25	4	0	0

Lower Tampa Bay

Fourteen transects were assessed for seagrass coverage in 2001 (Figure 10-5). *H. wrightii*, *S. filiforme*, and *T. testudinum* were the only species reported in Lower Tampa Bay (including Terra Ceia Bay) during 2001 (Table 10-4), although *H. engelmanni* and *R. maritima* have been documented in the Manatee River in previous monitoring years.

Generally, seagrass composition in Lower Tampa Bay has been dominated by *T. testudinum*. *S filiforme* has not been documented along the transects within the Manatee River; however, this species is common in the proximity of Terra Ceia Bay and Egmont Key. The ubiquitous *H. wrightii* was present on most transects.

There has been little change in species composition during the course of the study. However, there appears to be a slight decrease in *T. testudinum* abundance in southeastern Lower Tampa Bay. This trend has been most evident along transect S4T2 just south of Bishop Harbor.

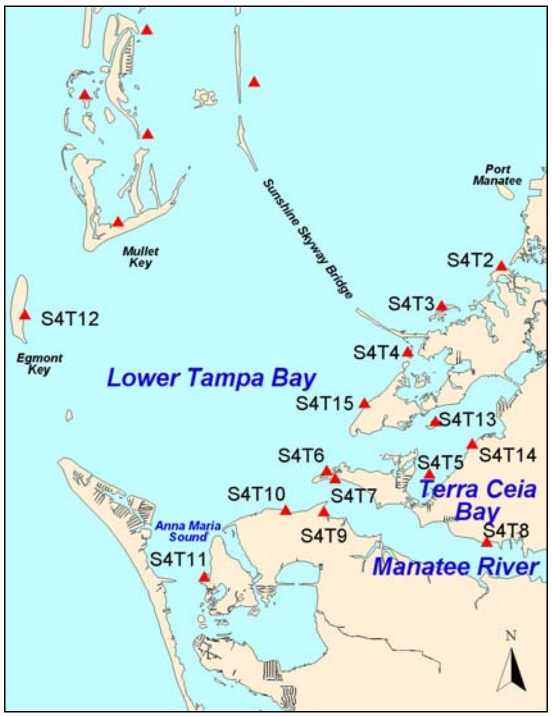

Figure 10-5. Locations of seagrass transects in Lower Tampa Bay.

Table 10-4. Percent occurrence of meter square placements for each seagrass species present along each Lower Tampa Bay transect during 2001. 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*.

Transect #	L	N	% Bare	% He	% Hw	% Rm	% Sf	% Tt
S4T2	450	46	63	0	11	0	0	26
S4T3	200	21	62	0	10	0	0	29
S4T4	520	53	45	0	0	0	2	55
S4T5	100	11	18	0	27	0	45	64
S4T6	470	48	23	0	27	0	8	65
S4T7	120	14	43	0	50	0	0	43
S4T8	200	21	62	0	38	0	0	0
S4T9	70	8	38	0	50	0	0	50
S4T10	340	35	9	0	34	0	0	66
S4T11	200	21	10	0	33	0	5	81
S4T12	350	16	31	0	13	0	19	56
S4T13	75	11	27	0	36	0	18	36
S4T14	150	12	33	0	33	0	33	8
S4T15	180	17	53	0	29	0	0	18

Boca Ciega Bay

Eleven transects have been assessed for seagrass coverage in Boca Ciega Bay (Figure 10-6). *H. wrightii*, *S. filiforme*, and *T. testudinum* have been documented within this bay segment (Table 10-5). Generally, *H. wrightii* has been the dominant species in the northern portion of Boca Ciega Bay and coverage transitions to a *T. testudinum* dominated community further south.

Generally, only minor fluctuations have been noted within the Boca Ciega Bay seagrass community since the start of the monitoring program. The major change has been an apparent shift from a *T. testudinum* dominated community present along transect S5T8 in 1998 to a *S. filiforme* meadow.

Figure 10-6. Locations of seagrass transects in Boca Ciega Bay.

Table 10-5. Percent occurrence of meter square placements for each seagrass species present along each Boca Ciega Bay transect during 2001. 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*.

Transect #	L	N	% Bare	% He	% Hw	% Rm	% Sf	% Tt
S5T1	372	7	14	0	86	0	0	0
S5T2	234	12	33	0	67	0	0	0
S5T3	94	9	33	0	67	0	0	0
S5T4	100	9	33	0	67	0	0	0
S5T5	106	11	27	0	73	0	0	0
S5T6	250	19	47	0	42	0	0	16
S5T7	236	18	6	0	22	0	0	89
S5T8	120	15	20	0	40	0	40	40
S5T9	600	28	0	0	18	0	0	96
S5T10	169	15	7	0	60	0	0	80
S5T11	131	9	0	0	100	0	0	0

CONCLUSION

We now have four years or more of data from most of the Tampa Bay seagrass monitoring transects. The collected information suggests that most seagrass meadows in Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay have been relatively stable in terms of species composition and abundance. The only major change detected has been the rapid development of *H. wrightii* meadows along southeastern Interbay Peninsula in Hillsborough Bay.

Nitrogen management has been the keystone to the recovery of Tampa Bay to date. The need to reduce nitrogen to the bay was identified in the 1960s and work began to control point source loading. As nitrogen sources were reduced in the late 1970s and early 1980s, there were soon improvements noted, such as reductions in macroalgae and phytoplankton biomass. Following these improvements, minor seagrass recolonization began to occur in some areas of Tampa Bay. With the advent of the Tampa Bay National Estuary Program in the early 1990s, work began on establishing acceptable levels of phytoplankton biomass needed to maintain adequate water clarity to promote seagrass recolonization.

Phytoplankton biomass during 1999-2001 has been near or below target levels set for all bay segments (Roger Johansson, City of Tampa; personal communication). However, information collected to date from the Tampa Bay Interagency Seagrass Monitoring Program suggests that seagrass recolonization in most areas of Tampa Bay has occurred at a relatively slow rate. Therefore, it cannot be disregarded that factors other than phytoplankton may affect seagrass recolonization.

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, Dave Tomasko (Southwest Florida Water Management District-Surface Water Improvement Management Program), Ray Kurz (Post, Buckley, Schue, and Jernigan), and Tom Reis (Scheda Ecological Associates, Inc.) provided guidance in the initial design of the monitoring protocols. Field collections were conducted by personnel from Florida Fish & Wildlife Conservation Commission - Florida Marine 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. 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.

B.A. Blakesley, D.M. Berns, M.F. Merello, M.O. Hall, and J. Hyniova (Florida Marine Research Institute, Florida Fish and Wildlife Conservation Commission)

-CHAPTER HIGHLIGHTS-

- *Labyrinthula has been proposed as a possible cause of a massive acute seagrass die-off of the subtropical seagrass Thalassia testudinum Banks ex König (turtlegrass) in Florida Bay that began in the summer and fall of 1987.*
- *The five different factors considered to be critical elements in determining the role(s) of Labyrinthula in seagrass health at a particular site in Florida Bay are: salinity, seagrass density, pathogenicity, abiotic factors, and resistance to disease.*
- *Based on Florida Bay studies, it has been speculated that Labyrinthula has its greatest impact on dense Thalassia beds due to ease of transmission and higher ambient salinities in dense beds.*

INTRODUCTION

Labyrinthulids are marine saprobes classified as stramenopiles in the kingdom Protista (Leander and Porter, 2001). *Labyrinthula* is a parasite of seagrass and when pathogenic, produces necrotic brown to black lesions (spots and streaks) on the leaves, compromising the plant's ability to photosynthesize (Durako and Kuss, 1994; Durako and Kunzelman, 2002). The "wasting disease" caused by a species of *Labyrinthula* in the temperate eelgrass *Zostera marina* decimated the seagrass beds of Europe and North America in the 1930s and 1940s. Some of these seagrass beds took 40 years to recover.

Labyrinthula had been proposed as a possible cause of a massive acute seagrass die-off of the subtropical seagrass *Thalassia testudinum* Banks ex König (turtlegrass) in Florida Bay that began in the summer and fall of 1987. No definitive cause of this acute die-off was ever determined, but many possible etiologies were proposed, including high temperatures and salinities, overdeveloped seagrass beds, elevated sediment sulfide levels, hypoxia, and disease (Porter and Muehlstein, 1989; Robblee et al., 1991; Durako and Kuss, 1994; Carlson et al., 1994).

Concern that *Labyrinthula* might now affect turtle-grass as severely as it had eelgrass in the past made it important to attempt to determine the distribution pattern of *Labyrinthula* in *Thalassia* populations in different Florida estuaries with varying environmental conditions. It was essential to try to understand this parasite's potential impacts on the health and survival of those seagrass beds. Data were collected in three separate studies of *Labyrinthula* distribution in different geographical areas. The most extensive data set was collected over five years in a study initiated in Florida Bay in 1995. Two other preliminary studies were also done, one in the eastern Gulf of Mexico, and the other in the Tampa Bay area. The same field methods were used in all three studies so that results could be easily compared. Results from the Florida Bay studies were extrapolated to propose potential impacts of this organism on *Thalassia* populations in the other areas of Florida where less extensive studies of *Labyrinthula* have been done (Blakesley et al., 2002).

The data collected both during the Florida Bay field study and from associated laboratory studies (Blakesley et al., 1998) resulted in the formulation of a preliminary hypothetical model (see Figures 11-1 and 11-2) describing the effects of *Labyrinthula* on *Thalassia* populations in Florida Bay (Blakesley et al., 1999a). Where seagrass densities are low, *Labyrinthula* does not cause major mortality. In moderate to high salinities with high seagrass densities, *Labyrinthula* plays a major role in seagrass mortality. In optimal conditions for seagrass, *Labyrinthula* can be a primary pathogen controlling seagrass densities. In suboptimal conditions for seagrass, such as lowered light levels, stressed seagrass may be weakened by opportunistic *Labyrinthula,* further contributing to chronic seagrass die-off. The theoretical model suggests three different roles that *Labyrinthula* might play in Florida Bay under different environmental conditions. These include:

(1) a nonpathogenic parasite;
(2) an opportunistic secondary pathogen; and
(3) a primary pathogen.

Five different factors are considered to be critical elements in determining the role(s) of *Labyrinthula* in seagrass health at a particular site in Florida Bay (Blakesley et al., 1999b). **Salinity** controls infection (infection does not occur at < 15 ppt). **Seagrass density** determines the extent to which *Labyrinthula* infection spreads because transmission is thought to depend on blade-to-blade contact (Muehlstein, 1992). **Pathogenicity** of a particular strain of *Labyrinthula* will determine severity of infection. **Environmental stressors** (abiotic factors) such as low light or high temperatures may weaken *Thalassia* and, in combination with the infection by pathogenic

Labyrinthula, cause seagrass die-off. **Resistance to disease** in *Thalassia* due to genetic factors or production of phenolic compounds may be important in determining the health of this seagrass in Florida Bay. The model predicts that in areas with high seagrass density, high salinity, "suboptimal seagrass conditions (environmental stress)", and presence of pathogenic *Labyrinthula*, the organism could contribute to either chronic or acute die-off by acting as an opportunistic secondary pathogen. With the same conditions, but without environmental stress, it suggests that *Labyrinthula* can still cause "thinning" or patchy die-off acting as a primary pathogen (Blakesley et al., 1999b).

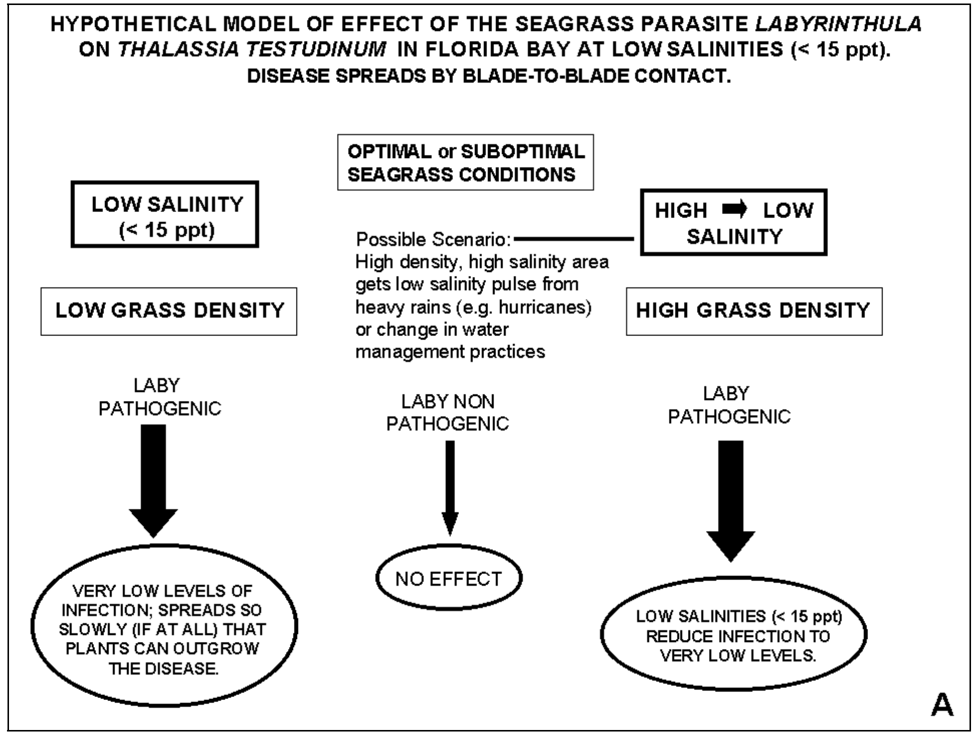

Figure 11-1. A hypothetical model developed using data from a 1995-1999 study of *Labyrinthula* on *Thalassia* in Florida Bay showing effects of the seagrass parasite at low salinities.

RESULTS

Tampa Bay Area (1999)

Samples were collected during the fall of 1999 as part of the Tampa Bay Baywide Monitoring Program to begin looking at the distribution of *Labyrinthula* and the severity of lesions in *Thalassia* in this area. The data are very limited, but our analysis of 5-10 shoots randomly collected from each of 22 transects in Tampa Bay showed that 82% of all transects with *Thalassia* were positive for *Labyrinthula* and all Tampa Bay segments were infected. Results of our monitoring studies show that the highest percentage of infected transects was in Old Tampa Bay (100%, n=2) and Lower Tampa Bay (90.9%, n = 11) (Table 11-1). All sites except Middle Tampa Bay (32%) had nearly 40 % of the shoots sampled infected. The highest lesion severity was found in Middle Tampa Bay (2.0 %; this is the average percent lesion cover of all blades examined from the site whether each individual blade had lesions or not).

Tampa Bay Area (2000)

In fall 2000 *Thalassia* shoots were collected as before at 30 transects in Tampa Bay, 84% of which were infected with *Labyrinthula*. All bay segments were infected. Again the highest percentage of infected transects was in Old Tampa Bay (100%, n = 2) and Lower Tampa Bay (90.9%, n = 11) (see Table 11-1). The percent of infected shoots was highest in Hillsborough Bay (50 %, n = 4) and Middle Tampa Bay (50%, n = 20). As in 1999, the highest lesion severity was found in Middle Tampa Bay (1.21% of all blades).

Tampa Bay Area (2001)

In fall 2001, 69% of the 32 transects sampled in Tampa Bay were infected with *Labyrinthula*. Again, all bay segments (sites) were infected. The highest percentage of transects infected was in the Lower Tampa Bay segment (83%, n = 12) (see Table 11-1). Average lesion severity was highest in Middle Tampa Bay (2.46% of all blades).

Tampa Bay Area 1999-2001

Results from the 17 transects sampled in all three years show that a higher percentage of transects were infected in fall 2000 than in fall 1999 or fall 2001 (see Table 11-2). The highest percentage of infected transects within a bay segment was in Old Tampa Bay in 1999 (100%); Old Tampa Bay, Boca Ciega Bay, and Lower Tampa Bay in 2000 (100% at all three); and in Lower Tampa Bay and Middle Tampa Bay in 2001 (75% in each). The percentage of infected shoots was highest in Old Tampa Bay during the first two years of the study and highest in Middle Tampa Bay in 2001. The bay segment with the highest average lesion severity was Middle Tampa Bay during year one and year three and Old Tampa Bay in year two.

DISCUSSION

Kurz and Avery (1999) reported that seagrass coverage had increased in Tampa Bay from 1988-1994 by a total of 14%. Approximately 90% of all of these seagrass beds occurred during those years at depths between 3 and 6 feet. They also reported that substantial increases had occurred in the percentage of seagrasses occupying depths between 6 and 18 feet, most probably due to increased water clarity. However, despite increasing trends in seagrass acreage, seagrass bed density declined between the years 1988 and 1994 (Kurtz and Avery, 1999). Based on our Florida Bay studies, we have speculated that *Labyrinthula* has its greatest impact on dense *Thalassia* beds due to ease of transmission, the higher ambient salinities in dense beds, and possible stresses on dense beds which may increase susceptibility of turtlegrass to disease. Although no data on *Labyrinthula* in *Thalassia* in Tampa Bay were collected until 1999, the high prevalence of infection in Tampa Bay in 1999-2001 may suggest that *Labyrinthula* is playing the role of thinning dense seagrass beds as predicted in our hypothetical model of Florida Bay *Thalassia* and *Labyrinthula*. If this is the case, *Labyrinthula* infection *per se* does not necessarily suggest that the seagrass beds are being adversely affected by disease. We suggest, based on our Florida Bay studies, that unless the beds are severely stressed by other factors such as environmental degradation (*e.g.* poor water clarity), unusual environmental conditions (*e.g.* continual high salinities and or high temperatures, very dense seagrass beds), or a primary pathogen or virus, *Labyrinthula* may only serve to thin dense, otherwise "healthy" *Thalassia* beds (Blakesley et al., 1999a). The percentages of bay segments, transects, shoots infected, and severity of lesions are as high or higher than our most diseased sites in Florida Bay. However, data from Tampa Bay are limited and conclusions drawn from Florida Bay may not be valid in the Tampa Bay area. Continued monitoring of *Labyrinthula* infection in Tampa Bay, along with other "health" factors, is recommended.

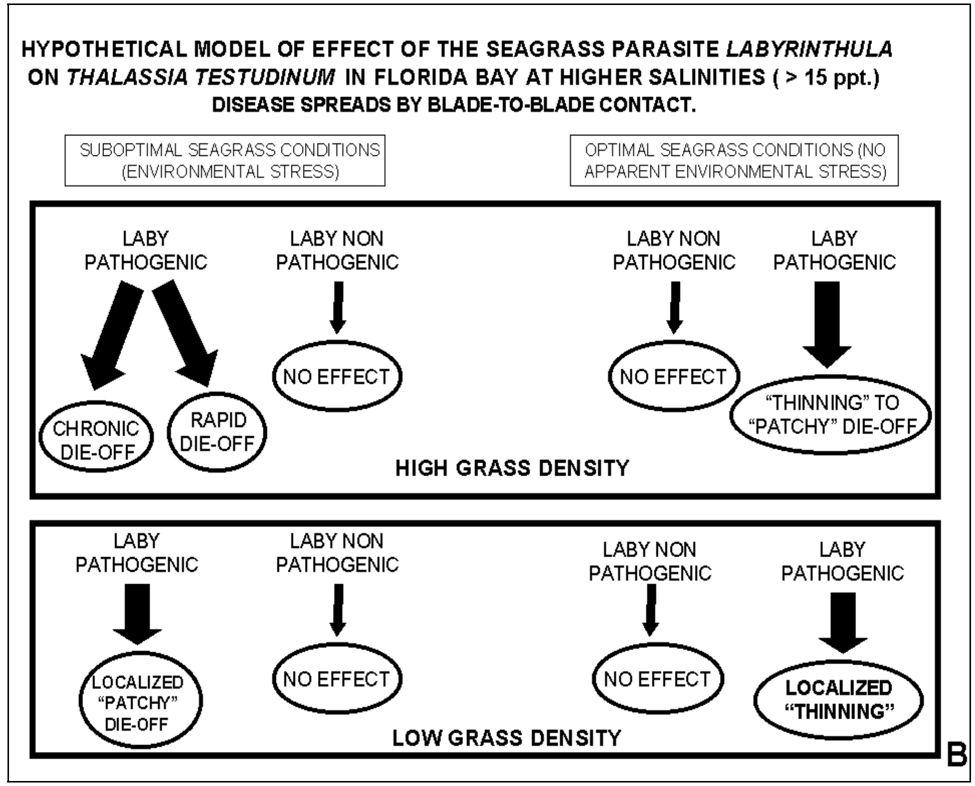

Figure 11-2. A hypothetical model developed using data from a 1995-1999 study of *Labyrinthula* on *Thalassia* in Florida Bay showing effects of the seagrass parasite at high salinities.

Table 11-1. Results of the Tampa Bay Estuary Program's seagrass transect monitoring studies showing the percentage of all transects and shoots from the Tampa Bay area infected with *Labyrinthula*, and average lesion severity for years 1999-2001.

Bay Segment	Infected Transects	Number of Transects (N)	% Infected	Infected Shoots	Number of Shoots (N)	% Infected	Average Lesion Severity Per Leaf	Number of Leaves (N)
1999								
Boga Ciega Bay	3	4	75	8	20	40	0.5	73
Lower Tampa Bay	10	11	91	41	104	39	1.69	329
Middle Tampa Bay	3	5	60	14	44	32	2	123
Old Tampa Bay	2	2	100	8	20	40	0.92	61
Total	18	22	82	71	188	38		586
2000								
Boga Ciega Bay	5	6	83	17	60	28	0.66	176
Hillsborough Bay	1	1	100	2	4	50	0.33	12
Lower Tampa Bay	10	11	91	33	123	27	0.96	321
Middle Tampa Bay	7	10	70	32	95	34	1.21	279
Old Tampa Bay	2	2	100	10	20	50	1.4	45
Total	25	30	83	94	302	31.13		833
2001								
Boga Ciega Bay	3	4	75	6	36	17	0.64	104
Lower Tampa Bay	10	12	83	44	102	43	1.61	335
Middle Tampa Bay	6	9	67	41	84	49	2.46	252
Old Tampa Bay	3	7	43	8	70	11	0.71	189
Total	22	32	69	99	292	34		880

Table 11-2. Results from the 17 transects sampled in all 3 years showing the percentage of transects and shoots from the Tampa Bay area infected with *Labyrinthula*, and average lesion severity for years 1999-2001

Bay Segment	Infected Transects	Number of Transects (N)	% Infected	Infected Shoots	Number of Shoots (N)	% Infected	Average Lesion Severity Per Leaf	Number of Leaves (N)
1999								
Boga Ciega Bay	2	3		5	15	33	0.75	57
Lower Tampa Bay	7	8		29	74	39	1.64	237
Middle Tampa Bay	2	4		12	40	30	2.05	111
Old Tampa Bay	2	2		8	20	40	0.92	61
Total	13	17	76	54	149	36		466
2000								
Boga Ciega Bay	3	3	100	10	30	33	0.8	95
Lower Tampa Bay	8	8	100	29	93	31	0.93	244
Middle Tampa Bay	3	4	75	13	40	33	0.57	115
Old Tampa Bay	2	2	100	10	20	50	1.4	45
Total	16	17	94	62	183	34		499
2001								
Boga Ciega Bay	2	3	67	5	30	17	0.64	85
Lower Tampa Bay	6	8	75	33	82	40	1.67	236
Middle Tampa Bay	3	4	75	20	40	50	3.3	112
Old Tampa Bay	1	2	50	1	20	5	0.17	59
Total	12	17	71	59	172	34		492

In summary, the distribution and potential impacts of *Labyrinthula* sp. infection on *T. testudinum* populations depend on a suite of interacting factors (salinity, seagrass density, pathogenicity, environmental stressors, seagrass resistance to disease). All of these factors, as well as others that may as yet not have been identified, need to be taken into consideration before the potential impacts of *Labyrinthula* sp. infections on *T. testudinum* populations in any particular geographic area can be predicted. The roles of *Labyrinthula* sp. in seagrass health in Florida Bay have been studied for 5 years. Only very preliminary *Labyrinthula* sp. and lesion distribution data have been collected elsewhere in the state. Long-term careful monitoring of *Labyrinthula* should be carried out in estuaries other than Florida Bay, especially in those with environmental stresses. The dynamics of *Labyrinthula* sp. distribution must be more clearly understood before the impacts of this organism on seagrass populations can be predicted. Seagrass recovery in urban estuaries must include health evaluations of seagrass beds to insure that gains in seagrass coverage can be maintained over time.

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T.M. Ash (Environmental Protection Commission of Hillsborough County)

- CHAPTER HIGHLIGHTS -

- *The Environmental Protection Commission manages eight permitted reef sites in Tampa Bay from the Courtney Campbell Causeway through Egmont Key.*
- *To date, nearly 40,000 tons of concrete has been placed on EPC reef sites within the bay.*
- *More than 50 species of fish are known to occur on the reefs including most of the locally popular recreational species.*
- *When added together the artificial reef sites account for over 125 acres of additional hard bottom habitat in Tampa Bay.*

INTRODUCTION

The Environmental Protection Commission of Hillsborough County (EPC) committed to developing and managing an artificial reef program for the waters of Tampa Bay in the fall of 1986. At the time, there was a grassroots effort by fishermen in the Ballast Point area to use local pollution recovery funds to improve the state of the ecosystem while enhancing recreational fishing opportunities. As a result, the EPC hired its first full-time Artificial Reef Program Coordinator and shortly thereafter began construction of it's first reef, the Port Tampa Reef, on March 21, 1987. Over the next several years, seven additional reef sites were developed.

ARTIFICIAL REEF MONITORING

Compliance Monitoring

One of the primary reasons for establishing a monitoring program as part of an overall reef management strategy is to assure compliance with both general and specific conditions required by any authorizing permits. For reefs inside Tampa Bay, permits are required by the United States Army Corps of Engineers, the Florida Department of Environmental Protection, and the Tampa Port Authority. Since EPC reefs have buoys marking their locations, a permit is also required by the United States Coast Guard.

GPS is used to ensure that each deployment falls within the reef area as it is defined in the permit. Corner coordinates define the size of the area and center coordinates allow the general public to find an easy reference point within the reef. The corners are most important to the reef managers during construction and monitoring, but the center of the reef is typically referenced when reporting its location (Figure 12-1).

In addition to ensuring the accuracy of the reefs' geographic location, an important part of compliance monitoring is the documentation of material stability and structural integrity throughout the life of the reef. Underwater photography and videography, sonar, and diver observation are used to track the history of the reef materials and to document any changes over time in the reef's physical characteristics. Strict navigational limits must also be maintained at all times to allow the safe transit of vessels over the reef area. Any signs of scouring, siltation, material breakdown, or movement can be reviewed on video and further investigated, thereby allowing staff to come up with possible corrective action or strategies for future deployments.

In 2001 and 2002, the EPC's Artificial Reef Program placed just over 8200 tons of concrete on four of its reefs as depicted in Figure 12-2. Approximately 6100 tons of this material was generated by the replacement of the Pinellas Bayway bridge leading to Fort Desoto Park. Most of this went to the Egmont Key Reef in Lower Tampa Bay, while roughly 800 tons was deployed on the Port Manatee Reef. This project was accomplished by 25 separate deployments over the course of five months. The remaining 2100 tons came from the repair of the St. Petersburg Municipal Pier. This material was added to the Bahia Beach Reef and to the Port Tampa Reef and took six separate deployments.

Since 1987, over 100 material deployments have taken place on EPC reefs totaling approximately 38,000 tons. Each of these events is documented in a spreadsheet format along with a formal "Materials Placement Form" and reported to the Florida Fish and Wildlife Conservation Commission's Division of Marine Fisheries/ Artificial Reef Program staff.

Each deployment of material is tracked using GPS and its coordinates are added to a grid map of the area used by staff to manage the overall layout of the reef (Figure 12-3).These grid maps, when coupled with material placement records, give reef managers an overall picture of the reef area and a history of dates and deployment sizes. With this information, it is easy to determine exactly how long any given piece of substrate has been in the water and therefore provide insight into the reef's physical and biological progress.

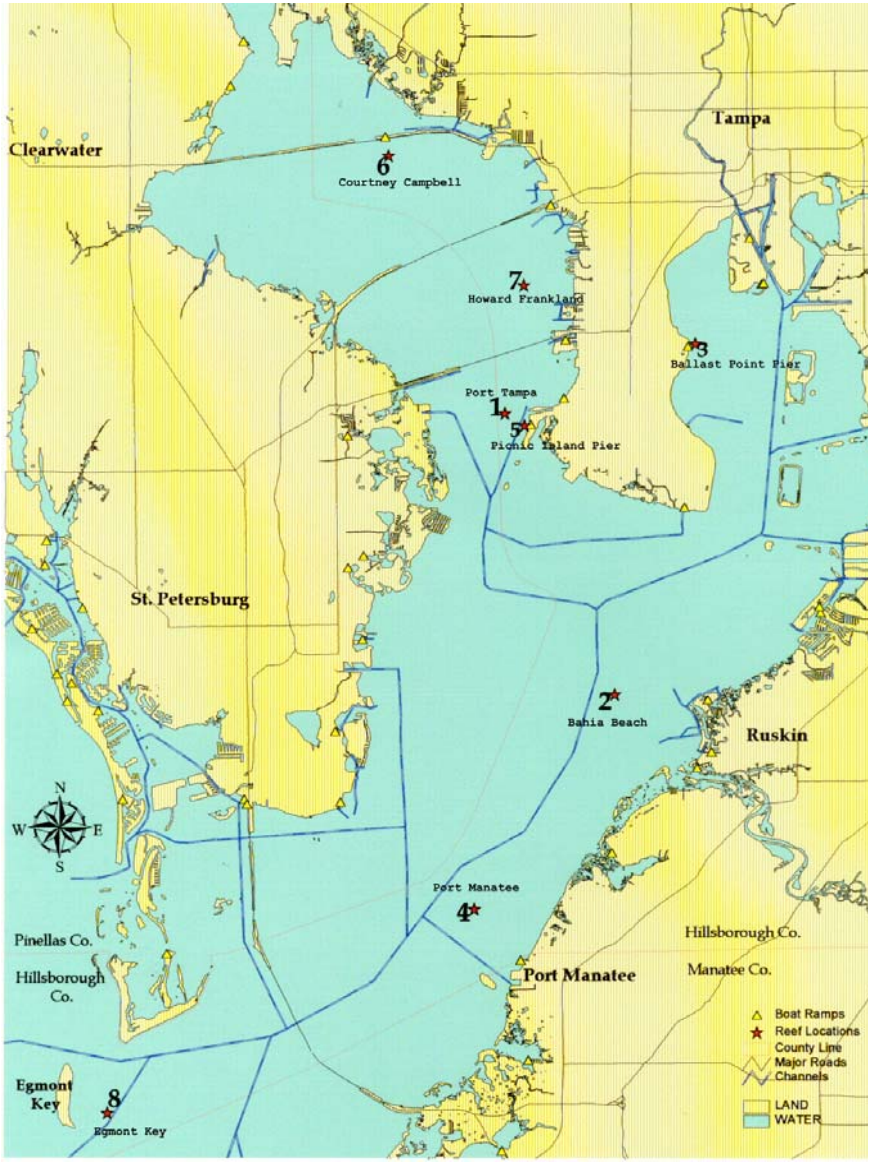

Figure 12-1. Locations of artificial reefs in Tampa Bay.

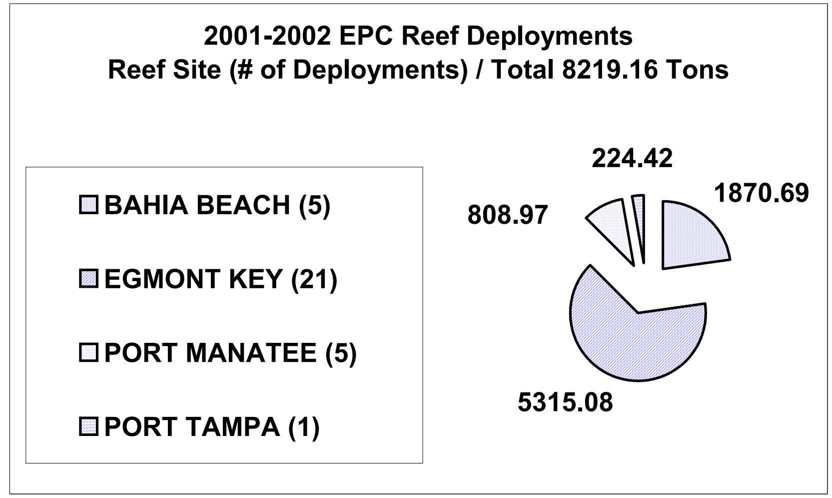

Figure 12-2. 2001-2002 reef material totals and distribution.

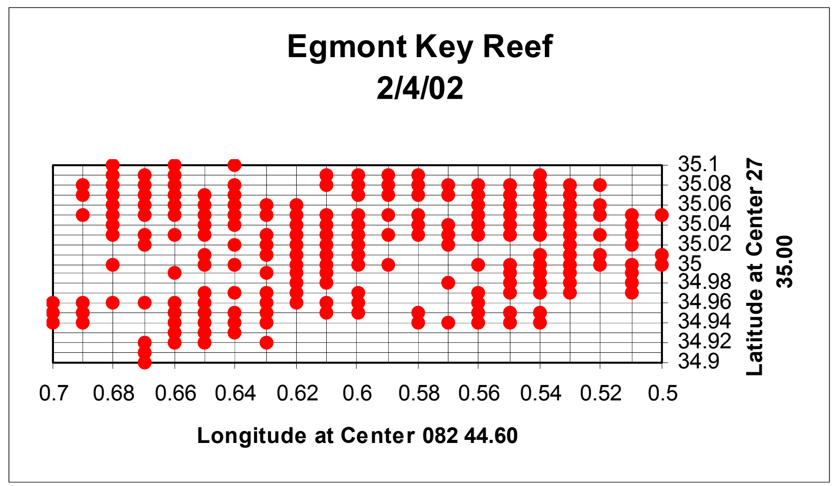

Figure 12-3. Grid map of Egmont Key Reef.

