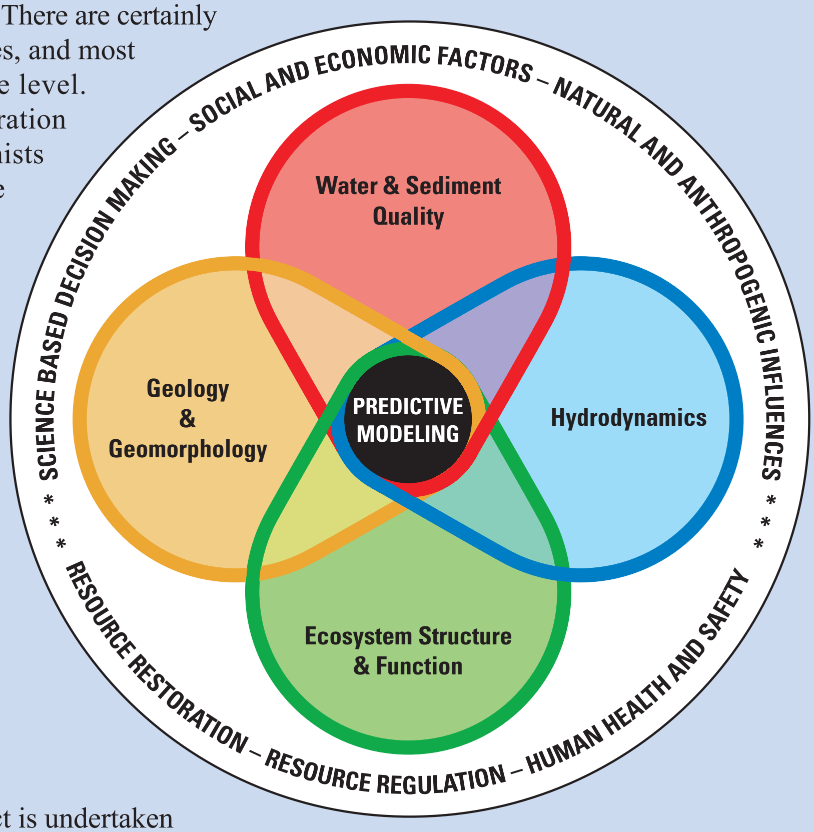
Box 1–1. Integrated Science

By Kimberly K. Yates (U.S. Geological Survey—St. Petersburg, Florida)

The USGS broadly defines integrated science as "multidisciplinary teams of scientists working together, across their scientific disciplines, to understand complex relations among the biology, geology, chemistry, and physical structure of an ecosystem" (Yates, 2003). There are certainly various levels of integration within science studies, and most multidisciplinary studies are integrated at some level. For example, the simplest level of project integration may be demonstrated when biologists and chemists work together in the same location to study the effects of various pollutants on the health of marine organisms. The most complex level of project integration, termed "fully integrated," includes integration of:

- People (scientists, resource managers, citizens, educators, and government officials) who work together using a partnership approach;
- Multiple science disciplines;
- Science culture from each discipline;
- The science planning process;
- Common business practices for carrying out science;
- Data collection and analysis; and
- Product development and distribution.

Additionally, a fully integrated science project is undertaken in response to social and economic factors, science-based decision making, resource conservation, restoration, and regulation, human health and safety, and in the context of both natural and anthropogenic impacts to the ecosystem as shown in the outer ring of the integrated science logo in box 1–1, figure 1. The integrated science process is both interactive and iterative among scientists and resource managers. As such, it requires that a high degree of flexibility and communication be maintained in planning and execution of science activities and development of science information products to respond to the changing needs of resource managers. Often projects and tasks in the Tampa Bay Study were modified as resource-management issues evolved or as linkages among estuarine system components were understood and modification of projects was needed to characterize them. Throughout the following chapters, highlight boxes describe some key research projects that exemplify the essence of integrated science. These represent only a few of the many projects that demonstrate the value of the integrated science process for the advancement of science and resource management. These research efforts were made possible by the dedication of scientists and resource managers from multiple agencies whom embraced true partnership and pushed forward the challenging frontier of integrated science.



Box 1–1, Figure 1. Integrated science logo for the U.S. Geological Survey Tampa Bay Study shows the four critical categories of science gaps that correspond to ecosystem components (labeled in each of the colored loops), and the factors and issues to which integrated science responds (labeled in the outer ring of the logo). Design by Renee Koenig, U.S. Geological Survey.

Box 1–2. The U.S. Geological Survey Tampa Bay Study

By Kimberly K. Yates (U.S. Geological Survey–St. Petersburg, Florida)

Historically, science programs of the TBEP and its partners have focused primarily on biological, surface-water, and sediment-quality monitoring and research in Tampa Bay. Four areas of critical science gaps were identified for USGS research, and these gaps correspond to the ecosystem components. Box 1–2, figure 1 shows a diagrammatic conceptual model that depicts the distribution of six project tasks among the four categories of critical science gaps:

- Geology and Geomorphology
- Water and Sediment Quality
- Hydrodynamics
- Ecosystem Structure and Function

USGS Tampa Bay Study science tasks were numbered according to the order of priority research elements defined among partnering agencies, and reflect the Tampa Bay scientific community's greatest need for USGS expertise in the physical sciences:

- Mapping and Modeling
- Water and Sediment Quality
- History and Prehistory
- Wetlands
- Benthic Habitats
- Data Management

Project tasks were developed to complement, not duplicate, efforts of partners. Thus, although seagrass recovery, wetland protection and restoration, and surface-water quality are high priorities of the TBEP, these areas represented smaller research components of the Tampa Bay Study, because much of the research in these areas was already being addressed by partnering agencies.

USGS Science Task Objectives

Task 1: Mapping and Modeling — Characterize and model natural and anthropogenic changes an the physical structure of Tampa Bay and their impact on ecosystem health.

Task 2: Water and Sediment Quality — Quantify and assess the source, quality, and impact of ground-water, sediment, and surface water on benthic and coastal habitats.

Task 3: History and Prehistory — Model the historical and prehistorical evolution of the bay to develop the structural setting for estuarine processes, provide the basis for predictive modeling, and serve as a guide for restoration planning.

Task 4: Wetlands — Assess the current ecological status of wetlands, and characterize natural and anthropogenic factors impacting wetland health and restoration.

Task 5: Benthic Habitats — Identify, quantify and model the impacts of urbanization on benthic-habitat distribution, health, and restoration.

Task 6: Data and Information Management — Develop and maintain a decision support system to facilitate science information exchange, product development and delivery, modeling exercises, and public outreach.

Box 1–2, Figure 1. U.S. Geological Survey Tampa Bay Study tasks are listed under the four critical science gaps, corresponding to ecosystem components, as indicated in the integrated science logo.

The Mapping and Modeling task (Task 1) was designed to develop the regional, spatial, and physical context of the Tampa Bay Region for all other research and monitoring components. The baseline maps and models produced in this task provided the foundation for all other efforts. The most important results from this work were the development of a seamless digital elevation model (10 m resolution) and the development of urbanization and integrated coastal models for Tampa Bay (See Chapter 2). The model results assist resource managers in predicting the future of urban extent and its impact on the environment, and provide critical information on the effects of urbanization, ship traffic, and anthropogenic modifications on water circulation and sediment dynamics within Tampa Bay.

Some of the most significant results from the Water and Sediment Quality task (Task 2) included the identification of groundwater sources in Tampa Bay. This was achieved by combining resistivity mapping results from Task 2 with seismic mapping results from Task 1. Resistivity mapping showed the location of freshened water masses below the seafloor, and seismic mapping identified geologic features on the seafloor that may act as conduits for freshwater flow into the bay. Additionally, the amount of groundwater coming into Tampa Bay was quantified for the first time and shown to be a significant source of nutrients to Tampa Bay (See Chapters 5 and 7).

The History and Prehistory task (Task 3) collected and analyzed over 100 sediment cores taken along seismic mapping track lines throughout Tampa Bay. Data from these analyses have provided the first comprehensive look at preanthropogenic and anthropogenic environmental conditions in the bay with respect to sediment accumulation rates, climate change, sea-level rise, trace metals, nutrients, and floral transitions. Characterization of surface sediments in the cores also provided critical information for sediment transport modeling in Task 1. Additionally, results from these analyses have shed new light on the controversies over how Tampa Bay originated (See Chapter 3).

The Wetlands task (Task 4) focused on providing data to resource managers that quantified impacts to flora and fauna from historical manmade alterations to wetland areas. This information has been used to assist with development and monitoring of wetland restoration activities in Tampa Bay. Significant results from this task include information on use of manmade and natural wetland ditches by 76 species of economically important fish for nursery habitat. Resource managers are using this information as a guide to make sure they achieve the intended results with their restoration plans. Additionally, methodologies and minimum standards were developed for wetland restoration techniques that have now been adopted in other estuaries around the world (See Chapter 8).

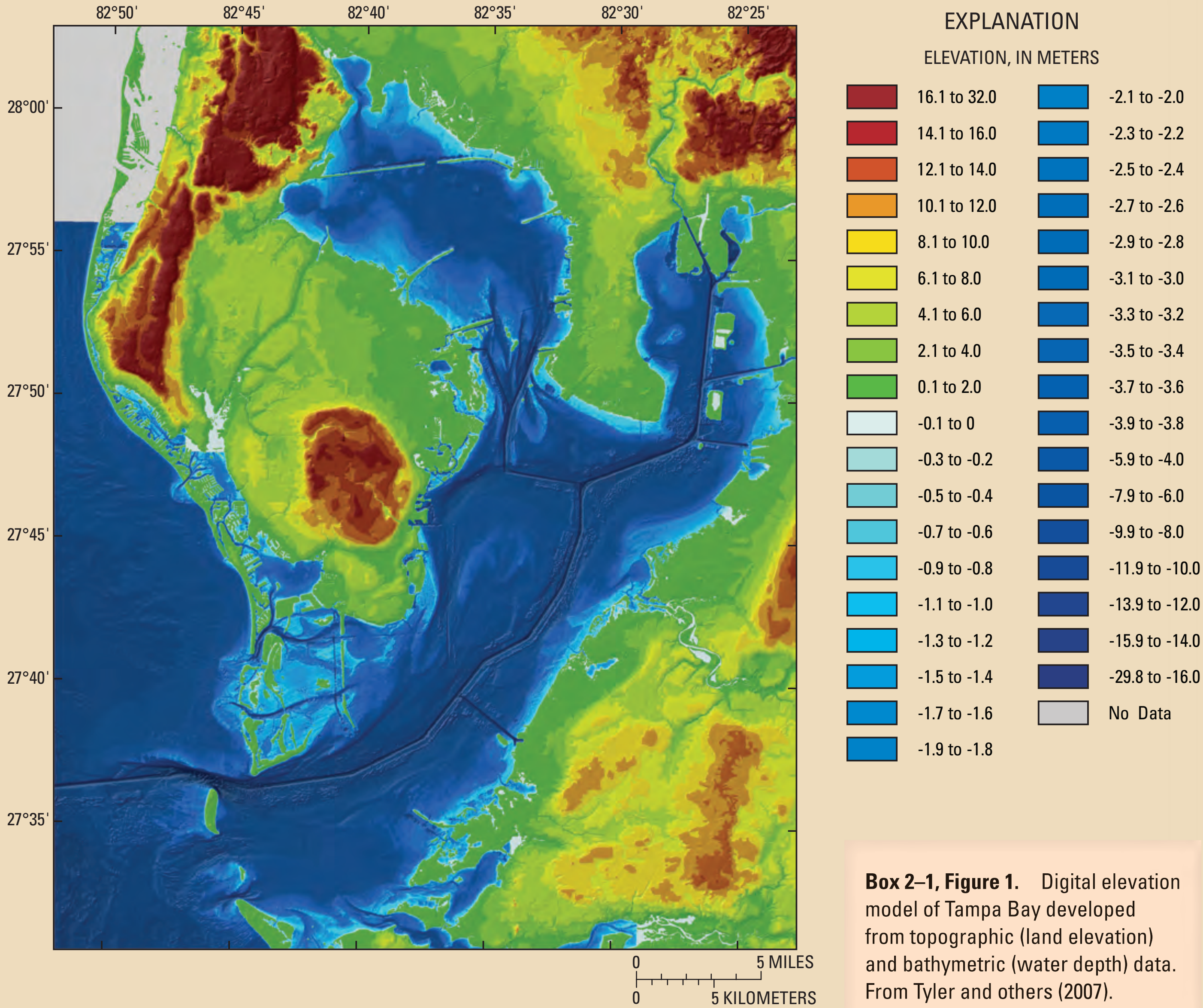
The Benthic Habitats task (Task 5) focused on the development of an Urban Extent/Seagrass distribution model that shows the relationship between urban development and changes in extent of seagrass over time. Other significant results of this task include the first measurements of community productivity in seagrass habitats in relation to available light, and the first documentation of bioaccumulation of metal contaminants in seagrass tissues within Tampa Bay (See Chapter 4).

The Data and Information Management task (Task 6) was designed to support rapid and efficient dissemination of science information and completed products to all collaborating scientists, stakeholders, and the general public, to facilitate communication among scientists and resource managers, and to collect and provide relevant historical research information required for Tampa Bay study projects. Significant products from this task include development of a web-site (*http://gulfsci.usgs.gov*) that provides online access to research information from the Tampa Bay Study, and has been expanded to include all USGS Gulf of Mexico research activities. The website also features a digital library containing data products from individual projects, and an interactive map server that allows the public to view and analyze geospatial data from the study.

Box 2–1. Digital Elevation Model of Tampa Bay

By Kimberly K. Yates (U.S. Geological Survey–St. Petersburg, Florida) and Dean Tyler (U.S. Geological Survey–Sioux Falls, South Dakota)

The USGS, in partnership with NOAA and the National Aeronautics and Space Administration (NASA), developed the first seamless digital elevation model of Tampa Bay at 10 m resolution from topobathymetric data. The model, depicted both on the cover of this report and in box 2–1, fig. 1, provided the baseline map for Tampa Bay that has been used for all of the other Tampa Bay Study projects and for generating the bathymetry and model grids for many of the recent numerical, circulation model activities. Topobathymetric data are a merged rendering of both topography (land elevation) and bathymetry (water depth), to provide a single product useful for mapping and a variety of other applications (Tyler and others, 2007). Topography was acquired from the USGS National Elevation Dataset. Bathymetry was provided by NOAA's Geophysical Data System, and from high resolution bathymetry acquired by NASA's Experimental Advanced Airborne Research LiDAR.



Box 2–1, Figure 1. Digital elevation model of Tampa Bay developed from topographic (land elevation) and bathymetric (water depth) data. From Tyler and others (2007).

Box 3–1. Coring to Reconstruct the Past in Tampa Bay

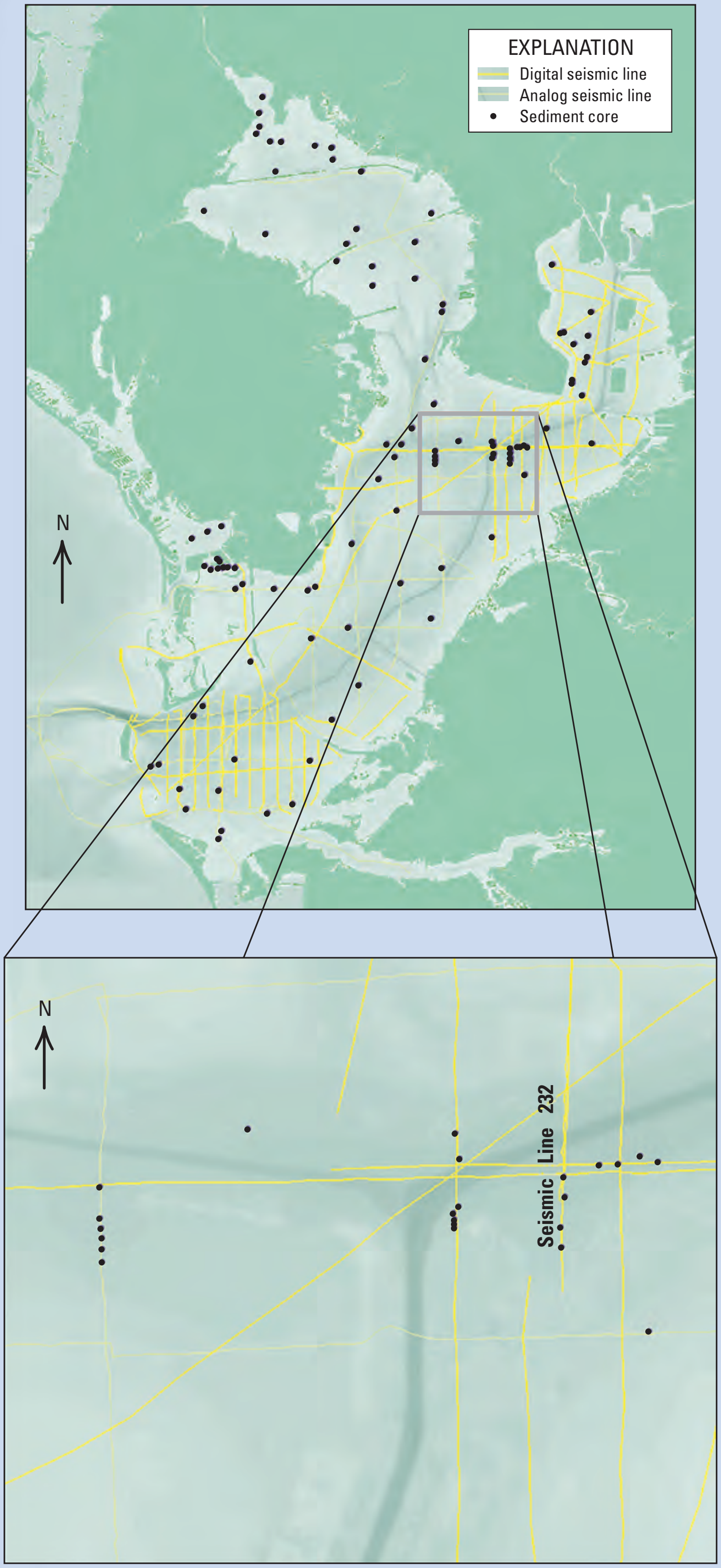
By Kimberly K. Yates and N. Terence Edgar (U.S. Geological Survey–St. Petersburg, Florida), and Thomas M. Cronin, (U.S. Geological Survey–Reston, Virginia)

Knowing the historical and prehistorical environmental conditions for a coastal ecosystem such as Tampa Bay can be very important when determining the effects of climate variability or sea-level change, conducting habitat restoration, or evaluating the health of ecosystems. Sediment cores are a common method for determining prehistorical conditions and the impact of human activity in the bay and its watershed during the historical period.

The USGS, in cooperation with Eckerd College and the University of South Florida (USF), collected over 100 sediment cores throughout Tampa Bay as part of the USGS Tampa Bay Study. The cores were collected from a boat or in the water using either a vibracore or push-core system, and then were brought back into the lab for analysis (box 3–1, fig. 1). The locations of these cores were coordinated with the same locations where seismic reflection profiles were collected. Seismic reflection profiles are also collected using boat-based instrumentation, and provide information on the stratigraphy underlying the sea floor of Tampa Bay. Coordinating core locations with stratigraphic profiles enables extrapolation of data from sediment layers in one core location to sediment layers in cores from other locations within the bay (box 3–1, fig. 2).

Many variables are studied and measured in the sediment, among them grain-size (useful in analysis of turbidity and water clarity), pollen grains (indicators of climate and land use), benthic microfossils (indicators of salinity and water quality), and a variety of geochemical proxies (indicators of salinity, water quality, pollution, etc).

Box 3–1, Figure 1. Vibracore apparatus used to take sediment cores in Tampa Bay. Photo from U.S. Geological Survey.



Box 3–1, Figure 2. Locations of sediment cores (black dots) and seismic track-lines throughout Tampa Bay. Map from U.S. Geological Survey

The temporal patterns obtained from these proxies, when interpreted in light of an age model developed from radiocarbon and other dating methods, tell researchers and managers about the environmental health of the bay and how to restore the bay to more pristine conditions.

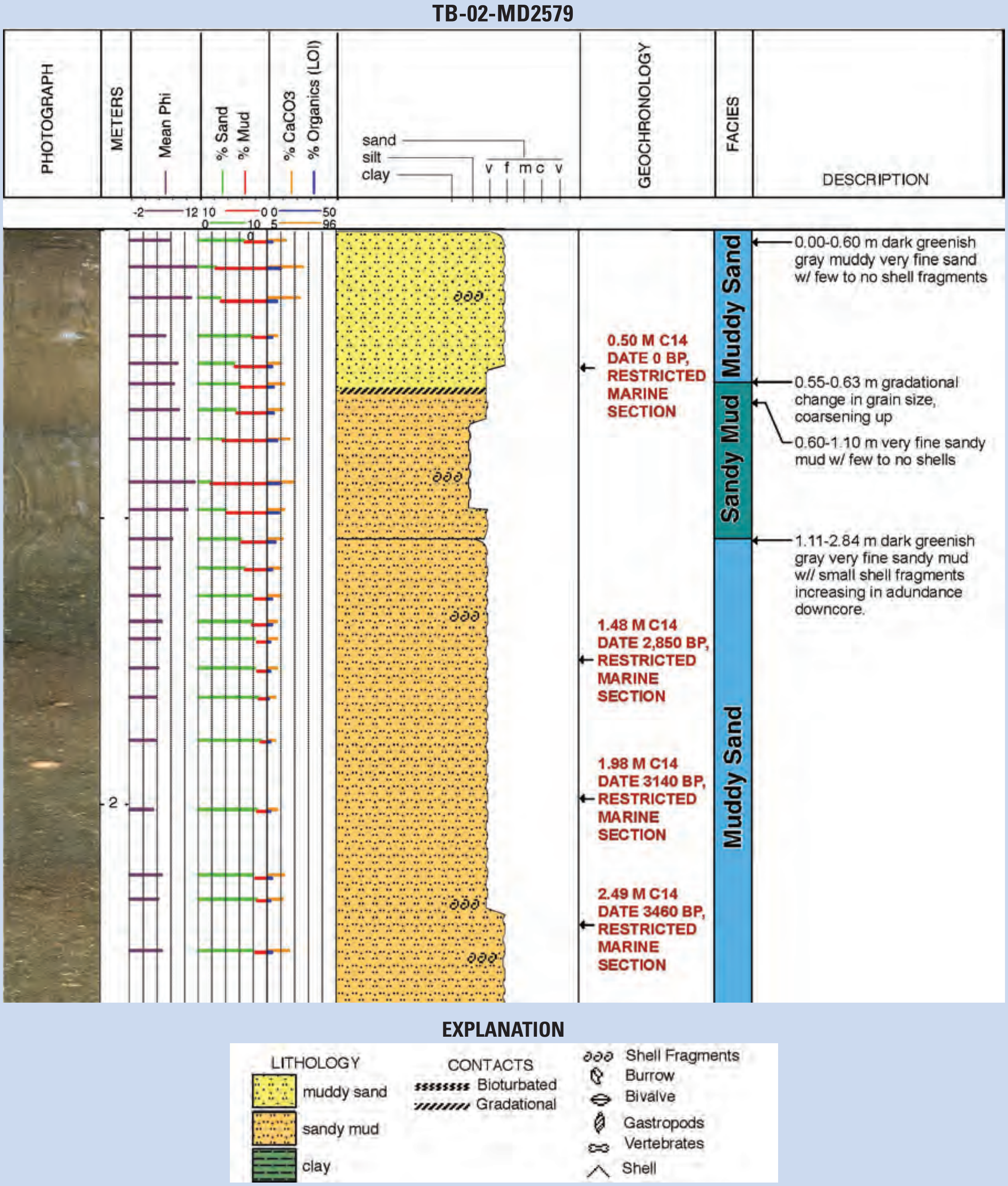
When France's large research vessel, *Marion Dufresne* (box 3–1, fig. 3), visited Tampa Bay in July of 2002, USGS researchers arranged to have the ship collect three "long" cores in the deepest natural depression, located in Middle Tampa Bay (Edgar, 2002). Seismic data collected by USF researchers indicated that about 16 to 17 m of sediment overlie the deepest recorded seismic reflection in this depression. Water depth in this location was 9 m, allowing the ship only 3 m of clearance between the hull and sea floor, the shallowest water depth from which the *Marion Dufresne* has ever attempted coring operations (box 3–1, fig. 4). The first core recovered 11.5 m of sediment that included marine sediment at the top, freshwater sediment in the middle, and marine sediment at the bottom of the core; this suggests that the oldest marine sediment is at least as old as the latest interglacial period (stage 5, about 125 ka). The second core parted at a weld and recovered no sediment. The third core bent and recovered only 4.5 m of sediment, terminating in the middle, nonmarine sediment sequence and providing the first observed evidence of the presence of a freshwater lake feature that once existed in Middle Tampa Bay (box 3–1, fig. 5). Data from these cores were instrumental in providing evidence that Tampa Bay formed as collapsed sinkhole features became inundated with water, rather than as a drowned river valley as previously hypothesized (box 3–1, fig. 6). More information on sediment coring in Tampa Bay is available at *http://gulfsci.usgs.gov*

Box 3–1, Figure 3. Research vessel *Marion Dufresne* from which sediment cores were taken in Middle Tampa Bay. Photo from Edgar (2002).