Biological Monitoring

Much of what is known about artificial reefs in Tampa Bay is based on diver observation, photographic evidence, and fishing reports. While these anecdotal sources have much value, they are clearly inadequate when subjected to scientific scrutiny and peer review. The reasons for such shortcomings with regard to data collection are numerous, but by no means foreign to many artificial reef managers throughout the country. Most of the programs in Florida are managed by local parks and recreation, pollution control, or environmental management personnel. For many of these individuals, managing a reef program is only a fraction of their routine responsibilities and may be the farthest thing from what they thought their career path would be like. For many, there are simply not enough dollars in the budget or enough hours in the day to design or properly implement a formal monitoring regiment, let alone manage the data collected.

Logistical limitations to monitoring reefs within an estuary are also a challenge. Most of the published work on artificial reef biology has been performed on open-water oceanic sites with better-than-average visibility and highly structured reef units of known size and volume. Point-counts, transects, and other visually dependent techniques are difficult to perform in an estuarine environment and could lead to erroneous data collection. Standard fish sampling strategies such as entangling gear (gill nets or trammel nets) or trawls are problematic due to the very nature of the reef materials themselves.

Perhaps one of the most universal reasons for this lack of data is simply because there is no demand for it. Aside from those few who are tasked with managing an artificial reef program, there seems to be very little genuine interest in how they perform or what impact they have, good or bad, on the environment in which they are placed. This is not a condemnation of the state of environmental management, it is simply a matter of priorities. Pollution control, public health and environmental protection will, and should, remain foremost in the collective minds of those who are tasked with those missions. Since there is no overwhelming perception of environmental harm or urgency with regard to artificial reef construction in Tampa Bay, anecdotal evidence will have to suffice for now.

There are over 50 species of fish known to occur on artificial reefs in the bay. While this number seems low, it does not include many species of baitfish, nor many cryptic species which are not immediately observed due to their size or habit of diver avoidance (Table 12-1).

Snook, grouper, cobia, speckled trout, mackerel, and tarpon are all popular sport fish that utilize the reefs at various times during the year. The three most common fish, however, are the sheepshead, spadefish, and mangrove snapper. While it is gratifying to see large fish using the habitat as intended, it is even more exciting to observe juvenile fish only 5-10 cm in length also present on the reefs and using the various sized holes and crevices for protection.

When substrate is placed on the reef for the first time, it can take anywhere from a few minutes to a few days for the first fish to arrive. Concrete pyramids placed on the Egmont Key Reef in Lower Tampa Bay had spadefish inside them 20 minutes after they touched bottom. Obviously, these fish did not just spontaneously generate, but it is interesting to note since there was no other similar habitat within one-half nautical mile of that area. Usually, the first species observed on a brand new reef are bottom dwellers such as inshore lizardfish and sand perch. Within a couple of weeks however, the reef will be dominated by spottail pinfish, large schools of baitfish, belted sandfish, and several black sea bass. Once the area is several weeks to six months old, those species that will become the permanent residents have arrived and from then on, the species richness will remain relatively stable with only minor seasonal fluctuations.

In contrast to a brand new reef, if additional concrete is added to an area adjacent to existing material, the new substrate will, within days, take on virtually the same fish species diversity.

Sessile invertebrate growth on the reef materials occurs very rapidly. Barnacle growth can be seen and felt as small white bumps within 24 hours. Within weeks, most surfaces are covered with an obvious layer of barnacles and the early stages of tunicate growth. After only a couple of months, various sponges, bryozoans, and sea whips have staked their claim on the available surface area as well.

One species in particular that has graduated from curiosity to concern on the reefs in Tampa Bay is the Asian green mussel. On the Courtney Campbell and Howard Frankland reefs in particular, this exotic species has not only displaced local mussels, but has virtually blanketed the surface of the reefs to the exclusion of most all other sessile invertebrates. Although small green shell fragments littering the bottom surrounding the reef suggest that the mussels are being eaten, clearly the fish on the reefs cannot keep up with this prolific invader.

Table 12-1. Fish known to occur on artificial reefs in Tampa Bay.

Common Name	Scientific Name
Atlantic Bumper	*Chloroscombrus chrysurus*
Atlantic Needlefish	*Strongylura marina*
Atlantic Spadefish	*Chaetodipterus faber*
Bay Anchovy	*Anchoa mitchilli*
Belted Sandfish	*Serranus subligarius*
Black Drum	*Pogonias cromis*
Black Sea Bass	*Centropristis striata*
Bull Shark	*Carcharhinus leucas*
Cobia	*Rachycentron canadum*
Common Snook	*Centropomus undecimalis*
Cownose Ray	*Rhinoptera bonasus*
Crested Blenny	*Hypsoblennius geminatus*
Crevalle Jack	*Caranx hippos*
Cubbyu	*Equetus umbrosus*
Filefish	Balistidae Family
Flounder	*Paralichthys spp.*
Gafftopsail Catfish	*Bagre marinus*
Gag Grouper	*Mycteroperca microlepis*
Goliath Grouper	*Epinephelus itajara*
Hammerhead Shark	*Sphyrna spp.*
Hardhead Catfish	*Arius felis*
Hogfish	*Lachnolaimus maximus*
Inshore Lizardfish	*Synodus foetens*
Ladyfish	*Elops saurus*
Lane Snapper	*Lutjanus synagris*
Lined Seahorse	*Hippocampus erectus*
Lookdown	*Selene vomer*
Mangrove Snapper	*Lutjanus griseus*
Mutton Snapper	*Lutjanus analis*
Oyster Toadfish	*Opsanus tau*
Permit	*Trachinotus falcatus*
Pilot Fish	*Naucrates ductor*
Pinfish	*Lagodon rhomboides*
Porkfish	*Anisotremus virginicus*
Puffer	*Sphoeroides spp.*
Red Grouper	*Epinephelus morio*
Redfish	*Sciaenops ocellatus*
Sand Perch	*Diplectrum formosum*
Scaled Sardines	*Harengula jaguana*
Sheepshead	*Archosargus probatocephalus*
Southern Stingray	*Dasyatis americana*
Spanish Mackerel	*Scomberomorus maculatus*
Spotfin Butterflyfish	*Chaetodon ocellatus*
Spottail Pinfish	*Diplodus holbrooki*
Spotted Eagle Ray	*Aetobatus narinari*
Spotted Seatrout	*Cynoscion nebulosus*
Striped Burrfish	*Chilomycterus schoepfi*
Threadfin Herring	*Opisthonema oglinum*
Tiger Goby	*Gobiosoma macrodon*
Tomtate	*Haemulon aurolineatum*
Tripletail	*Lobotes surinamensis*
White Grunt	*Haemulon plumieri*

There does seem to be a correlation between salinity and the green mussels since they are not quite as dominant on the reefs farther south as they are in the upper part of the bay.

An example of this species stronghold on the Courtney Campbell reef is the fact that our marker buoys are held in place using 5/16" galvanized chain which is attached directly to the reef materials. In roughly six months in 2001, those chains grew to 5 inches in diameter each over the entire 20 ft. length.

Maintenance Monitoring

Once an artificial habitat has been created it becomes necessary, from a resource management perspective, to continue to monitor the progress of the reef, both as a whole and as an assemblage of parts, to gauge the effectiveness of the habitat. In other words, is the reef performing the function(s) for which it was originally established? Are the materials breaking down or otherwise causing the reef to be less effective? Are they sinking into the bottom, thus minimizing profile and becoming less useful as a refuge? Have the components of the reef moved or shifted beyond the permitted area? Could construction techniques or material layouts be improved upon in future deployments?

Tampa Bay artificial reefs have been remarkably stable since 1987. The protection the estuary provides from high energy storm events has insulated the materials from the fate that many reefs throughout the State of Florida and the coastal U.S. have suffered in the past. Hurricanes such as Andrew and Hugo have virtually demolished artificial reefs that were seemingly deep enough and big enough to withstand the impacts. Thousands of tons of concrete and ships hundreds of feet long have been twisted and strewn over areas half a mile wide or more. With the exception of some expected settling and siltation, none of the materials on the EPC's permitted sites has ever shown any evidence of movement beyond their original resting place.

Concrete materials of opportunity (bridges, pilings, rubble) remain the preferred substrate for EPC's reef program due to their availability, weight, complexity, and cost. The effectiveness of this type of concrete when used as reef material has been proven time and again, and in the 15 years that this program has been in place, not one dime has been spent to purchase substrate. That is the equivalent of 125 acres of hard-bottom habitat, or in today's economy, \$1.5-2.0 million dollars.

Additional maintenance responsibilities include removing fishing line and tackle from the reefs when needed and performing routine repairs on six marker buoys. Buoy maintenance typically involves replacement of mooring hardware (chains, shackles, swivels etc.) or replacing lost buoys to their exact permitted coordinates.

RECOMMENDATIONS

1. Continue to support the efforts of the artificial reef program in providing habitat diversity and essential fish habitat within an estuarine environment.

2. Promote technical support and interest in compiling a comprehensive species list for both vertebrates and invertebrates that utilize both natural and man-made hard-bottom habitats in Tampa Bay.

3. Encourage local colleges and universities to explore special projects and research related to the economic and fisheries management aspects of natural and man-made hard-bottom habitats in Tampa Bay.

D. J. Karlen (Environmental Protection Commission of Hillsborough County)

- CHAPTER HIGHLIGHTS -

- *Salinity appears to be a factor affecting diversity and abundance throughout the bay.*
- *Benthic community structure is also influenced by DO and the silt and clay content of the sediments.*
- *Within the bay as a whole, there is generally an increase in species richness, diversity, and the TBBI score towards the mouth of the bay.*
- *The TBBI scores indicate that the benthic community in the majority of Tampa Bay is relatively "healthy". The few areas that had low index scores were concentrated around the Port of Tampa, the mouth of the Hillsborough River, and near the St. Petersburg-Clearwater Airport.*

INTRODUCTION

The benthic community consists of the organisms living on and within the bottom sediments. Since these organisms have a limited mobility and exhibit varying tolerances to environmental stress, the benthic community is an important indicator of changes in the quality of the surrounding waters and sediments. In 1993, a baywide benthic monitoring program was initiated for Tampa Bay. This monitoring program is incorporated into the Tampa Bay Estuary Program's (TBEP) Comprehensive Conservation and Management Plan (CCMP) for Tampa Bay (TBNEP, 1996).

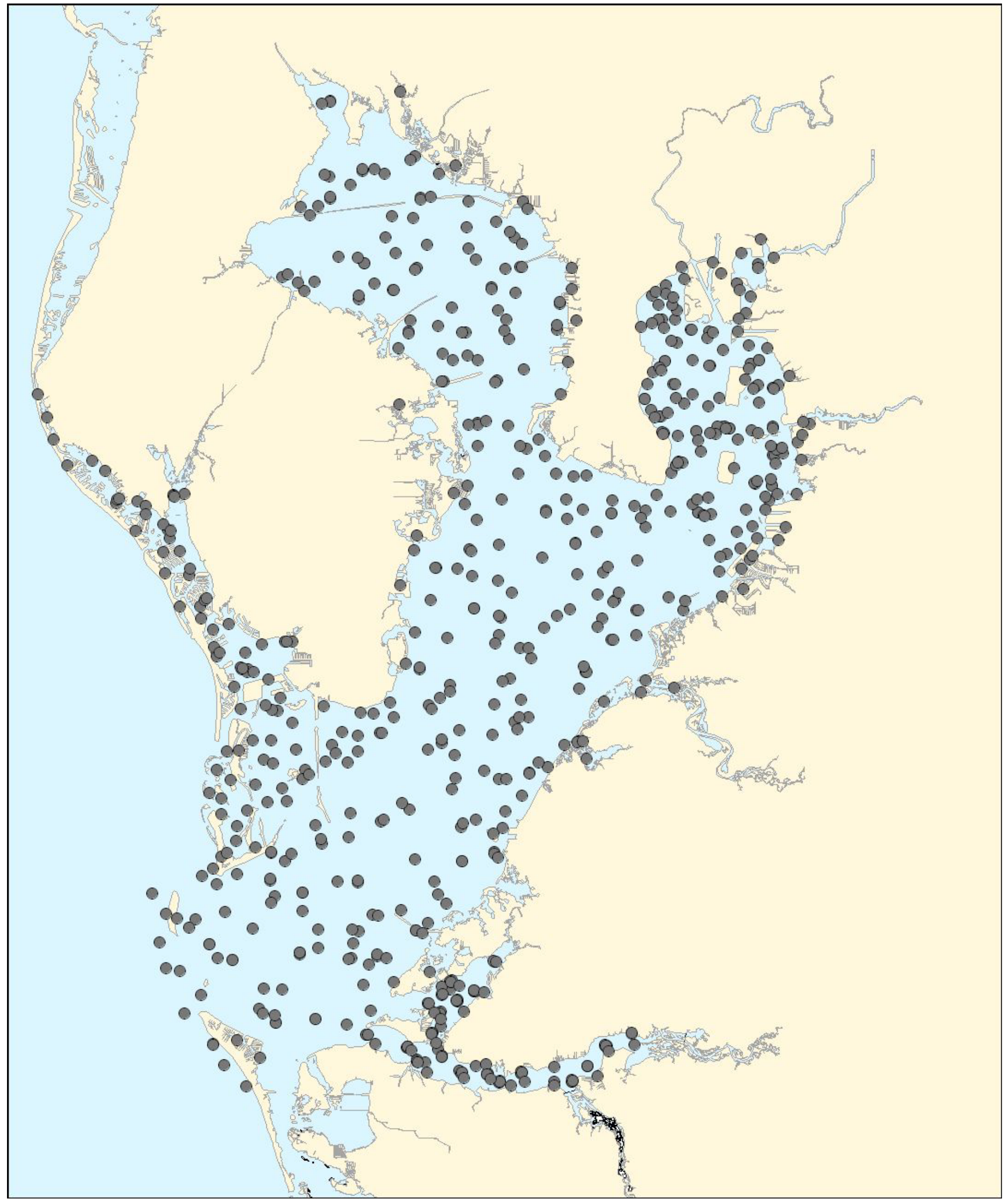

Figure 13-1. Sampling locations for the Tampa Bay Benthic Monitoring Program 1993-1998.

A stratified random probability-based study design was applied (Versar 1992; Courtney et al., 1993). Stratification was by bay segment (Lewis and Whitman 1985). Sample locations for 1993-1998 are shown in Figure 13-1. Samples were collected during the late summer/early fall period to reduce the effects of seasonality. This time of year was also chosen because it is believed to be the time of greatest stress on the benthic community (referred to as the Index Period). During this period, the bay experiences high water temperatures, low salinity, and low dissolved oxygen (DO) concentrations.

Several physical and biological parameters were examined to describe the condition of the benthic community within each bay segment (Tables 13-1 through 13-14). Physical parameters presented include depth, temperature, salinity, DO, and percent silt + clay (%SC) of the sediment. Biological parameters examined include the number of taxa (richness), abundance, Shannon-Wiener diversity (H'), evenness (J'), and the dominant taxa present.

The Tampa Bay Benthic Index (TBBI) was developed to assess the health of Tampa Bay (Coastal Environmental, 1995). Components of this index include H', abundance of tubificid oligochaetes, capitellid polychaetes, gastropods, and amphipods.

In this chapter, results from the first six years (1993-1998) of the Tampa Bay benthic monitoring program are described for Hillsborough Bay, Old Tampa Bay, Middle Tampa Bay, Lower Tampa Bay, Terra Ceia Bay, and the Manatee River segments. For the Boca Ciega Bay segment, data are described for 1995-1998.

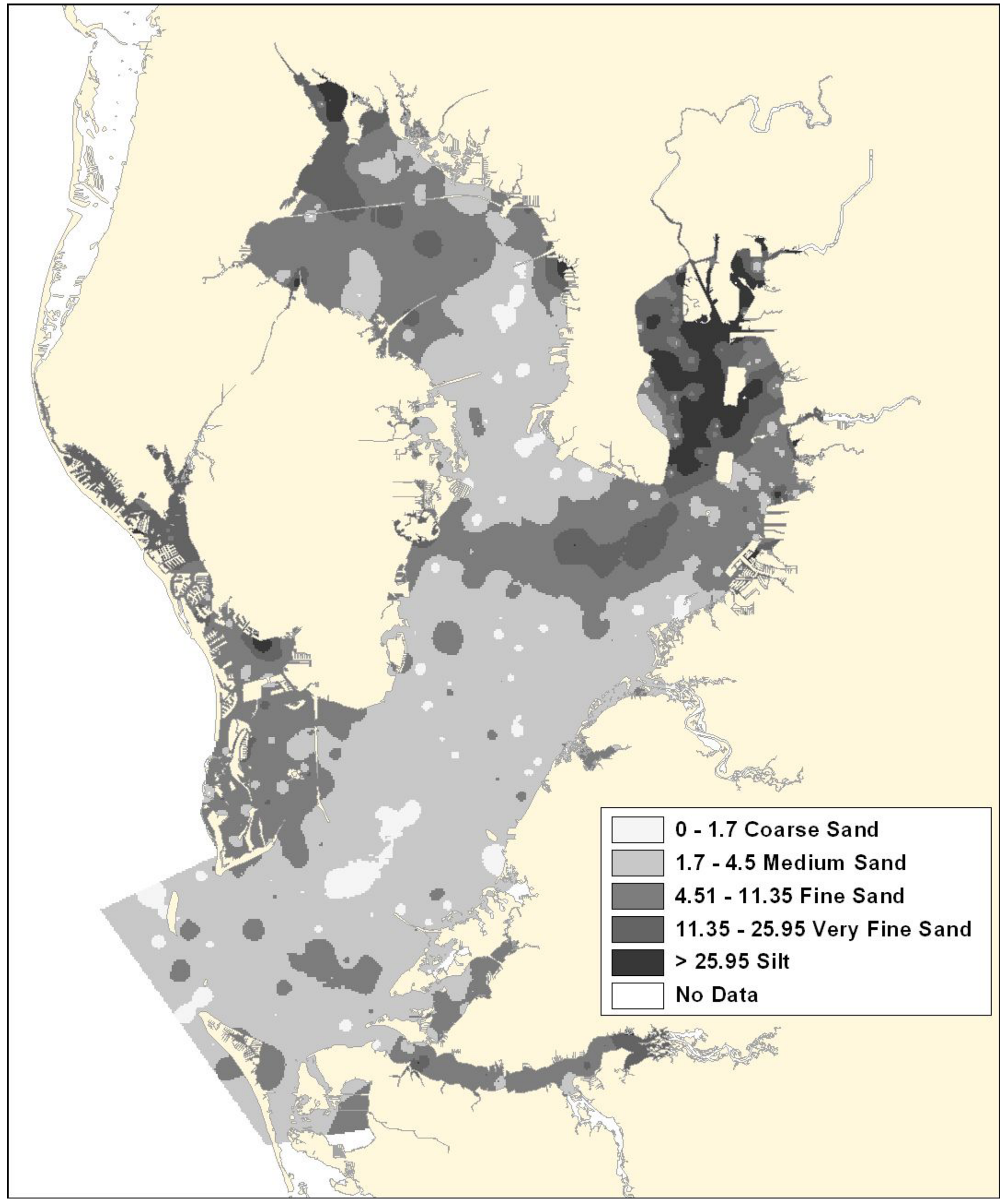

Figure 13-2 Distribution of %SC 1993-1998.

HILLSBOROUGH BAY

Table 13-1 summarizes the physical and biological variables for Hillsborough Bay. Mean bottom temperatures were fairly consistent from year to year, fluctuating by approximately 1°C between years. Mean bottom salinity showed a definite decrease from 1993-1995, increasing again in 1996 - 1997, and dropping again in 1998.

These changes were driven by precipitation, with 1995 and 1998 representing years of higher rainfall. Mean values for bottom DO ranged over 3.6-4.7 mg/L. Minimum DO levels in Hillsborough Bay tended to be lower than the other bay segments. The %SC values were higher relative to other areas of Tampa Bay, with means ranging over 13.0-27.8% and a maximum value of 86.8%.

All of the biological measures showed a decline from 1993-1995, with an increase in 1996. The species richness and abundance were higher in 1997 then dropped again in 1998. The mean abundance was variable, ranging over 4,005-10,034 individuals/m^2. The H', J', and TBBI values were lower in 1997 and 1998 relative to the other years. All years except 1993 had some sites with TBBI scores in the "degraded" range (<4.6; MacDonald et al. 2002).

Table 13-2 lists the top five dominate taxa in Hillsborough Bay by year. The polychaete *Mediomastus ambiseta* and the bivalve mollusk *Mysella planulata* were the dominant species in 1993 and 1994. *M. ambiseta* was absent from the Hillsborough Bay samples in 1995 and 1996 and was found only in low abundance in 1997 and 1998. In 1995, a new assemblage of species dominated Hillsborough Bay. The dominant taxa included the mussel *Amygdalum papyrium* and the amphipod *Ampelisca holmesi*. This change may have been due to the lower salinity observed in that year (Karlen, 1999). However, neither species were among the dominant taxa in 1998, which was also a low salinity year. The composition of dominant taxa was also unique in 1998. The summers of 1995 and 1998 saw a higher amount of rainfall that contributed to lower salinities.

Hillsborough Bay is considered to be the most degraded segment of Tampa Bay (Hall, 1972; Grabe, 1997a and 1997b), due to the presence of the Port of Tampa and its associated industries, high population density, surface runoff, and point source discharges.

OLD TAMPA BAY

Table 13-3 summarizes the physical and biological measures for Old Tampa Bay. Mean bottom temperatures were fairly stable from year to year. The mean bottom salinity ranged over 18.2-24.5 psu. The lowest mean salinities occurred in 1995 and 1998, while the widest salinity range occurred in 1996. Mean DO was relatively high in Old Tampa Bay, ranging over 4.2-6.1 mg/L. Old Tampa Bay was characterized by sandy sediments.

The mean species richness ranged over 27-35 taxa per sample. Benthic abundance ranged over 9,161-14,775 organism/m^2. Measures for H', J', and the TBBI were fairly similar for 1993-1996, and than dropped in 1997 and 1998. The TBBI for all years indicated a "healthy" benthic community. The dominant taxa varied from year to year (Table 13-4), but the cephalochordate *Branchiostoma floridae* and bivalve *Mysella planulata* were most frequently among the dominant species.

MIDDLE TAMPA BAY

Table 13-5 highlights the physical and biological parameters measured in Middle Tampa Bay by year. The mean bottom temperature was reasonably consistent from year to year. The mean salinity ranged over 20.7-28.6 psu, with the lowest values occurring in 1995. The mean bottom DO was relatively high in all years (>4.0 mg/L). The %SC in Middle Tampa Bay sediments was low for all years.

The mean species richness ranged over 32-45 taxa per sample. Benthic abundance was variable from year to year with mean values ranging over 6770-14,067 organisms/m^2. H', J', and TBBI showed a pattern similar to that seen in Old Tampa Bay, with fairly consistent values over 1993-1996 and then dropping in 1997 and 1998. Overall, the TBBI suggested that the benthic community was "healthy" in Middle Tampa Bay.

Middle Tampa Bay shared many of the same dominant taxa as Old Tampa Bay (Table 13-6). *Branchiostoma floridae* and the gastropod *Caecum strigosum* were particularly common among the dominants over the six-year period.

LOWER TAMPA BAY

Table 13-7 summarizes the physical and biological data for Lower Tampa Bay by year. The mean bottom temperature and bottom salinity ranged over 27.0-29.6°C and 27.5-32.2 psu, respectively. The bottom DO measures were high in Lower Tampa Bay, with the yearly means >5.0 mg/L.

None of the sampling sites over the six year period were found to be hypoxic (<2.0 mg/L). The sediments at the Lower Tampa Bay sites were characterized by a low %SC, and generally consisted of course grained calcareous sand and shell.

The mean species richness ranged over 38-52 taxa per sample and the mean abundance ranged over 4,975-10,101 individuals/m^2. Mean H', J', and benthic indices showed a pattern similar to those seen in the other bay segments, with lower values occurring in 1997 and 1998. All TBBI scores indicated a "healthy" benthic habitat.

Branchiostoma floridae was the dominant taxa in Lower Tampa Bay for all years except 1996, when it ranked second. *B. floridae* was present at 100% of the sites in 1993 and 1994, and was found at ≥75% of the sites in all other years. The other dominant taxa varied from year to year (Table 13-8).

TERRA CEIA BAY

Table 13-9 summarizes the variations in physical and biological parameters in Terra Ceia Bay. The mean bottom temperature varied over 26.3-28.8°C and salinity ranged over 11.9-30.8 psu, with the lowest salinities occurring in 1995. The mean bottom DO values were all >4.0 mg/L. The %SC was low, and the sediments were sandy.

Species richness varied with a mean of 29-50 taxa per site. The benthic abundance ranged over 4,045-9,347 organisms/m^2. Mean H' and J' values varied annually, with the lowest mean values occurring in 1998. The TBBI scores for all years indicated a "healthy" benthic habitat.

Table 13-10 shows the top five dominate taxa in Terra Ceia Bay by year. The amphipod *Ampelisca holmesi*, and the polychaetes *Monticellina dorsobranchialis* and *Paraprionospio pinnata* were consistently found from year to year.

MANATEE RIVER

Table 13-11 summarizes the physical and biological parameters in the Manatee River by year. The mean bottom temperature ranged over 25.9-29.5°C. The yearly mean bottom salinity varied between 9.3 psu and 26.7 psu, with the lowest mean salinity occurring in 1995. Low salinities were also seen in 1993 and 1998. The mean bottom DO ranged over 3.8-5.6 mg/L. Bottom DO was generally >4.0 mg/L, with some hypoxia evident in 1994 and 1996. The mean %SC ranged between 5.4% and 15.6%.

Mean species richness varied between 15 and 39 taxa per site. Benthic abundance was variable from year to year, with mean values ranging over 1,729-19,785 organisms/m^2. H', J' and TBBI all were lower in 1998 relative to the preceding five years. All TBBI scores were >4.6, indicating a "healthy" benthic system.

The top five dominant taxa for each year are presented in table 13-12. Some of the recurring dominants include the amphipods *Ampelisca abdita, Grandidierella bonnieroides,* and the polychaete *Monticellina dorsobranchialis.*

BOCA CIEGA BAY

Table 13-13 summarizes the physical and biological parameters for 1995-1998 by year. Mean bottom temperatures ranged over 27.3-29.5°C and mean bottom salinities were 28.2-33.7 psu. The mean bottom DO levels were all >5.0 mg/L and the minimum DO was >3.0 mg/L. Sediments were generally composed of sand and shell, although %SC >50% were found at a few sites.

Mean species richness varied between 35 and 45 taxa per sample. Abundance was variable too, with mean values ranging over 5,132-10,129 organisms/m^2. Mean H', J,' and TBBI values were lower in 1998 relative to other years. All TBBI scores were >13.0, indicating a "healthy" benthic habitat.

Table 13-14 shows the top five dominant taxa in Boca Ciega Bay by year. The polychaete *Monticellina dorsobranchialis* and tubificid oligochaetes were frequently among the dominant taxa in Boca Ciega Bay. The spirorbid polychaetes *Janua steueri* and *Pileolaria rosepigmentata* were numerically dominant in some years, although their distribution was limited to seagrass sites.

NOTES ON SELECTED TAXA

Many of the dominant taxa are widespread throughout Tampa Bay, although their abundances may vary spatially and temporally. Details on the life histories of some of the more common taxa, and some that have been the focus of earlier studies, are discussed below.

Branchiostoma floridae: *Branchiostoma* (Cephalochordata) is a filter feeder commonly found in sand and courser shell substrates. In this study, *Branchiostoma* occurred throughout the bay, but was particularly dominant in Old, Middle, and Lower Tampa Bay. Stokes (1996) conducted a life history study on *B. floridae* in Old Tampa

Bay, and found that juveniles settled from late May through mid-October, which corresponds to our sampling period. Stokes found densities of *B. floridae* as high as 1200/m^2 (Stokes, 1996).

***Ampelisca abdita*:** The amphipod *Ampelisca abdita* was dominant only in the Manatee River in our samples. Past studies have found *A. abdita* to be an important component of benthic community structure in other parts of Tampa Bay. Santos and Simon (1980) found *A. abdita* to be the numerically dominant species in Hillsborough Bay in 1975-1978. The population tended to crash in late summer due to hypoxia (Santos and Simon 1980). Thoemke (1979) found that the Hillsborough Bay population of *A. abdita* had a lifespan of 6-7 weeks during warm months and females were capable of producing two or more broods in a lifetime.

***Ampelisca holmesi*:** *Ampelisca holmesi* was most prevalent in Hillsborough Bay, and was occasionally present in Old Tampa Bay and Middle Tampa Bay. Although *A. holmesi* was consistently among the dominant taxa in Hillsborough Bay during 1993-1998, it was not a dominant during the 1970s (Thoemke, 1979; Santos and Simon, 1980). Earlier studies (Thoemke, 1979; Santos and Simon, 1980; Lombardo, 1981) may have identified this species as *Ampelisca verrilli*.

***Rudilemboides naglei*:** The amphipod *Rudilemboides naglei* was most abundant in Old and Middle Tampa Bay. Simon and Dauer (1977) also recorded *R. naglei* in Old Tampa Bay. Thoemke (1979) found that *R. naglei* was associated with fine sand with a low silt/clay content in his study of amphipods in Hillsborough Bay.

Mysella planulata: *Mysella planulata* is a small bivalve mollusk which is wide-spread throughout Tampa Bay, but was found in highest density in Hillsborough Bay. *Mysella planulata* was present at only a single station in a 1963 Bureau of Commercial Fisheries (BCF) study (Taylor et al., 1970), but was one of the most abundant mollusks present in 1969, when the BCF stations were re-sampled (Hall, 1972). Santos and Simon (1980) also found that *M. planulata* was dominant initially during their study, and could rapidly regain dominance after hypoxia events.

***Caecum strigosum*:** *C. strigosum* (Gastropoda) was found abundantly in Middle Tampa Bay in courser sediments and was often associated with *Branchiostoma floridae*. Lyons (1989) also found this species associated with *Branchiostoma* (*B. virginiae*) on the east coast of Florida. This species was identified as *Caecum* cf. *johnsoni* during the first few years of the program.

***Streblospio gynobranchiata*:** This spionid polychaete was originally identified as *Streblospio benedicti* prior to 1998, but was recently described as a distinct species (Rice and Levin, 1998). This species was typically found in areas of lower salinity in our study.

***Monticellina dorsobranchialis*:** This cirratulid polychaete is ubiquitous throughout Tampa Bay, except in Lower Tampa Bay. Cirratulids are classified as deposit feeders (Fauchald and Jumars, 1979), and *M. dorsobranchialis* was frequently found in high abundance at sites with a high %SC.

***Mediomastus ambiseta* and *Mediomastus californiensis*:** Two species of the polychaete genus *Mediomastus* (Family: Capitellidae) have been reported from Tampa Bay: *Mediomastus ambiseta* and *Mediomastus californiensis*. Both are deposit feeders and have been found in the same samples, although *M ambiseta* appears to be more prevalent in Hillsborough Bay, while *M. californiensis* is more common in Old Tampa Bay and the southern portions of Tampa Bay. *M. ambiseta* has been reported to occur in mud and muddy sand substrates, while *M. californiensis* has been found in sandier sediments (Warren et al., 1994). *Mediomastus ambiseta* was absent in the 1963 BCF survey (Taylor, 1971). Santos and Simon (1980) and Santos and Bloom (1983) recorded the dominance of *Mediomastus californiensis* in 1977 following a summer defaunation event in Hillsborough Bay. *Mediomastus californiensis* dominated the community for five months then disappeared from the system in their study (Santos and Simon, 1980; Santos and Bloom, 1983).

***Janua steueri*:**
The polychaete *Janua steueri* (Spirorbidae) is epifaunal on seagrass, particularly *Thalassia testudinum* (turtle grass). *J. steueri* was first found in Boca Ciega Bay in 1995, and was identified simply as "Spirorbidae" along with another species, *Pileolaria rosepigmentata*. This species was also reported as *Spriorbis spirillum* in earlier reports (Grabe and Karlen, 1996; Grabe, 1998). Both species were found to be numerically abundant at several stations, but their distribution was limited to seagrass sites.

CONCLUSIONS

Salinity appears to be a factor affecting H' and abundance throughout Tampa Bay, since annual differences in these parameters appear to correspond with changes in salinity. This is most apparent in Hillsborough Bay. In addition to salinity, benthic community structure is also influenced by DO and the %SC content of the sediments. Typically, the benthic community is “healthier” in areas of higher DO and lower %SC, and this is reflected in the species composition and higher TBBI scores. Within the bay as a whole, there is generally an increase in species richness, H', and the TBBI score towards the mouth of the bay.

The TBBI scores indicate that the benthic community in the majority of Tampa Bay is relatively "healthy". The few areas that had low index scores were concentrated around the Port of Tampa and the mouth of the Hillsborough River in Hillsborough Bay and near the St. Petersburg-Clearwater Airport in Old Tampa Bay (Figure 13-3a-f).

Table 13-1. Summary table of physical and biological parameters - Hillsborough Bay.
Mean values shown, minimum and maximum values in parenthesis.

	1993	1994	1995	1996	1997	1998
Sample Size	19	19	29	27	22	23
Depth (meters)	2.6 (0.9 - 4.3)	2.2 (0.9 - 4.3)	2.0 (0.1 - 6.7)	3.8 (0.1 - 14.7)	2.9 (0.2 - 11.8)	3.7 (0.4 - 12.5)
Bottom Temp. (^oC)	29.8 (29.1 - 30.6)	28.6 (27.4 - 29.9)	29.9 (27.4 - 32.7)	28.7 (25.5 - 32.2)	28.8 (27.6 - 29.9)	28.5 (26.2 -33.4)
Bottom Salinity (psu)	24.4 (18.9 - 27.5)	21.4 (16.9 - 25.0)	18.0 (13.0 - 21.8)	24.5 (18.1 - 27.0)	26.0 (1.8 - 28.7)	17.1 (5.3 - 21.5)
Bottom DO (mg/L)	3.9 (0.3 - 7.7)	3.84 (0.5 - 7.2)	4.66 (0.2 - 8.1)	4.14 (1.1 - 6.8)	3.73 (0.0 -5.8)	3.57 (0.3 - 9.5)
% Silt + clay	17.7 (1.7 - 69.7)	27.8 (1.5 - 86.8)	17.5 (1.0 - 70.3)	21.7 (2.7 - 75.4)	20.7 (2.6 - 81.1)	13.0 (1.0 - 39.4)
Species Richness (S)	27 (3 - 47)	20 (0 - 45)	15 (0 - 40)	24 (0 - 48)	27 (1 - 54)	20 (3 - 31)
Abundance (#/m^2)	8933 (150 - 24,538)	5228 (0 - 17,025)	4005 (0 - 15,325)	8794 (0 - 35,750)	10,034 (25 - 31,300)	4046 (150 - 16,100)
Diversity (H')	3.1 (1.3 - 4.0)	2.3 (0 - 4.3)	2.1 (0 - 4.1)	2.6 (0 - 4.1)	2.1 (0 - 2.8)	2.1 (0.2 - 2.9)
Evenness (J')	0.7 (0.4 - 0.9)	0.7 (0 - 1.0)	0.5 (0 - 1.0)	0.6 (0 - 0.9)	0.3 (0 - 0.4)	0.4 (0.0 - 0.6)
Benthic Index	15.9 (8.3 - 22.0)	11.7 (-2.7 - 21.4)	12.5 (-2.0 - 24.0)	15.2 (1.0 - 26.1)	10.1 (1.0 - 15.5)	10.6 (-3.0 - 15.6)

Table 13-2. Hillsborough Bay dominant taxa
(% abundance : frequency of occurrence).

Rank	1993	1994	1995	1996	1997	1998
1	Mediomastus ambiseta [P] (19.8% : 58%)	Mysella planulata [B] (11.5% : 53%)	Amygdalum papyrium [B] (13.1% : 40%)	Mysella planulata [B] (26.4% : 58%)	Mysella planulata [B] (14.2% : 55%)	Prionospio perkinsi [P] (20% : 74%)
2	Mysella planulata [B] (10.6% : 68%)	Mediomastus ambiseta [P] (11.0% : 53%)	Ampelisca holmesi [A] (13.0% : 40%)	Ampelisca holmesi [A] (4.2% : 58%)	Ampelisca holmesi [A] (12.8% : 41%)	Tubificidae [O] (5.0% : 70%)
3	Carazziella hobsonae [P] (7.2% : 74%)	Monticellina dorsobranchialis [P] (8.6% : 32%)	Tubificidae [O] (8.5% : 40%)	Monticellina dorsobranchialis [P] (6.6% : 27%)	Monticellina dorsobranchialis [P] (6.8% : 59%)	Monticellina dorsobranchialis [P] (9.7% : 35%)
4	Paraprionospio pinnata [P] (3.9% : 89%)	Paraprionospio pinnata [P] (4.0% : 58%)	Paraprionospio pinnata [P] (5.1% : 57%)	Podarkeopsis levifuscina [P] (2.3% : 73%)	Prionospio perkinsi [P] (3.5% : 73%)	Carazziella hobsonae [P] (4.8% : 65%)
5	Prionospio perkinsi [P] (3.3% : 95%)	Tubificoides brownae [O] (6.7 % : 32%)	Nereis succinea [P] (3.9% : 53%)	Carazziella hobsonae [P] (5.2% : 27%)	Carazziella hobsonae [P] (3.0% : 64%)	Paramphinome sp. B [P] (6.2% : 44%)
CC = Cephalochordate Br = Brachiopod A = Amphipod Crustacean T = Tanaid Crustacean C= Cumacean Crustacean D = Decapod Crustacean B = Bivalve Mollusk G = Gastropod Mollusk O = Oligochaete Annelid P = Polychaete Annelid S = Sipunculid						
Taxa dominance was calculated from the geometric mean of the relative abundance and frequency of occurrence: $[(\text{relative abundance})^2 \times (\text{frequency of occurrence})^2]^{0.5}$						

Table 13-3. Summary table of physical and biological parameters – Old Tampa Bay.
Mean values shown, minimum and maximum values in parenthesis.

	1993	1994	1995	1996	1997	1998
Sample Size	17	17	23	15	16	16
Depth (meters)	2.2 (0.5 - 4.3)	2.2 (0.6 - 4.0)	2.1 (0.1 - 6.1)	3.3 (0.8 - 7.5)	2.3 (0.3 - 4.8)	2.3 (0.1 - 4.6)
Bottom Temp. (^oC)	28.8 (26.5 - 30.4)	29.3 (28.0 - 30.7)	28.1 (26.7 - 29.3)	30.3 (29.4 - 31.2)	28.7 (26.0 - 29.5)	28.7 (27.5 - 29.3)
Bottom Salinity ($^o/_{oo}$)	24.5 (20.4 - 26.3)	23.0 (19.3 - 24.2)	18.2 (14.6 - 20.4)	23.1 (20.6 - 26.8)	22.4 (0.0 - 26.8)	19.0 (11.8 - 22.8)
Bottom DO (mg/l)	6.1 (2.5 - 11.0)	5.8 (0.2 - 10.2)	5.8 (2.7 - 7.7)	4.2 (0.6 - 6.7)	4.8 (2.6 - 6.8)	5.3 (3.4 - 7.5)
% Silt + clay	5.6 (1.2 - 22.2)	7.6 (0.9 - 62.1)	6.0 (0.9 - 58.2)	7.3 (1.4 - 38.9)	9.0 (3.9 - 23.1)	6.8 (1.1 - 20.5)
Species Richness (S)	35 (12 - 54)	31 (5 - 46)	34 (2 - 54)	35 (13 - 58)	34 (7 - 51)	27 (2 - 64)
Abundance (#/m^2)	10,278 (2738 -25,288)	9161 (1550 - 19,700)	14,775 (425 - 183,400)	11,515 (1250 - 23,750)	13,220 (2350 - 42,200)	9239 (400 - 44,500)
Diversity (H')	3.6 (2.4 - 4.8)	3.5 (1.2 - 4.4)	3.5 (0.3 - 4.9)	3.4 (2.0 - 4.5)	2.2 (0.7 - 2.9)	1.9 (0.1 - 2.7)
Evenness (J')	0.7 (0.5 - 0.9)	0.7 (0.5 - 0.9)	0.7 (0.1 - 0.9)	0.7 (0.4 - 0.9)	0.3 (0.1 - 0.5)	0.4 (0.0 - 0.5)
Benthic Index	19.9 (9.3 - 25.6)	19.6 (7.5 - 28.0)	20.4 (-3.2 - 29.4)	19.5 (4.80- 26.8)	12.2 (0.1 - 20.4)	9.5 (-3.3 - 17.6)

Table 13-4. Old Tampa Bay dominant taxa
(% abundance : frequency of occurrence).

Rank	1993	1994	1995	1996	1997	1998
1	Branchiostoma floridae [CC] (15.3% : 76%)	Branchiostoma floridae [CC] (11.4% : 71%)	Mysella planulata [B] (6.6% : 83%)	Mysella planulata [B] (21.7% : 80%)	Rudilemboides naglei [A] (13.1% : 63%)	Mysella planulata [B] (24.2% : 69%)
2	Rudilemboides naglei [A] (10.7% : 76%)	Prionospio perkinsi [P] (5.8% : 76%)	Caecum strigosum [G] (9.5% : 30%)	Ampelisca holmesi [A] (8.7% : 80%)	Branchiostoma floridae [CC] (10.2% : 56%)	Mulinia lateralis [B] (15.1% : 63%)
3	Prionospio perkinsi [P] (5.5% : 88%)	Eudevenopus honduranus [A] (5.6% : 76%)	Branchiostoma floridae [CC] (4.3% : 48%)	Rudilemboides naglei [A] (8.4% : 67%)	Glottidia pyramidata [Br] (7.0% : 63%)	Amygdalum papyrium [B] (10.8% : 50%)
4	Nucula crenulata [B] (4.4% : 82%)	Metharpinia floridana [A] (6.6% : 59%)	Rudilemboides naglei [A] (4.5% : 44%)	Ampelisca sp. C [A] (5.8% : 47%)	Mysella planulata [B] (5.9% : 63%)	Monticellina dorsobranchialis [P] (5.2% : 44%)
5	Ampelisca sp. C [A] (3.7% : 76%)	Rudilemboides naglei [A] (5.1% : 71%)	Tellina spp. [B] (3.4% : 57%)	Tubificidae [O] (3.8% : 60%)	Monticellina dorsobranchialis [P] (4.0% : 63%)	Ampelisca holmesi [A] (3.5% : 56%)

CC = Cephalochordate Br = Brachiopod A = Amphipod Crustacean T = Tanaid Crustacean C= Cumacean Crustacean D = Decapod Crustacean
B = Bivalve Mollusk G = Gastropod Mollusk O = Oligochaete Annelid P = Polychaete Annelid S = Sipunculid

Taxa dominance was calculated from the geometric mean of the relative abundance and frequency of occurrence:
$[(\text{relative abundance})^2 \times (\text{frequency of occurrence})^2]^{0.5}$

Table 13-5. Summary table of physical and biological parameters – Middle Tampa Bay. Mean values shown, minimum and maximum values in parenthesis.

	1993	1994	1995	1996	1997	1998
Sample Size	20	20	21	24	22	20
Depth (meters)	3.5 (0.6 - 9.8)	3.2 (0.9 - 7.3)	2.7 (0.4 - 6.0)	4.1 (0.5 - 11.1)	4.1 (0.1 - 8.0)	3.8 (0.5 - 7.5)
Bottom Temp. (^oC)	29.7 (28.9 - 31.2)	27.9 (27.0 -28.9)	29.6 (27.9 - 33.0)	30.2 (28.3 - 39.2)	28.3 (27.4 - 30.2)	27.8 (26.7 - 28.7)
Bottom Salinity ($^o/_{oo}$)	27.2 (25.3 - 29.4)	24.0 (20.7 - 29.4)	20.7 (8.2 - 25.1)	27.4 (25.5 - 31.0)	28.6 (26.9 - 32.0)	24.2 (17.2 - 29.7)
Bottom DO (mg/l)	6.2 (4.3 - 9.6)	5.4 (3.8 - 7.4)	5.2 (0.3 - 9.1)	4.9 (3.0 - 8.2)	5.3 (3.1 - 9.3)	5.4 (3.3 - 7.2)
% Silt + clay	3.6 (0.8 - 13.2)	4.1 (1.0 - 36.3)	3.6 (0.6 - 11.5)	6.7 (1.5 - 35.8)	6.9 (4.0 - 17.5)	3.2 (1.0 - 6.4)
Species Richness (S)	34 (23 - 46)	32 (17 - 50)	32 (6 - 59)	34 (3 - 61)	45 (8 - 84)	35 (7 - 71)
Abundance (#/m^2)	8566 (3250 - 18,950)	6770 (2000 - 27,800)	8261 (250 - 67,750)	11,449 (75 - 25,975)	14,067 (1400 - 49,400)	8966 (1250 - 23,200)
Diversity (H')	3.4 (2.2 - 4.6)	3.4 (1.5 - 4.5)	3.5 (1.5 - 4.8)	3.3 (1.4 - 4.4)	2.5 (1.4 - 3.4)	2.4 (1.1 - 3.6)
Evenness (J')	0.7 (0.4 - 0.8)	0.7 (0.3 - 0.9)	0.7 (0.3 - 0.9)	0.7 (0.3 - 1.0)	0.4 (0.2 - 0.5)	0.4 (0.2 - 0.7)
Benthic Index	18.7 (9.1 - 24.3)	19.5 (4.7 - 26.7)	21.2 (5.1 - 29.8)	19.8 (9.8 - 25.7)	12.8 (3.8 - 17.9)	13.2 (2.8 - 20.3)

Table 13-6. Middle Tampa Bay dominant taxa (% abundance : frequency of occurrence).

Rank	1993	1994	1995	1996	1997	1998
1	Monticellina dorsobranchialis [P] (14.8% : 45%)	Caecum strigosum [G] (14.6% : 55%)	Janua steueri [P] (27% : 10%)	Caecum strigosum [G] 18.4% : 33%)	Branchiostoma floridae [CC] (21% : 73%)	Branchiostoma floridae [CC] (14.3% : 70%)
2	Prionospio perkinsi [P] (7.6% : 85%)	Branchiostoma floridae [CC] (8.5% : 85%)	Branchiostoma floridae [CC] (4.1% : 57%)	Rudilemboides naglei [A] (9.8% : 38%)	Caecum strigosum [G] (11.7% : 50%)	Caecum strigosum [G] (17.9% : 40%)
3	Branchiostoma floridae [CC] (8.3% : 75%)	Monticellina dorsobranchialis [P] (18.2% : 35%)	Bittiolum varium [G] (10.2% : 19%)	Mysella planulata [B] (4.9% : 42%)	Tubificidae [O] (3.3% : 55%)	Prionospio perkinsi [P] (6.4% : 75%)
4	Caecum strigosum [G] (6.5% : 40%)	Prionospio perkinsi [P] (3.7% : 75%)	Laeonereis culveri [P] (4.4% : 33%)	Branchiostoma floridae [CC] (4.1% : 46%)	Pinnixa spp. [P] (1.6% : 95%)	Monticellina dorsobranchialis [P] (8.1% : 40%)
5	Ampelisca sp. C [A] (2.2% : 75%)	Nucula crenulata [B] (3.5% : 60%)	Tellina spp. [B] (2.9% : 48%)	Pinnixa spp. [P] (2.2% : 75%)	Tellina versicolor [B] (2.6% : 59%)	Tubificidae [O] (3.6% : 65%)
CC = Cephalochordate Br = Brachiopod A = Amphipod Crustacean T = Tanaid Crustacean C= Cumacean Crustacean D = Decapod Crustacean B = Bivalve Mollusk G = Gastropod Mollusk O = Oligochaete Annelid P = Polychaete Annelid S = Sipunculid						
Taxa dominance was calculated from the geometric mean of the relative abundance and frequency of occurrence: $[(\text{relative abundance})^2 \times (\text{frequency of occurrence})^2]^{0.5}$						

Table 13-7. Summary table of physical and biological parameters – Lower Tampa Bay.
Mean values shown, minimum and maximum values in parenthesis.

	1993	1994	1995	1996	1997	1998
Sample Size	17	17	22	24	21	17
Depth (meters)	5.0 (0.9 - 9.0)	4.2 (0.9 - 8.2)	4.6 (0.4 - 12.2)	3.5 (0.1 - 8.5)	3.2 (0.5 - 6.0)	4.0 (0.4 - 8.2)
Bottom Temp. (^oC)	29.6 (28.4 - 30.2)	27.7 (26.2 - 28.4)	29.4 (28.5 - 30.5)	27.2 (24.1 - 30.3)	27.0 (23.8 - 29.6)	27.7 (26.3 - 28.9)
Bottom Salinity ($^o/_{oo}$)	32.3 (27.9 - 34.3)	28.5 (19.3 - 34.8)	27.5 (23.7 - 30.4)	31.8 (27.7 - 34.7)	29.9 (23.1 - 33.9)	29.7 (25.2 - 32.7)
Bottom DO (mg/l)	5.4 (3.4 - 6.4)	5.2 (3.6 - 6.0)	6.0 (4.3 - 7.2)	6.3 (5.0 - 9.2)	6.3 (5.3 - 9.0)	6.0 (4.4 - 8.2)
% Silt + clay	2.6 (1.4 - 5.9)	2.5 (1.2 - 7.7)	2.5 (0.2 - 7.3)	2.6 (0.8 - 6.9)	6.4 (2.3 - 12.1)	2.3 (0.9 - 5.3)
Species Richness (S)	48 (30 - 79)	39 (16 - 69)	41 (11 - 91)	38 (7 - 56)	52 (2 - 84)	38 (13 - 75)
Abundance (#/m^2)	10,101 (1438 - 30,875)	6218 (1150 - 13,300)	9841 (2125 - 42,950)	9060 (2775 - 27,325)	9357 (50 - 21,500)	4975 (675 - 17,500)
Diversity (H')	4.0 (2.3 - 4.9)	3.9 (1.8 - 4.9)	3.5 (1.0 - 4.7)	3.5 (1.0 - 4.7)	2.8 (0.7 - 3.6)	2.9 (1.6 - 3.5)
Evenness (J')	0.8 (0.6 - 0.9)	0.8 (0.4 - 1.0)	0.7 (0.2 - 0.9)	0.7 (0.3 - 0.9)	0.4 (0.1 - 0.6)	0.5 (0.3 - 0.6)
Benthic Index	20.1 (12.0 - 25.8)	22.1 (10.1 - 28.4)	21.3 (4.2 - 30.4)	21.7 (7.1 - 30.0)	14.5 (5.0 - 19.6)	16.9 (12.6 - 22.6)

Table 13-8. Lower Tampa Bay dominant taxa
(% abundance : frequency of occurrence).

Rank	1993	1994	1995	1996	1997	1998
1	Branchiostoma floridae [CC] (19.9% : 100%)	Branchiostoma floridae [CC] (10.5% : 100%)	Branchiostoma floridae [CC] (6.3% : 77%)	Axiothella mucosa [P] (10.8% : 79%)	Branchiostoma floridae [CC] (14.3% : 81%)	Branchiostoma floridae [CC] (28.9% : 82%)
2	Prionospio steenstrupi [P] (4.6% : 71%)	Caecum strigosum [G] (13.5% : 47%)	Phascolion cryptum [S] (7.1% : 68%)	Branchiostoma floridae [CC] (9.3% : 75%)	Phascolion cryptum [S] (6.1% : 71%)	Pinnixa spp. [P] (3.5% : 82%)
3	Caecum strigosum [G] (3.4% : 53%)	Prionospio perkinsi [P] (4.1% : 71%)	Janua steueri [P] (17.9% : 14%)	Leptochelia sp. [T] (8.0% : 38%)	Leptochelia sp. [T] (2.7% : 57%)	Caecum strigosum [G] (4.7% : 35%)
4	Spio pettiboneae [P] (2.5% : 65%)	Travisia hobsonae [P] (4.6% : 59%)	Fabricinuda trilobata [P] (4.6% : 50%)	Caecum strigosum [G] (7.2% : 38%)	Mediomastus spp. [P] (2.0% : 71%)	Tubificidae [O] (1.9% : 71%)
5	Travisia hobsonae [P] (2.2% : 71%)	Mediomastus californiensis [P] (3.7% : 65%)	Tellina spp. [B] (3.6% : 59%)	Fabricinuda trilobata [P] (8.0% : 25%)	Pomatoceros americanus [P] (5.2% : 19%)	Tellina spp. [B] (1.9% : 65%)
CC = Cephalochordate Br = Brachiopod A = Amphipod Crustacean T = Tanaid Crustacean C= Cumacean Crustacean D = Decapod Crustacean B = Bivalve Mollusk G = Gastropod Mollusk O = Oligochaete Annelid P = Polychaete Annelid S = Sipunculid						
Taxa dominance was calculated from the geometric mean of the relative abundance and frequency of occurrence: $[(\text{relative abundance})^2 \times (\text{frequency of occurrence})^2]^{0.5}$						

Table 13-9. Summary table of physical and biological parameters – Terra Ceia Bay.
Mean values shown, minimum and maximum values in parenthesis.

	1993	1994	1995	1996	1997	1998
Sample Size	7	7	7	8	8	8
Depth (meters)	1.9 (0.6 - 4.0)	2.2 (0.9 - 3.4)	1.5 (0.6 - 2.4)	1.9 (1.0 - 3.0)	2.2 (1.2 - 3.5)	2.2 (1.0 - 3.7)
Bottom Temp. (^oC)	28.0 (26.9 - 29.0)	26.3 (25.1 - 26.9)	27.8 (27.5 - 28.0)	27.7 (26.7 - 28.7)	28.3 (27.5 - 29.3)	28.8 (28.0 - 30.0)
Bottom Salinity ($^o/_{oo}$)	17.4 (15.3 - 18.0)	16.5 (15.3 - 17.5)	11.9 (10.5 - 13.8)	30.4 (28.5 - 32.0)	22.5 (15.0 - 28.0)	30.8 (28.0 - 33.0)
Bottom DO (mg/l)	5.7 (3.6 - 8.1)	5.6 (3.9 - 7.0)	4.7 (3.3 - 5.8)	6.3 (5.0 - 8.7)	5.9 (5.0 - 7.2)	6.5 (6.0 - 7.0)
% Silt + clay	5.4 (2.2 - 10.9)	5.3 (1.7 - 9.4)	3.2 (2.4 - 5.3)	3.4 (2.2 - 5.2)	6.6 (4.7 - 8.4)	4.0 (2.3 - 5.8)
Species Richness (S)	45 (33 - 61)	34 (13 - 69)	29 (15 - 43)	34 (11 - 61)	50 (28 - 80)	39 (14 - 96)
Abundance (#/m^2)	5266 (2088 - 8313)	6293 (1650 - 15,275)	4428 (1300 - 6300)	4075 (500 - 9525)	9347 (1650 - 13,750)	4225 (425 - 13,375)
Diversity (H')	5.6 (4.2 - 5.1)	3.4 (1.2 - 4.8)	3.3 (1.9 - 3.9)	4.0 (3.3 - 4.8)	4.3 (2.9 - 5.0)	2.9 (2.6 - 3.5)
Evenness (J')	0.9 (0.8 - 0.9)	0.7 (0.3 - 0.9)	0.7 (0.5 - 0.8)	0.8 (0.7 - 1.0)	0.8 (0.6 - 0.9)	0.6 (0.5 - 0.7)
Benthic Index	25.5 (21.7 - 30.2)	16.9 (3.2 - 28.0)	16.2 (7.1 - 20.7)	23.8 (21.8 - 28.7)	22.7 (14.8 - 25.2)	16.4 (13.0 - 18.8)

Table 13-10. Terra Ceia Bay dominant taxa
(% abundance : frequency of occurrence).

Rank	1993	1994	1995	1996	1997	1998
1	Ampelisca holmesi [A] (10.0%: 86%)	Monticellina dorsobranchialis [P] (28.2% : 71%)	Tubificidae [O] (27.6% : 100%)	Tubificidae [O] (16.2% : 88%)	Mulinia lateralis [B] (13.1% : 88%)	Ampelisca holmesi [A] (5.9% : 100%)
2	Mediomastus spp. [P] (5.6% : 71%)	Tubificidae [O] (12.0% : 86%)	Monticellina dorsobranchialis [P] (8.4% : 71%)	Monticellina dorsobranchialis [P] (8.3% : 88%)	Cyclaspis cf. varians [C] (5.2% : 75%)	Mysella planulata [B] (3.3% : 88%)
3	Tubificidae [O] (4.3% : 86%)	Paraprionospio pinnata [P] (8.1% : 71%)	Paraprionospio pinnata [P] (6.8% : 71%)	Ampelisca holmesi [A] (7.4% : 88%)	Ampelisca holmesi [A] (4.0% : 88%)	Tubificidae [O] (3.5% : 75%)
4	Monticellina dorsobranchialis [P] (2.7% : 86%)	Mulinia lateralis [B] (6.4% : 43%)	Scolelepis texana [P] (5.2% : 57%)	Cyclaspis cf. varians [C] (4.6% : 63%)	Mediomastus californiensis [P] (3.3% : 100%)	Monticellina dorsobranchialis [P] (3.2% : 75%)
5	Paraprionospio pinnata [P] (3.2% : 71%)	Apoprionospio pygmaea [P] (3.5% : 57%)	Acteocina canaliculata [G] (4.1% : 71%)	Apoprionospio pygmaea [P] (2.6% : 100%)	Acteocina canaliculata [G] (3.9% : 75%)	Phascolion cryptum [S] (2.1% : 100%)

CC = Cephalochordate Br = Brachiopod A = Amphipod Crustacean T = Tanaid Crustacean C= Cumacean Crustacean D = Decapod Crustacean
B = Bivalve Mollusk G = Gastropod Mollusk O = Oligochaete Annelid P = Polychaete Annelid S = Sipunculid

Taxa dominance was calculated from the geometric mean of the relative abundance and frequency of occurrence:
$[(\text{relative abundance})^2 \times (\text{frequency of occurrence})^2]^{0.5}$

Table 13-11. Summary table of physical and biological parameters – Manatee River.
Mean values shown, minimum and maximum values in parenthesis.

	1993	1994	1995	1996	1997	1998
Sample Size	11	11	11	13	13	13
Depth (meters)	2.7 (0.6 - 5.0)	2.8 (0.6 - 4.9)	2.7 (0.5 - 4.0)	2.6 (0.2 - 5.0)	1.8 (0.2 - 4.0)	2.3 (0.5 - 5.0)
Bottom Temp. (^oC)	27.0 (25.9 - 28.8)	25.9 (24.6 - 28.0)	29.2 (25.0 - 33.0)	28.8 (26.5 - 31.0)	29.5 (27.7 - 31.2)	28.4 (27.5 - 30.0)
Bottom Salinity ($^o/_{oo}$)	14.4 (4.3 - 19.7)	21.3 (15.0 - 28.0)	9.3 (4.3 - 14.9)	26.7 (16.0 - 32.0)	23.3 (15.5 - 29.2)	15.4 (2.0 - 30.0)
Bottom DO (mg/l)	4.6 (3.2- 6.5)	3.8 (0.5 - 5.9)	4.1 (2.4 - 5.3)	5.0 (0.3 - 7.8)	5.7 (4.7 - 7.0)	5.6 (4.3 - 8.0)
% Silt + clay	6.6 (1.3 - 13.5)	6.8 (1.3 - 12.6)	5.4 (1.2 - 10.7)	7.8 (2.0 - 15.1)	15.6 (4.0 - 55.4)	6.4 (1.2 - 23.6)
Species Richness (S)	39 (21 - 75)	28 (16 - 50)	32 (23 - 52)	33 (19 - 50)	32 (17 - 59)	15 (1 - 46)
Abundance (#/m^2)	13,008 (4050 - 39,350)	6216 (1550 - 12,650)	10,350 (3325 - 20,800)	19,785 (5000 - 91,700)	8735 (1925 - 29,075)	1729 (300 - 6450)
Diversity (H')	3.4 (1.6 - 4.9)	3.1 (2.0 - 4.3)	3.4 (2.6 - 4.4)	3.0 (1.6 - 4.7)	3.3 (2.0 - 5.0)	1.8 (0.0 - 2.8)
Evenness (J')	0.7 (0.3 - 0.8)	0.7 (0.5 - 0.9)	0.7 (0.6 - 0.9)	0.6 (0.4 - 0.9)	0.7 (0.4 - 0.9)	0.4 (0.0 - 0.6)
Benthic Index	20.8 (10.1 - 27.5)	17.6 (10.1 - 23.9)	18.4 (12.8 - 25.0)	18.1 (8.3 - 26.0)	17.9 (6.7 - 25.3)	9.8 (-2.9 - 17.2)

Table 13-12. Manatee River dominant taxa
(% abundance : frequency of occurrence).

Rank	1993	1994	1995	1996	1997	1998
1	Ampelisca abdita [A] (21.3% : 64%)	Monticellina dorsobranchialis [P] (18.8% : 73%)	Grandidierella bonnieroides [A] (17.5% : 55%)	Ampelisca abdita [A] (42.9% : 77%)	Mediomastus californiensis [P] (14.4% : 85%)	Monticellina dorsobranchialis [P] (10.0% : 31%)
2	Mulinia lateralis [B] (10.9% : 73%)	Paraprionospio pinnata [P] (6.5% : 73%)	Cyclaspis cf. varians [C] (7.8% : 91%)	Grandidierella bonnieroides [A] (5.4% : 92%)	Monticellina dorsobranchialis [P] (12.3% : 69%)	Mediomastus spp. [P] (4.0% : 54%)
3	Amygdalum papyrium [B] (10.5% : 55%)	Mediomastus spp. [P] (4.5% : 83%)	Monticellina dorsobranchialis [P] (8.4% : 64%)	Monticellina dorsobranchialis [P] (7.6% : 62%)	Mysella planulata [B] (7.9% : 77%)	Paraprionospio pinnata [P] (5.5% : 31%)
4	Cyclaspis cf. varians [C] (4.5% : 82%)	Aricidea taylori [P] (5.4% : 55%)	Amygdalum papyrium [B] (6.6% : 64%)	Cyclaspis cf. varians [C] (3.5% : 92%)	Streblospio gynobranchiata [P] (13.9% : 31%)	Branchiostoma floridae [CC] (8.9% : 15%)
5	Ampelisca holmesi [A] (3.9% : 91%)	Mediomastus ambiseta [P] [P] (2.7% : 82%)	Mulinia lateralis [B] (4.5% : 82%)	Amygdalum papyrium [B] (5.2% : 62%)	Paraprionospio pinnata [P] (4.5% : 69%)	Ampelisca holmesi [A] (4.3% : 31%)
CC = Cephalochordate Br = Brachiopod A = Amphipod Crustacean T = Tanaid Crustacean C= Cumacean Crustacean D = Decapod Crustacean B = Bivalve Mollusk G = Gastropod Mollusk O = Oligochaete Annelid P = Polychaete Annelid S = Sipunculid						
Taxa dominance was calculated from the geometric mean of the relative abundance and frequency of occurrence: $[(\text{relative abundance})^2 \times (\text{frequency of occurrence})^2]^{0.5}$						

Table 13-13. Summary table of physical and biological parameters – Boca Ciega Bay.
Mean values shown, minimum and maximum values in parenthesis.

	1995	**1996**	**1997**	**1998**
Sample Size	21	21	21	21
Depth (meters)	1.6 (0.3 - 3.1)	1.6 (0.2 - 4.6)	1.7 (0.5 - 3.0)	1.8 (0.1 - 5.6)
Bottom Temp. (^oC)	27.3 (21.6 - 28.9)	27.9 (22.9 - 31.1)	29.5 (27.9 - 30.5)	28.0 (25.1 - 29.2)
Bottom Salinity ($^o/_{oo}$)	30.2 (27.1 - 34.1)	32.7 (29.6 - 34.4)	33.7 (30.2 - 36.0)	28.2 (25.0 - 32.3)
Bottom DO (mg/l)	6.4 (4.3 - 11.3)	5.9 (3.2 - 8.9)	5.7 (3.8 - 14.0)	5.9 (3.7 - 7.6)
% Silt + clay	7.5 (2.1 - 25.9)	10.4 (1.5 - 36.0)	11.9 (5.2 - 53.5)	7.9 (1.1 - 21.4)
Species Richness (S)	45 (0 - 88)	42 (0 - 72)	35 (0 - 63)	40 (2 - 82)
Abundance (#/m^2)	10,129 (0 - 51,150)	6644 (0 - 24,900)	5132 (0 - 18,100)	6231 (100 - 37,500)
Diversity (H')	3.7 (0.0 - 5.7)	4.1 (0.0 - 5.3)	3.8 (0.0 - 5.1)	2.7 (0.6 - 3.5)
Evenness (J')	0.7 (0.0 - 0.9)	0.8 (0.0 - 1.0)	0.8 (0.0 - 0.9)	0.5 (0.1 - 0.6)
Benthic Index	20.5 (1.0 - 30.9)	23.3 (1.0 - 31.9)	20.5 (1.0 - 33.6)	14.0 (4.3 - 19.7)

Table 13-14. Manatee River dominant taxa
(% abundance : frequency of occurrence).