Box 3–1, Figure 4. Core apparatus located on the *Marion Dufresne*, used to take cores from Middle Tampa Bay. Photo from Edgar (2002).

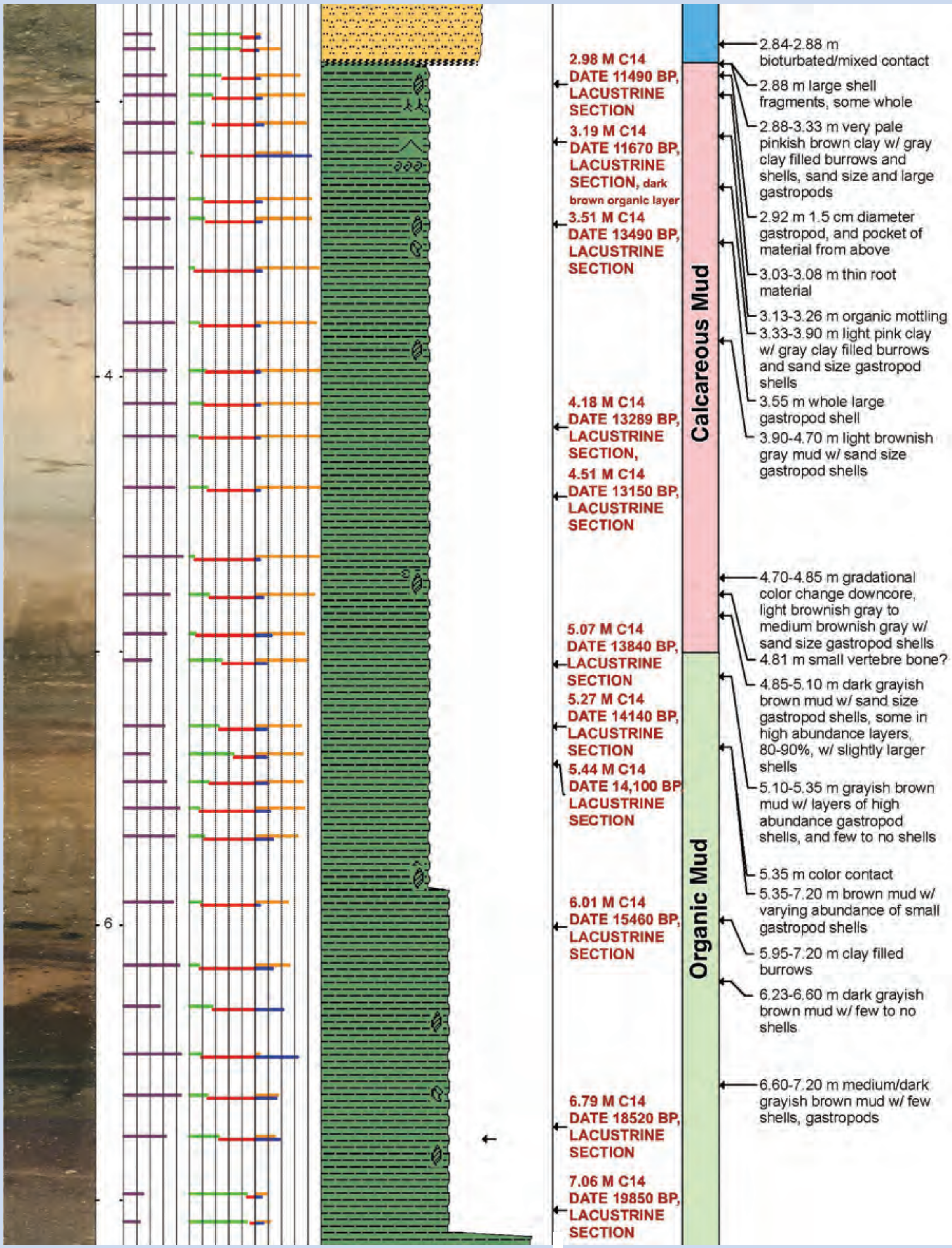
Box 3–1, Figure 5. Bent core pipe retrieved from Middle Tampa Bay while coring from the French research vessel *Marion Dufresne.* Photo from Edgar (2002).

A



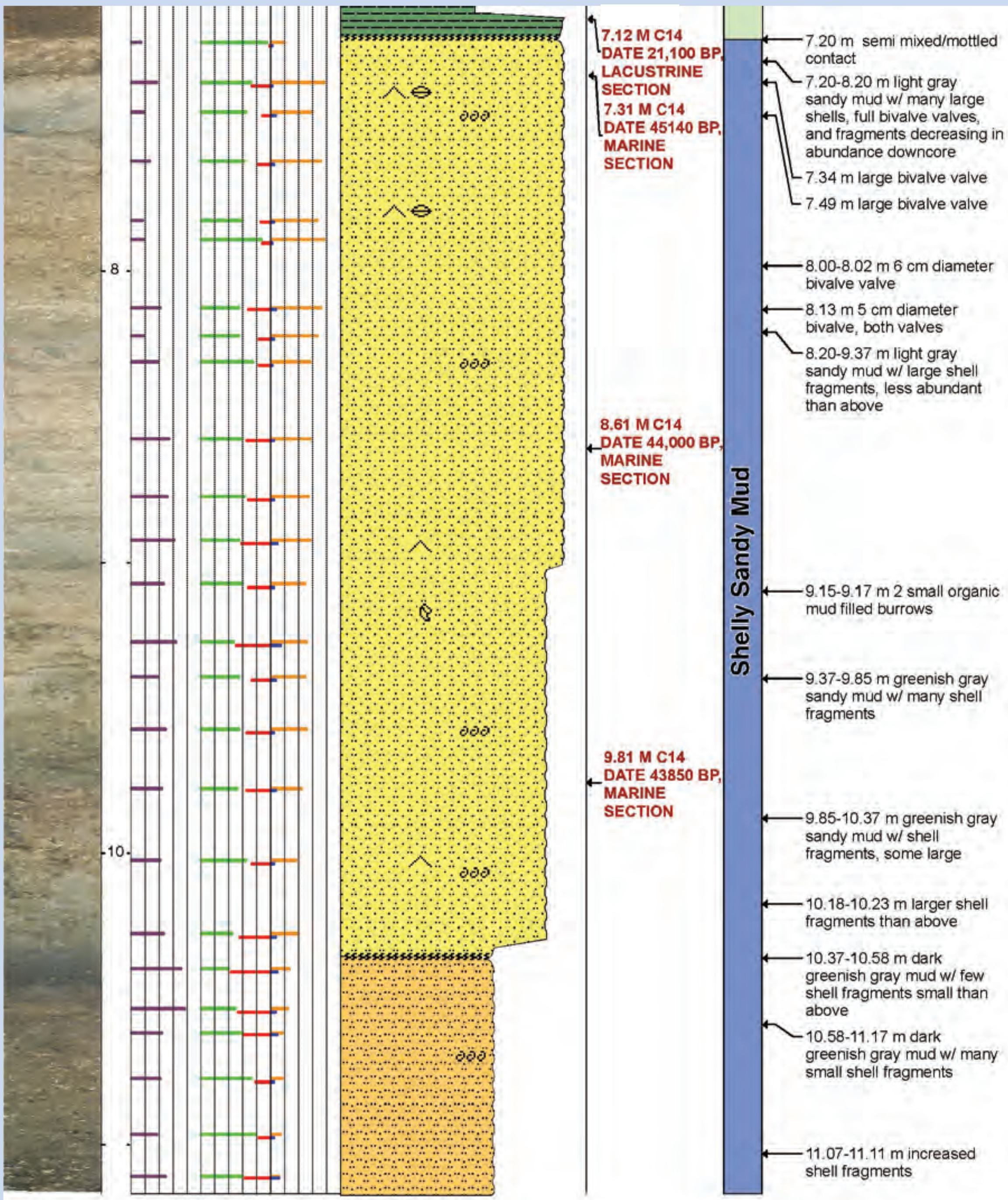
Box 3–1, Figure 6. *A*, Core log describing the 11.5-meter core collected from the *Marion Dufresne*. This stratigraphic sequence was instrumental in determining the origin of Tampa Bay. Core log from U.S. Geological Survey.

B



Box 3–1, Figure 6. *B*, Core log describing the 11.5-meter core collected from the *Marion Dufresne*. This stratigraphic sequence was instrumental in determining the origin of Tampa Bay. Core log from U.S. Geological Survey.—Continued

C



Box 3–1, Figure 6. *C*, Core log describing the 11.5-meter core collected from the *Marion Dufresne*. This stratigraphic sequence was instrumental in determining the origin of Tampa Bay. Core log from U.S. Geological Survey.—Continued

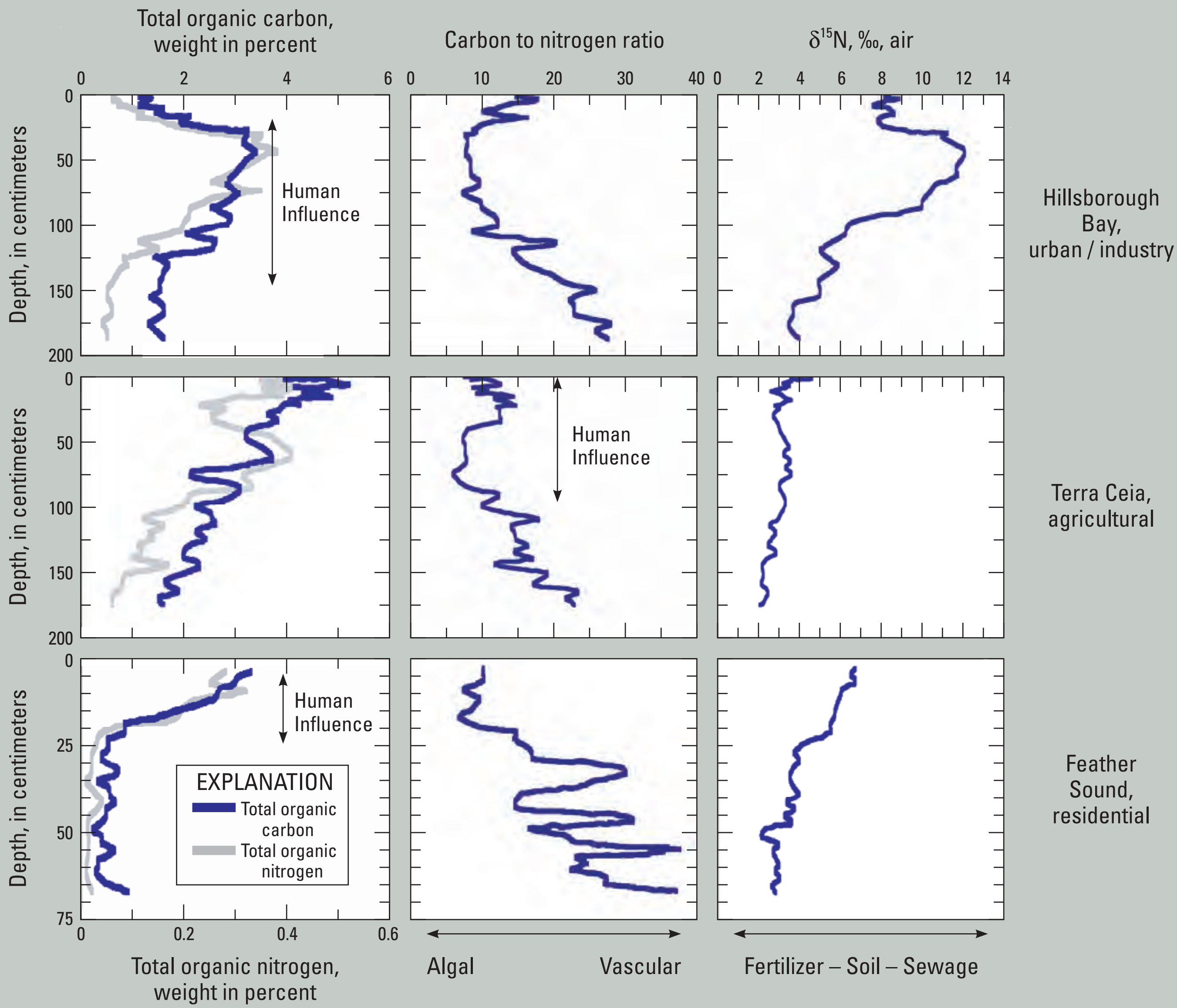
Box 3–2. Sedimentary Indicators of Human Effects on Tampa Bay