Rank	**1995**	**1996**	**1997**	**1998**
1	Tubificidae [O] (7.1% : 71%)	Leptochelia sp. [T] (7.7% : 33%)	Tubificidae [O] (8.8% : 57%)	Tubificidae [O] (5.1% : 76%)
2	Janua steueri [P] (16.7% : 24%)	Axiothella mucosa [P] (2.4% : 62%)	Tellina spp. [B] (4.6% : 71%)	Janua steueri [P] (15.9% : 19%)
3	Tellina spp. [B] (3.3% : 81%)	Paraprionospio pinnata [P] (2.5% : 57%)	Mediomastus californiensis [P] (3.5% : 67%)	Monticellina dorsobranchialis [P] (3.7% : 62%)
4	Pileolaria rosepigmentata [P] (14.7% : 14%)	Mysella planulata [B] (2.2% : 62%)	Streblospio gynobranchiata [P] (4.2% : 38%)	Tellina spp. [B] (2.7% : 76%)
5	Monticellina dorsobranchialis [P] (3.1% : 62%)	Monticellina dorsobranchialis [P] (1.8% : 67%)	Monticellina dorsobranchialis [P] (3.2% : 48%)	Branchiostoma floridae [CC] (2.8% : 33%)
CC = Cephalochordate Br = Brachiopod A = Amphipod Crustacean T = Tanaid Crustacean C= Cumacean Crustacean D = Decapod Crustacean B = Bivalve Mollusk G = Gastropod Mollusk O = Oligochaete Annelid P = Polychaete Annelid S = Sipunculid				
Taxa dominance was calculated from the geometric mean of the relative abundance and frequency of occurrence: $[(\text{relative abundance})^2 \times (\text{frequency of occurrence})^2]^{0.5}$				

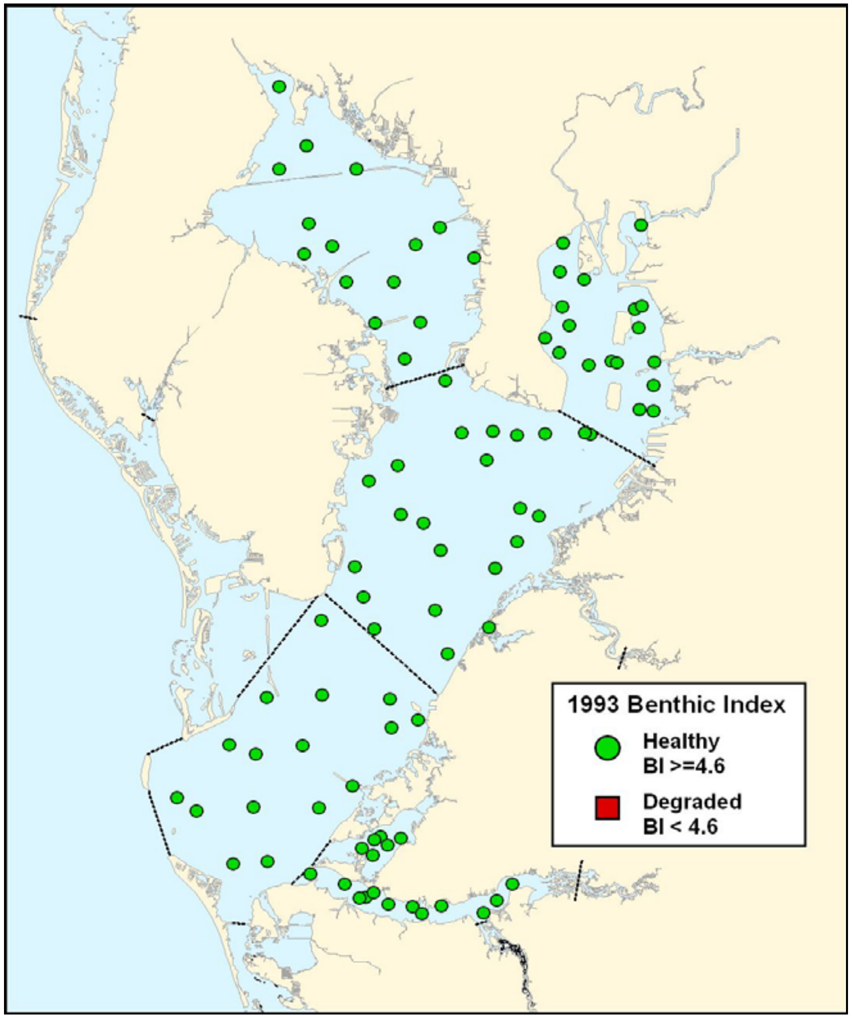

Figure 13-3a. 1993 Benthic Index scores.

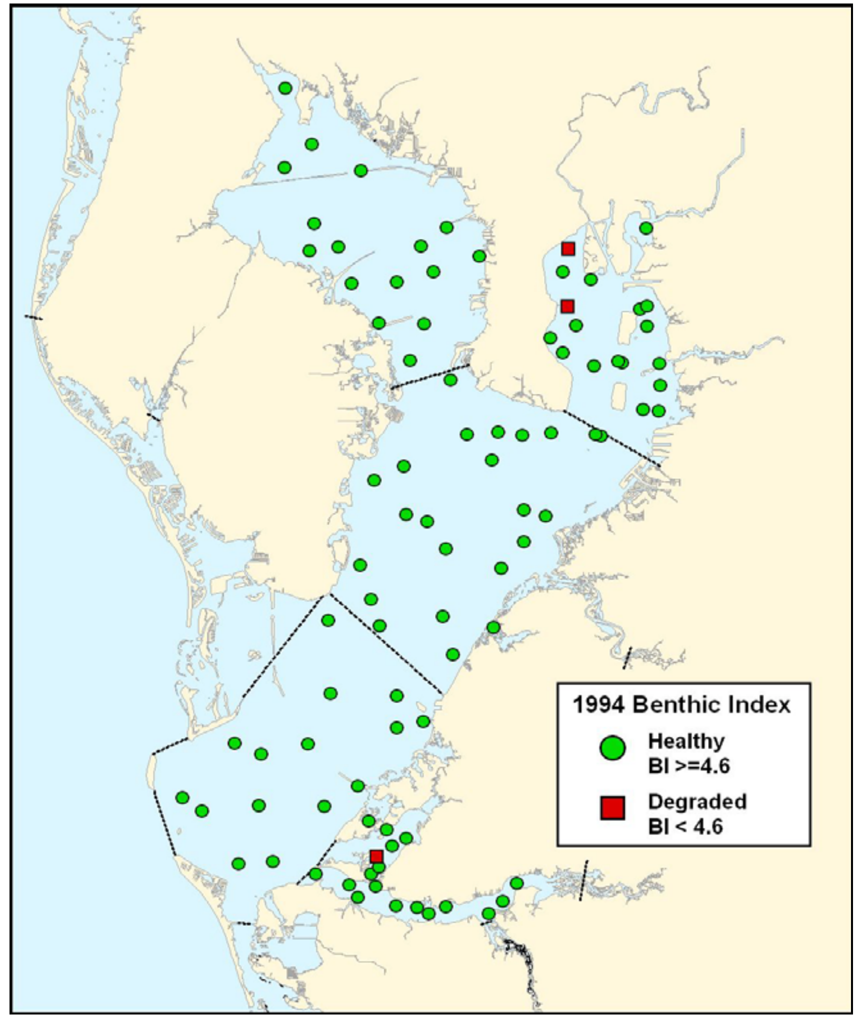

Figure 13-3b. 1994 Benthic Index scores.

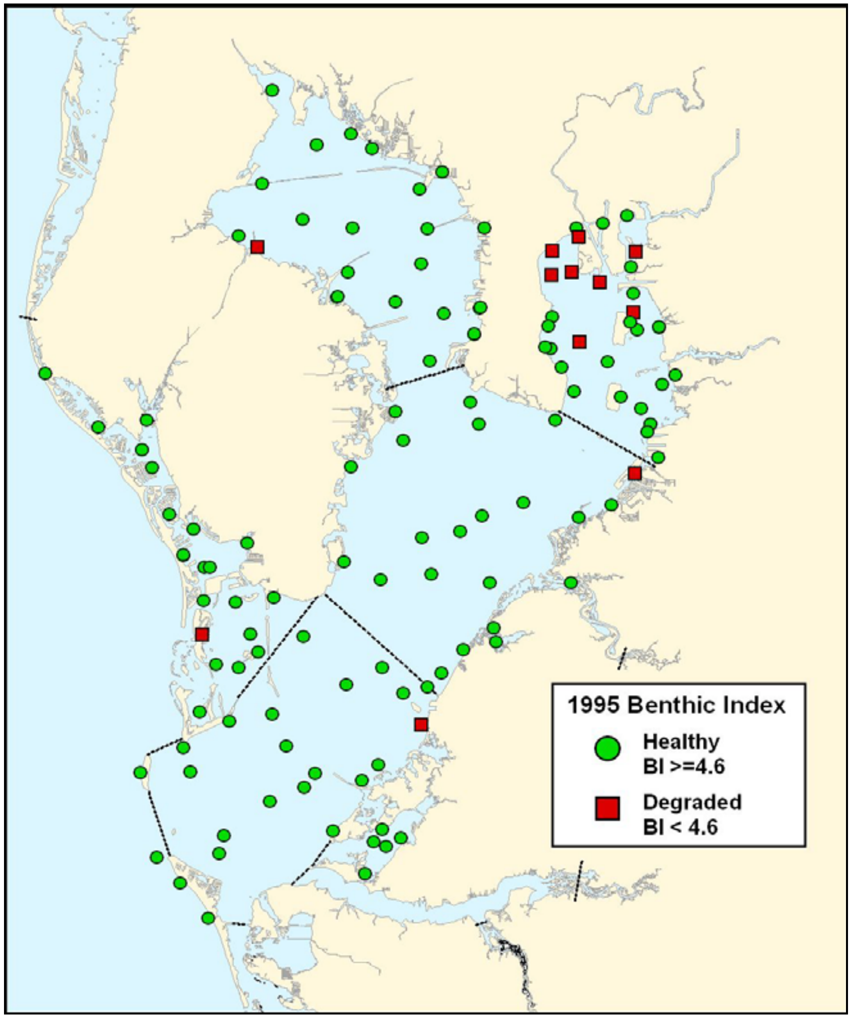

Figure 13-3c. 1995 Benthic Index scores.

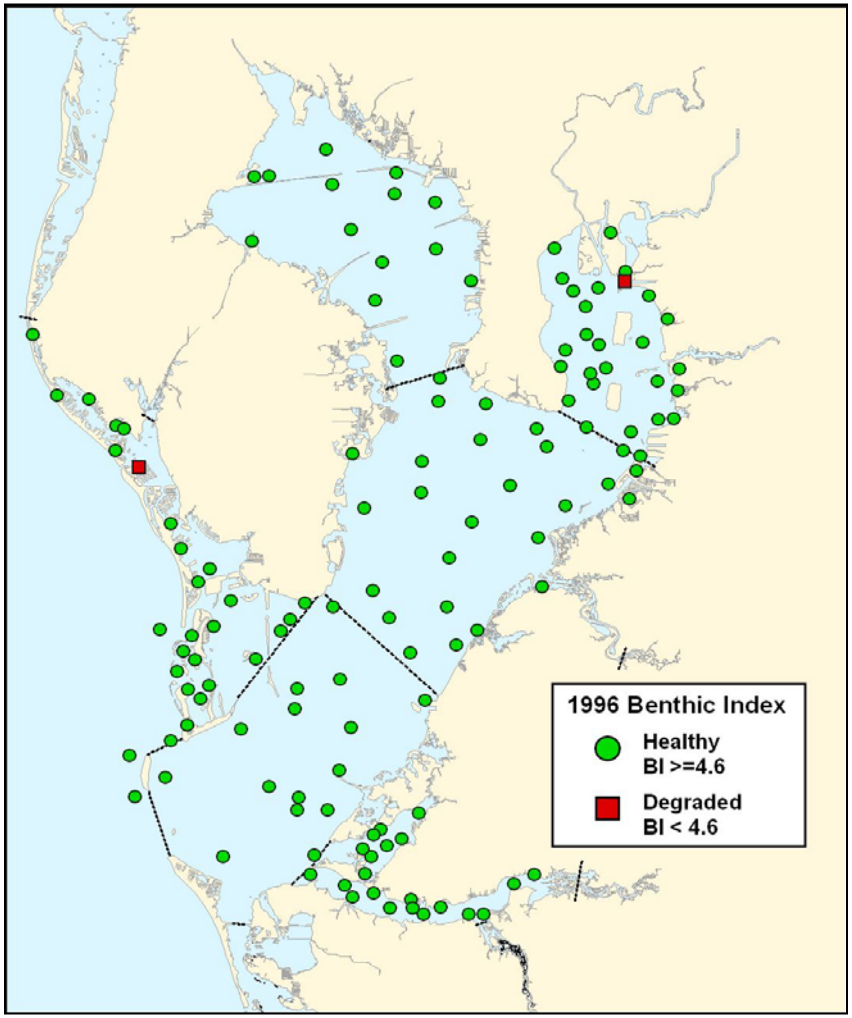

Figure 13-3d. 1996 Benthic Index scores.

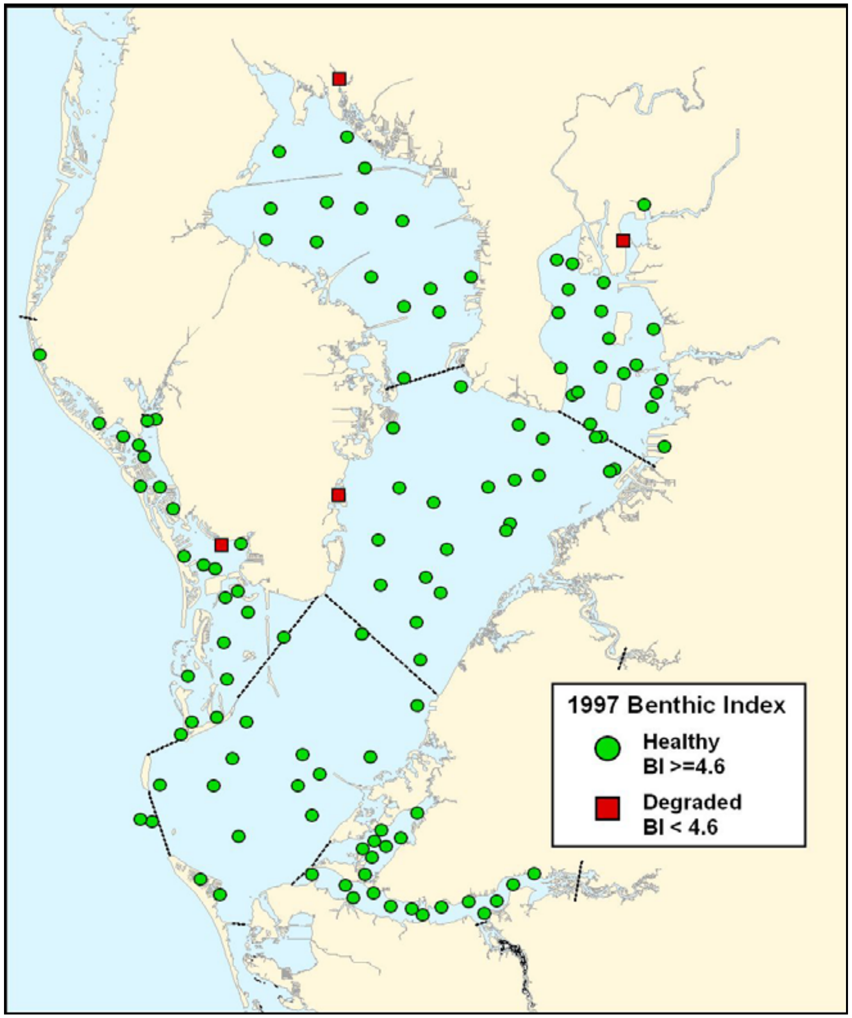

Figure 13-3e. 1997 Benthic Index scores.

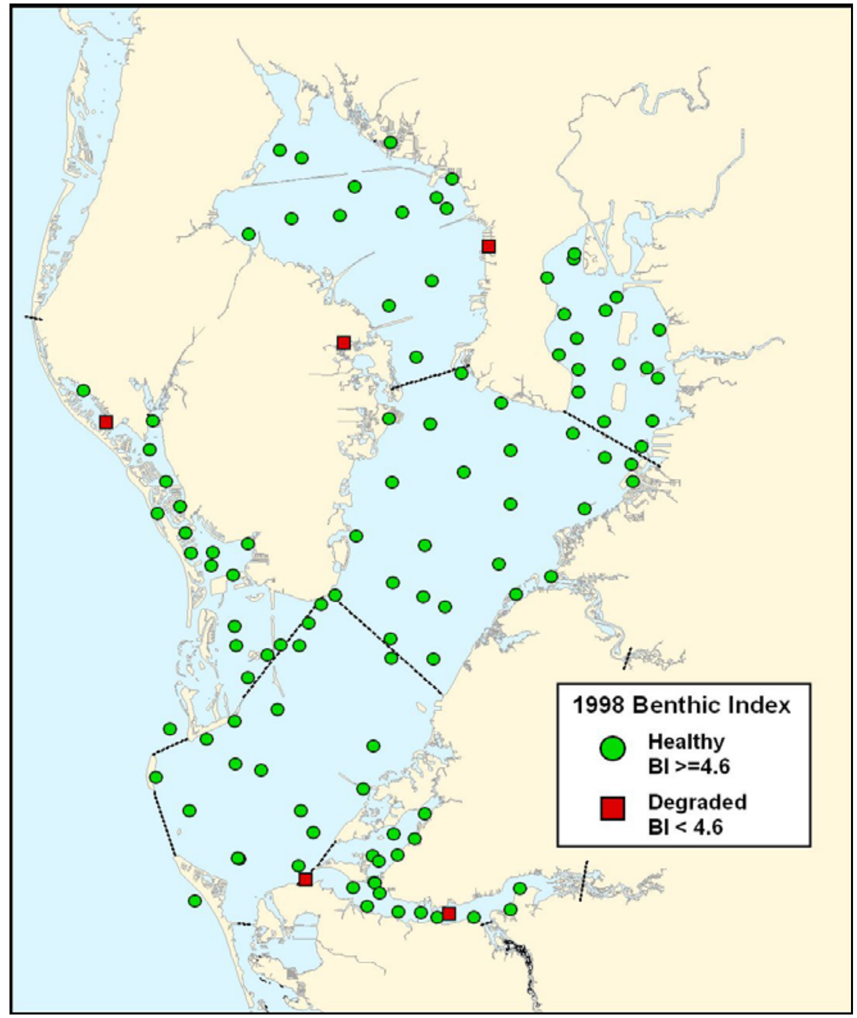

Figure 13-3f. 1998 Benthic Index scores.

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-CHAPTER HIGHLIGHTS-

- *Near-bottom salinities differed by year (i.e., "Index Period") and among tributaries. Tributary salinities generally increased from 1997-2000, a consequence of regional drought conditions. Salinities were generally highest in the Palm River.*

- *Near-bottom dissolved oxygen (DO) concentrations varied spatially within individual tributaries. The Palm River (>75% of measurements <2 ppm) and the Lower Hillsborough River exhibited widespread hypoxia.*

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

- *Benthic community structure differed among tributaries. Mean diversity and mean numbers of taxa were highest in the Little Manatee and Lower Hillsborough rivers. However, the taxa contributing to these metrics differed considerably. The Lower Hillsborough River benthos was characterized by high numbers of polychaete worms whereas crustaceans predominated in the Little Manatee. The Palm River had a relatively high frequency of "empty" samples—a consequence of DO stress within this tributary. Tampa Bay Benthic Index scores were associated with depth (Palm and Lower Hillsborough), DO (Palm and Little Manatee), % silt+clay content of the sediments (Palm and Alafia), salinity (Palm), metals (Lower Hillsborough, Palm, and Alafia), PAHs (Palm), and PCBs (Little Manatee).*

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 1997-2000, 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 during the 1995-2000 sampling period.

METHODS

A total of 269 samples were collected for benthic macroinvertebrates and 130 samples collected for sediment chemistry during the six-year period. 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). Table 14-1 shows the statistics for temperature, salinity, and DO. The frequency distributions of salinity were similar in the Little Manatee and Lower Hillsborough rivers, where mesohaline salinities (5-18 ppt) predominated; the Palm River was predominantly polyhaline (18-30 ppt) (Figure 14-1). Median salinities ranged from 7 ppt (Lower Hillsborough River) to 25 ppt (Palm River), with highest salinities during 2000 and 1996 and lowest salinities recorded during 1997, 1995, and 1998.

Median DO concentrations were lowest in the Palm and Lower Hillsborough rivers and highest in the Little Manatee River. More than 75% of the Palm River samples and approximately 50% of the Lower Hillsborough and Alafia river samples near-bottom DO measurements were indicative of hypoxia (DO<2 ppm) (Figure 14-2). Statistical analysis showed that the distributions of DO in the Alafia and Hillsborough rivers were similar.

Trace Metals: Trace metal concentrations were generally highest in the Lower Hillsborough River and lowest in the Little Manatee River. The frequency distributions of silver, arsenic, cadmium, chromium, nickel, and lead

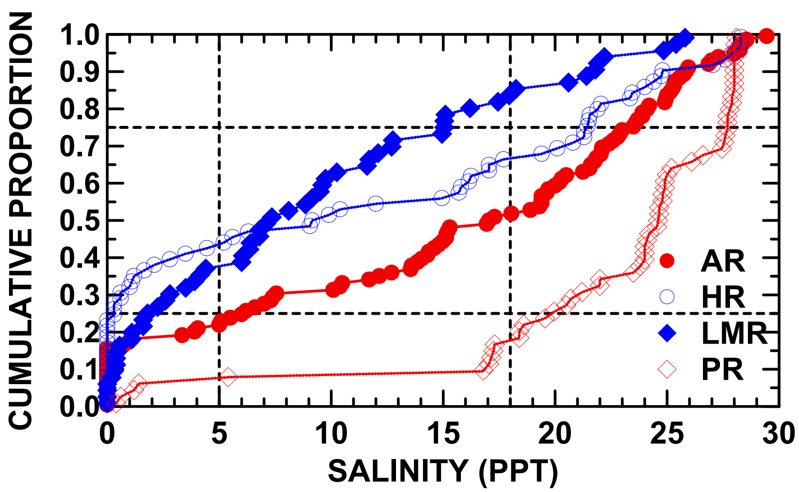

Figure 14-1. Cumulative distribution function plot of near-bottom salinities by tributary, 1995-2000.

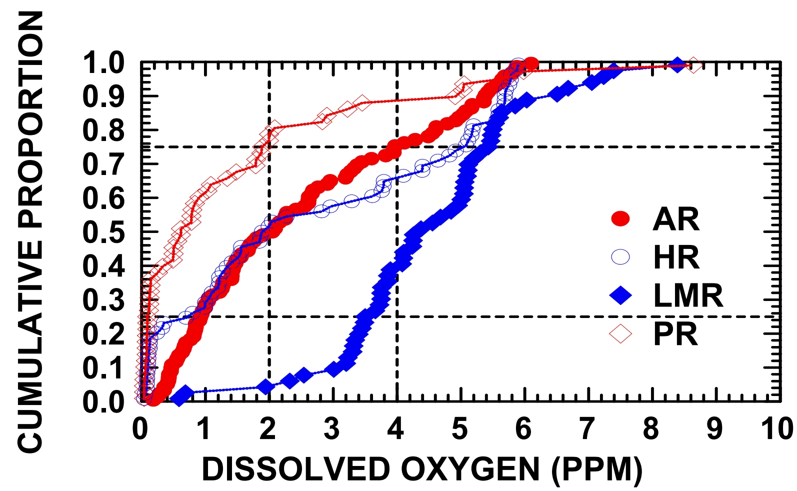

Figure 14-2. Cumulative distribution function plot of near-bottom dissolved oxygen: by tributary, 1995-2000.

concentrations in the Little Manatee River differed from the other tributaries. The frequency distribution of copper in the Lower Hillsborough River differed from the other tributaries and the distribution of lead in the Lower Hillsborough River differed from that of the Alafia River. Concentrations of metals above the Probable Effects Level (PEL) (MacDonald Environmental Sciences, Ltd., 1994)—the concentration above which a contaminant has a high (>50%) likelihood of being toxic to aquatic life—were most frequently observed in the Lower Hillsborough River, especially for copper, lead, and zinc. Lead and zinc concentrations were also above the PEL in >30% of the Palm River samples.

Polycyclic Aromatic Hydrocarbons (PAHs): Total PAH concentrations were highest in the Lower Hillsborough and generally less than the laboratory's method detection limit (MDL) in the Little Manatee River (Figure 14-3). KS tests showed the distributions differed among the four rivers. Approximately 50% of the Lower Hillsborough River samples exceeded the PEL (Figure 14-3) and approximately 50% of the Palm River samples exceeded the Threshold Effects Level (TEL) (MacDonald Environmental Sciences, Ltd., 1994), a concentration that is indicative of moderate levels of contamination.

Organochlorine Pesticides: Total chlordane concentrations were highest in the Lower Hillsborough River and the frequency distribution of chlordane in the Lower Hillsborough River differed from the other rivers (Figure 14-4). Approximately 80% of the Lower Hillsborough River samples exceeded the PEL and none of the Little Manatee River samples exceeded the TEL. Total DDTs also were highest in the Lower Hillsborough River and the frequency distributions were similar among the Alafia, Palm, and Little Manatee rivers (Figure 14-5). Approximately 80% of the Lower Hillsborough River samples exceeded the TEL and none of the Little Manatee and Alafia river samples exceeded the TEL.

Polychlorinated Biphenyls (PCBs): PCB concentrations were generally highest in the Palm and Hillsborough rivers (Figure 14-6), although the frequency distributions for all tributaries were similar (KS test; p>0.05). Lowest (generally <MDL) PCB concentrations were found in the Little Manatee River.

Table 14-1. Summary of near-bottom temperature, salinity, and dissolved oxygen (DO) in four tributaries to Tampa Bay, 1995-2000.

	TEMPERATURE				SALINITY				DISSOLVED OXYGEN			
	HR	PR	AR	LMR	HR	PR	AR	LMR	HR	PR	AR	LMR
MIN	25.5	25.5	25.3	25.5	0.0	0.4	0.0	0.0	<0.1	<0.1	0.2	0.6
MAX	31.1	31.1	30.7	30.9	28.3	28.1	29.5	25.8	6.9	8.9	6.1	8.4
MEDIAN	29.1	30.4	28.7	27.7	9.2	24.6	17.0	7.2	1.9	0.6	2.0	4.3
MEAN	28.9	29.8	28.5	27.9	11.1	22.3	14.9	9.1	2.7	1.5	2.5	4.5

HR= Lower Hillsborough River; PR=Palm River; AR= Alafia River; LMR=Little Manatee River

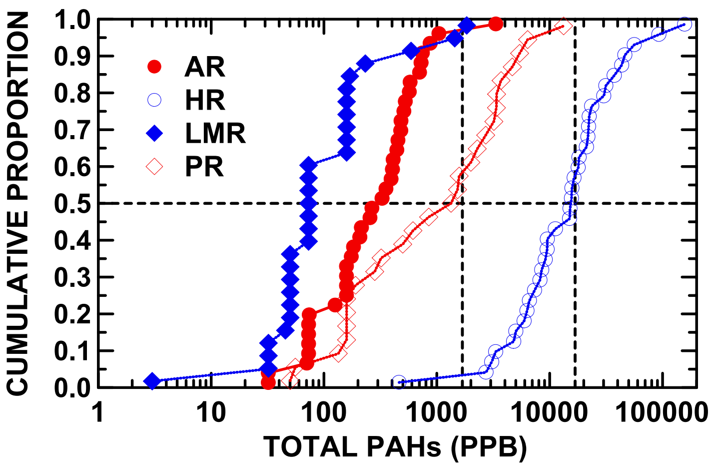

Figure 14-3. Cumulative distribution function plot of total PAHs (ppb) in sediments, by tributary, 1995-2000. Vertical lines demarcate the TEL (1684) and PEL (16770).

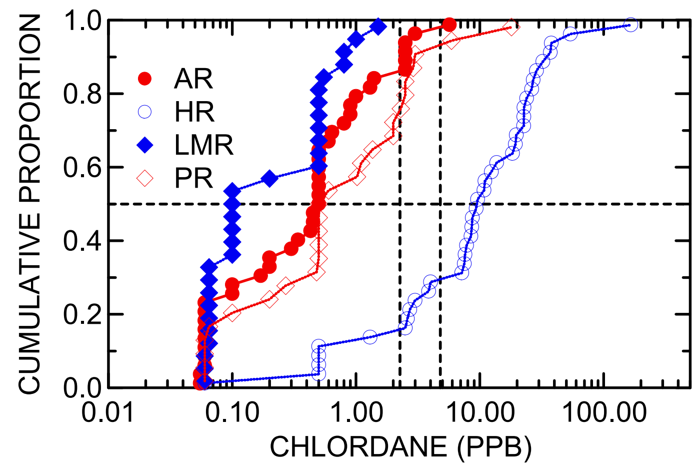

Figure 14-4. Cumulative distribution function plot of total chlordane (ppb) in sediments, by tributary, 1995-2000. Vertical lines demarcate the TEL (2.26) and PEL (4.79).

***Benthic Community**:* Species richness (numbers of taxa) and diversity were generally highest in both the Little Manatee and Lower Hillsborough rivers (Table 14-2). At least 331 taxa were identified from the four tributaries during 1995-2000. Sixty-one taxa were common to the four tributaries; the percentage of taxa identified from only a single tributary ranged from 13.4% (Palm River) to 25.0% (Alafia River). Although almost 200 taxa have been identified from 53 Little Manatee River samples, <100 have been identified from 57 Palm River samples. Approximately 30% of the taxa were polychaete worms and >17% were Crustacea. 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.

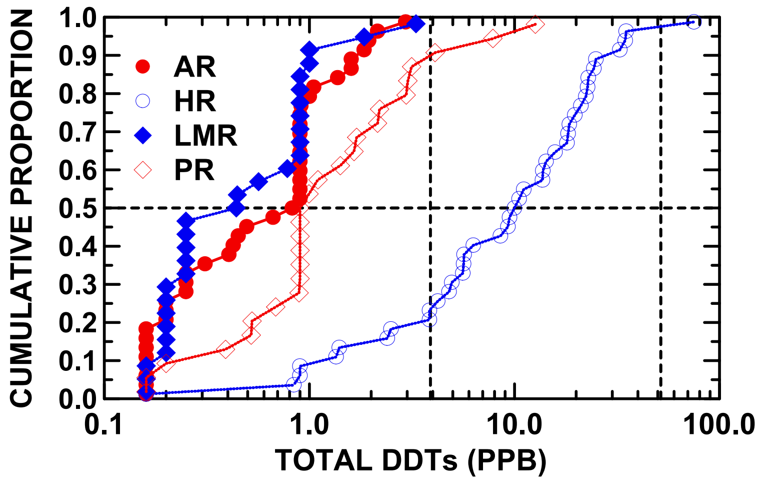

Figure 14-5. Cumulative distribution function plot of total DDTs (ppb) in sediments, by tributary, 1995-2000. Vertical lines demarcate the TEL (3.89) and PEL (51.7).

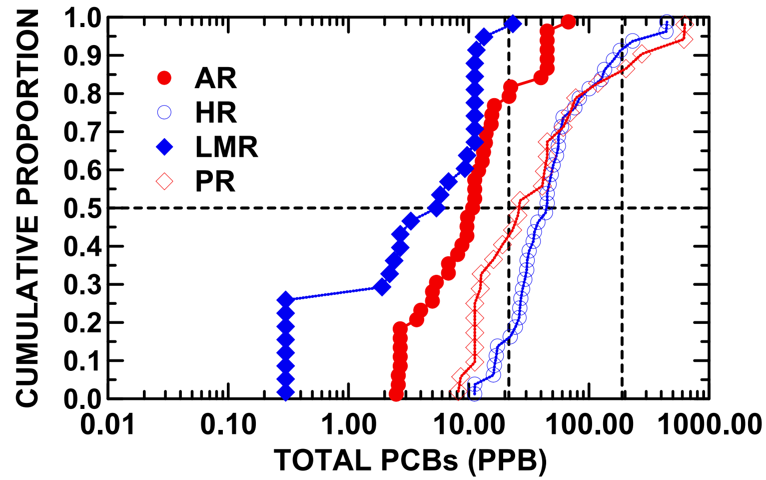

Figure 14-6. Cumulative distribution function plot of total PCBs (ppb) in sediments: by tributary, 1995-2000. Vertical lines demarcate the TEL (21.6) and PEL (189).

The Lower Hillsborough River was dominated primarily by polychaete species (especially *Monticellina dorsobranchialis*) and tubificid oligochaetes (Table 14-3). Polychaetes were the most abundant and most speciose group during each year except 1995. Subdominants varied from year to year and included bivalves, gastropods, tubificid oligochaetes, and, during 1998, insect larvae. The Palm River was also dominated primarily by polychaete worms (especially *Streblospio gynobranchiata*) and bivalves (especially *Mysella planulata* and *Mytilopsis leucophaeata*) (Table 14-4). Amphipod Crustacea were less important and insect larvae were among the subdominants only during 1997.

Tubificid oligochaetes, a spionid polychaete *(S. gynobranchiata*.) and an amphipod (*Ampelisca abdita*) were the dominant taxa in the Alafia River (Table 14-5). There were interannual differences in the abundant and dominant taxa: gastropods in 1995, crustaceans in 1996, oligochaetes in 1997, polychaetes in 1998 and 2000, and bivalves in 1999. Polychaetes were the most speciose group during each year except 1996, when insect larvae contributed considerably to the species inventory.

The dominant taxa in the Little Manatee River were primarily amphipod crustaceans and tubificid oligochaetes (Table 14-6). Amphipod crustaceans were the most abundant taxa during each year. With respect to taxonomic composition, polychaetes, crustaceans, and bivalves were generally the most speciose groups, although aquatic insect larvae represent approximately 15% of the taxa during 1997.

Tampa Bay Benthic Index (TBBI): Frequency distributions differed by tributary. 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 (Figure 14-7). Approximately 60% of the Palm River samples had TBBI scores indicative of "degraded" benthic habitat whereas in the Little Manatee River only approximately 10% of the samples were "degraded" (Figure 14-7). Interannual differences in mean TBBI were observed. Scores were lower in 1997 than during all other years with the exception of 1995 and 2000. TBBI scores were also higher in the mesohaline (5-18 ppt) zone than in the polyhaline (18-30 ppt) zone.