Excerpt from Yates and others (2006)

As part of the USGS Tampa Bay Study, the sedimentary record of Tampa Bay was examined for evidence of human influences on ecosystems during the past century (Yates and others, 2006). Comparative molecular organic geochemistry and stable isotopes were used to investigate a suite of sediment cores from relatively pristine (for example, Terra Ceia) and highly anthropogenically altered (for example Hillsborough Bay, Feather Sound, Safety Harbor, Bishop Harbor, and Lake Maggiore) regions of the bay. Results from this study were used to reconstruct and evaluate changes in carbon and nitrogen (N) cycling, and population dynamics and bioassemblage succession of upland plants, macrophytes, and phytoplankton. Using precisely dated sediment cores, the geochemical records were correlated with historical records of changes in land use, nutrient loading, contaminant input, and the distribution and abundance of estuarine fauna (mangroves, sea grasses, and other macrophytes), surface-dwelling plankton populations, and terrestrial plant ecosystems. Preliminary results indicate that sediment cores from Old Tampa Bay (Feather Sound and Safety Harbor areas), the city of St. Petersburg (Lake Maggiore), Hillsborough Bay, Central Bay, and Terra Ceia contain a well-preserved sediment archive, recording the most recent anthropogenic influences. All sites show significant changes in N cycling. Terra Ceia, Feather Sound, and Hillsborough Bay sites are located adjacent to watersheds dominated by agricultural, residential, and urban/industrial land uses, respectively, and effects from these land uses are reflected in the cores (box 3–2, fig. 1). Organic carbon and N concentrations have increased at all sites, with Hillsborough Bay sediments showing a 15-fold increase in N during the past 100 years. Sediments from Safety Harbor show a 5-fold N increase whereas those from Terra Ceia show a 3-fold increase during the past 100 years. The timing of the increase in organic carbon and N concentrations, indicating a transition from vascular plants to algal sources of organic matter in the cores, coincides with the increase in human impacts to the different regions. This reflects the strong anthropogenic influence in these areas.

Analyses of the N isotopic composition of organic matter reflect a dominant input from terrestrial plant material. In Hillsborough Bay, recent sediments show a transition to values up to 12‰, reflecting increased contributions from treated wastewater, septic inputs, or N contributions from livestock. In Terra Ceia, agricultural development in the watershed is reflected in the N isotopic composition of the recent sediments, which have an isotopic signature associated with the use of atmospheric N_2 for the synthesis of agricultural nutrients. Feather Sound displays intermediate values (+6 ‰), reflecting a combination of inputs from soil-derived N and treated wastewater. All sites also show significant changes in carbon cycling, including a recent 8-fold increase in carbon at Safety Harbor and Feather Sound, a 30-fold increase at Lake Maggiore, and a 2 to 3-fold increase in Central Bay and Hillsborough Bay.

Carbon isotopic composition of the organic matter reveals significant changes in biogeochemical cycling of carbon and the widespread development and influence



Box 3–2, Figure 1. Weight percent total organic carbon and total organic nitrogen, elemental atomic carbon to nitrogen ratio, and $\delta^{15}N$ composition of sedimentary organic matter in three sediment cores from Hillsborough Bay, Terra Ceia, and Feather Sound. From Yates and others (2006).

of anaerobic recycling processes. For example, in Lake Maggiore, carbon isotopic composition shifted over 20‰ in association with the historical record of nutrient loading and the relative importance of bacterial recycling processes associated with progressive lake eutrophication. Molecular organic geochemical studies reveal that, prior to anthropogenic changes to the aqueous and upland environments surrounding Safety Harbor and Central Bay, the distribution of organic compounds was strikingly similar; this suggests that both sites were once influenced by the same biological, chemical, and physical processes.

Of particular note is the selective onset of anaerobic conditions in the most recent sediments in Safety Harbor and Lake Maggiore. Molecular distributions indicate that the development of anoxic conditions is coincident with enhanced input of labile organic matter attributable to algal, zooplankton, and sewage sources. The biological and chemical consequences and overall environmental implications associated with the onset of anaerobic sedimentary conditions are significant because of the potential for remobilization of toxic metals, release of carcinogenic organic contaminants, and deterioration and absolute demise of the benthic floral and faunal communities. Other effects of human activities on the ecology, hydrology, water and sediment quality, and living resources of the bay and its watershed are discussed in more detail in Chapters 6, 7 and 8, below.

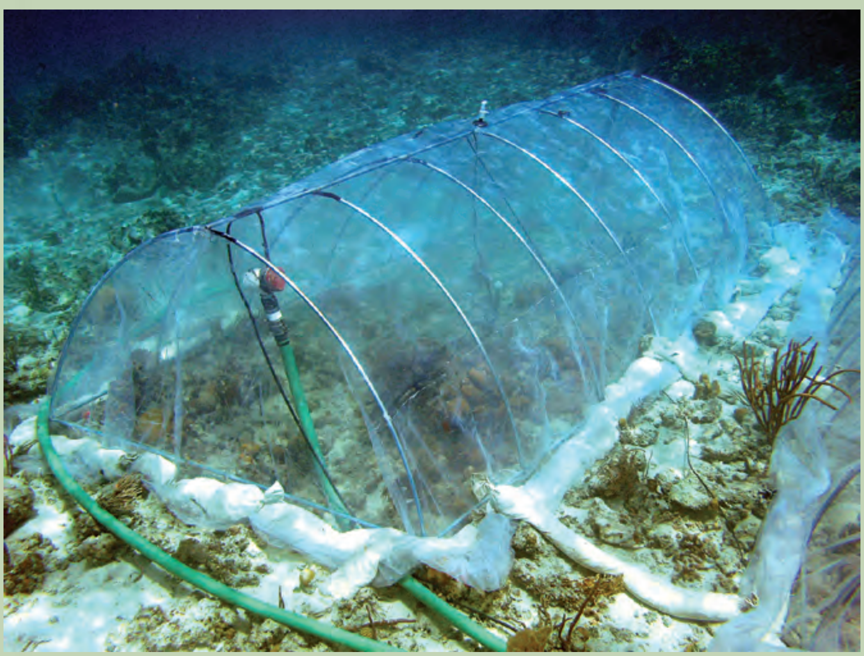
A follow-up sediment characterization study was performed in the Safety Harbor area by the USGS, in cooperation with the Tampa Bay Estuary Program (TBEP), Southwest Florida Water Management District (SWFWMD), University of South Florida (USF), and Eckerd College, in 2008–2009. Project objectives were to develop a 3-D map of the extent and volume of organic-rich sediment accumulation in Safety Harbor, to determine the origin of recent and historic sediment accumulations, and to investigate the ecological context of accumulations of organic-rich sediments. Results indicate that highly organic “muck” sediments are currently accumulating in three areas, the central part of the Harbor, dredged areas, and nearshore areas landward of shallow shoals. The muck has been accumulating more rapidly in recent years, and may be influenced by changes in circulation (associated with bridge construction and the Lake Tarpon Outfall Canal) and nutrient loading from the watershed. It is primarily the remains of microscopic algae and small crustaceans that live in the water column. Isotope ratios indicate that the source of nutrients for these organisms has changed over time, with inorganic fertilizer serving as an increasingly important N source in recent decades (Peebles and others, 2009).

Box 4–1. Community Metabolism, Primary Production, and Irradiance Relations in Tampa Bay Seagrass Beds

By Kimberly K. Yates (U.S. Geological Survey–St. Petersburg, Florida)

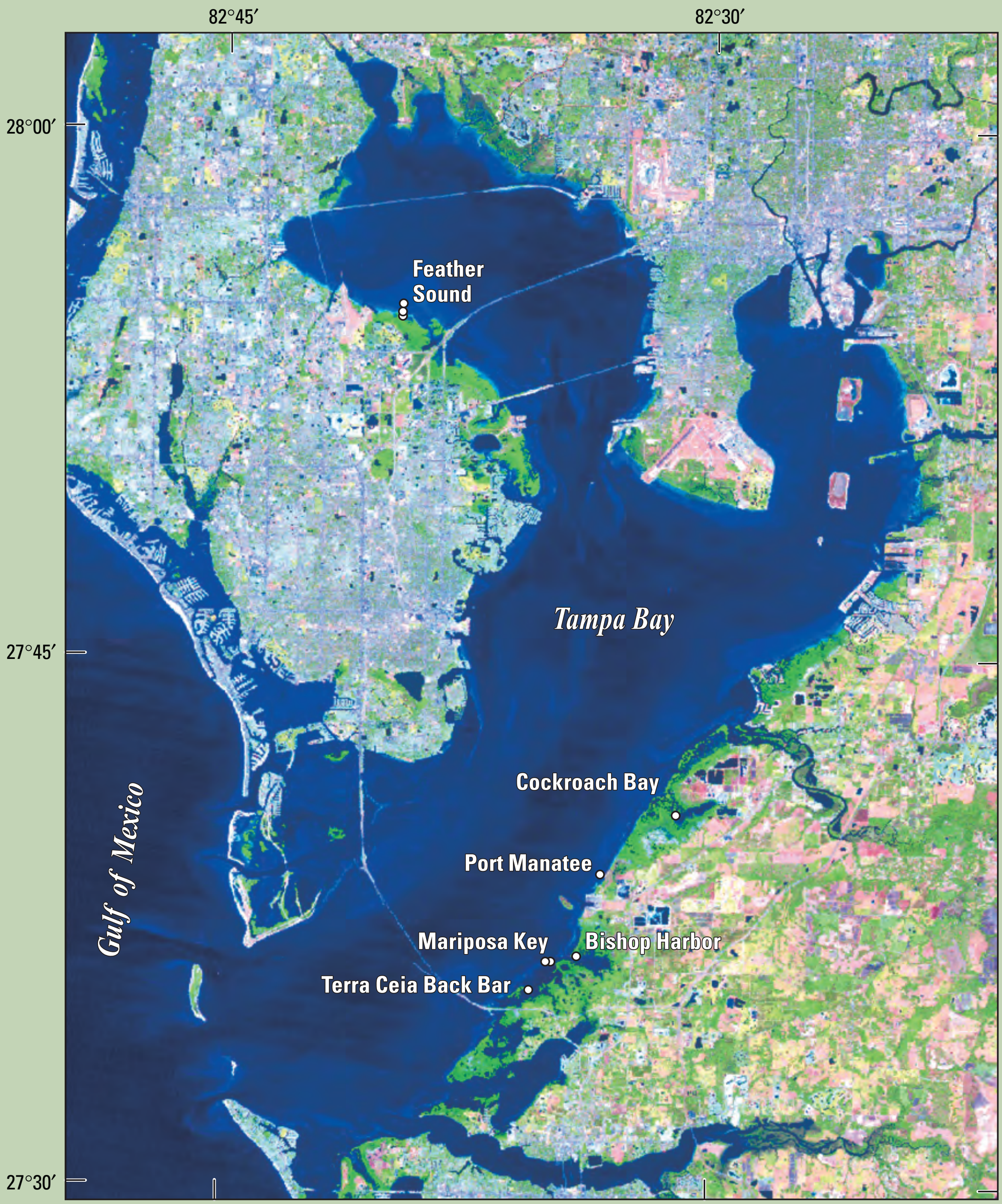
Yates and others (2007) examined daily primary production and respiration rates of the biota within and immediately above seagrass beds and bare-sand habitats in the bay, using a submersible chamber known as the Submersible Habitat for Analyzing Reef Quality (SHARQ) and described by Yates and Halley (2003) (box 4–1, fig. 1). The SHARQ chamber was deployed for 24-hour periods at 17 locations in six different areas of the bay (box 4–1, fig. 2) during spring and fall, 2001–2003. Rates of gross daily primary production (P) and 24-hour respiration (R) by the plant and animal communities present within the chamber were recorded at each location.