Table 14-2. Summary of benthic community measures: total abundance (number m^{-3}), species richness and diversity

	ABUNDANCE				SPECIES RICHNESS				DIVERSITY			
	HR	PR	AR	LMR	HR	PR	AR	LMR	HR	PR	AR	LMR
MIN	0	0	0	75	0	0	0	1	0.0	0.0	0.0	0.0
MAX	50225	13325	21475	69650	54	35	47	59	3.1	3.6	4.1	4.1
MEDIAN	2975	25	1050	2650	7	1	8	13	1.7	0.0	1.4	2.2
MEAN	6510	1349	3639	5952	13	6	11	16	1.6	0.8	1.5	2.1

HR= Lower Hillsborough River; PR=Palm River; AR= Alafia River; LMR=Little Manatee River

Table14- 3. Five dominant macroinvertebrate taxa by year: Lower Hillsborough River

RANK	1995-1998	1999	2000
1	*Stenoninereis martini (P)*	*Laeonereis culveri (P)*	*Monticellina dorsobranchialis (P)*
2	*Tubificidae(O)*	*Mytilopsis leucophaeata (B)*	*Tubificidae(O)*
3	*Mytilopsis leucophaeata (B)*	*Stenoninereis martini (P)*	*Laeonereis culveri (P)*
4	*Corbicula fluminea (B)*	*Tubificidae(O)*	*Ampelisca holmesi (A)*
5	*Grandidierella bonneroides (A)*	*Monticellina dorsobranchialis (P)*	*Ampelisca abdita (A)*

A= Amphipoda; B=Bivalvia; O=Oligochaeta; P=Polychaeta

Table 14-4. Five dominant macroinvertebrate taxa by year: Palm River

RANK	1995-1998	1999	2000
1	*Mysella planulata (B)*	*Mytilopsis leucophaeata (B*	*Paraprionospio pinnata (P)*
2	*Streblospio gynobranchiata.(P)*	*Tagelus plebius (B)*	*Streblospio gynobranchiata.(P)*
3	*Stenoninereis martini (P)*	*Streblospio gynobranchiata.(P)*	*Stenoninereis martini (P)*
4	*Ampelisca abdita (A)*	*Mysella planulata (B)*	*Mulinia lateralis (M)*
5	*Mytilopsis leucophaeata (B)*	*Macoma constricta (B)*	*Ampelisca holmesi (A)I*

A= Amphipoda; B=Bivalvia; G=Gastropoda;O=Oligochaeta; P=Polychaeta

TBBI and Physico-Chemical Variables: Pearson correlation coefficients for the association between the TBBI for the Lower Hillsborough River (untransformed) and the variables DO, salinity, and %SC were not significant; there was evidence of an increased TBBI as river depth decreased.

Within the Palm River the TBBI was positively associated with near-bottom DO (r^2=0.4) and decreasing sample depth (r^2=0.6) and negatively associated with both %SC (r^2=0.4), and salinity (r^2=0.1). At depths down to approximately 2 m the TBBI was not significantly associated with depth ; at stations deeper than 2-m the TBBI and depths were positively associated (r^2=0.24).

In the Alafia and Little Manatee rivers, Pearson correlation coefficients (untransformed data) were generally not associated with the TBBI. The TBBI was associated with %SC in the Alafia River (r^2=0.07) and with DO in the Little Manatee River (r^2=0.08).

Table 14-5. Five dominant macroinvertebrate taxa by year: Alafia River

RANK	1995-1998	1999	2000
1	*Streblospio gynobranchiata (P)*	*Mytilopsis leucophaeata (B*	*Streblospio gynobranchiata (P)*
2	*Mytilopsis leucophaeata (B)*	*Ampelisca abdita(A)*	*Tubificidae- (O)*
3	*Grandidierella bonneroides (A)*	*Glottidia pyramidata (Br)*	*Ampelisca abdita(A)*
4	*Ampelisca abdita(A)*	*Tubificidae- (O)*	*Mulinia lateralis (B)*
5	*Laeonereis culveri (P)*	*Streblospio gynobranchiata (P)*	*Prionospio perkinsi (P)*

A= Amphipoda; B=Bivalvia; Br=Brachiopoda;O=Oligochaeta; P=Polychaeta

Table 14-6. Five dominant macroinvertebrate taxa by year: Little Manatee River

RANK	1996-1998	1999	2000
1	*Grandidierella bonneroides (A)*	*Tubificidae- (O)*	*Cerapus sp. C (A)*
2	*Tubificidae- (O)*	*Ampelisca abdita (A)*	*Ampelisca holmesi (A)*
3	*Apocorophium louisianum (A)*	*Xenanthura brevitelson (I) & Cyathura polita (I)*	*Grandidierella bonneroides (A)*
4	*Cyathura polita (I)*		*Tubificidae- (O)*
5	*Mytilopsis leucophaeata (B)*	*Glottidia pyramidata (Br)*	*Monticellina dorsobranchialis (P) &Ampelisca abdita (A)*

A= Amphipoda; B=Bivalvia; Br=Brachiopoda; I=Isopoda; ;O=Oligochaeta; P=Polychaeta

TBBI and Sediment Contaminants: Pearson correlation coefficients for the association between the Lower Hillsborough River TBBI (untransformed) and the PEL quotients for PAHs, organochlorine pesticides, and PCBs were not significant; there was a negative association with the PEL quotient for metals (r^2=0.24). Within the Palm River the TBBI was negatively associated with both PAHs (r^2=0.23) and metals (r^2=0.3). Within the Alafia River the TBBI was negatively associated with metals (r^2=0.14). Within the Little Manatee River the TBBI was negatively associated with PCBs (r^2=0.2).

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 1995-2000 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 stormwater discharges, reduction of freshwater inflow, and diminished flushing. The results, similar to those reported from the Lower Hillsborough River, 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. 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). By the fall of 2001 the SWFWMD is scheduled to adopt minimum flows for the Alafia "to establish limits to withdrawals that will not cause significant harm to the water resources or ecology of the area" (SWFWMD 2001).

The Little Manatee River has been the least impacted of these four tributaries, although the watershed has been modified. 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).

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.

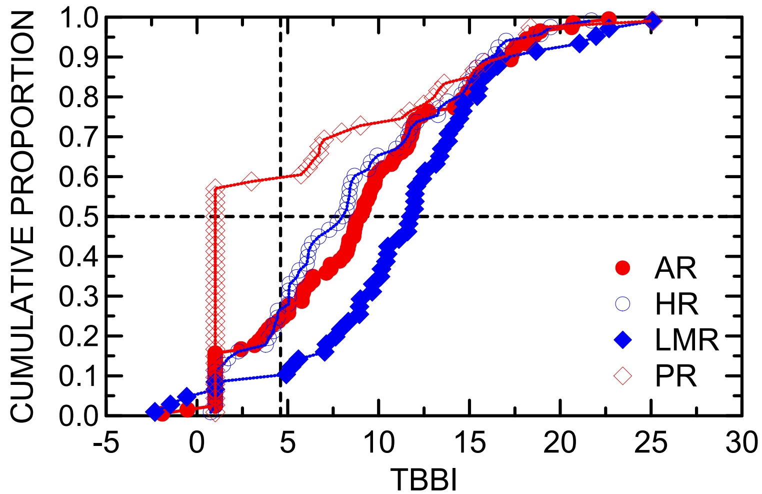

Figure 14-7. Cumulative distribution function plot of the Tampa Bay Benthic Index (TBBI), by tributary, 1995-2000. Scores <4.6 are indicative of "degraded" benthic habitat.

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- CHAPTER HIGHLIGHTS -

- *The Fisheries-Dependent Monitoring program began conducting the field portion of the National Marine Fisheries Service's Marine Recreational Fisheries Statistics Survey (MRFSS) in 1997, providing more reliable catch and effort estimates for the recreational fishery in the Tampa Bay area than had been previously available.*

- *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 and 1995 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 pre-fishery-sized snook were highest in 1999 and2000.*

- *Recruitment of young-of-the-year spotted seatrout has been relatively stable since 1991.*

- *Relative abundance estimates of young-of-the-year blue crab were lowest in 1990 and highest in 1989, 1992, 1995, and 1998.*

INTRODUCTION

Since 1983, the Florida Fish and Wildlife Conservation Commission (FWC) at the Florida Marine Research Institute (FMRI) 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.

FISHERIES-DEPENDENT MONITORING (FDM) PROGRAM

Two of the programs conducted by the Fisheries-Dependent Monitoring (FDM) staff at FMRI obtain information regarding Florida's commercial fisheries. The marine fisheries trip ticket system requires dealers to report their landings and fishing effort so that the commercial fishery can be monitored. The Trip Interview Program (TIP) staff conducts dockside sampling and obtains fish measurements and other characteristics of the fishing trip directly from the commercial fishermen as the catch is being landed. Both the marine fisheries trip ticket system and TIP are designed to monitor the commercial fishery over a larger geographic area than Tampa Bay and will not be discussed further in this chapter.

Since 1981, the Marine Recreational Fishery Statistics Survey has collected data used to estimate the catch and fishing effort of the recreational fishery in Florida. The survey was initially established to provide these estimates for Florida's east (Nassau-Dade counties) and west (Monroe-Escambia counties) coasts. Since 1997, through a cooperative agreement between NMFS, GSMFC, and FWC, the FDM staff has conducted the field portion of the MRFSS in Florida. The FDM staff has increased the number of anglers interviewed by 33% each year and has doubled the number of fish measured and weighed each year. Consequently, estimates of recreational catch and effort for Tampa Bay (Hillsborough, Pinellas and Manatee counties), as well as other areas of the state, are more precise than those produced prior to 1998. In addition to providing catch and effort estimations, these data can be used to describe the abundance and species composition of the recreational harvest.

Beginning in 2001, FMRI's FDM staff, in cooperation with the GSMFC's Fisheries Information Network (FIN), began to conduct biostatistical sampling independent of MRFSS. The focus of the FIN biostatistical project is to collect length and weight data, and otoliths so that age and growth of species harvested by the recreational fishery can be estimated. Additionally, tissue samples of select species are collected to analyze the genetic stock structure and to determine the mercury content of edible tissues.

By the end of 2002, FDM will have collected four complete years of catch and effort data from the recreational fishery in the Tampa Bay area.

Moreover, two complete years of age and growth data about fishes harvested by the recreational fishery will be available. These data are important for assessing the status of recreationally important stocks in Tampa Bay and will be included in subsequent Tampa Bay Environmental Monitoring Reports.

Fisheries-Independent Monitoring (FIM) Program

The Fisheries-Independent Monitoring program at FMRI 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 animals 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.

Monthly stratified-random sampling surveys in which multiple sampling gears are used (21-m seines, 6-m otter trawls, 183-m haul seines, and 183-m purse 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 (1995), Cedar Key (1996), Apalachicola Bay (1997), and St. John's River (2000).

RESULTS

Nearly seven million animals (fishes and select macroinvertebrates), representing 202 taxa, have been collected and released in the 16,745 stratified-random samples (Table 15-1) collected by the FIM program in Tampa Bay since 1989. In the 2001 stratified-random-sampling survey alone, more than 1,200 samples were taken (Figure 15-1); in these samples, more than 500,000 animals were collected and all of Tampa Bay's major areas were sampled. The 21-m seine has collected 85% (n=5,801,228) of the animals since 1989 and has sampled the most diverse species assemblage (169 taxa; Table 15-1). 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 1980s. Strict federal and state regulations effectively eliminated the inshore and offshore fisheries, both commercial and recreational, in 1987. In 1990, 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 three years, at which time they move offshore and join the spawning population of adult red drum.

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 fluctuated between 0.4 and 1.6 fish per set prior to 1996 (Figure 15-2). In Figure 15-2, 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 circles (young-of-the-year) and triangles (pre-fishery) represent the median number of fish collected per set and the vertical line extends from the 25th to 75th percentile. Since 1996, annual relative abundance estimates have been lower, but have fluctuated less (0.2-0.5 fish per set). 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; the peaks in relative abundance of young-of-the-year fish in 1995 and 1997 are apparent, although at different magnitudes, in the pre-fishery-sized fish collected one year later (1996 and 1998, respectively).

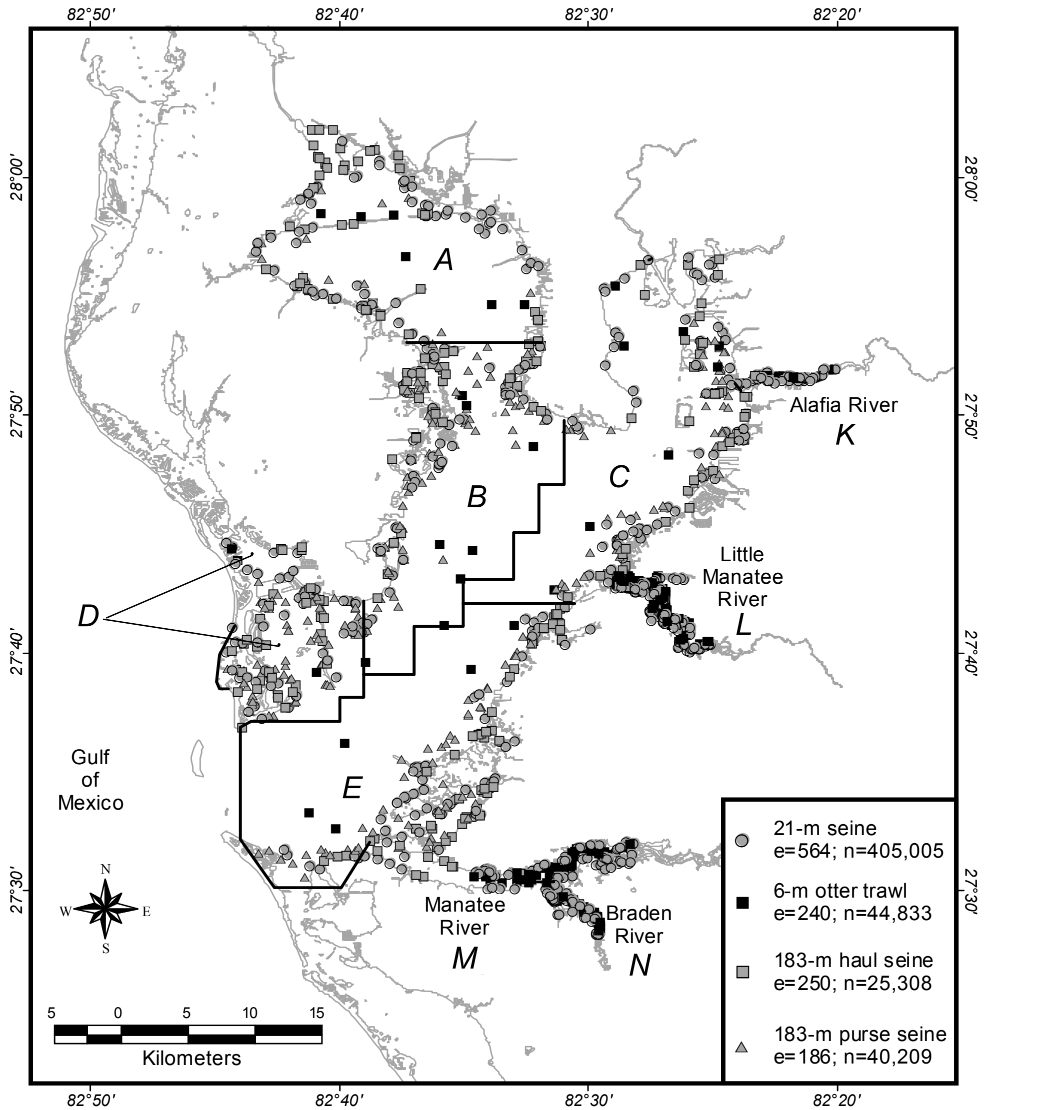

Figure 15-1. Zones (designated by capital letters *A-E* and *K-N*) and sites sampled by the Fisheries-Independent Monitoring program during stratified-random sampling in Tampa Bay, 2001. In the key, "e" denotes the number of samples taken and "n" indicates the number of animals collected.

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 15-3). Figure 15-3 provides 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. The circles (young-of-the-year) and triangles (pre-fishery) represent the median number of fish collected per set and the vertical line extends from the 25th to 75th percentile. 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, and 2000. Estimates of the relative abundance of pre-fishery-sized sheepshead (131-267 mm standard length), which are mostly fish aged one to four years old, peaked in 1996 and 1999.

Table 15-1. The FIM program's stratified-random sampling survey, 1989-2001; 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 - 2001	10,099	5,801,228	169	33
6-m otter trawl	1989 - 2001	3,971	626,919	150	49
183-m haul seine	1996 - 2001	1,375	208,748	120	148
183-m purse seine	1997 - 2001	1,300	152,329	95	170
Total		*16,745*	*6,789,224*	*202*	

Snook (*Centropomus undecimalis*)

Snook are one of the most sought after and illusive 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 and slot limits and 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. Annual estimates of the relative abundance of young-of-the-year snook have generally been less than 0.3 fish per set between 1996 and 2000, but peaked at 0.6 fish per set in 1999 (Figure 15-4). In Figure 15-4, 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 circles (young-of-the-year) and triangles (pre-fishery) represent the median number of fish collected per set and the vertical line extends from the 25th to 75th percentile.

Snook become available to 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 15-4), possibly indicating that the number of snook in the fishery will be relatively higher during the next few years.

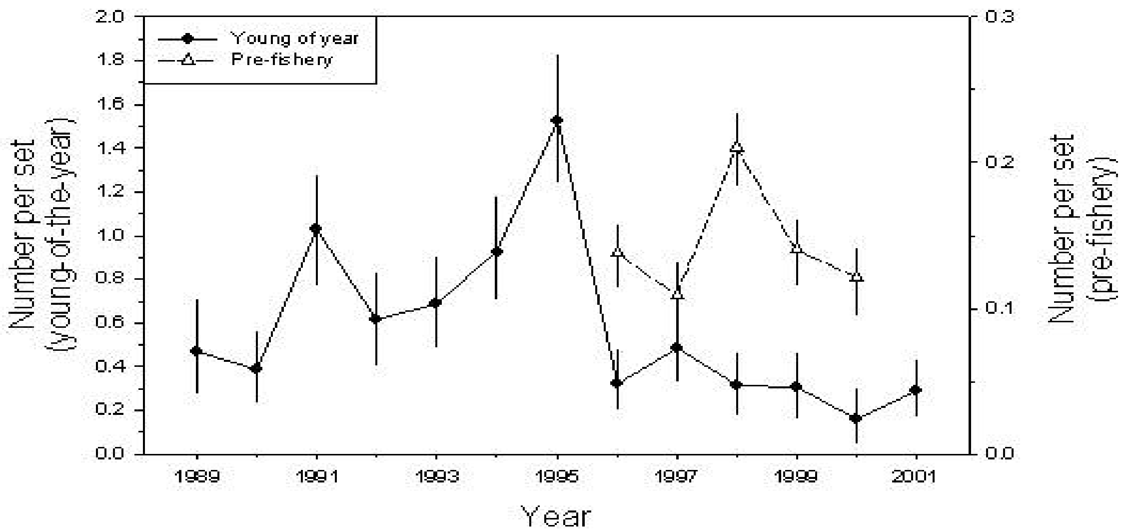

Figure 15-2. Annual estimates of relative abundance of red drum collected in Tampa Bay.

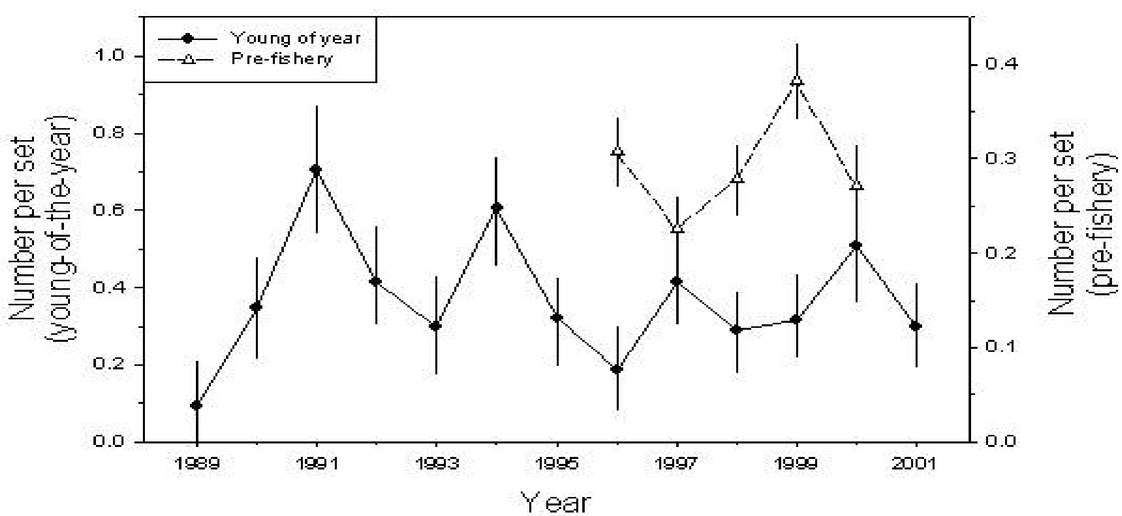

Figure 15-3. Annual estimates of relative abundance of sheepshead collected in Tampa Bay.

Spotted Seatrout

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, 1991, and 1996 (1.2-1.3 fish per set) and lowest in 1990 (0.4 fish per set). Figure 15-5 presents 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 (100-330 mm standard length) spotted seatrout collected per set in 183-m haul and purse seines between May and April are presented. The circles (young-of-the-year) and triangles (pre-fishery) represent the median number of fish collected per set and the vertical line extends from the 25^{th} to 75^{th} percentile. Since 1991, annual recruitment has been relatively constant, fluctuating between 0.6 and 1.2 fish per set. Similarly, the relative abundance estimates of pre-fishery-sized spotted seatrout (100-330 mm standard length) have been relatively stable since 1996.

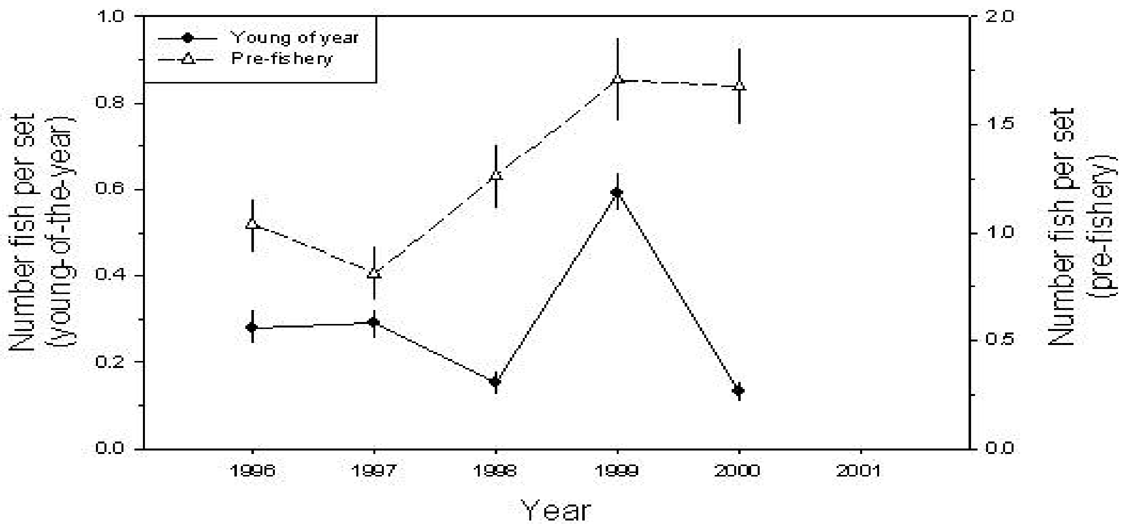

Figure 15-4. Annual estimates of relative abundance of snook collected in Tampa Bay.

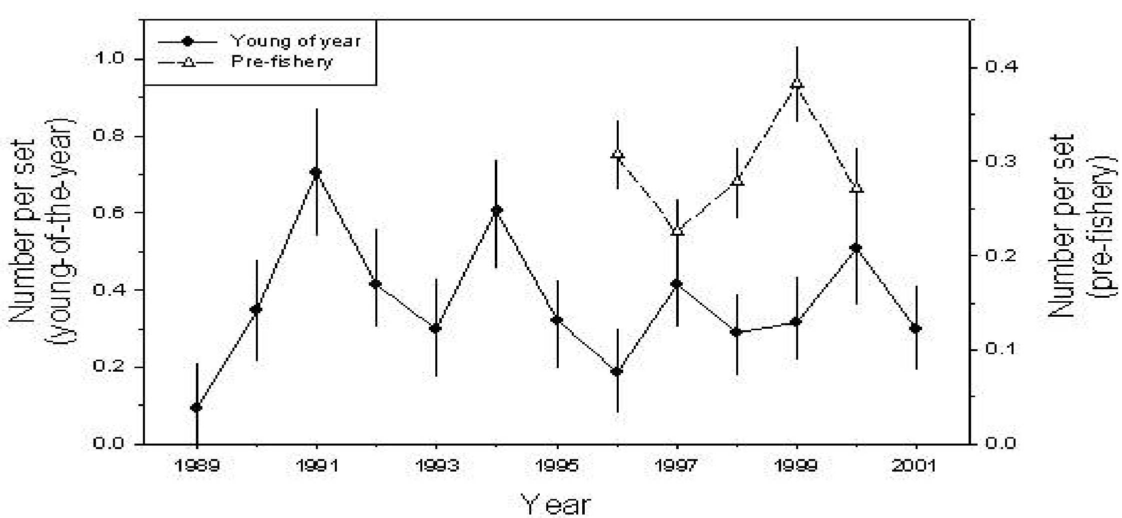

Figure 15-5. Annual estimates of relative abundance of spotted seatrout collected in Tampa Bay.

Blue Crabs

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 1990s 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 annually the 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 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, and 1998; Figure 15-6) have typically been followed by two years of relatively lower abundance. Figure 15-6 presents numbers of young-of-the-year (≤40 mm carapace width) blue crabs collected per set in 21-m seines between September and April. The circles (young-of-the-year) represent the median number of crabs collected per set and the vertical line extends from the 25th to 75th percentile.

Relative abundance estimates from 1989 to 1995 (0.20 crabs per set) and from 1996 to 2000 (0.24 crabs per set) 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.

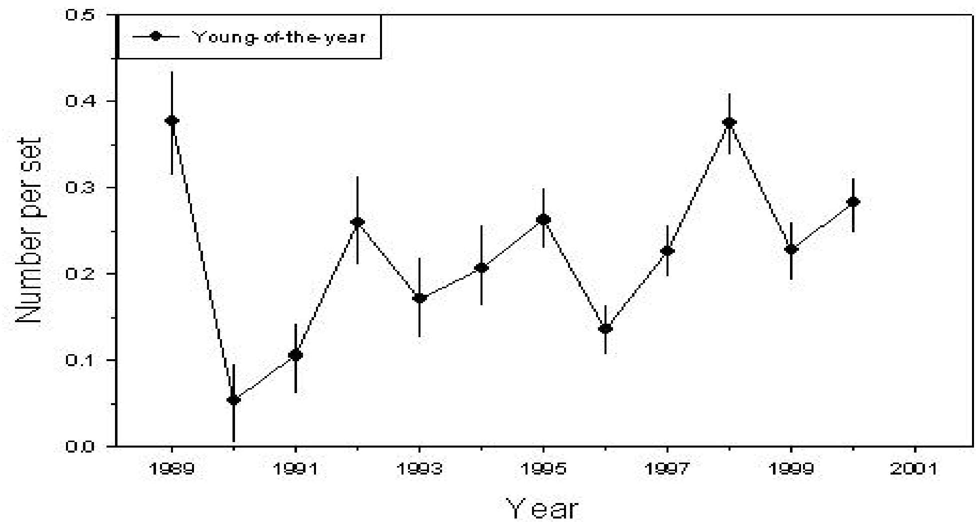

Figure 15-6. Annual estimates of relative abundance of blue crabs collected in Tampa Bay.

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- CHAPTER HIGHLIGHTS -

- *Manatee watercraft mortality for the period 1998-2001 has exceeded perinatal mortality, which was previously the highest category of mortality for the Tampa Bay area.*
- *Manatee aerial survey counts are influenced by a variety of factors and are not a direct measure of the population size.*
- *Bottlenose dolphin sightings data continue to point toward the existence of multiple, stable resident communities of dolphins in Tampa Bay.*
- *Bottlenose dolphin population sizes change more quickly than expected from year to year, which may correlate with changes in resource bases.*

INTRODUCTION

The endangered Florida manatee, *Trichechus manatus latirostris*, and the bottlenose dolphin, *Tursiops truncatus*, can be found year round in Tampa Bay waters. During warmer months, manatees can be found throughout the area, but because of their lack of tolerance to water less than 20°C (68°F), manatees aggregate at the warm water discharges of power plants and at natural warm water springs during cold fronts. Dolphins have a more protective layer of blubber and can tolerate bay water temperatures during any month. Other species of dolphins and an occasional whale are sometimes observed in nearby Gulf of Mexico waters and infrequently strand on Gulf beaches, but are not commonly found within the bay.

Studies of manatees and dolphins in Tampa Bay were not extensive before the mid-1980s. As a result, a number of studies were developed or expanded in the late 1980s to fill gaps in data concerning marine mammals in Tampa Bay. Many of these studies continued through the 1990s and additional projects were initiated as needs were identified.

MANATEE MONITORING PROGRAMS

Mortality

In 1974, scientists at the USGS Sirenia Project (at that time under the USFWS) in Gainesville and Dr. Daniel Odell at the University of Miami established a carcass recovery and necropsy program to determine causes of manatee deaths reported in the southeast U.S (Ackerman et al., 1995; Wright et al., 1995). The Florida Fish and Wildlife Conservation Commission (FWC, formerly the Florida Department of Environmental Protection) assumed responsibility for the program within Florida in 1985, initially using FWC staff, manatee scientists (under contract with the FWC) at the University of Miami, and veterinarians at Sea World of Florida to conduct necropsies. Field staff was gradually hired by the FWC to replace the contracted services, and a pathobiologist was hired by the FWC in 1989 to oversee the necropsy and rescue program. The FWC Marine Mammal Pathobiology Laboratory (MMPL) was built in 1993 at Eckerd College in St. Petersburg with funds from a USFWS Endangered Species Grant. There are four other FWC field stations, located in Jacksonville, Melbourne, and Tequesta on the east coast, and Port Charlotte on the west coast. FWC field staff uses trailers to transport manatee carcasses to the MMPL. Staff of the FWC also coordinates manatee rescues statewide.

From 1998 through 2001, 89 manatee deaths were verified in Hillsborough, Manatee, and Pinellas counties (Table 16-1, Figure 16-1), a mean of 22.25 animals per year (SD=7.45, n=4 years). Deaths are classified into seven categories (Ackerman et al., 1995; Wright et al., 1995). Collisions with watercraft caused 23 deaths, approximately 26% of the total.

In the marine mammal chapter of the previous BEMR report (Ackerman et al., 1999), "perinatal" deaths (natural causes of death to newborn manatees, less than 1.5 m long and still dependent on their mothers) constituted the largest class of manatee deaths (31% of the total) in Tampa Bay. [Unfortunately, perinatal deaths were exceeded by watercraft mortality (approximately 26%) as the largest class of mortality during the period 1998-2001.] However, perinatal deaths still account for approximately 23% (n=20) of mortalities during this time period.

The category of "Other Natural" causes of death (18% of all deaths) includes animals that died as a result of natural phenomena such as disease, infections, cold-related stress, and red tide toxicity. The "Undetermined" category (approximately 31%) includes juveniles and adults that are generally too decomposed for a specific cause of death to be determined. During this period, only two deaths (approximately 2% of mortalities) were determined to be "Human other", the smallest number of deaths by category.

Rescue and Rehabilitation

Staff at the FWC MMPL is responsible for coordinating the rescue of injured manatees statewide, in cooperation with the USFWS Manatee Coordinator in Jacksonville. A manatee-rescue boat was designed by MMPL staff to deploy a net 120 m long and 9 m deep, so that injured animals can be captured in most situations encountered. Injured manatees rescued in Tampa Bay are usually transported to either of two manatee rehabilitation facilities: SeaWorld of Florida in Orlando or the Lowry Park Zoo in Tampa. SeaWorld has participated in manatee rehabilitation since the 1970s. The Lowry Park manatee hospital was completed and began taking injured animals in mid-1991.

The goal of the rescue and rehabilitation process is to treat manatees that need care, by bringing them into permitted oceanaria facilities if needed, and then release them back into the wild population. FWC continues to tag and monitor rehabilitated manatees on the west coast of Florida. During the period 1998-2001, FWC monitored thirteen rehabilitated manatees statewide. However, none of these animals were released into Tampa Bay.

Aerial Surveys

Aerial surveys are valuable for acquiring information on manatee distribution, relative abundance, and use of habitat types. However, it is important to note that aerial survey data should not be considered a direct count of the numbers of manatees in the population. Several types of surveys, in combination with other methods, are used by the FWC to help scientists assess manatee populations: synoptic surveys, distributional surveys, and power plant surveys.

Table 16-1. Causes and numbers of manatee deaths reported in the Tampa Bay area from 1998 to 2001. Data from the Florida Fish & Wildlife Conservation Commission, Marine Mammal Program.