Relations between gross daily primary production (P) and irradiance (I) were measured during 2001–2003 SHARQ deployments. Results indicate that, in study areas along the southeastern shoreline of Tampa Bay, daily P–I relations can be described using the exponential or hyperbolic tangent curves that are typically used to delineate seagrass P–I responses (Zimmerman and others, 1994; Neely, 2000) (box 4–1, table 1). However, in an intermediate-density *Halodule* habitat in Old Tampa Bay, the best-fit P–I relations were linear (box 4–1, fig. 3), showing no evidence of light saturation occurring even at PAR levels as high as 600 to 800 $\mu E\ m^{-2}\ s^{-1}$. The linear P–I relations observed in Old Tampa Bay were at PAR levels much higher than those that Neely (2000) found to cause light saturation in *Halodule* leaf segments collected from beds in Lower Tampa Bay. This indicates that seagrass responses to varying irradiance levels may differ substantially in different parts of the bay.



Box 4–1, Figure 1. The Submersible Habitat for Analyzing Reef Quality (SHARQ) benthic incubation chamber. This chamber consists of an aluminum frame covered by clear, flexible plastic-sheeting to trap water over the seafloor enabling scientists to analyze water chemistry using flow-through analytical systems. Photo by U.S. Geological Survey.

Similar levels of variability in P–I relations have been reported for other seagrass species and geographic regions, and in several cases have been related to spatial variations in water depth or seasonal variations in water clarity (Tomasko, 1993). In the case of Tampa Bay, the available data indicate that



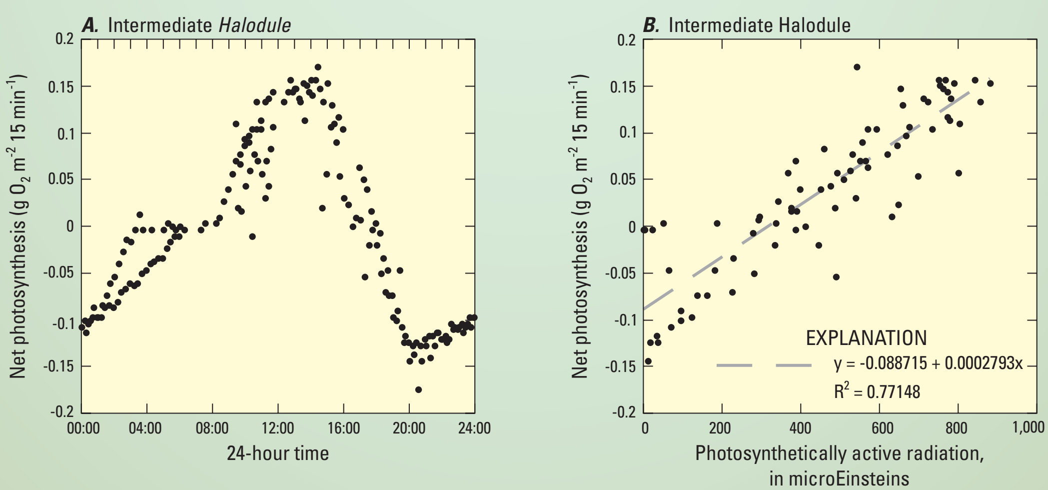
Box 4–1, Figure 2. Submersible Habitat for Analyzing Reef Quality deployment locations. From Yates and others (2007).

P–I relations may exhibit considerable spatio-temporal variability and that caution should be used when modeling seagrass productivity in the bay based solely on theoretical P–I curves (Yates and others, 2007). The variability observed in the bay may be related, in part, to the different sources of light attenuation, such as colored dissolved organic material, phytoplankton, and nonphytoplankton turbidity, which are present at different times in different bay segments.

Box 4–1, Table 1. Summary of community production and respiration observations collected during Submersible Habitat for Analyzing Reef Quality deployments during 2001–2003.

[Metabolic parameters for representative substrate types in Tampa Bay. P, daily gross production (g O_2 m^{-2}), integration of metabolism curve with respect to *y* + *r* from sunrise to sunset; R, 24-hour respiration (g O_2 m^{-2}) calculated from the average nighttime respiration rate; P/R, ratio of daily gross production to 24-hour respiration; n, number of net photosynthesis and respiration data points collected and used to generate each metabolism curve; %, percent; Int., intermediate seagrass coverage. From *http://gulfsci.usgs.gov*]

Substrate description	Date	Hours sunlight	Linear regression equation *y* = *mx* + *b*	Correlation coeficient (R)	P	R	P/R	n
Bishop Harbor								
Int. *Thalassia*/100% drift algae	04/05/02	12.7	*y* = 1.7164e-4x – 0.030808	0.73	5.33	5.71	0.93	533
Int. *Thalassia*/50% drift algae	04/05/02	12.7	*y* = 1.5943e-4x – 0.025627	0.68	4.92	5.03	0.98	496
Cockroach Bay								
Int. *Thalassia*/decaying algae	04/30/02	13.2	*y* = 1.494e-4x – 0.043975	0.68	4.60	5.97	0.77	233
Dense *Halodule*/decaying algae	04/30/02	13.2	*y* = 1.5374e-4x – 0.045568	0.68	4.99	6.90	0.72	246
Feather Sound								
Int. *Halodule*	05/04/02	13.3	*y* = 2.793e-4x – 0.088715	0.87	6.56	7.44	0.88	172
Int. *Halodule*	05/04/02	13.3	*y* = 2.8802e-4x – 0.10265	0.88	6.53	8.17	0.80	154
Sand bottom	05/06/02	13.4	*y* = 1.1341e-4 – 0.02149	0.62	3.08	3.67	0.84	232
Sand bottom	05/06/02	13.4	*y* = 1.0109e-4x – 0.022375	0.41	3.77	4.01	0.94	246
100% drift algae	05/09/02	13.4	No light data	No data	6.91	5.94	1.16	170
Int. *Halodule*	05/09/02	13.4	No light data	No data	7.25	5.75	1.26	161
Mariposa Key								
Sparse *Thalassia*	04/19/01	13.0	*y* = 1.406e-4x – 0.032323	0.61	6.70	7.12	0.94	221
Int. *Thalassia*	04/19/01	13.0	*y* = 9.8041e-5x – 0.009488	0.54	5.69	6.12	0.93	300
Port Manatee								
Sparse *Syringodium*	05/14/01	13.5	No light data		6.16	6.12	1.01	224
Dense *Syringodium*	05/14/01	13.5	No light data		7.92	8.27	0.96	174
Terra Ceia Back Bar								
Sparse *Thalassia*/deep edge	10/07/03	11.7	*y* = 1.0683e-4x – 0.016921	0.71	2.35	3.23	0.73	289
Int. *Thalassia*	10/11/03	11.6	*y* = 2.98e-4x – 0.030689	0.66	2.82	4.70	0.60	222
Int. *Thalassia*	10/11/03	11.6	*y* = 3.9056e-4x – 0.046291	0.73	3.24	5.39	0.60	200



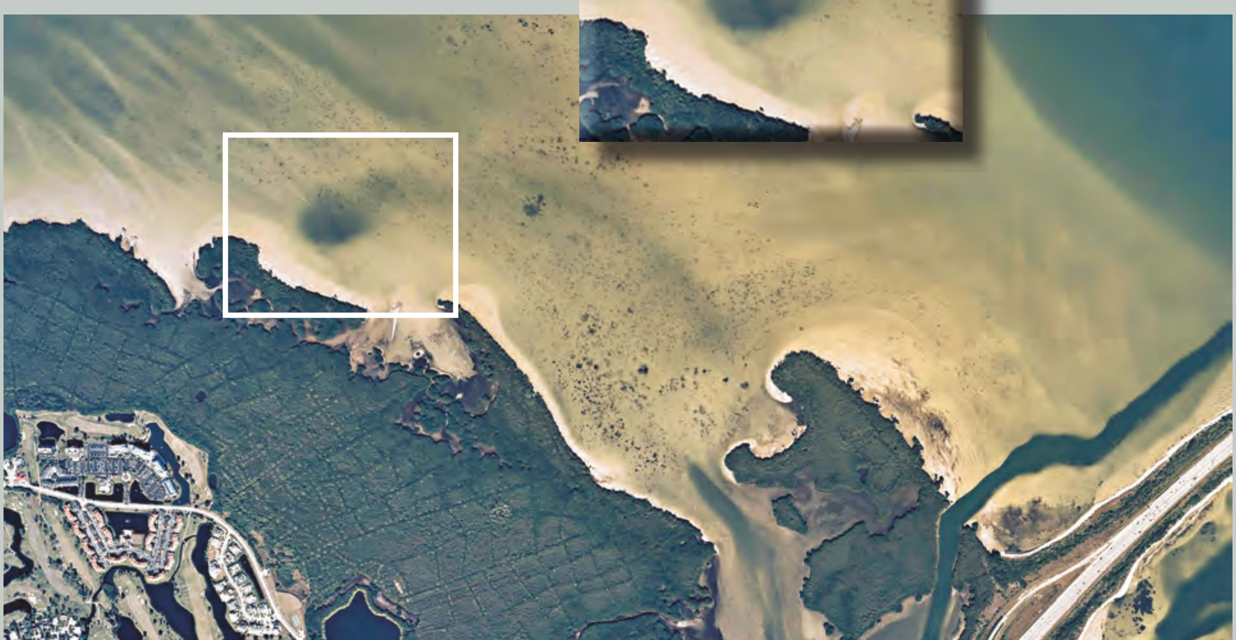
Box 4–1, Figure 3. *A*, Diurnal net primary productivity; and *B*, primary production and irradiance relation, observed within a Submersible Habitat for Analyzing Reef Quality incubation chamber during a 24-hour deployment within a *Halodule* bed in the Feather Sound part of Old Tampa Bay, May 4–6, 2002. From Yates and others (2007).

Box 5–1. Coastal Groundwater Exchange in Tampa Bay

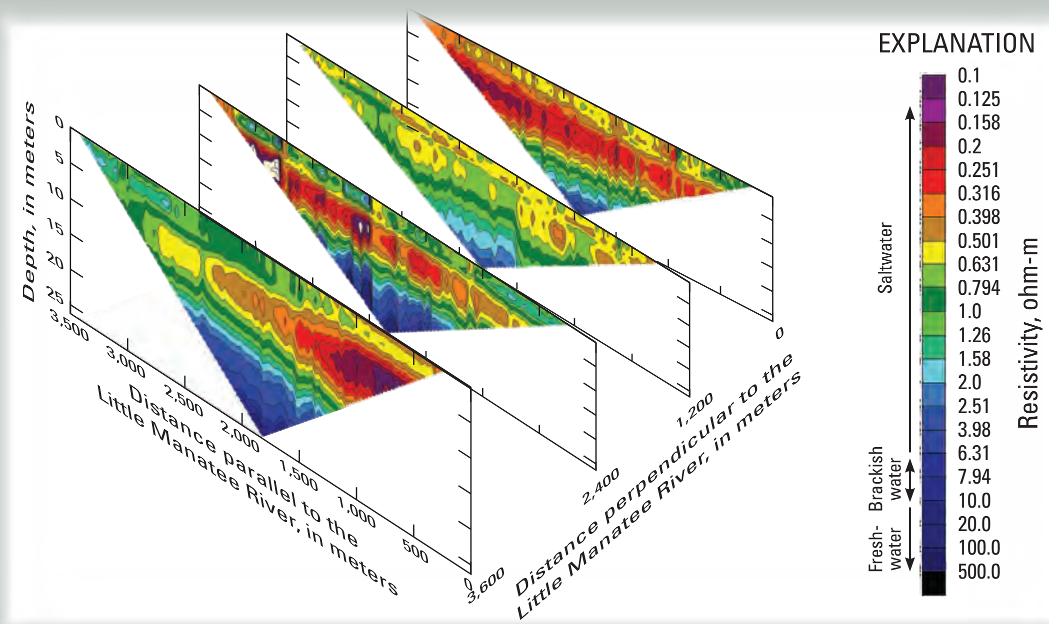
By Kimberly K. Yates (U.S. Geological Survey–St. Petersburg, Florida) and
Peter W. Swarzenski (U.S. Geological Survey–Santa Cruz, California)

Developing an accurate water budget for the Tampa Bay region is a critical component for monitoring the quantity and quality of freshwater available for human consumption, and to ensure a healthy estuarine ecosystem today. An accurate water budget is also needed to manage Tampa Bay wisely into the future under expected environmental stressors, such as sea-level change and continued urbanization. Surface-water runoff from principal rivers and creeks into the bay can be quantified using routine streamgauging techniques. However, the coastal rivers of Florida also contain an additional hydrologic component — base flow (Swarzenski and Yates, 2005). The underlying geology of the Tampa Bay area is characterized by karstic limestone topography and porous sediment that provides conduits for significant groundwater flow toward Tampa Bay (see Chapter 4). This persistent flow of coastal groundwater plays an important role in the transport of nutrients and some contaminants to the bay. The quantity and quality of this submarine groundwater discharge has until recently been overlooked in water and constituent budgets for the bay.

The USGS combined data on the structural geology of Tampa Bay with a variety of geochemical and modeling techniques to measure the quantity and quality of submarine groundwater discharge to Tampa Bay. Seismic profile data (see Chapter 4) were used to identify geologic features, such as sinkholes and collapse features that may act as conduits for submarine ground-water flow (box 5–1, fig. 1). A technique called marine continuous resistivity profiling was used to identify whether or not specific geologic features were associated



Box 5–1, Figure 1. A sinkhole feature located near the coastline of Feather Sound in Old Tampa Bay. This particular feature is associated with submarine groundwater discharge to the bay.



Box 5–1, Figure 2. Three dimensional resistivity profile taken near the Little Manatee River located on the eastern shoreline of Middle Tampa Bay. Axes indicate position of the transect relative to the river mouth. Dark blue colors indicate fresh and brackish water, green and red colors indicate saltier water. Depth (in meters) is the depth below the bay floor.

with freshwater masses located beneath the bay floor. Continuous resistivity mapping is performed by towing a series of current-producing and potential electrodes behind a boat. These sensors send an electrical pulse into the seafloor that bounces back to the sensors, indicating whether the water or sediment below the seafloor is fresh or salty. Box 5–1, Figure 2 shows a three-dimensional resistivity profile taken near the Little Manatee River in Tampa Bay, which depicts a freshened water lens that extends out into the bay and beneath the bay floor (Swarzenski and Yates, 2005; Swarzenski and others, 2007a; Kroeger and others, 2007). Salinity was measured in pore water from sediment cores (see Chapter 4) that correspond to locations with freshened water masses to confirm their presence (Swarzenski and Baskaran, 2007). Groundwater samples were also taken from about 70 locations throughout the bay area for groundwater-salinity and nutrient analyses (Kroeger and others, 2007).

Three different methods were used to quantify submarine groundwater discharge into the bay:

(1) Measurement of naturally occurring radionuclides, including radium and radon (Swarzenski and others, 2007a)

(2) Calculation of a watershed water budget (Kroeger and others, 2007); and

(3) Numerical modeling (Cliff Hearn, ETI contractor, personal comm., 2005).

Submarine groundwater discharge rates calculated from the distribution of radium-223, 224, 226, and 228 ranged from 1.6 to 10.3 m^3 d^{-1} per meter of shoreline length depending on the sampling season. Based on the watershed water-budget method, the rate of submarine groundwater discharge to the bay is estimated at 2.9 m^3 d^{-1} per meter of shoreline. Estimates of these discharge rates based on continuous radon measurements were 5.6 m^3 d^{-1} per meter of shoreline. These radon-based measurements indicate that flow of brackish and saline groundwater to the bay also represents a significant component of submarine groundwater discharge. Results indicate that the ratio of freshwater submarine groundwater discharge flux to streamflow into the bay is about 20 to 50 percent. Based on these estimated discharge rates and measurement of nutrient concentrations in groundwater samples, nutrient loads (N as TDN, DIN, or $NO^{2+}NO^{3}$ and phosphate as PO_4^{3-}) to the bay due to freshwater submarine groundwater discharge was estimated at 40 to 100 percent of the stream-discharge loads. These results indicate that the transport of groundwater and nutrients to the bay via submarine groundwater discharge is significant compared to river and stream loads.

Box 5–2. Bay Region Atmospheric Chemistry Experiment (BRACE) Study

By Holly Greening (Tampa Bay Estuary Program); Noreen Poor, (University of South Florida); and Tom Atkeson (Florida Department of Environmental Protection)

The Bay Region Atmospheric Chemistry Experiment (BRACE) study was developed in response to the persistent increasing trend in N oxide emissions in Florida. It assessed potential effects of these emissions on the air quality and ecological health of the Tampa Bay area to:

- Improve estimates of N deposition to the bay;
- Apportion atmospheric N between local, regional, and remote sources;
- Assess the impact of utility controls on N deposition; and
- Provide a technical basis for developing more effective community control strategies to reduce N deposition.

Box 5–2, Figure 1. The Bay Region Atmospheric Chemistry Experiment (BRACE) data-collection station, located at the east end of the Gandy Bridge. Photo by Noreen Poor.

In response to an initial estimate that direct deposition of atmospheric N contributed about 30 percent to the total N load to Tampa Bay, the TBEP began monitoring rainfall and ambient air concentrations of N at an urban bayside location in 1996. Flux calculations from observational data supported the initial loading estimate, and raised questions about contributions from indirect atmospheric N deposition and the sources of N to the airshed. Model predictions describe this region as centered over peninsular Florida, roughly elliptical, and roughly three times the size of the bay region (see fig. 5–3).

The BRACE study began in 2000 and included both long-term and short-term intensive measurement campaigns, as well as concurrent special studies. BRACE planners sought experimental designs that balanced project resources between measurements that would support mesoscale modeling, offered direct evidence of source contributions and N deposition rates, took advantage of new technologies, and explored new theoretical constructs. BRACE participants included managers, scientists, engineers, and technicians from the Argonne National Laboratory, EPCHC, FDEP, NOAA, Pinellas County Department of Environmental Management, TBEP, Texas Tech University, USEPA, University of Maryland, University of Miami, University of Michigan, University of South Florida (USF), and URG. The project was supported by the FDEP, Tampa Electric Company, and in-kind contributions from BRACE participants.

Within the framework established by the project goals, BRACE researchers improved N deposition estimates by expanding the air pollutant monitoring network (box 5–2, figs. 1 and 2), by deploying state-of-the-art sensors and monitors, and by analyzing and interpreting meteorological and air pollutant concentration data with sophisticated atmospheric chemistry and physics models. Coupled with the meteorological and emissions data, BRACE measurements enabled researchers to reconstruct a four-dimensional image of N emissions, dispersion, transport, and transformation; to analyze the role in N processing and transport of the land-sea breeze and regional wind convergence zones; to identify deficiencies in N emissions inventories; and to calculate total N deposition rates over the Tampa Bay watershed, including the direct total N deposition rate to Tampa Bay. The N species of interest were NO, NO_2, HNO_3, HNO_2, NO_z (that is, NO_y-NO_x), NH_3, NH_4^+, and organic amines. NO, NO_2, HNO_3, HNO_2, PAN and other organic nitrates, $NO_3^{\bullet}$, and N_2O_5 comprise NO_y.

The pollutants of interest, the models, and the modeling objectives dictated the temporal and spatial scales of the observations. Measurements on shorter time scales, for example, allowed better resolution of regional air pollution plumes and improved agreement with equilibrium and kinetic assumptions inherent in many model algorithms. New technologies made possible near real-time monitoring of solar radiation, actinic flux, wind speed and direction, temperature, relative and specific humidity, and concentrations of nitrogen oxide and nitrogen dioxide, nitric acid, total oxidized nitrogen species (NO_y), nitrate, ammonia, ozone, carbon monoxide, sulfur dioxide, mercury, organic carbon (OC), black carbon (EC), volatile organic compounds (VOCs), metals, and aerosol mass and number.
The measurements provided a better understanding of:

- The magnitude and composition of gaseous and aerosol N species;
- Nitrogen-deposition velocities and fluxes, both to the watershed and directly to the bay surface;
- Source emissions and the contributions of those emissions to regional air quality; and
- The limitations on instrument and model performance. Results from the BRACE study were summarized by Atkeson and others (2007).

Box 5–2, Figure 2. Meteorological data (wind speed and direction, air temperature) and physical data from Tampa Bay (current speed and direction, water temperature) are collected at several stations within Tampa Bay. Photo by Mark Luther.

Box 5–3. Tracking Progress Toward Water-Quality Goals—Application of the Tampa Bay Decision Framework

By Edward Sherwood (Tampa Bay Estuary Program) and Holly Greening (Tampa Bay Estuary Program)

The continued monitoring of water quality and seagrasses in Tampa Bay will allow managers to assess progress toward meeting established goals. An important component of this effort is the routine comparison of mean annual chlorophyll *a* concentrations and light attenuation to desired targets. TBEP has developed a tracking process to determine if water-quality targets are being achieved. The process to track status of chlorophyll *a* concentration and light attenuation involves two steps. The first step utilizes a decision framework to evaluate differences in mean annual ambient conditions from established targets. The second step incorporates results of the decision framework into a decision matrix, leading to possible outcomes dependent upon magnitude and duration of events in excess of the established target (Janicki and others, 2000; Greening and Janicki, 2006).

The recommended management actions resulting from the decision matrix are classified by color (green, yellow and red) into three categories for presentation to the Tampa Bay resource-management community (box 5–3, fig. 1). When outcomes for chlorophyll *a* concentration and light attenuation indicate that both targets are being met (green), no management response is required. When conditions are intermediate (yellow), with the monitoring data indicating relatively small and/or short-lived failures to meet the targets, further examination is needed to determine an appropriate management response. When conditions are problematic (red), with relatively large or longer-term exceedances of one or both targets, stronger management responses are considered for implementation.

Green	"Stay the course;" partners continue with planned projects to implement the CCMP. Data summary and reporting via the Baywide Environmental Monitoring Report and annual assessment and progress reports.
Yellow	TAC and Management Board on caution alert; review monitoring data and loading estimates; attempt to identify causes of target exceedences; TAC report to Management Board on findings and recommended responses needed.
Red	TAC, Management and Policy Boards on alert; review and report by TAC to Management Board on recommended types of responses. Management and Policy Boards take appropriate actions to get the program back on track.

Box 5–3, Figure 1. Management responses to decision matrix outcomes.