CAUSE OF DEATH	**YEAR DEATH REPORTED**				**TOTAL**
	98	**99**	**00**	**01**	
Watercraft	6	9	2	6	23
Gate/Lock	0	0	0	0	0
Other Human	0	0	0	2	2
Perinatal	4	7	3	6	20
Other Natural	1	3	3	9	16
Undetermined	10	5	5	8	28
TOTAL	21	24	13	31	89

A statewide synoptic survey of all manatee wintering habitats in Florida and southeast Georgia is coordinated on an annual basis by the FWC and has been flown 17 times since 1991. The surveys were conducted by numerous biologists from 15 state, federal, county, and private cooperating agencies. The record statewide count of 3,276 manatees was made during the synoptic count in January 2001, with 1,756 manatees on the West coast of Florida, and 356 manatees counted in Tampa Bay (10.9% of the state total, 20.2% of west coast). Synoptic survey data are now available in GIS format.

Year-round aerial surveys of manatees and dolphins in Tampa Bay's nearshore waters were also conducted to determine their distribution and relative abundance by marine mammal biologists from FWC and Eckerd College, between November 1987 and June 1997 (Reynolds et al., 1991; Weigle et al., 1990; FWC, 2000; Wright et al., 2002). A total of 121 surveys were conducted from small, high-winged airplanes flying at a height of 150 m and a speed of 130 km/hr. Each survey required two airplanes flying simultaneously, one covering each side of the bay. The flights were designed to maximize manatee counts by concentrating on shallow nearshore waters where manatees and their primary food source, seagrasses, are usually located. Wintering and summering manatee usage of the Tampa Bay area has increased since 1994 from approximately 190 in the winter of 1994 to 300 in 2001 and from 100 to 150 animals in the summer. Data collected for each sighting included location, species, number of adults and calves, and behavior. All data were recorded on copies of navigation charts and entered into the FWC's Marine Resources Geographic Information System (MRGIS) for spatial analysis. All of the aerial survey data and flight paths are available on the FWC Atlas of Marine Resources CD-ROM (FWC, 2000) in

ArcView and Arc/Info (Environmental Systems Research Institute, Redlands, California) GIS software format.

Winter distribution of manatees in the bay was centered around the area's power plants. During periods between the passages of cold fronts, manatees leave the power plants to feed on nearby seagrass beds. The four Tampa Bay area power plants are surveyed for manatees each year during the period November-March: most manatees are typically found around the Tampa Electric Company's (TECO) Big Bend power plant discharge at Apollo Beach and the Florida Power Corporation's Bartow power plant discharge in St. Petersburg. The surveys that directly observe manatee use of these warm water sites were also used as part of a manatee-boat interaction study and a calibration study. The calibration study combined repeated winter aerial counts at the Tampa Bay power plants (1999-2002), radio tagged manatees with time/depth recorders, and marking flags to estimate the proportion of manatees that are missed on aerial counts. A correction factor will be developed that integrates the effects of the environment on counts and the bias that occurs during surveys (number of animals undetected by observer) (Edwards et al., in prep).

Manatees also inhabit the waters of Tampa Bay during the warm months, March through November, but are dispersed throughout the Tampa Bay area, making them more difficult to count. Manatees that continue to use the bay during warm months disperse to favored habitats throughout the bay. Spatial analysis of the aerial survey data revealed that areas showing medium to high use by manatees included McKay Bay, Apollo Beach near the TECO power plant,

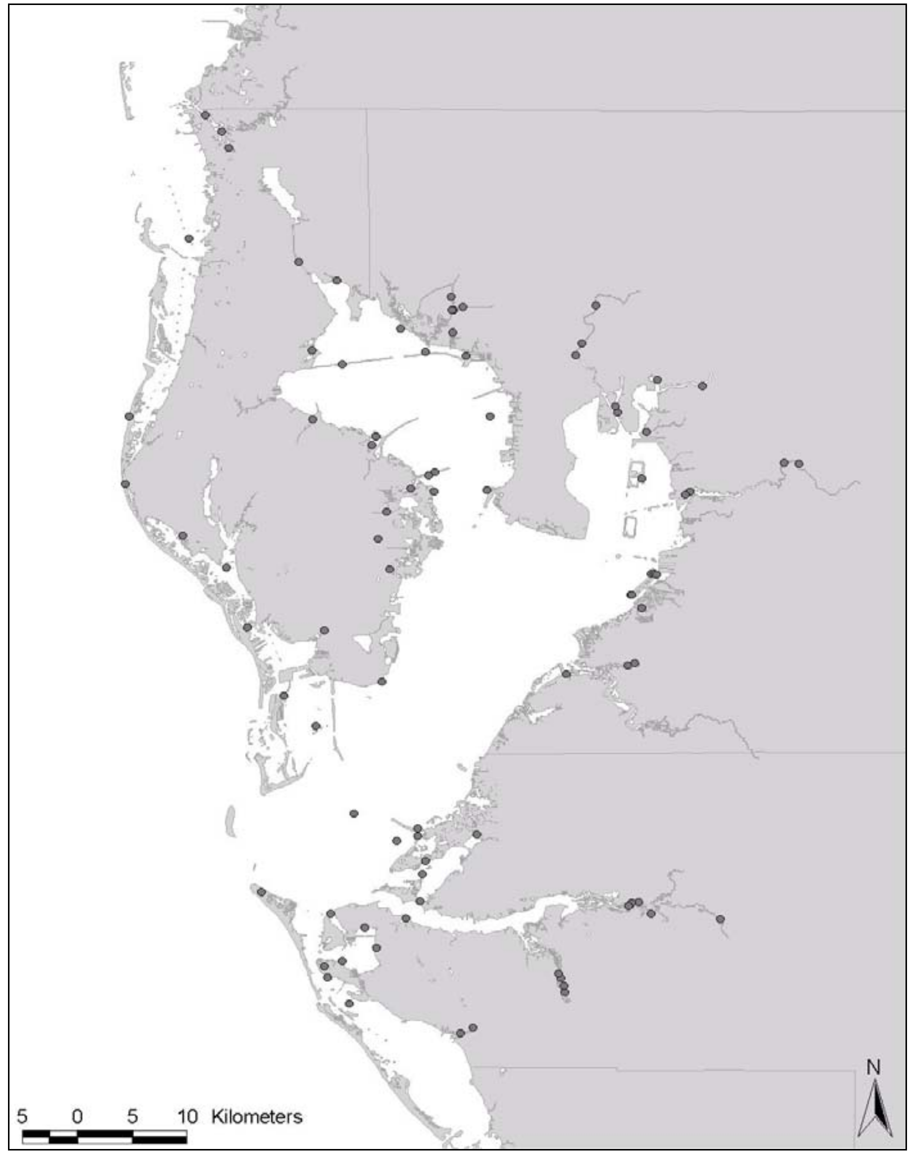

Figure 16-1. Spatial distribution of manatee mortality in the Tampa Bay area, 1998-2001. Data provided by the Florida Fish and Wildlife Conservation Commission (with thanks to T. Pulfer)

Simmons Park in Ruskin, the mouth of the Little Manatee River, Terra Ceia Bay, and the adjoining lower Manatee River, Braden River, Anna Maria Sound, Weedon Island, Safety Harbor, Rocky Point, and Culbreath Bayou.

West Coast Telemetry

While the FWC's West Coast telemetry project ended in February 1997, manatees continue to be tagged and tracked for other projects. The projects in the Tampa Bay area included data collected by monitoring of rehabilitated animals released through the oceanaria program and the calibration study mentioned above. The tagging process involves fastening a belt around the narrow part of the tail stock, and attaching a floating transmitter housing to the belt with a 1.2 m semi-rigid nylon tether. When each animal was tagged, body measurements were taken and scar patterns were recorded for future recognition. The signal from the satellite transmitter was received by NOAA's TIROS weather satellites, and processed by the Service Argos (Largo, MD) receiver, giving a set of location coordinates with date and time, water temperature, and animal activity. Data were delivered daily via Internet or downloaded by FWC staff in St. Petersburg immediately after a satellite pass.

The collection of these data has allowed staff to monitor the movement, behavior, and physical condition of newly released manatees to determine whether they are successfully adapting to their environment. Tagging manatees at the TECO power plant for the calibration study is helping researchers develop a correction factor to apply to the initial aerial count to adjust for animals that are not detected but are present. In addition, results of a major tracking effort from 1991-1996 were recently published in a technical report: "Movements of radio-tagged manatees in Tampa Bay and along Florida's west coast 1991-1996" by Weigle, Wright, Ross, and Flamm (2001).

Other projects have also benefited from the field activities of the telemetry study. Additional beneficial data on the physical conditions of the captured manatees are collected for other projects. When manatees are captured for tagging, FWC staff collects blood and tissue samples from healthy, wild individuals. Ultrasound measurements of blubber thickness are collected during captures for comparison with measurements from dead and injured animals, to provide data for a technique used to evaluate animal condition via blubber thickness.

During tracking and at aggregations, manatees from Tampa Bay to the Everglades were photographed for inclusion in the statewide Manatee Individual Photo Identification System (MIPS) coordinated by the U.S. Geological Survey's (USGS) Sirenia Project and FWC. The computerized system is a catalog of photos of distinctively scarred manatees, which allows researchers to track the movements and life events of individuals over time, as well as examine survival and calving rates. Photographs of all manatees brought to the FWC Marine Mammal Pathobiology Laboratory are compared to those in the catalog.

BOTTLENOSE DOLPHIN MONITORING PROGRAMS

Photo-Identification

Dolphin Biology Research Institute (DBRI) /Chicago Zoological Society: Dr. Randall Wells and his colleagues conducted low-level monitoring of bottlenose dolphins in Tampa Bay between 1988 and 1993 (Wells et al., 1996a; Urian et al., 1997). Funded by the National Marine Fisheries Service, the project was designed to detect large-scale interannual changes in the abundance and production of dolphin stocks in Tampa Bay and to establish a historical database for determining trends in dolphin populations in the Tampa Bay area.

During a six-week period from early September through October of each year, research staff conducted dolphin photo-ID surveys from small boats to estimate a variety of population-rate parameters. Staff used photo-IDs of distinct characteristics of the dolphin's dorsal fin, along with body scars and coloration patterns, to catalog distribution and behavioral patterns of individual animals. When surveys are conducted over an extended study period, resightings of recognizable individuals provide data to estimate population size based on mark-recapture analyses and to monitor birth rates, mortality, immigration, emigration, and transience.

A catalog of 858 different dolphins was developed for Tampa Bay during the project, building on a catalog of 150 individuals first identified in the area during 1975-1987. Identifiable dolphins constituted a high proportion (62% to 82% annually) of all dolphins sighted. The yearly proportion of first-time identifications declined steadily from 74% in 1988 to 14% in 1993, suggesting a relatively closed population of dolphins in Tampa Bay.

Staff used three methods to estimate unmarked animals and the total population:

1) estimation based on the marked (recognizable) proportion of the total group size for each sighting,
2) estimation based on the resightings of marked animals during surveys, and
3) estimation based on the resighting rate of marked animals.

All three methods produced similar mean population estimates for the study: 524 using mark-proportions, 569 using mark-resight, and 516 using resighting-rate methods.

Linear regression analyses of the abundance estimates indicated that there were no significant changes in dolphin abundance during the surveys because the slopes of the regression lines for estimated population vs. year were not significantly different from zero. The birth rate also showed little variation, ranging from 2.8% to 4.0%. Mortality was difficult to measure because of the changes in coverage by stranding network participants, as discussed below.

By combining annual mean maximum rates for immigration (5.5%), emigration (2.3%), and transience (4.5%), the annual proportion of the dolphin population that experienced a change in range (or habitat use) was estimated at 12.3%. These data also suggest that a relatively closed population of dolphins use Tampa Bay.

The estimates of the dolphin population in the bay are considerably higher than the mean and maximum counts made during aerial surveys conducted during the same time period (Weigle *et al.*, 1991). Previous studies have concluded that due to water turbidity and the similar coloration of the water and dolphins, aerial surveys tend to substantially underestimate the numbers of dolphins. Also, aerial surveys were not conducted in the deeper portions of Tampa Bay because the route was planned to cover only shallow-water habitats, which are favored by manatees. Observers in boats also have other methods for locating dolphins that the aerial surveyors could not use, such as noting behavior of birds over dolphin groups and being able to spend more time searching an area.

Several recommendations were made in the final report. Monitoring on at least an annual basis should be continued; more frequent surveys could allow researchers to detect patterns in seasonal fluctuations and better determine population parameter changes. Unfortunately, funding constraints have limited effort to opportunistic surveys since 1993 in the regions not covered regularly by Eckerd College.

Dolphin community structure continues to be a focus of research by Chicago Zoological Society and Mote Marine Laboratory staff and colleagues, in order to define meaningful geographic units for managing the dolphin populations. Photographic identification efforts were expanded up to 9.3 km offshore from Mullet Key southward to Stump Pass; resulting in more than 600 dolphin sightings collected during July 1997-August 1998 (Fazioli, 1999). Comparisons with other photo-ID projects north (as far as Cedar Key, Quintana-Rizzo and Wells, 2001) and south along the central west coast of Florida (Wells et al., 1996b; 1997) have resulted in no evidence of large-scale exchange with Tampa Bay, although a few individuals identified first in Tampa Bay have been subsequently identified in the Gulf of Mexico offshore of Sarasota, and in Charlotte Harbor (Wells et al., 1996a; Fazioli, 1999; K. Hull, pers. comm.). Other sighting data continue to point toward the existence of multiple stable resident communities of dolphins in Tampa Bay (Wells *et al.*, 1996a; Urian et al., 2001, in review). Some individuals have been observed in the same or nearby regions of Tampa Bay over many years (Wells et al., 1996a). For example, two young male bottlenose dolphins returned to Tampa Bay after two years in a research laboratory in California have been re-sighted regularly in Tampa Bay, in or near their original home ranges, over the nearly 12 years since they were released (Wells et al., 1998). One of these two has been known from Tampa Bay since 1984, when he was first tagged near Ruskin. Recently completed genetic studies using samples from biopsy darting provide additional evidence of the genetic distinctions of dolphins living in Tampa Bay vs. the adjacent waters of the Gulf of Mexico (Sellas, 2002). Ongoing genetic studies are testing the population unit designations along the central west coast of Florida (Duffield and Wells, 2002) as well as the Tampa Bay community structure hypothesized by Urian *et al.* (2001; in review). Ongoing studies of bottlenose dolphin in Tampa Bay and elsewhere around the world are reviewed for both general and scientific audiences by Reynolds et al. (2000).

Eckerd College: In 1993, Dr. John Reynolds and undergraduate students at Eckerd College began an intensive study to understand biology and habitat use of bottlenose dolphins in Boca Ciega Bay and adjacent areas of Tampa Bay and the Gulf of Mexico. The work involves identification of individual dolphins using photo-ID techniques and is conducted under a letter of General Authorization issued by the National Marine Fisheries Service to Dr. Reynolds. Now in their tenth summer of research, a number of databases or analytical tools have been developed, including:

1) a catalog containing 600 distinctively marked individual dolphins;
2) a GIS-compatible (Arc/Info and ArcView) database which includes locations of dolphin sightings, environmental factors (tides, bathymetry, seagrasses, weather, and water conditions); dolphin behaviors and other parameters, to permit determination of high use habitats for local dolphins; and
3) dolphin group size and composition.

They are also working in cooperation with Dr. Kelly Debure (Computer Science Department, Eckerd College - Computer Vision) and Dr. Edmund L. Gallizzi (Computer Science Department, Eckerd College - Videography) to develop and refine software (called DARWIN) designed to facilitate and automate the process of matching dolphin dorsal fins.

The Eckerd College Dolphin Project communicates and interacts with Dr. Randy Wells and his colleagues at the Dolphin Biology Research Institute (Chicago Zoological Society/Mote Marine Laboratory) as well as with scientists at the Clearwater Marine Aquarium and the Marine Mammal Pathobiology Lab in St. Petersburg. Over 200 of the animals in the Eckerd College catalog have also been recorded by Wells and his colleagues during their surveys of Tampa Bay waters or by Brad Weigle (1990) at the University of South Florida in the early 1980s. Some of the animals originally sighted by Weigle are still observed by Eckerd College personnel.

Research conducted by the Eckerd College Dolphin Project has resulted in several senior theses and professional presentations; ongoing study topics include

- GIS studies of dolphin habitat use;
- changes in dolphin habitat use and in production of calves following the commercial net ban enacted in July 1995;
- home ranging patterns;
- association patterns among individual dolphins;
- development and application of the DARWIN computer matching program;
- foraging behavior; and
- population size estimates.

Mortality

Reports of cetacean strandings in Florida are managed by Dr. Daniel K. Odell and Dr. Nelio B. Barros, co-scientific coordinators for the Southeastern U.S. Marine Mammal Stranding Network. The primary participants in the Tampa Bay portion of the Network are volunteers from four marine research organizations who are issued Network permits by the National Marine Fisheries Service to retrieve dolphin and whale carcasses and perform necropsies to determine cause of death and obtain tissue samples for other research projects. The Clearwater Marine Aquarium, Mote Marine Laboratory, the FWC Marine Mammal Pathobiology Laboratory, and the Tampa Bay Marine Animal Stranding Team respond to most of the reported strandings. Other permitted individuals assist in the Tampa Bay area on an "as-needed" basis.

From 1998 through 2001, 96 bottlenose dolphin deaths were verified in Hillsborough, Manatee, and Pinellas counties (Table 16-2), a mean of 25.25 animals per year

Table 16-2. Bottlenose dolphin deaths in the Tampa Bay area, 1998-2001. Data provided by Daniel K. Odell, Southeastern U.S. Marine Mammal Stranding Network.

COUNTY	YEAR DEATH REPORTED				TOTAL
	98	99	00	01	
Hillsborough	1	6	0	1	8
Manatee	3	3	6	9	21
Pinellas	13	18	29	7	67
TOTAL	17	27	35	17	96

Rescue and Rehabilitation

Mote Marine Laboratory: Mote Marine Laboratory's (MML) Marine Mammal Stranding Program has successfully rehabilitated and released four bottlenose dolphins and two rough-toothed dolphins since 1992. One adult male bottlenose dolphin, "Freeway," was known from the DBRI photo-ID catalog as a long-term Tampa Bay resident. He was treated for 107 days and released back into his home range, where he was tracked and/or resighted for at least six months following release. In 1994, MML expanded its program, opening a state-of-the-art whale and dolphin hospital in Sarasota, and has accepted animal patients from as far away as North Carolina.

Clearwater Marine Aquarium: The Clearwater Marine Aquarium (CMA) has been a member of the Southeast United States (SEUS) Stranding Network since 1979. It is one of the few facilities on the west coast of Florida that holds a Letter of Authorization from the National Marine Fisheries Service (NMFS) to respond to marine mammal stranding events. CMA's Marine Animal

Stranding Response Team is on call twenty four hours a day, seven days a week. The team consists of biologists, animal handlers, veterinarians, and many specially trained volunteers. Over the years, the team has responded to more than 350 marine mammal stranding events, which include several species of cetaceans, including bottlenose dolphin (*Tursiops truncatus*), short-snouted spinner dolphin (*Stenella clymene*), rough-tooth dolphin (*Steno bredanensis*), sperm whale (*Physeter macrocephalus*) dwarf sperm whale (*Kogia simus*), pygmy sperm whale, (*Kogia breviceps*), beaked whale (*Mesoplodon*), striped dolphin (*Stenella coeruleoalba*), Atlantic spotted dolphin (*Stenella frontalis*), pantropical spotted dolphin (Stenella attenuata) Risso's dolphin (*Grampus griseus*), Fraser's dolphin (*Lagenodelphis hosei*), and Bryde's whale (*Balaenoptera edeni*). Most of the animals CMA responded to were dead when discovered or reported. In such cases, information and samples (if possible) were collected and dispersed to other scientists for ongoing research. When cetaceans strand alive, the chances of successful rehabilitation are usually considered to be minimal.

CMA has cared for many live stranded cetaceans over the past few years. Since 1998, all cetaceans that received rehabilitative care at CMA were originally stranded in Florida with the exception of one striped dolphin (*Stenella coeruleoalba*) from Virginia Beach.

In 1999 CMA successfully released two pantropical spotted dolphins (S*tenella attenuata*) after approximately 10 weeks of care. The original stranding location was Indian River Shores, Florida and the animals were released several miles off of Fort Pierce, Florida. Both animals were fitted with satellite-linked transmitters which yielded 21 days and 42 days, respectively, of post-release tracking information. The last location data were received from an area east of the Bahamas.

In 2000 CMA responded to one live stranded bottlenose dolphin (*Tursiops truncatus*) which died prior to arrival at CMA's rehabilitation facility. Another live animal that was documented by CMA in the year 2000 was a 670 centimeter (approximate measurement) sperm whale (*Physeter macrocephalus*) that entered the intracoastal waterway via Clearwater Pass in October 2000. It remained in shallow water against the shoreline for several hours, then began swimming back under the Sand Key bridge and out the pass escorted by several CMA vessels which cleared the way of boat traffic and helped to guide the whale out into the Gulf of Mexico. There was much cooperation between the National Marine Fisheries Service (NMFS), CMA, The U.S. Coast Guard Station Sand Key, and the Pinellas County Sheriff's Office in forming a response to this event. The whale's movements off of the sand, back out Clearwater Pass, and into the Gulf were fortunate. The third and last live stranded cetacean that CMA dealt with was a juvenile dwarf sperm whale (*Kogia simus)* transferred from the east coast. She survived for approximately one month.

CMA had many cetaceans in rehabilitative care in 2001. One Atlantic spotted dolphin (*Stenella frontalis*), a striped dolphin (*Stenella coeruleoalba*) from Virginia, two separate events of live pygmy sperm whales (*Kogia breviceps*) for a total of three live animals, a bottlenose dolphin (*Tursiops truncatus*), a Risso's dolphin (*Grampus griseus*) and one unprecedented patient, an infant sperm whale (*Physeter macrocephalus*). The sperm whale "George" was named for the stranding site, St. George Island in the Florida panhandle. The 1200 pound, 365 cm whale survived for 43 days before succumbing to infection stemming from severe bite wounds. His presence provided a unique opportunity to gather information.

In December 2001 CMA and the Tampa Bay community said goodbye to its ambassador bottlenose dolphin when long term aquarium resident "Sunset Sam" died unexpectedly. Sunset, a young Atlantic bottlenose dolphin that stranded in Tampa By in May of 1984, resided at the Clearwater Marine Aquarium for over 17 years. His presence gave thousands of community members and visitors an intimate appreciation of the cetaceans that inhabit Florida's coastal waters.

CMA's work is made possible by the efforts of its dedicated volunteers and staff members, supporters, and countless other professionals and facilities that share their knowledge and experience for the improvement of the rehabilitative care of cetaceans. Special thanks go to scientists from Mote Marine Laboratory, Sea World of Florida, Gulf World, Gulfarium, Florida Fish and Wildlife Conservation Commission (FWC), the Marine Mammal Pathobiology Laboratory (MMPL), and the National Marine Fisheries Service (NMFS).

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Richard T. Paul and Ann F. Paul (Audubon of Florida)

- CHAPTER HIGHLIGHTS -

- *The Tampa Bay system is home to 28 species of colonial waterbirds totaling nearly 200,000 individuals, arguably the largest population in the state outside the Everglades.*

- *The breeding population totals 35,000-45,000 pairs annually at 25 or more sites. Up to half the total occurs in Hillsborough Bay alone.*

- *Most rare or coastal species have stable or increasing populations, while many of those that forage commonly or primarily in freshwater wetlands are decreasing.*

- *Raccoons greatly affect the size and stability of nesting colonies.*

- *Human disturbance, however unintentional, can also cause significant nesting failure.*

INTRODUCTION

The Tampa Bay system is home to 28 species of colonial waterbirds and allies, annually totaling about 30,000-45,000 breeding pairs and their young, or nearly 200,000 individuals (Table 17-1). This population is probably the largest and most diverse in Florida outside the Everglades. Maintaining present diversity and overall numbers in a growing metropolitan area of over 2.2 million people is a major challenge that will require the best efforts of both the public and private sectors.

Pelicans and other species that nest in groups (called "colonies") are among the most visible, beautiful, and popular 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 health of coastal and wetland ecosystems. The National Audubon Society (NAS) annually attempts to find and census all known coastal colonies in Tampa Bay. Results from 1994-2001 are reported here.

1994-2001 CENSUS

During the eight-year period, total numbers ranged from 30,000 to 46,000 breeding pairs (Table 17-1). Two species, White Ibis and Laughing Gull, accounted for half to two-thirds of all individuals in most years. Year-to-year fluctuation was probably due in most cases to rainfall patterns and wetland productivity. Longer-term changes, however, were likely a response to urbanization and loss of breeding sites and foraging habitats, especially wetlands. A few uncommon species (Reddish Egret, Roseate Spoonbill, American Oystercatcher, Caspian, Royal, and Sandwich Terns) have experienced sustained population increases.

Twenty-six active or recently active sites were censused (Figure 17-1, Table 17-2). Twenty were islands, five were on causeways along shorelines or on undeveloped lots, and one was on a pair of power line towers. Seven were abandoned during our study period (Table 17-3). Four of the five causeway sites were abandoned due to raccoon predation, and the fifth -- Courtney Campbell Causeway -- was abandoned for the same reason but then was reestablished in 2000 after the raccoon was run over. Two sites were lost to residential development, one to chronic human disturbance, and four to raccoon predation. The seventh site, Howard Frankland Causeway, was abandoned due to habitat manipulations intended to decrease risk to drivers and birds alike. In addition, two large colonies where raccoons have avoided capture in recent years, Tarpon Key and Washburn Sanctuary (Terra Ceia Bird Key), have both had below-normal numbers since 1994, with impacts especially severe on Brown Pelicans. Intensive efforts to capture raccoons prior to the nesting season at Alafia Bank, the largest wading bird colony, have allowed the colony to flourish despite annual return of the predators. Intensive live-trapping efforts have nearly eliminated raccoons on Shell Key, and this colony began to recover in 2002. Likewise, Little Bird Key also recovered following removal of one raccoon in 2001. Trapping continues at Shell Key, Tarpon Key, and Washburn Sanctuary, and remains an annual priority.

Isolation from mammalian predators, particularly raccoons, is a major determinant of colony site selection. In Tampa Bay, most colonies (and all large, persistent ones) are located on islands. But no island is completely inaccessible. During this study, raccoons reached at least 12 colonies. Population numbers at 11 sites declined while predators remained. Despite active live-trapping efforts, at the end of 2001 raccoons remained on four colonies: Alafia Bank, Tarpon Key, Shell Key, and Washburn Sanctuary.

Breeding populations of several species of wading birds, particularly White Ibis, increased dramatically in 1998 due to extremely advantageous foraging conditions provided by the El Niño/Southern Oscillation (ENSO) event of 1997-98. Unseasonable winter rains were followed by extreme drought conditions from late March through June, causing rapid wetland drydown and concentration of prey organisms. Drier conditions since probably resulted in local declines noted in White Ibis, Glossy Ibis, Wood Storks, and Great Blue Herons; see below.

Colony Species Diversity

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 15 or 16 nesting species annually (Table 17-4). Piney Point is also extremely diverse, with 13 species. Alafia Bank appears to have lost species since 1994 when 21 were present, but this is slightly misleading: beach-nesting species including Laughing Gull, Black Skimmer and three species of terns all left Alafia for 3D as vegetation changes occurred. In general, colonies of beach-nesting species held fewer species than colonies of wading birds and allies (pelicans, cormorants, anhingas). Among wading bird colonies, larger colonies tended to have greater diversity. Dot-Dash had 12 nesting species, while Dogleg Key, Coffeepot Bayou, and Alligator Lake all had 10. This is outstanding diversity in even modest colonies of 250-500 pairs.

Diversity and abundance are not the only measures of a colony's significance. Some small colonies may harbor just 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 of the species noted here are listed as Endangered, Threatened, or Species of Special Concern (Table 17-3), while others such as the Gull-billed, Caspian, Royal, and Sandwich Terns nest in a

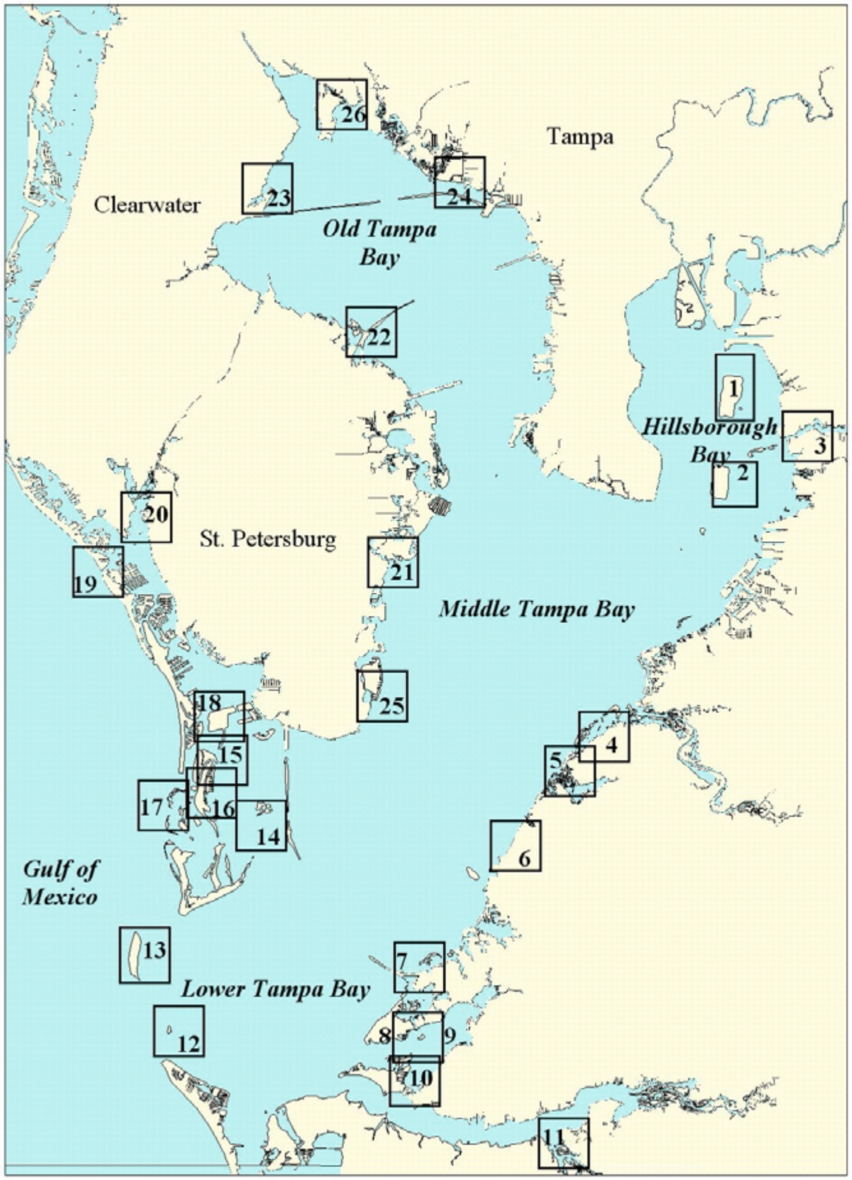

Figure 17-1. Bird colonies of Tampa Bay. Colonies identified by numbers designated in Table 17-2.

very small number of colonies statewide, and are extremely vulnerable to the effects of a single poorly-timed storm, high tide, or careless intrusion.

Species Population Status

Brown Pelican - The decline of the last decade continued, with Brown Pelicans numbering just over 1000 pairs in 2000 and 2001. The cause of their decline is unknown, but may involve food shortage since we have observed a high rate of nesting failure early in nesting, and low average brood size in successful nests. Two key colonies, Tarpon Key and Washburn Sanctuary, have been severely affected by raccoons in recent years.

Double-crested Cormorant - Data suggest possible decline from 650 to fewer than 400 pairs during the period. More intensive surveys are needed, since this species has a very long nesting season and early (or late) pairs may be underrepresented.

Anhinga - About 200-300 pairs breed at three colonies in Tampa Bay, with the largest numbers at Alligator Lake. Numbers have declined recently at Washburn Sanctuary and Tarpon Key, perhaps due to raccoon predation. Anhingas are primarily freshwater nesters, with only small numbers on the coast.

Great Blue Heron - Population appeared stable through 1998, but has declined in last three years. Actual population is somewhat higher, since peak nesting effort precedes censuses at most colonies. Attempts are underway to improve early season coverage. This is probably the most resilient, adaptable wading bird in the region, so if population declines are confirmed in this species others may be at serious risk.

Table 17-1. Breeding birds of the Tampa Bay system, 1994-2001: Annual population estimates *(breeding pairs)*.

Species	Listed Species	1994	1995	1996	1997	1998	1999	2000	2001
Brown Pelican	SSC	1648	2065	1650	1121	1664	1490	1063	1085
Double-crested Cormorant		648	645	543	457	459	505	412	369
Anhinga		210	272	333	223	276	276	199	249
Great Blue Heron		278	312	333	284	314	196	177	161
Great Egret		532	687	786	506	875	492	507	645
Snowy Egret	SSC	807	1060	883	709	844	441	701	831
Little Blue Heron	SSC	305	302	253	308	273	245	273	334
Tricolored Heron	SSC	681	596	697	420	744	464	533	894
Reddish Egret	SSC	71	76	67	62	57	57	72	66
Cattle Egret		5800	4841	4337	6647	2382	3355	3750	9190
Green Heron**		+	+	+	+	+	34	15	30
Black-crowned Night-Heron		79	199	266	113	265	163	189	134
Yellow-crowned Night-Heron		190	174	183	102	91	112	94	125
White Ibis	SSC	7300	10,795	9301	6241	17,232	5217	6916	5985
Glossy Ibis		405	507	740	328	546	253	301	336
Roseate Spoonbill	SSC	109	148	111	139	186	164	180	162
Wood Stork	E	64*	36	103	74	53	163	141	117
Snowy Plover**	T	0	1	0	1	1	1	0	0
Wilson's Plover**		+	+	0	4	30	13	3	2
American Oystercatcher**	SSC	67	76	77	94	88	91	84	84
Willet**		11	11	31	3	16	46	42	21
Laughing Gull		15,020	19,300	10,500	11,500	13,000	13,950	10,100	17,100
Gull-billed Tern		2	2	0	0	1	0	1	7
Caspian Tern		80	91	93	67	75	92	102	82
Royal Tern		2170	2694	2255	3250	2977	3090	3068	3672
Sandwich Tern		270	444	445	528	539	310	524	752
Least Tern	T	170	45	85	107	150	42	25	87
Black Skimmer	SSC	600	580	685	756	767	810	552	623
Totals		37,518	45,960	34,757	34,044	43,905	32,047	30,046	43,216

Table 17-2. Coastal bird colonies of the Tampa Bay System, 1994-2001: population size.