Results of the decision matrix from 1974 through 2008 are shown in box 5–3, figure 2 (Sherwood, 2009). The poor water conditions are clearly seen in early years of this time series, followed by marked improvements since 1984.

Since 1996, application of the decision framework has indicated two problematic ("red") time periods: in 1997 and 1998 in all bay segments (corresponding to high rainfall associated with a strong El Niño event), and in 2003 and 2004 in one bay segment, Old Tampa Bay. Recommendations from the TBEP Technical Advisory Committee (TAC) for management response to the El Niño-associated period were to support immediate actions toward repair of sewer transport and pumping systems and industrial treatment-water holding systems that had failed during high rainfall periods. Actions were taken by municipalities and industrial facilities to address these failed systems. In addition to these immediate actions, the TAC recommendations were to continue monitoring to assess the need for further action following the El Niño event.

Recommendations for action in Old Tampa Bay in response to the decision matrix results in 2003–2004 were quite different than for the bay-wide El Niño-associated event. Following an extensive review of existing data and information, the TAC recommended that an Old Tampa Bay seagrass recovery research program be implemented to examine factors potentially affecting seagrass recovery in that segment of Tampa Bay, followed by development of a recovery and management plan. Initial monitoring results (summarized in Cross, 2007) indicated that some shallow areas in Old Tampa Bay had poorer water quality (and, thus, less light available for seagrasses) than in three other study areas. Epiphytes caused significant light reduction (25 to 32 percent) in all parts of Old Tampa Bay. Transplanted seagrass survival was very low — 0.9 percent after two growing seasons, compared with 21 percent in other areas of Tampa Bay. Additional factors were examined, including high wave energy and loads from submarine groundwater. However, neither of these appeared to be responsible for slower seagrass recovery rates (Griffen and Greening, 2004).

Further evaluations examined additional potential causes of poor water quality and slower seagrass recovery in Old Tampa Bay, including examination of reduced circulation and slower flushing rates (possibly resulting in higher chlorophyll *a* concentrations), local sources of N loading, increased epiphyte loads, high rates of bioturbation (by stingrays and burrowing organisms), and the potential influence of hydrogen sulfide concentrations. Results indicated that the lack of seagrass recovery in Feather Sound was probably due to multiple factors, and that a multipronged management strategy would be required. Ongoing efforts include plans to reduce runoff from adjacent land uses and restoration of fringing mangroves to promote sheet flow through the mangrove system (Cross, 2007).

Historic 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
2002	Yellow	Green	Green	Green
2003	Red	Yellow	Green	Yellow
2004	Red	Green	Green	Yellow
2005	Green	Green	Yellow	Yellow
2006	Green	Green	Green	Green
2007	Green	Green	Green	Green
2008	Yellow	Green	Green	Yellow
2009	Yellow	Yellow	Green	Green

Box 5–3, Figure 2. Decision matrix outcomes for 1975–2008. From Sherwood (2009).

Box 5–4. Tampa Bay Nitrogen Management Consortium (TBNMC)—A Collaborative Approach to Meet Water-Quality Targets and Support Seagrass Recovery in Tampa Bay

By Holly Greening (Tampa Bay Estuary Program)

A landmark agreement between more than 40 area government and private industry representatives to limit N pollution in Tampa Bay was finalized in September 2009. The agreement spells out how much N can enter Tampa Bay through stormwater, air pollution, treated wastewater, and industrial discharges through 2012. The limits will maintain N loadings to the bay at existing levels; additional N associated with growth must be offset through additional pollution controls.

In 1996, the TBEP local government and agency partners adopted numeric management targets to restore and protect seagrass beds and restore environmental conditions in Tampa Bay. These resource-based targets include the goal of restoring seagrass acreage to the extent observed in 1950, and numeric targets for water clarity, chlorophyll *a* concentrations, and the total N loads necessary to meet and maintain water-quality targets that support seagrass recovery (detailed in Chapter 5). A multipronged management strategy, implemented by the TBNMC was initiated in 1996 to meet these targets.

In 1998, FDEP proposed and USEPA approved a TMDL for N for Tampa Bay required by Section 303(d) of the Federal Clean Water Act. The TMDL total N loads were based on the resource-based management targets (water clarity, chlorophyll *a* concentrations and the total N loads observed to meet these targets) developed by the TBEP partners to support the environmental recovery of Tampa Bay.

Since 1998, FDEP chlorophyll *a* targets have been met in all four major bay segments, with the exception of 1 year in Lower Tampa Bay and 3 years in Old Tampa Bay (box 5–4, fig 1). Seagrass acreage has increased by more than 4,800 acres bay-wide over this same period, and more than 6,000 acres since the mid 1980s (fig. 4–29).

In December 2007, the public and private participants in the TBNMC (box 5–4, table 1) committed to develop a process to allocate N loads among all sources, to support continued attainment of bay management targets and to be consistent with the required TMDL. The Consortium participants developed N load allocations that equitably distribute the burden of N management across the sectors and sources of N loading within the basin, as well as the total maximum loading of N to each major bay segment. Through this consensus-based process, Consortium participants defined limits to the amount of N they

Year	Old Tampa Bay	Hillsborough Bay	Middle Tampa Bay	Lower Tampa Bay
1975	No	No	No	Yes
1976	No	No	No	Yes
1977	No	No	No	No
1978	No	No	No	Yes
1979	No	No	No	No
1980	No	No	No	No
1981	No	No	No	No
1982	No	No	No	No
1983	No	No	No	No
1984	Yes	Yes	No	Yes
1985	No	No	No	Yes
1986	No	No	Yes	Yes
1987	No	Yes	No	Yes
1988	Yes	Yes	Yes	Yes
1989	No	Yes	Yes	Yes
1990	No	Yes	Yes	Yes
1991	Yes	Yes	Yes	Yes
1992	Yes	Yes	Yes	Yes
1993	Yes	Yes	Yes	Yes
1994	No	No	No	No
1995	No	No	No	Yes
1996	Yes	Yes	Yes	Yes
1997	Yes	Yes	Yes	Yes
1998	No	No	No	No
1999	Yes	Yes	Yes	Yes
2000	Yes	Yes	Yes	Yes
2001	Yes	Yes	Yes	Yes
2002	Yes	Yes	Yes	Yes
2003	No	Yes	Yes	Yes
2004	No	Yes	Yes	Yes
2005	Yes	Yes	Yes	No
2006	Yes	Yes	Yes	Yes
2007	Yes	Yes	Yes	Yes
2008	Yes	Yes	Yes	Yes
2009	No	Yes	Yes	Yes

Box 5–4, Figure 1. Compliance with Florida Department of Environmental Protection approved annual average chlorophyll *a* thresholds for each major bay segment, 1974–2008. The thresholds are: Hillsborough Bay, 15.0 μg/L; Old Tampa Bay, 9.3 μg/L; Middle Tampa Bay, 8.5 μg/L; and Lower Tampa Bay, 5.1 μg/L. Green indicates compliance with these thresholds; red indicates noncompliance. From Tampa Nitrogen Management Consortium.

are permitted to discharge. For example, communities that hold permits to discharge more treated wastewater than they currently are must "hold the line" at current levels — unless they can prove they have lowered N pollution elsewhere in their communities. Participating private sector partners must meet the same restrictions.

Box 5–4, Table 1. Parcipants of the Tampa Bay Nitrogen Management Consortium.

Alafia Preserve (Mulberry), LLC	Hillsborough County
CF Industries	Janicki Environmental, Inc. (technical support)
City of Bradenton	Kerry I & F Contracting
City of Clearwater	Kinder Morgan Bulk Terminals, Inc.
City of Gulfport	LDC Donaldson Knoll Investments, LLC
City of Lakeland	MacDill Air Force Base
City of Largo	Manatee County
City of Mulberry	Mosaic Company
City of Oldsmar	Pasco County
City of Palmetto	Pinellas County
City of Plant City	Polk County
City of Safety Harbor	Southwest Florida Water Management District
City of St. Petersburg	Tampa Bay Estuary Program (coordinator and facilitator)
City of Tampa	Tampa Bay Regional Planning Council
CSX Transportation	Tampa Bay Water
Eagle Ridge (Mulberry), LLC	Tampa Electric Company
Eastern Associated Terminals	Tampa Port Authority
Environmental Protection Commission of Hillsborough County	Trademark Nitrogen
Florida Department of Agriculture and Consumer Services	Tropicana Products
Florida Department of Environmental Protection	U.S. Environmental Protection Agency
Florida Department of Transportation	Yara North America

In September 2009, the Consortium participants finalized and approved their technical process, and proposed total N allocations to all 189 point and nonpoint sources within the Tampa Bay watershed (TBNMC, 2009). In December 2009, FDEP provided their concurrence with the technical basis and allocations. The TBNMC's collaborative approach to meeting water-quality targets is unique in the country in that public and private N dischargers worked together to define the technical process and N load limits for each of the sources within the watershed. FDEP and USEPA participated in the Consortium and provided concurrence at each major step.

Box 5–5. Frequently Asked Questions about Florida Red Tide

Excerpt from Alcock (2007)

Are Florida red tides getting worse?

"Possibly. Harmful algal blooms appear to be getting worse throughout the world. Some of the forcing factors believed to play a role in the worldwide trend are increased nutrient enrichment resulting from population growth and land use practices and increased water temperatures due to global climate change. Although the general trend appears to be worsening, trends for specific harmful algal blooms can embody more uncertainty. This is particularly true for offshore blooms, such as *Karenia brevis*, the organism that causes Florida red tides. Southwest Florida has endured red tide blooms on a near-annual basis over the past two decades, and the 2005 bloom was one of the most severe on record. However, Florida red tide blooms of similar intensity and duration have been confirmed as far back as 1948–1949, and anecdotal evidence suggests that severe blooms have scourged the region for hundreds, if not thousands of years. There is broad consensus that Florida red tides have been especially active in recent years, but putting this decade into historical perspective is extremely difficult due to a lack of data suitable for determining historical trends" (Alcock, 2007).

Can coastal pollution exacerbate Florida red tides?

"Probably. The recipe for Florida red tides is complex. The relative importance of different ingredients - nutrient sources and other environmental factors — varies over the different stages of a bloom and it is possible that the specific recipe responsible for red tides varies from bloom to bloom. Terrestrial nutrient fluxes are one of many ingredients that can contribute to a red tide bloom, and coastal pollution exacerbates these fluxes. Most scientists agree that red tide blooms initiate offshore before being transported inshore by wind and ocean currents. They believe coastal runoff is unlikely to affect the early stages of a bloom, but when a bloom moves inshore, they acknowledge that runoff can play a role in intensifying or prolonging a bloom. Assessing the relative importance of terrestrial nutrient sources, including coastal pollution, remains a top research priority" (Alcock, 2007).