Colony Name	Breeding Pairs							
	1994	1995	1996	1997	1998	1999	2000	2001
1. Spoil Island 2D	6180	526	554	35	35	86	72	35
2. Spoil Island 3D	124	5301	4144	5018	7160	9580	6291	5618
3. Alafia Bank	10,499	13,801	11,075	7596	18,122	6573	7316	6746
4. Cockroach Bay ELAPP	120	144	ND	150	102	133	112	55
5. Hole in the Wall	ND	15	ND	9	ND	9	ND	31
6. Piney Point	3865	3274	3320	3715	2990	3323	2621	4023
7. Skyway Sandbar	ND	0	ND	17	0	0	ND	0
8. Miguel Bay	ND	11	ND	3	10	6	ND	ND
9. Washburn Sanctuary	3434	1993	2155	892	2061	1881	1689	2004
10. Washburn Jr.	0	0	0	40	0	35	0	0
11. Dot-Dash	97	1158	831	2890	349	254	1571	5635
12. Passage Key NWR	8682	8698	6447	9003	8325	7640	6079	2423
13. Egmont Key SP/NWR	ND	162	0	142	49	902	2039	14,599
14. Tarpon Key	2234	1720	1643	1129	886	856	762	480
15. Little Bird Key	3	ND	11	17	78	100	58	0
16. Tierra Verde	-	-	75	0	0	0	0	0
17. Shell Key	1192	7775	3194	2293	2401	477	90	21
18. Isla Colony	100	0	0	0	0	0	0	125
19. Johns Pass	46	258	10	19	58	0	45	48
20. Dogleg Key	75	126	327	395	424	474	543	543
21. Coffeepot Bayou	64	184	142	239	315	333	220	285
22. Howard Frankland	90	0	0	0	0	0	0	0
23. Alligator Lake	458	498	781	447	553	340	358	464
24. Courtney Campbell	172	319	53	0	5	0	78	29
25. Little Bayou	ND	ND	ND	ND	ND	ND	ND	20
26. Mobbly Bay Powerlines	ND	ND	ND	ND	ND	ND	ND	16

ND = no data/no survey - = site not previously active

Great Egret - Stable in recent years with about 500-800 pairs annually. Increased to 875 pairs in 1998 (and increased sharply in Clearwater and Sarasota colonies as well), undoubtedly due to ENSO. Numbers have subsided some since 1998.

Snowy Egret - About 800-1000 pairs annually in most years. Population appears stable for now, but this species has declined significantly since the early 1980s in Tampa Bay, and probably statewide.

Little Blue Heron - The Tampa Bay nesting population appears stable at about 300 pairs. This species nests and forages primarily in freshwater habitats, and is vulnerable to continuing alteration of wetlands.

Tricolored Heron - About 500-700 pairs annually, but 900 in 2001. Currently stable, but like the Snowy Egret and Little Blue Heron, this species has declined significantly in the last 30 years.

Reddish Egret - Hunted for their nuptial plumes and extirpated from Tampa Bay by 1900, this species was found nesting here again in 1974. Since then numbers have increased to 60-75 pairs locally, about 15-20% of the state population. Although numbers seem to have stabilized, a slow increase continues at northern Pinellas colonies and overall the local nesting population appears to be increasing slightly. Still an uncommon bird.

Cattle Egret - The most abundant heron in Florida, with about 5000 pairs nesting in Tampa Bay colonies. The low number in 1998 (2400 pairs) was thought to be due to impact of drought on insect prey (ENSO). Over 9000 pairs in 2001, a recent high for this species. This species nests later than other species, and may be underestimated in our surveys.

Green Heron - Not a colonial nester, so not censused comprehensively during annual surveys. A few nests found annually. No trend available.

Black-crowned Night-Heron - About 200-250 pairs estimated in Tampa Bay, but this species is most active at night and very difficult to census; trends are difficult to document. Black-crowns are believed to be declining in Florida and in the Tampa Bay area over the past 30 years.

Yellow-crowned Night-Heron - Another species that defies census efforts, Yellow-crowns often nest in small mainland colonies that are not detected. The estimates presented here (90-190 pairs) do not reflect true numbers, and the true population trend is not known.

White Ibis - About 6000-11,000 pairs locally, with a remarkable increase to 17,000 in 1998 (ENSO). Annual numbers strongly reflect local wetland conditions, and numbers were sharply lower again in 1999-2001. This species is believed to have declined locally by about two-thirds since the 1940s, due to loss of wetlands and wet pastures. Despite these losses, the Alafia Bank population remains one of the largest in the state.

Glossy Ibis - First recorded nesting at Alafia Bank in 1969, so perhaps a recent recruit to Tampa Bay breeding fauna. Primarily an inhabitant of freshwater habitats, with about 400-600 pairs at two Tampa Bay colonies. Lower nesting numbers in dry years after 1998 and ENSO event. Numbers appear to have increased slowly over the last 20 years but continuing urbanization may reverse this trend. About 10% of the state population occurs here.

Roseate Spoonbill - Absent from Tampa Bay for over 60 years until rediscovered nesting in 1975. Strong increase during 1990s. During this study, numbers grew from 110 pairs to 180. High number in 1998 due to strong ENSO conditions (and probably relocation of some pairs from Florida Bay). About 20% of the state population.

Wood Stork - This endangered species nests at a single site in Tampa Bay (plus two others in the watershed but inland, so not included here), the Dot-Dash colony at the mouth of the Braden

Table 17-3. Coastal bird colonies of the Tampa Bay system, 1994-2001: Protected status and presence of mammalian predators.

Colony Name	Raccoons 1994-98	Raccoons 1999	Raccoons 2000	Raccoons 2001	Colony Abandoned	Protected Status/Agency
1. Spoil Island 2D	X					TPA/NAS
2. Spoil Island 3D						TPA/NAS
3. Alafia Bank	X	X	X	X		NAS
4. Cockroach ELAPP Pits						HCRM
5. Hole in the Wall						AP/HCRM
6. Piney Point						TECO
7. Skyway Sandbar	X				X	AP
8. Miguel Bay						
9. Washburn	X	X	X	X	-50%	NAS
10. Washburn Jr.						NAS
11. Dot-Dash						NAS
12. Passage Key NWR						FWS
13. Egmont Key SP/NWR						FPS/FWS
14. Tarpon Key NWR	X	X	X	X	-75%	FWS
15. Little Bird Key NWR				X	X	FWS
16. Tierra Verde					X	
17. Shell Key	X	X	X	X	X	PCP
18. Isla Colony					X	
19. Johns Pass	X	?			X	SSS/?
20. Dogleg Key						TBW/NAS
21. Coffeepot Bayou						PF
22. Howard Frankland	?				X	FDOT
23. Alligator Lake						SH
24. Courtney Campbell	X	?				FDOT/TAS
25. Little Bayou						AP
26. Mobbly Bay Powerlines						FP

TPA = Tampa Port Authority NAS = National Audubon Society/Audubon of Florida
HCRM = Hillsborough County Resource Management Team
TECO = Tampa Electric Company AP = Aquatic Preserve, FDEP
FWS = United States Fish and Wildlife Service FPS = Florida Park Service PCP = Pinellas County Parks
SPAS = St. Petersburg Audubon Society TBW = Tampa BayWatch SSS = Suncoast Seabird Sanctuary
SH = Town of Safety Harbor PF = Pelican Fund FP = Florida Power
FDOT = Florida Department of Transportation TAS = Tampa Audubon Society

River. Numbers varied from about 40 to 160 pairs annually, with the high in 2000. In 1994 the colony was abandoned following disturbance by jet skiers, and numbers were reduced in 1995. Possibly increasing with improved protection of colony by Audubon.

Snowy Plover - An obligate inhabitant of barrier beaches, particularly near passes and intertidal sand flats. As a beach-nester, highly vulnerable to human disturbance and raccoon predation. With a maximum of three pairs of birds found annually on the beaches of Tampa Bay (especially Ft. DeSoto and Shell Key), and no more than 10 or so estimated for the entire region, this species is on the brink of local extinction.

Wilson's Plover - More common than the Snowy and more flexible in its habitat requirements, but rarely surveyed. Inhabits barrier island sand dunes, spoil islands, and salt barrens. We estimate the Tampa Bay population at about 100 pairs, but this is little more than a wild guess useful only for order of magnitude.

American Oystercatcher - Stable or increasing with up to 94 pairs censused at area colonies, but not all pairs surveyed annually. Including known pairs at other localities, Tampa Bay population is a minimum of 125 pairs, the largest local population in the state (the first-ever statewide census in 2001 found 400 pairs). Erosion threatens beach nesting habitat at several key sites, human disturbance a chronic problem at others.

Table 17-4. Coastal bird colonies of the Tampa Bay System, 1994-2001: Species diversity.

Colonies	Number of Nesting Species							
	1994	1995	1996	1997	1998	1999	2000	2001
1. Spoil Island 2D	3	2	3	1	1	3	3	2
2. Spoil Island 3D	5	7	7	6	7	7	8	8
3. Alafia Bank	21	21	17	17	17	17	16	16
4. Cockroach Bay ELAPP	7	9	ND	8	8	8	6	4
5. Hole in the Wall	ND	1	ND	1	ND	2	ND	2
6. Piney Point	12	12	12	11	12	11	13	13
7. Skyway Sandbar	ND	0	ND	3	0	0	ND	0
8. Miguel Bay	ND	1	ND	2	1	1	ND	ND
9. Washburn Sanctuary	16	16	16	16	16	16	16	16
10. Washburn Jr.	0	0	0	8	0	3	0	0
11. Dot-Dash	4	9	8	12	8	8	10	12
12. Passage Key NWR	8	8	8	10	9	8	9	7
13. Egmont Key SP/NWR	ND	2	0	3	2	3	4	9
14. Tarpon Key	15	16	15	16	16	14	15	15
15. Little Bird Key	1	ND	4	6	7	9	5	0
16. Tierra Verde	-	-	1	0	0	0	0	0
17. Shell Key	6	7	5	7	7	7	4	3
18. Isla Colony	1	0	0	0	0	0	0	2
19. Johns Pass	2	7	2	2	3	0	6	9
20. Dogleg Key	6	7	12	10	9	9	9	10
21. Coffeepot Bayou	10	10	10	10	11	10	9	10
22. Howard Frankland	1	0	0	0	0	0	0	0
23. Alligator Lake	9	11	9	11	9	10	9	10
24. Courtney Campbell	6	8	4	0	1	0	5	5
25. Little Bayou	ND	ND	ND	ND	ND	ND	ND	2
26. Mobbly Bay Powerlines	ND	ND	ND	ND	ND	ND	ND	1

ND = no data/no survey - = site not previously active

Willet - Breeds in high marsh habitats along islands and beaches, where difficult to census. Local population size unknown; we typically find about 20-30 pairs on islands in Hillsborough Bay and more elsewhere. Vague guesstimate of Tampa Bay population is 100 pairs.

Laughing Gull - This species has declined sharply from the early 1980s, when 50,000 pairs were estimated in careful censuses. Currently only 10-15,000 pairs occur locally. Key factors may be reduced food supply due to improved garbage disposal practices, and raccoon predation at Shell Key. Sharp increase to 17,000 pairs in 2001, from a low of 10,000 just the year before, should be viewed with caution. Laughing Gulls nest in large numbers and are difficult to census, so the uncertainty inherent in the censuses is high. Currently a very large colony at Egmont Key, possibly comprised of birds relocating from Shell Key (raccoons) and Passage Key (erosion), and possibly Island 3D (plant succession, ants). Predation by red imported fire ants may be significant, particularly on spoil islands, and should be studied.

Gull-billed Tern - Very rare and difficult to find in Tampa Bay. Sporadic nester with 0-10 nesting pairs found annually over last 2 decades. Usually nests among Black Skimmers, Least Terns, or Black-necked Stilts.

Caspian Tern - For over 20 years, from the mid-1970s to the mid-1990s, the Hillsborough Bay colony was the only one in the state. During that time numbers increased from 10-15 pairs to 80+. Now three or four colonies in the state, with about 90 pairs in Hillsborough Bay and statewide total approaching 250 pairs.

Royal Tern - Two colonies in Tampa Bay totaling ca. 3700 pairs, about 70% of state population. Numbers have increased steadily over the past two decades due to careful protection at Passage Key, Island 3D, and Egmont Key. Current population is probably the highest for our area in over 100 years. The large colony on Passage Key shifted to Egmont Key in 2000 and 2001 due to erosion at Passage.

Sandwich Tern - Nests with Royal Terns. In 2001 numbers reached 750 at two colonies (75% of state population). Known population statewide in early 1980s was less than 20 pairs!

Least Tern - Typically 100-150 pairs censused annually in our surveys, only a fraction of the local population. Most pairs now nest on gravel rooftops where they may be difficult to locate or survey. Colonies at the Skyway Sandbar, Isla and Tierra Verde have been lost to development or chronic human disturbance, while the Shell Key colony failed in 1988-2001 due to raccoon predation. St. Petersburg Audubon volunteers began monitoring over 40 rooftop colonies in 2001.

Black Skimmer - About 600-700 pairs in 6 colonies locally. Including another 300 pairs at colonies near Clearwater, 50-67% of the state population nests in the region.

MANAGEMENT NEEDS

It is remarkable that virtually every active colony in the Tampa Bay system receives some measure of protection as of 1998 (Table 17-1). These efforts are uneven, however, and must be expanded and improved. Certain sites (and species) are especially vulnerable to disturbance by humans, pets, and 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 Brown Pelicans.

Watershed issues remain extremely important to the long-term welfare of many colonial waterbird species. They are highly mobile, and may move throughout the watershed during the nesting season seeking food. Following nesting, they may move 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. A few inland colonies are now censused in the Tampa Bay watershed, but coverage is selective and incomplete. However well intended and supported by the public, local land acquisition programs have not kept pace with development, and critical wetlands continue to be lost or functionally impaired. Clearly, food supply and foraging habitat will remain critical issues in an urbanizing region where wildlife competes with bulldozers for open space.

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 remaining coastal areas and functional watersheds, especially wetlands. 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 responsibility for our community.

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- CHAPTER HIGHLIGHTS -

- *Historical literature suggests that marine turtle populations in the Tampa Bay area were once more robust, but became depleted at the end of the last century.*

- *All but two nests recorded in the TBEP area between 1982 and 2001 were attributable to loggerhead turtles; a single green turtle nest and a single Kemp's ridley were also recorded.*

- *Data from stranding records, aerial surveys, incidental catch and various other sources indicate that sea turtles are common inhabitants of the bay.*

- *A total of 298 records of dead or injured marine turtles exist for the inshore waters of the TBEP area for 1980-2001; these include 159 loggerheads, 42 green turtles, 75 Kemp's ridleys, 10 hawksbills, and 12 of unidentified species.*

- *Mortality factors in the bay area include boat collisions, entanglement, incidental catch, and disease such as fibropapillomatosis.*

INTRODUCTION

Four species of sea turtles (loggerhead--*Caretta caretta*, green turtle--*Chelonia mydas*, Kemp's ridley--*Lepidochelys kempii*, and hawksbill--*Eretmochelys imbricata*) occur in the area encompassed by the Tampa Bay Estuary Program (TBEP). The loggerhead is listed as Threatened and the other three are listed as Endangered under the Endangered Species Act.

Very little information is available in the scientific literature that is specifically about the sea turtles that occur in Tampa Bay. However, two programs, the Statewide Nesting Beach Survey program and the Sea Turtle Stranding and Salvage Network (STSSN), exist that include long-term monitoring of turtles in the TBEP area. The nesting surveys are conducted annually by various governmental and private entities on beaches near the mouth of Tampa Bay (e.g., Anna Maria Island, Egmont Key, Fort DeSoto). These data collection efforts are coordinated by the Florida Marine Research Institute (FMRI), under whose auspices data summaries are produced and distributed to the public and to various government agencies. FMRI also coordinates the recovery and documentation of injured or dead sea turtles found stranded in the Tampa Bay area (and throughout the state) through the STSSN. Eighteen states participate in the network, which is coordinated at the federal level by the National Marine Fisheries Service (NMFS).

Neither the Statewide Nesting Beach Survey program nor the STSSN specifically addresses the occurrence of live turtles in the bay. In 1994, FMRI began a pilot study of this topic, which was continued and expanded under the auspices of TBEP funding. Field work was carried out through 1998. Federal recovery plans for the various species (U.S. Fish and Wildlife Service and National Marine Fisheries Service, 1992; National Marine Fisheries Service and U.S. Fish and Wildlife Service, 1991a, 1991b, 1992) emphasize the need for in-water studies to document distribution patterns, seasonality, and habitat use of sea turtles.

HISTORICAL BACKGROUND

Several publications from the early and mid-1800s suggest that loggerhead and green turtles were once numerous in Tampa Bay. A report by Williams (1837) stated that "Fish and turtle are abundant; in the SW part in particular,... The Spanish fishermen keep a schooner here, to carry fish and turtle to Havana. From 15-20 men are constantly employed in curing them and in conveying them away to market." Pizzo (1968) reported that in 1824-1886, "Tampa Bay teemed with fish and turtle," and Sunshine (1880) stated that in Tampa Bay, "(g)reen and loggerhead turtles are taken, and form a lucrative traffic." According to the diary of Captain Wyche Hunter written in 1840, turtle steaks were frequently issued to the soldiers stationed on the peninsula where Macdill Air Force Base is now located (Wik, 1960).

Collins and Smith (1893) reported that 10,000 lbs of marine turtles were landed in 1889 in Hillsborough County (which at that time also included Pinellas County); in 1890, 10,244 lbs were landed. It is not known where these turtles were captured, and thus it remains unknown whether any were taken from within Tampa Bay. Turtle eggs were also reported in the fisheries statistics, so it is possible that some of the catch included turtles slaughtered on the nesting beach. Curiously, catch statistics given by these authors for adjacent Manatee County show approximately six times as many pounds of turtles landed than for Pinellas County, yet fewer turtle eggs. Turtles were not identified to species.

Brice (1897) noted that the turtle fishery along Florida's west coast had been considered comparatively important in an investigation made in 1890 by the United States Fish Commission. However, by the time of his study, it was reported that "in the Tampa region the green turtles are nearly all killed off and that it does not now pay to follow the business." One vessel from Tampa and two from Punta Rassa fished for turtles part of the year using a total of four nets and caught 9,375 lbs. Most references to the natural resources of the Tampa Bay area and the turtle industry of the Gulf of Mexico after 1900 no longer mention the marine turtles of Tampa Bay (McKay, 1924; Ingle and Smith, 1949; Carr, 1969; Lewis and Courser, 1972; Rebel, 1974). The Gulfport Historical Council (1985) reported that fishermen in the Gulfport area (southern Pinellas County) during the early part of the century were sometimes treated to sea turtles. Parsons (1962) reported that green turtles were trucked from Tampa for the turtle soup industry, but the origin of these turtles is not identified. Limoges (1975) stated that sea turtles are sighted in the bay on rare occasions.

Reynolds and Patton (1985) provided the most detailed account of marine turtles in the Tampa Bay area, including comments on nesting activity, research initiatives, and recommendations for future conservation and management action. Most other reports and publications about the bay that mention marine turtles are brief and refer to this source (Department of Environmental Regulation, 1986; Lewis, 1987; Lewis and Estevez, 1988).

A report on statewide nesting activity of marine turtles by Meylan et al. (1995) includes data for specific beaches within the TBEP area for 1982-1992 (Table 18-1). Data for subsequent years are available as an addendum to this publication from the FMRI.

The Army Corps of Engineers conducted trawling surveys and satellite tracking experiments in the Tampa Bay ship channel in 1997 and 1998 in order to assess the abundance, seasonality and behavior of turtles in areas that are subject to maintenance dredging (Nelson, 1999). Five loggerheads, three Kemp’s ridleys and one green turtle were captured during 460 bottom tows; seven of these animals were satellite tracked in order to study movement patterns. Recommendations were developed from this study for timing of future dredging activities in order to minimize negative impacts.

NESTING ACTIVITY

Nesting surveys in the Tampa Bay area are conducted by numerous entities, including county parks, state parks, conservation organizations, and private citizens. All parties carrying out the surveys are permitted by the Florida Fish & Wildlife Conservation Commission. Annual summaries submitted to FMRI include the following data: number of kilometers of beach surveyed, survey frequency, dates of survey, dates of the first and last nest, number of false crawls (unsuccessful nesting attempts), and total number of nests.

Data on nesting activity of marine turtles in the TBEP area during the period of 1982-2001 are presented in Table 18-1. The TBEP area is defined in this chapter as the inshore waters between 27^{o}22'07"N and 28^{o}07'05"W, but nest survey areas extended slightly beyond this at both the north and south boundaries. All but two nests recorded in this area have been attributed to loggerhead turtles; a single nest at Ft. DeSoto in 1994 was that of a green turtle, and a nest on Madeira Beach in 1989 was made by a Kemp’s ridley (Meylan et al., 1994).

Although the Statewide Nesting Beach Survey database was created in 1979, TBEP area beaches were not monitored until 1982 (Table 18-1). From 1982 to 1987, surveys were conducted on an irregular basis in several areas; in Pinellas County, results for all beaches were pooled under the single category "County Beaches." This category includes beaches within Pinellas County that are north of the TBEP area. The extent of beach within each survey zone and the frequency of the surveys have varied from year to year, with increasingly thorough coverage over time.

Nearly all ocean-facing (Gulf) sandy beaches in the TBEP area are used as nesting habitat by marine turtles. One loggerhead nest was documented well inside Tampa Bay (at Northshore Park in St. Petersburg) on 16 June 1993 (confirmed by FWC staff), but nesting inside the bay appears to be rare. Reconnaissance by FMRI of 48 sandy beach areas inside the bay during eight days in June and July of 1995 revealed only one previously undocumented nesting site, Passage Key, in the mouth of the bay. Evidence of four emergences (one certain nest) were noted on this key on July 7 and July 24, and attributed to loggerhead turtles on the basis of track characteristics. In August 1995, we were informed by U.S. Fish and Wildlife personnel that the refuge manager for Passage Key (a National Wildlife Refuge) had observed a loggerhead nesting on June 8, 1995. This was apparently the first documented nest on the island, which is only infrequently visited by humans for the purpose of assessing seabird populations.

Table 18-1. Nesting activity of marine turtles, by location, in the Tampa Bay area (from 27° 22'07" N to 28° 01'05" N), 1982 - 2001. IRR = irregular survey. All nests are those of loggerheads (*Caretta caretta*) unless otherwise noted. (Data source: Florida Statewide Nesting Survey Database).

Beach length (km)	Year	# Days per week	Survey start date	Survey end date	# of Nests
(Pinellas) County Beaches					
--	1982	IRR	--	--	5
--	1983	IRR	--	--	17
--	1984	IRR	--	--	19
--	1985	IRR	--	--	25
--	1986	IRR	--	--	27
	1987	IRR			50
Mid County Beaches (One Kemp's ridley nested on Madeira Beach in 1989)					
15.0	1988	7	05/01	10/01	7
15.0	1989	7	04/11	11/30	35
15.0	1990	7	04/01	10/31	57
22.4	1991	7	04/01	10/15	29
15.0	1992	7	--	--	59
6.8	1993	7	05/01	10/31	41
6.8	1994	7	05/01	10/31	33
6.8	1995	7	05/01	10/31	77
6.8	1996	7	05/01	10/07	56
6.8	1997	7	05/01	10/05	61
6.8	1998	7	04/01	10/11	55
6.8	1999	7	04/01	10/01	33
6.8	2000	7	04/01	09/16	63
6.8	2001	7	04/01	10/30	60
St. Pete Beach					
6.4	1988	7	04/01	10/--	7
9.7	1989	7	04/01	10/31	5
6.4	1990	7	05/01	10/10	8
6.5	1991	7	05/01	11/01	19
6.5	1992	7	04/01	08/15	11
6.7	1994	7	04/01	10/31	12
6.4	1995	7	04/15	11/15	29
6.4	1996	7	04/15	11/15	32
6.4	1997	7	04/15	10/15	14
6.4	1998	7	04/01	10/20	18
6.4	1999	7	04/15	10/05	21
6.4	2000	7	04/15	10/31	25
6.4	2001	7	04/15	10/31	16
Ft. DeSoto County Park (One green turtle nested in 1994)					
8.0	1988	7	05/15	08/10	11
8.8	1989	7	01/01	12/31	8
8.4	1990	7	01/01	12/31	23
10.4	1991	7	02/01	12/31	22
8.9	1992	7	01/01	12/31	15
9.7	1993	7	02/01	12/31	24
9.7	1994	7	05/01	10/15	15
9.7	1995	7	01/01	12/31	50
9.7	1996	7	01/01	12/31	25
9.7	1997	7	04/15	10/15	26
9.7	1998	7	04/15	10/15	48
9.6	1999	7	04/15	10/15	23
9.6	2000	7	04/01	10/30	53
9.6	2001	7	04/01	10/31	32

Beach length (km)	Year	# Days per week	Survey start date	Survey end date	# of Nests
Egmont Key					
4.8	1982	3	06/01	10/01	17
4.8	1984	4	06/01	10/01	6
4.0	1988	3	--	09/06	11
6.4	1989	3	05/25	10/01	40
8.8	1990	7	05/01	07/30	14
6.4	1991	7	05/01	09/05	16
6.4	1992	7	05/30	09/07	22
6.4	1993	7	05/01	09/30	31
6.4	1994	7	05/01	10/16	31
6.4	1995	7	04/01	10/10	56
5.2	1996	7	05/01	10/02	37
4.8	1997	7	05/01	10/19	72
4.8	1998	7	05/01	10/27	71
5.1	1999	7	05/01	10/14	54
5.1	2000	7	05/11	08/31	30
5.1	2001	7	05/18	09/24	15
7.4	1982	7	05/07	08/31	21

Beach length (km)	Year	# Days per week	Survey start date	Survey end date	# of Nests
Anna Maria Island					
8.6	1983	7	05/16	08/13	23
8.6	1984	7	05/15	08/16	36
8.8	1985	7	05/18	08/01	23
9.7	1986	7	05/12	08/15	70
11.3	1987	7	05/15	08/15	59
9.7	1988	7	05/13	08/20	25
9.2	1989	7	05/07	08/21	106
9.6	1990	7	05/08	08/22	100
11.2	1991	7	05/04	08/21	96
11.3	1992	7	05/01	08/25	102
11.3	1993	7	05/01	09/30	155
11.3	1994	7	05/10	08/25	136
11.3	1995	7	05/09	10/10	214
11.7	1996	7	05/11	0825	171
11.7	1997	7	05/01	10/16	161
11.7	1998	7	05/01	08/22	225
11.7	1999	7	05/01	08/25	244
11.7	2000	7	05/01	08/26	207
11.7	2001	7	04/01	10/31	174

Nesting also occurs inside Tampa Bay at Shell Key (also called Cabbage Key), south of Pass-a-Grille. This and other sandy keys in the vicinity are known to support low-level nesting by loggerhead turtles. Nesting activity was noted during aerial surveys conducted by FWC during 1989-91 (A. Foley, personal communication).

The most pristine nesting beach in the TBEP area is Egmont Key, which lies in the mouth of Tampa Bay. An average of 44 loggerhead nests has been documented on the key annually from 1989-2001. The lack of artificial lights, beachfront development, and beach armoring make the key a particularly valuable control site for studies of human-related impacts. The key is a state park, and thorough coverage of the nesting beach is provided by park personnel.

Because of variability in survey effort and data collection methods, the number of nests presented in Table 18-1 cannot be used to evaluate long-term trends in the nesting activity of loggerheads in the TBEP area. Large natural fluctuations in the number of turtles arriving annually at nesting beaches is a common, well-documented phenomenon that further complicates trend evaluation. The relative contribution of loggerhead nests in the TBEP area to the state total is small: in 2001, nesting in the TBEP area comprised 0.4% of the state total of 69,657 loggerhead nests. Despite this small quantitative contribution, nesting in the TBEP area is important from the standpoint of maintaining a wide geographic nesting distribution of the Florida loggerhead population. An extensive range provides the population with resilience in the event of catastrophic events such as hurricanes, and it also helps to preserve genetic diversity within the population. Marine turtle nesting habitat is seriously threatened in Florida and elsewhere by coastal construction (and its attendant artificial lighting), coastal armoring, and an increasing human presence on the beach (Meylan et al.,1995).

STRANDINGS OF MARINE TURTLES

Strandings of dead or injured marine turtles along Florida's coastline are monitored by FMRI as part of the STSSN. All records of inshore strandings in the Tampa Bay area (defined herein to be between latitudes 27°22'07"N and 28°07'05"W) for 1980 through 2001 were reviewed. In addition to the coordinate description, inshore strandings from Longboat Pass north to The Narrows were included in the review. Information recorded on each stranded turtle included: species identification, stranding location, stranding date, size of the turtle, presence/absence of tags, condition of the carcass, and visible carcass anomalies (evidence of entanglement, propeller wounds, fish hooks, etc.).

A total of 298 records of dead or injured turtles exists for the inshore waters of the Tampa Bay area for 1980-2001 (Table 18-2). Loggerhead turtles are by far the species most frequently documented, followed by Kemp's ridleys, green turtles, and hawksbills. Reporting efficiency has increased significantly since the network was initiated, partly as a result of increased public awareness, and hence the increase in the number of recorded strandings over the reporting period is partly attributable to this. It is important to note that these data reflect only inshore strandings; offshore strandings, which occur on Gulf beaches, are far more numerous. Also, stranding records represent a minimum estimate of mortality because not all dead turtles wash ashore, and some of those that do are either not found or not reported.

The size class distributions of stranded turtles documented from Tampa Bay are shown in Figure 18-1. The distributions are markedly different for loggerheads as compared with green turtles and Kemp's ridleys. The distribution is skewed towards large size classes ($\bar{x}$ = 93.3 ± 12.4 cm curved carapace length, N = 87, range 58.4 - 121.9) with the majority being adults (sexually mature). The size distributions of green turtles (Figure 18-1) ($\bar{x}$ = 41.2 ± 12.2 cm, N = 37, range 27.0 - 89.5) and Kemp's ridleys ($\bar{x}$ = 45.6 ± 8.6 cm, N = 54, range 29.8 - 67.0) are similar to each other, and document the presence of mostly juvenile and subadult (immature) turtles. In fact, with the exception of the four ridleys in the 60-70 cm size category, all can be considered immature. The largest number of both green turtles and ridleys fall in the 40-50 cm size interval. All ten hawksbill strandings have involved subadults ($\bar{x}$ = 40.0 ± 11.8 cm, N = 9, range 27.3 – 54.6).

Figure 18-2 shows the seasonality of documented strandings of loggerheads, green turtles, and ridleys during 1980-2001. Strandings of loggerheads were most numerous from March through June, with a smaller peak in October and November. Green turtle strandings were documented primarily outside the summer months, with a peak in February and March. Strandings of Kemp's ridleys have occurred in all months, with no obvious seasonal pattern.

Figures 18-3 through 18-5 depict locations at which stranded turtles have been found in the bay area. Dead or injured loggerheads and Kemp's ridleys have been recovered in all sectors of the bay; green turtle strandings have been far more restricted in distribution, with most occurring near the mouth of the bay. All hawksbill strandings (not shown) have been in the outer bay area.

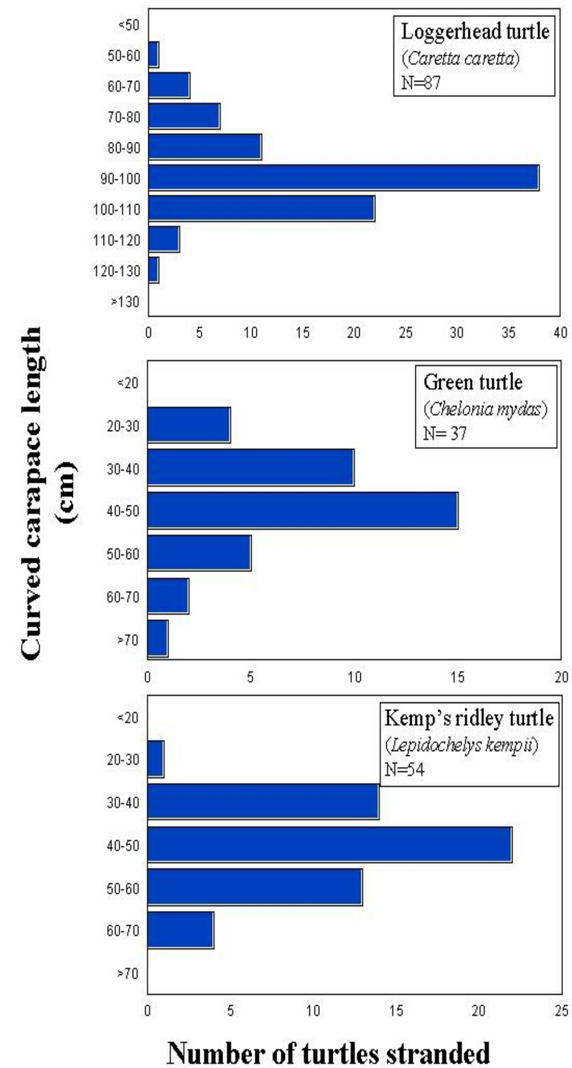

Figure 18-1. Size-class distributions of marine turtles that stranded in inshore waters of the Tampa Bay area, 1980-2001 (data source: Florida Sea Turtle Stranding and Salvage Network Database).

Table 18-2. Strandings of dead or injured marine turtles in inshore waters of the Tampa Bay area (from 27° 22'07" N to 28°07'05" N), 1980-2001 (Data source: Florida Sea Turtle Stranding and Salvage Network Database).

Year	**Species**					
	Caretta caretta (logger-head)	***Chelonia mydas (green turtle)***	***Lepidochelys kempii (Kemp's ridley)***	***Eretmochelys imbricata (hawksbill)***	**Unknown**	**Total**
1980	0	0	0	0	0	0
1981	1	0	0	0	0	1
1982	3	0	0	0	0	3
1983	3	0	0	0	0	3
1984	1	0	0	0	1	2
1985	2	0	0	0	1	3
1986	12	0	0	0	0	12
1987	9	0	5	0	0	14
1988	8	1	3	0	2	14
1989	20	1	3	1	0	25
1990	13	0	3	0	0	16
1991	8	0	3	0	1	12
1992	8	1	1	0	1	11
1993	4	0	8	0	1	13
1994	4	3	3	0	1	11
1995	3	9	10	2	1	25
1996	7	9	5	3	0	24
1997	8	3	6	0	1	18
1998	8	0	8	0	1	17
1999	9	0	5	0	0	14
2000	17	5	8	0	0	30
2001	11	10	4	4	1	30
Total	159	42	75	10	12	298

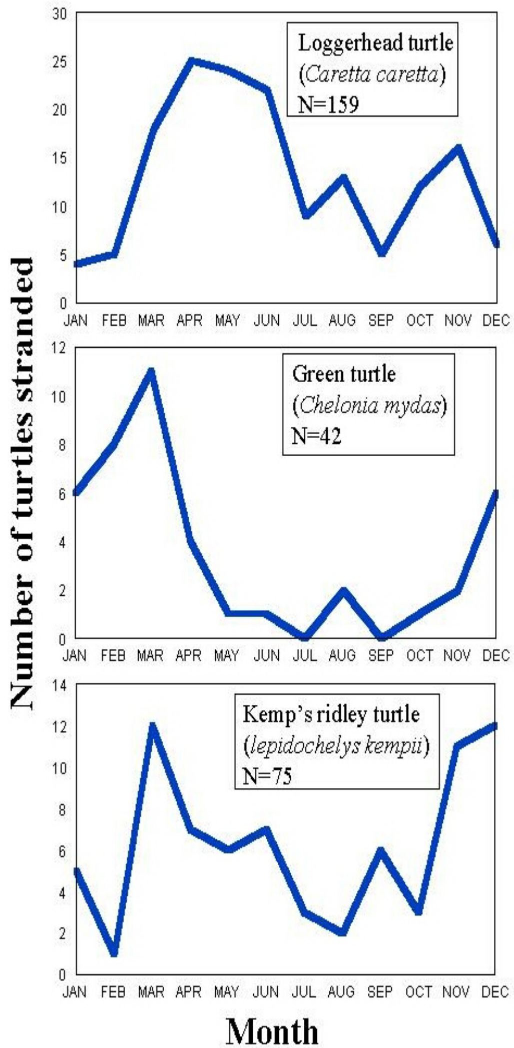

Figure 18-2. Seasonality of strandings of marine turtles in inshore waters of the Tampa Bay area, 1980-2001 (data source: Florida Sea Turtle Stranding and Salvage Network Database).

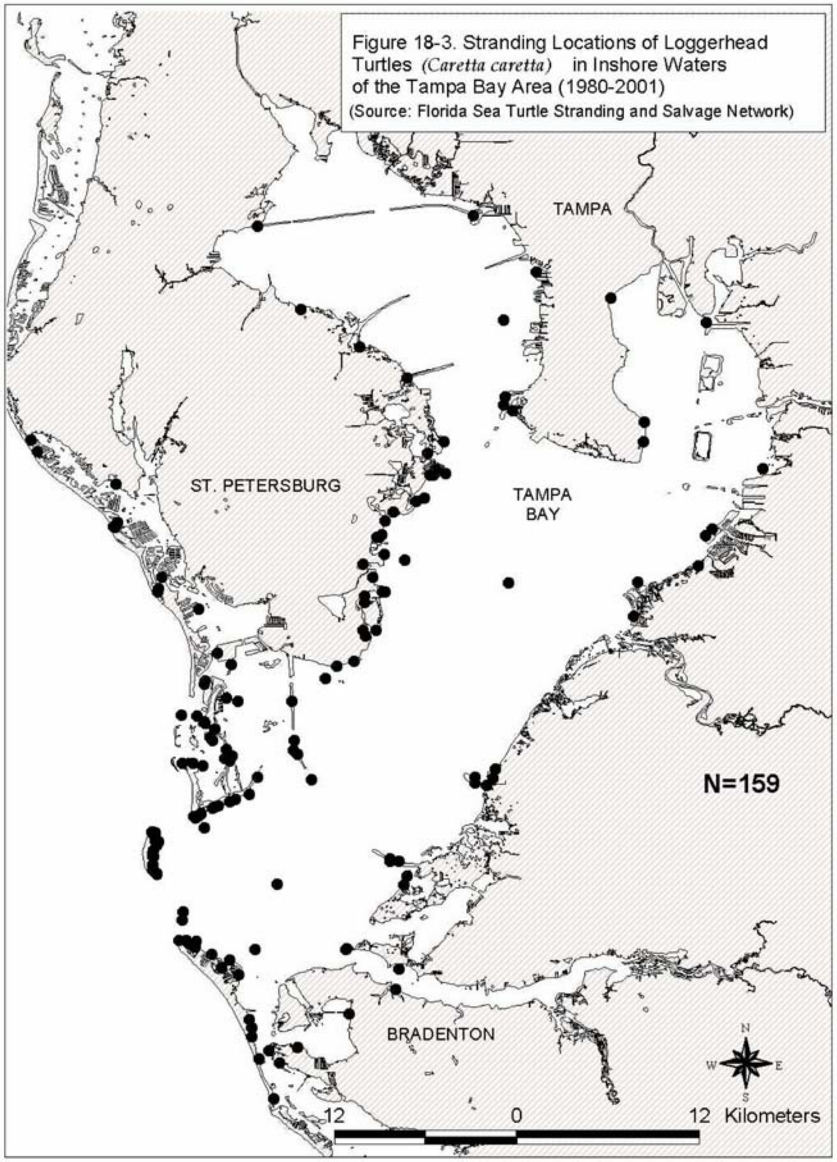

Figure 18-3. Stranding Locations of Loggerhead Turtles (*Caretta caretta*) in Inshore Waters of the Tampa Bay Area (1980-2001)
(Source: Florida Sea Turtle Stranding and Salvage Network)

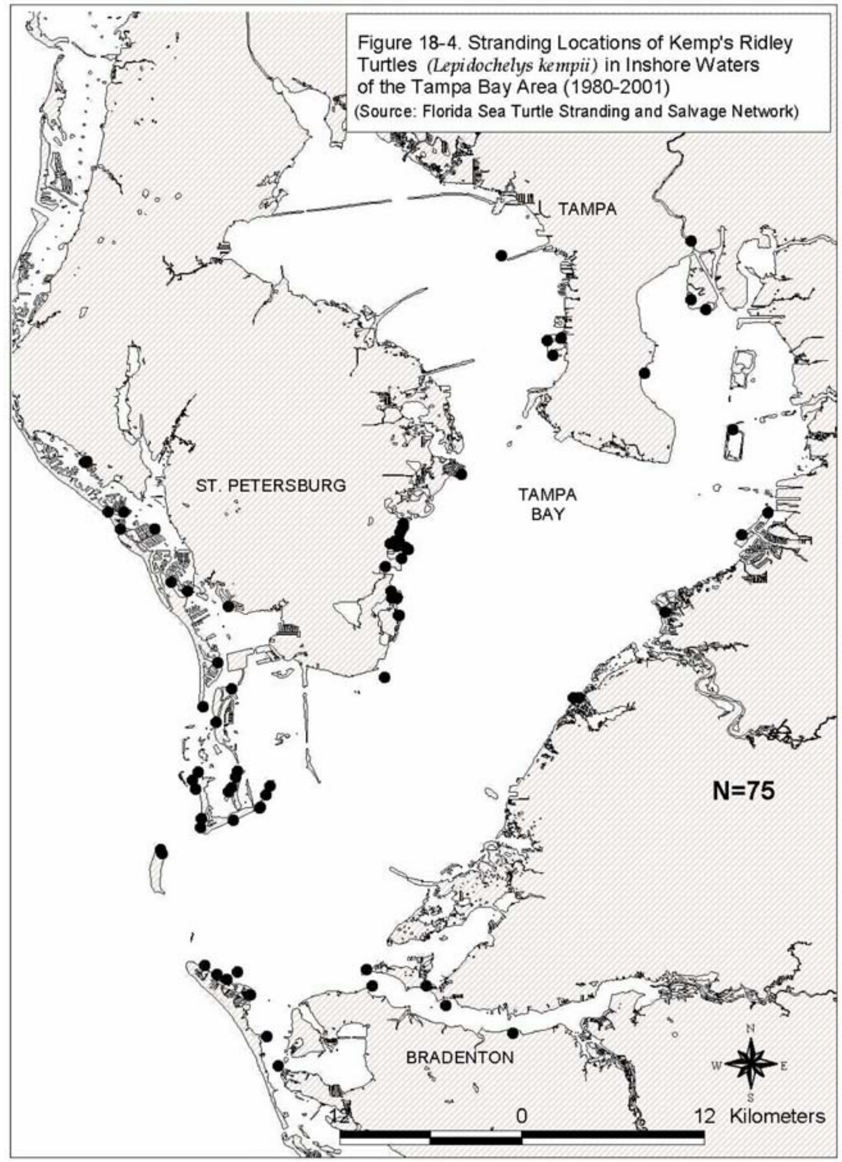

Figure 18-4. Stranding Locations of Kemp's Ridley Turtles (*Lepidochelys kempii*) in Inshore Waters of the Tampa Bay Area (1980-2001)
(Source: Florida Sea Turtle Stranding and Salvage Network)

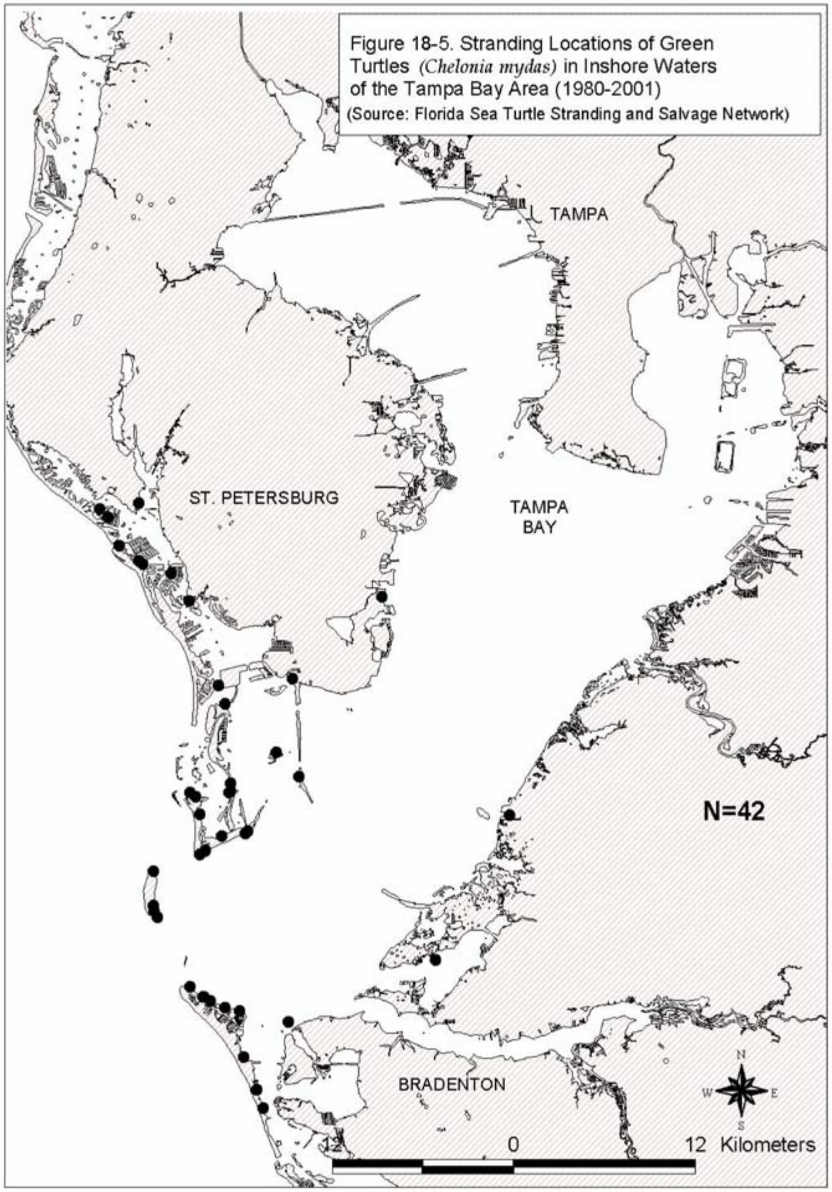

Figure 18-5. Stranding Locations of Green Turtles (*Chelonia mydas*) in Inshore Waters of the Tampa Bay Area (1980-2001)
(Source: Florida Sea Turtle Stranding and Salvage Network)

Although stranding distributions provide some useful information about distributions of live turtles, particularly in inshore waters, it is important to note that dead turtles can be transported considerable distances by tides or currents. Also, turtles that strand in areas frequently visited by people are more likely to be reported. Bearing these caveats in mind, the data still seem to suggest that loggerheads and ridleys have a wider distribution within the bay than green turtles and hawksbills.

External carcass anomalies (not necessarily causes of death) reported in the stranding records are given in Table 18-3. These numbers are considered absolute minimum occurrences because the lack of remarks on a stranding form does not necessarily indicate the lack of carcass anomalies. It is important to note that the factors causing carcass anomalies may occur either ante- or post-mortem, and it is not always possible to distinguish between the two.

Boat-related injuries (including propeller wounds and possible boat collision injuries), were the most frequently observed carcass anomaly for loggerheads; sixteen ridleys and one hawksbill also showed evidence of boat injuries. Seven cases of entanglement were reported, affecting all species. Fibropapillomas, which are large tumors occurring on the soft parts of the turtle, were the most common carcass anomaly on stranded green turtles. The disease fibropapillomatosis is known to occur in other species of sea turtles, but is by far most commonly seen in green turtles. Tumors were not observed on individuals of any other species that stranded in Tampa Bay.

The size class distribution of green turtles found with papilloma-type tumors is shown in Figure 18-6. The distribution is similar to the overall size class distribution of green turtles in the bay with the exception that the smallest size class (20-30 cm curved carapace length) is not represented. That may be a reflection of the small sample size, but it may also be related to the timing of onset of the disease (or at least the manifestation of tumors).

DISTRIBUTION IN TAMPA BAY

To investigate the distribution and seasonality of live marine turtles in Tampa Bay, we compiled records of sightings from various sources. We reviewed all manatee aerial survey data collected during 121 flights made between November 1987 and June 1997 by FMRI's Endangered and Threatened Species section and Dr. John Reynolds of Eckerd College. These consisted of flights made at monthly or bi-monthly intervals. Turtles were noted opportunistically during these flights and their locations were marked on detailed nautical charts. The surveys were conducted in

Table 18-3. Occurrence of carcass anomalies reported for marine turtles stranded in inshore areas of the Tampa Bay region (from 27°22'07"N to 28°07'05"N), 1980-2001. (Data source: Florida Sea Turtle Stranding and Salvage Network Database.) Carcass anomaly categories are not mutually exclusive (individual turtles may have exhibited more than one carcass anomaly.)

Carcass anomaly	***Caretta caretta* *(loggerhead)* (n=139)**	***Chelonia mydas* *(green turtle)* (n=42)**	***Lepidochelys kempii* *(Kemp's ridley)* (n=75)**	***Eretmochelys imbricata* *(hawksbill)* (n=10)**	**Unknown species (n=12)**	**Total**
Boat related injuries	43	2	16	1	2	64
Emaciated	3	10	0	0	0	13
Fibropapillomas	0	26	0	0	0	26
Fishing gear entanglement*	2	1	3	1	0	7
Shark bites	6	0	2	0	0	8
Deliberate mutilations	4	1	4	0	1	10

nearshore waters (from the shoreline to about 1.0 km offshore), at an altitude of 600' and an airspeed of 80-85 knots. Further details of survey methodology are given by Reynolds et al. (1991).

Another source of live turtle distribution data was aerial surveys flown from July 1995 through

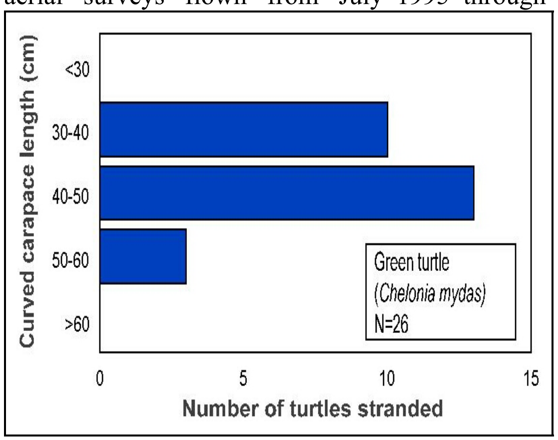

Figure 18-6. Size-class distribution of green turtles (*Chelonia mydas*) with papilloma-type tumors that stranded in inshore waters of theTampa Bay area, 1980-2001.

October 1996 as part of a study of recreational anglers being conducted by the FMRI Fisheries Dependent Monitoring group. These surveys were conducted at approximately 500' altitude at 90-110 knots, following a route along the shorelines, boat channels, and bridges of Tampa Bay (and other areas). Each of the zones in the study were flown two or four times during each two-month period. Turtle locations were recorded with a Global Positioning System (GPS) unit.

We also compiled sightings of turtles made by personnel of the National Marine Fisheries Service during aerial surveys for marine mammals along the west Coast of Florida in September and October of 1994, and for red drum in November of 1995. Positions of turtles were recorded with a GPS unit. Our database of live marine turtles in Tampa Bay also included captures made incidental to research on sharks conducted by Mote Marine Laboratory's Center for Shark Research. Turtles were captured in monofilament gill nets.

In addition to compiling existing records of marine turtles in the bay, FMRI marine turtle staff directly sampled for marine turtles in the bay. Thirty-one scouting trips designed to spot turtles surfacing to breathe and six netting trips were made from 1995-1998. Large-mesh nets connected end-to-end were set in a linear array extending approximately 300 m. The nets were tended continuously in order to remove captured turtles and bycatch. We had two separate opportunities to sample for marine turtles in Tampa Bay with shrimp trawls. On May 15-16 and June 12-13 of 1995, we chartered a 55' shrimp boat (the Seaweed IV) that was equipped with two 25' trawls. The nets were not outfitted with Turtle Excluder Devices (TED's). We conducted 30 30-minute paired tows on these four days. Endpoints of the tows were recorded with GPS.

Three records from the STSSN involved healthy live turtles and were therefore included in the live sighting database. We also included miscellaneous sightings made by FMRI personnel conducting field work in the bay.

Figure 18-7 depicts the spatial distribution of live turtles as recorded by the various sources above.

Miscellaneous reports include observations made by individuals other than FMRI staff. It should be noted that two surveys (the FMRI Recreational Fisheries Aerial Survey and the NMFS aerial surveys) included waters adjacent to the TBEP area, and these sightings are also included in Figure 18-7. The majority of sightings were attributable to the FMRI manatee aerial surveys (n=54 turtles) and to the FMRI Recreational Fisheries Aerial surveys (n=85).

Live turtles were sighted in all sectors of the bay, with more observed in the southern part of the bay than in the northern part. The greatest number of sightings was made in the area around Terra Ceia, just south of the southern end of the Skyway Bridge. A variety of data sources (aerial surveys, net captures, and sightings from boats) confirmed the importance of this area.

Many of the live sightings were ancillary to other studies and the turtles were not identified to species. Interpretation of these survey data with regard to marine turtle distributions is also complicated by differences in data collection methods (aerial sightings, in-water sightings, and netting), behavioral differences among species (some are more cryptic than others), and the occurrence of smaller size classes in some species (which may cause them to go unnoticed).

In addition, marine turtles spend most of their lives submerged and thus not visible. Renaud (1995) reported an average submergence time of 89% for ridleys, and Renaud et al. (1995) reported a 91% average submergence time for green turtles. An additional bias is created by the fact that aerial surveys concentrated on shorelines, boat channels, and bridges.

CONCLUSIONS

Our compilation of data from various sources (stranding records, aerial surveys, incidental captures, etc.) on the occurrence of marine turtles in the TBEP area suggests that turtles are common, although perhaps inconspicuous, inhabitants of the bay. Their great mobility and tendency to remain submerged most of the time contribute to their cryptic nature. Four species are represented, with the following apparent order of abundance: loggerheads, Kemp's ridleys, green turtles, and hawksbills. During the 1980s, Kemp’s ridley was listed as one of the twelve most endangered animals in the world by the International Union for the Conservation of Nature.

Although data on the seasonality of the various species in the bay are limited, it appears that at least the loggerhead and ridley are year-round residents; this may eventually prove to be the case for the green turtle, as

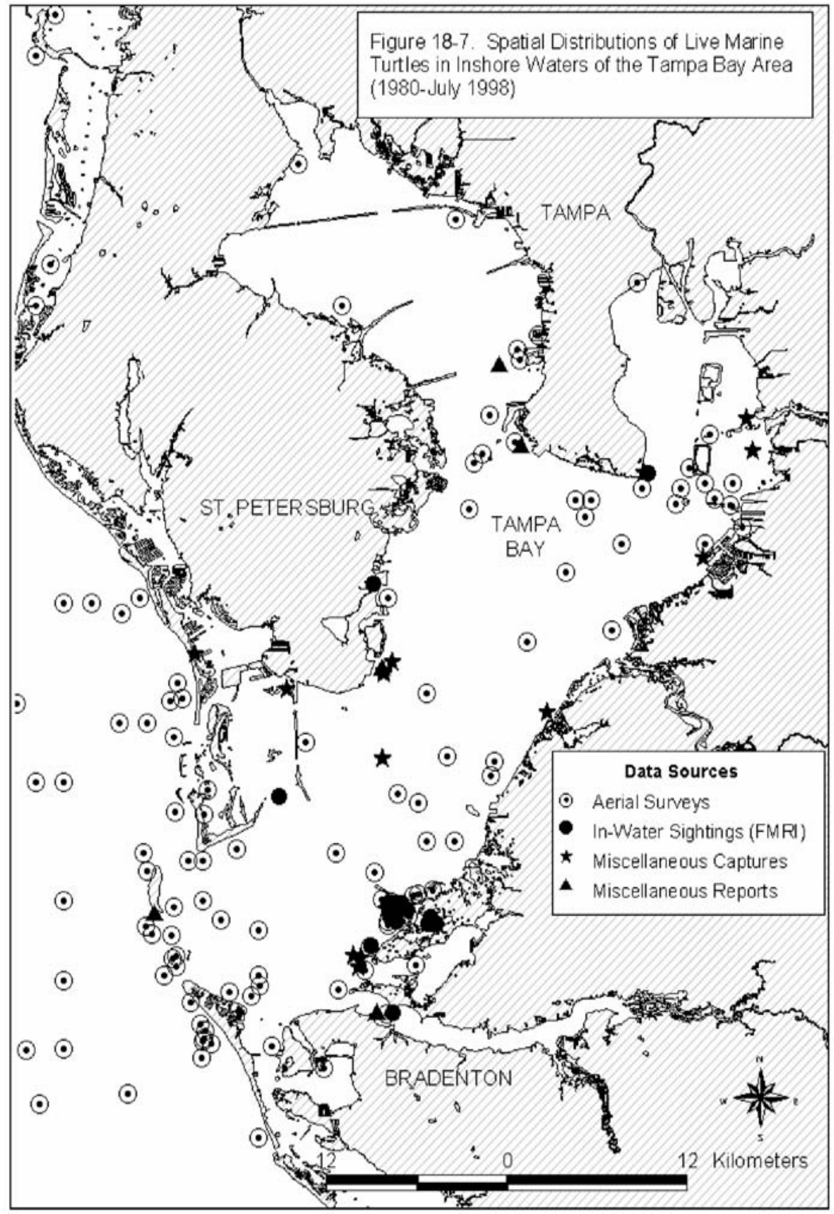

Figure 18-7. Spatial Distributions of Live Marine Turtles in Inshore Waters of the Tampa Bay Area (1980-July 1998)

well. The hawksbill, a more tropical species than the others, appears to be rare in the bay.

The bay serves as habitat for several life history stages of marine turtles, including foraging adults, foraging juveniles and subadults, and nesting females. The Gulf waters adjacent to Anna Maria Island, Egmont Key, and all of Pinellas County can be expected to be visited by both reproductive males and females during the mating and nesting season.

Historical literature suggests that marine turtle populations in the Tampa Bay area were once more robust, but became depleted at the end of the last century. Their current population status remains unknown, but there is no current evidence that densities are high. Although they are all now protected by law from harvesting, it is clear from stranding records that numerous mortality factors are still operating. Many are human-related, such as boat collisions, entanglement, and incidental catch. For green turtles, fibropapilloma disease is a major mortality factor. It has been suggested that environmental conditions such as pollution may play a part in the etiology of this disease, but this hypothesis remains unproven. A herpes virus is suspected to be the pathologic agent.

Current monitoring efforts of nesting beaches in the TBEP area are adequate. With the exception of Passage Key and some small islands in the Ft. DeSoto area, nearly all nesting beaches are monitored daily during the nesting season. Given the small number of nests believed to be deposited in the unmonitored areas, and the potential disturbance to seabirds on Passage Key, we would not recommend extending surveys to these areas.

Monitoring of strandings of marine turtles in the bay has improved dramatically in recent years, but there is no question that marine turtle carcasses sometimes go unreported. A campaign to inform the public of the importance of reporting sightings of dead turtles would be helpful in this regard. A further enhancement of STSSN activities would be support for professional necropsies of selected carcasses to better investigate mortality factors.

Perhaps the most neglected aspect of sea turtle monitoring in the bay has been that of assessing the distribution, abundance, and seasonality of live turtles. Our study will hopefully bring together a body of data that has heretofore existed in widely scattered places. However, our knowledge of these topics remains preliminary. Understanding the biology and ecology of the bay's turtles will take a concerted, long-term effort. The rewards will be improved management of these species, and a better understanding of the marine ecosystems of which they are a vital part.

RECOMMENDATIONS

1. Maintain the quality and quantity of existing nesting and foraging habitats of marine turtles in Tampa Bay. Address issues such as artificial lighting, coastal construction, beach armoring, beach nourishment, and human use of beaches, which can negatively impact marine turtles and their habitats.

2. Continue monitoring of nesting activity on bay area beaches.

3. Improve stranding response for marine turtles in the bay through a public awareness campaign. Enhance assessment of mortality factors by providing for professional necropsies of selected carcasses.

4. Promote basic research on the distribution, abundance, seasonality, population structure, habitat usage, growth rates, and migrations of marine turtles. Encourage research on the cause of fibropapillomatosis.

5. Maintain and update GIS coverages of marine turtle distributions in the bay area; overlay turtle distributions with habitat and other coverages.

ACKNOWLEDGMENTS

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H. Greening (Tampa Bay Estuary Program)

Goals adopted to restore and protect the living resources of Tampa Bay and results from the 1998-2001 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, along with a brief description of recently initiated actions to address these areas of potential concern.

The impacts to water quality and seagrass acreage from heavy winter rains during the 1997-1998 El Niño climatic event were evident during the 1998-2001 time period. Results also indicate the following:

Water and sediment quality:

- All four major bay segments continue to show long-term improvements in chlorophyll *a* concentrations, and met target levels in 1999, 2000 and 2001. None of the bay segments met chlorophyll *a* targets during the El Niño year (1998).

- 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, and near the St. Petersburg/Clearwater Airport.

Nutrient and contaminant loading:

- The inflow and loading of total nitrogen and total suspended solids increased substantially during the El Niño rainfall event in 1997-1998. TN loading ranged between 5,000 and 6,500 tons during wet years and 3,000 and 4,000 tons during relatively dry years.

- Direct atmospheric deposition of total nitrogen to the bay is about 780 tons/year based on a 5-year average, with roughly equal average wet and dry deposition rates, or between 20 and 25% of the total nitrogen load from all sources. Ammonia concentrations in the vicinity of Port Sutton do not indicate a major impact to Tampa Bay as a whole, but do represent a potential impact to Hillsborough Bay.

Habitats:

- The parasitic protista *Labyrinthula* infected between 69% and 83% of the seagrass transects sampled in Tampa Bay in 1999, 2000 and 2001, a high rate of infection relative to statewide rates. The high infection rate in Tampa Bay in 1999-2001 may suggest that *Labyrinthula* is playing a role in the observed thinning of dense *Thalassia* beds in Tampa Bay, and does not necessarily suggest that the disease is adversely affecting the seagrass beds.

- Artificial reefs in Tampa Bay account for over 125 acres of additional hard bottom habitat in Tampa Bay. Over 50 species of fish are known to occur on these sites, including snook, grouper, cobia, spotted seatrout, mackerel and tarpon. The three most common fish species observed are sheepshead, spadefish and mangrove snapper (adults and juveniles).

Animal populations:

- Wintering and summering manatee usage of the Tampa Bay area has increased since 1994 from approximately 190 in the winter of 1994 to 300 in 2001, and from 100 to 150 animals in the summer. In January 2001, the record statewide count of 3,276 manatees was made, with 356 manatees counted in Tampa Bay (10.9% of the statewide total, and 20.2% of the west coast total).

- Most rare or coastal species of birds nesting in Tampa Bay have experienced sustained population increases between 1994-2001, including Reddish Egret, Roseate Spoonbill, American Oystercatcher, and Caspian, Royal and Sandwich Terns. Wet conditions due to El Nino rains resulted in extremely advantageous foraging conditions in 1998, and breeding populations of some species, such as White Ibis, almost tripled before returning to pre-1998 conditions in 1999.

- 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 and 1995, and were relatively constant from 1996-2001.
  - Sheepshead juvenile abundance peaks seem to occur in three-year cycles, with high recruitment in 1991, 1994, 1997 and 2000.
  - Snook juvenile abundance estimates were highest in 1999 and 2000.
  - Spotted seatrout juvenile abundance has been relatively stable since 1991.
  - Blue crab abundances were lowest in 1990 and highest in 1989, 1992, 1995 and 1998.

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 1998-2001 BEMR reports, several areas indicate the need for careful consideration and action. These areas of potential concern as identified during this monitoring period include the following:

1. **Seagrass acreage declined approximately 8% baywide between 1996 and 1999 (from 26,916 acres in 1996 to 24,841 acres in 1999)**, most likely in response to the heavy El Niño rains in 1997-1998 and accompanying increased nutrient and suspended solids loads. Data from 2002 (not included in this time period) shows an increase in baywide seagrass coverage of 5% between 1999 and 2001. Old Tampa Bay has experienced a 24% loss of seagrass over this time period and previous losses between 1994 and 1996, suggesting a more serious condition could exist in this part of the bay.

2. Chlorophyll *a* concentrations in all bay segments met target levels with the exception of 1998, but **light attenuation did not meet target levels in three of the four major bay segments during this period.** Continuation of the management strategy adopted by the Tampa Bay Nitrogen Management Consortium will be critical to maintain steady progress toward maintaining water quality goals, and an evaluation of non-chlorophyll light attenuation factors is underway.

3. Although the total quantity of freshwater loading to the major bay segments has not changed over the last 60 years, **the seasonality of freshwater inflow has changed, most notably in those watersheds most subjected to land use changes.** In addition, estimates of freshwater inflow and loading of total nitrogen suggest a weak increasing trend during the period 1985-2001.

4. **In the Lower Hillsborough River, some contaminants (PAHs, the pesticide chlordane, and zinc) were detected at concentrations likely to be toxic to aquatic life, as were PCBs in the Palm River.** The Palm River also had a relatively high frequency of "empty" samples indicative of DO stress and hypoxia in this river.

5. **Direct atmospheric deposition rate estimates of heavy metals (mercury, copper, zinc and iron) to Tampa Bay were higher than previously estimated. Estimated PAH direct atmospheric deposition rate to Tampa Bay was high enough to indicate a significant anthropogenic contribution.**

6. **Manatee watercraft mortality for the period 1998-2001 exceeded perinatal mortality, which was previously the highest category of mortality for the Tampa Bay area.** In 2000 and 2001, several county-initiated no-wake slow zones were adopted in Tampa Bay to help protect manatees and seagrass. The initiation of the Tampa Bay Manatee Watch Program in 1999 is aimed at educating boaters about manatees and the need to reduce speeds in shallow seagrass areas.

7. **Wading bird species populations which nest on bay islands but forage in freshwater wetlands have declined.**