Box 6–1. Regional Drinking-Water Supply — Groundwater, Surface Water, and Desalination

By Robert McConnell (Tampa Bay Water)

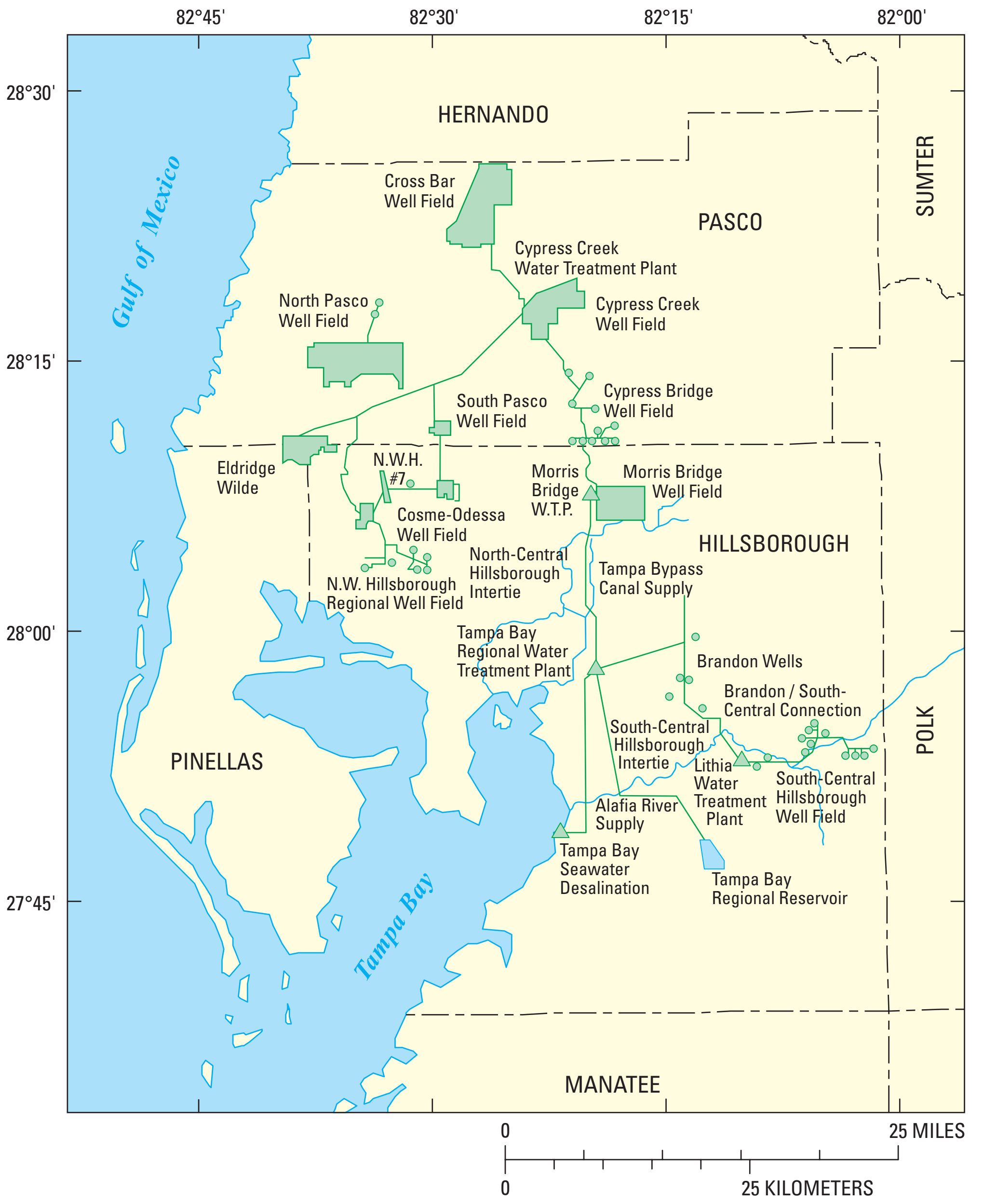
An important aspect of resource-based management for Tampa Bay includes drinking-water supply. About 244 Mgal/d of drinking water were provided to more than 2.5 million residents in the region during 2008 by Tampa Bay Water and its member governments. Drinking water is supplied through a diverse water-supply system that minimizes environmental impacts by avoiding over-reliance on individual groundwater or surface-water-supply sources.

Tampa Bay Water is a regional water-supply authority created in 1998 by interlocal agreement among six member governments: Hillsborough County, Pasco County, Pinellas County, New Port Richey, St. Petersburg and Tampa. Tampa Bay Water owns and operates interconnected water-supply facilities to meet drinking water demands. These facilities include groundwater well fields, river and canal surface-water intakes, a seawater desalination facility, treatment facilities, storage facilities including a large off-stream reservoir, pumping stations, and transmission mains (box 6–1, fig. 1).

For all current and future drinking water supplies, detailed environmental assessments are conducted to determine if projects are environmentally sustainable as well as technically feasible. Typical environmental protection activities include: impact assessment and permitting, evaluation of minimum flows and levels requirements, and development of environmental monitoring programs. Environmental monitoring is coordinated with Tampa Bay Water's Optimized Regional Operations Plan system that utilizes monitoring data and sophisticated computer models to analyze and forecast conditions to rotate and adjust production activities to ensure environmental impacts are minimized.

Groundwater

Major regional groundwater supplies include the 11 Central System Well fields, the South-Central Hillsborough Regional Well field and the Brandon Urban Dispersed Wells (box 6–1, fig. 1). Tampa Bay Water has been able to reduce groundwater pumping



Box 6–1, Figure 1. Tampa Bay Water regional drinking-water supply system.

from historical levels to allow aquifer levels and associated wetlands to recover through development of new alternative surface-water-supply sources. The average annual production permitted from the 11 well fields was 158 Mgal/d from 1995–2002. However, with development of alternative sources, annual average production was below 90 Mgal/d by the end of 2008. Water use permits for well field areas include comprehensive environmental management plans to monitor the status of wetlands, lakes and other natural systems in these areas for any changes associated with groundwater withdrawals including recovery in areas of reduced pumping.

Surface Water

Tampa Bay Water's Enhanced Surface Water System includes withdrawals from major surface waters including the Tampa Bypass Canal, the Hillsborough River and the Alafia River that have been part of the regional system since 2002–2003. About 42 Mgal/d of treated surface water was supplied to the regional system in 2008. For each source, water-use permits specify a withdrawal schedule that varies with available flows, and includes minimum and maximum flow limits to minimize environmental impacts. These permits also require implementation of hydrobiological monitoring programs that include extensive sampling and analysis of water-quality and biological data (fish, plankton, benthos and vegetation) to ensure these estuarine systems are not adversely impacted. Water not treated and used immediately in the regional system is stored in the 15 billion gallon C.W. Bill Young Regional Reservoir added to the system in 2005 to help meet drinking water demand during dry periods.

Desalination

The Tampa Bay Seawater Desalination Facility is located on Hillsborough Bay in the southeastern part of Tampa Bay. This facility initially went online in 2003, was off-line in 2005–2007 for repairs and improvements, and in 2008 contributed an average of 20.1 Mgal/d or about 11 percent of regional supply. The desalination facility uses reverse osmosis, a mechanical process that forces seawater through semipermeable membranes under high pressure, squeezes freshwater from saltwater and leaves salts and minerals behind in a concentrated seawater solution. The facility is co-located with Tampa Electric's Big Bend Power Plant and is designed to withdraw up to 44 Mgal/d from powerplant cooling water yielding up to 25 Mgal/d of potable water along with about 19 Mgal/d of concentrate discharged back into the cooling water conduits. The withdrawal is a small fraction of the 1.4 billion gallons of cooling water used by the powerplant, and the concentrate is typically diluted about 70:1 with cooling water before discharge so salinity is about the same as Tampa Bay.

Development of the desalination facility included extensive modeling and assessment of potential impacts to water-quality and biological components of the Tampa Bay ecosystem (fish, benthos, and seagrass). Based on results from water-quality and biological monitoring through 2008, there has been no indication that discharge from the desalination facility has had an adverse impact on Tampa Bay (R. McConnell, Tampa Bay Water, personal commun., 2009).

Supply Planning and Protection

Tampa Bay Water's regional supply system also includes long-term planning to ensure that regional water supplies are sufficient to meet future demands. It takes up to 10 years to plan, permit, design and build drinking water facilities. Therefore, planning for the future ensures the region's supply can meet demand in an environmentally sound and cost-effective manner. Tampa Bay Water's Board of Directors has selected potential new supply sources for further study, including brackish groundwater, seawater desalination, additional well field and surface-water withdrawals, and use of reclaimed water for augmentation or aquifer recharge to meet anticipated demands over the next 20 years.

Another critical aspect of regional drinking-water supply and resource-based management includes source water protection. Maintaining a diverse regional water-supply system to minimize environmental impacts requires maintaining source water quality so that all sources can be used reliably. Protection of groundwater supplies has been accomplished in the past through adoption of wellhead protection programs with associated regulations and ordinances to limit land use activities that could pollute aquifers. Although protection of drinking water has environmental benefits, source water protection has become increasingly complex with the development of new surface-water-supply sources due to potentially conflicting uses such as industrial or municipal wastewater disposal and uncertain future land use changes. Tampa Bay Water is working with State and local governments, private stakeholders, and the public to evaluate and implement actions to ensure water-quality protection for the future.

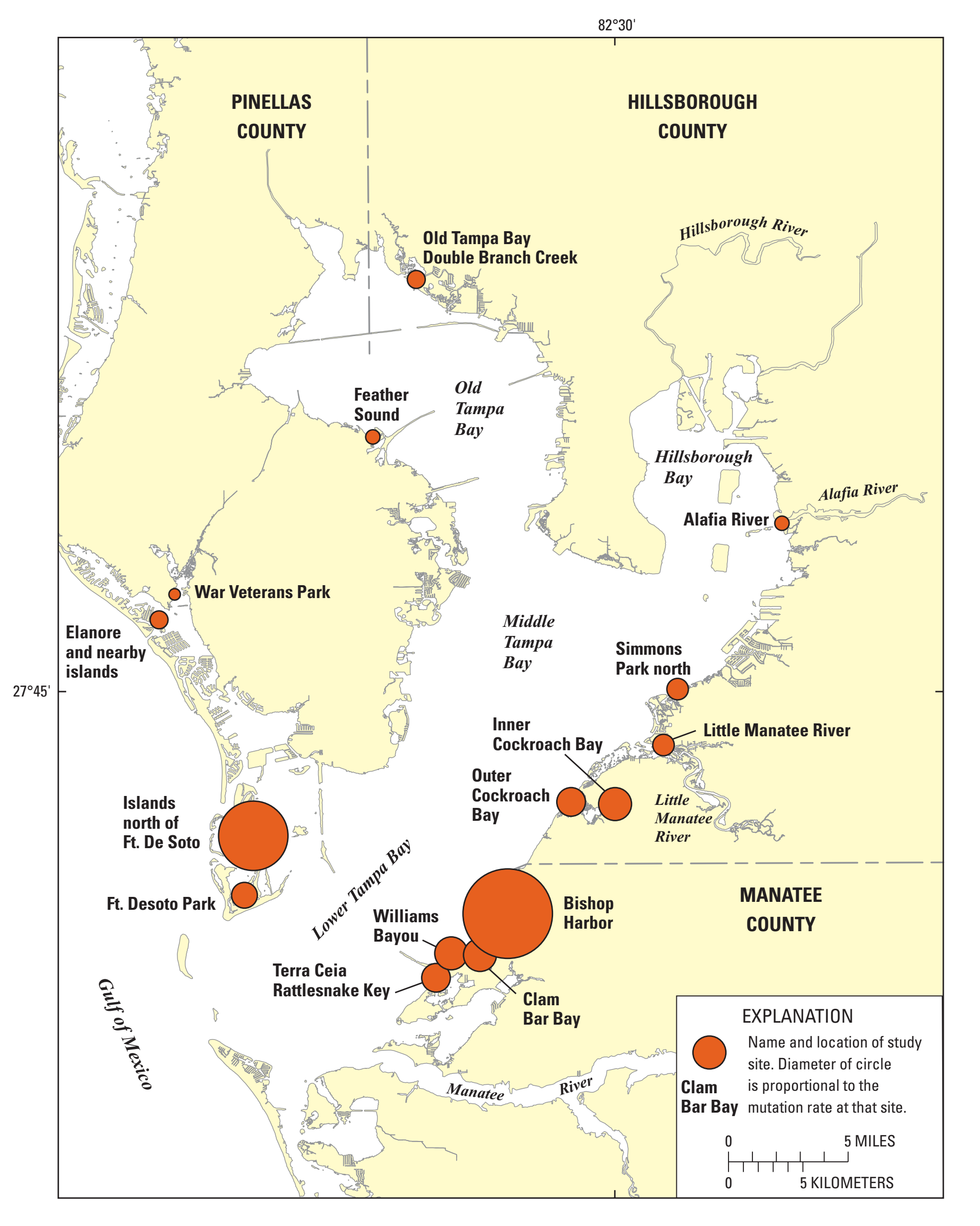
Box 7–1. Albino Mutation in Red Mangroves

By Kimberly K. Yates (U.S. Geological Survey–St. Petersburg, Florida) and Ed Proffitt (Florida Atlantic University)

Mutagens are substances that tend to increase the frequency of genetic mutations and may include inorganic and organic chemicals, metals, radioactive substances, ultra-violet light, and high temperatures, among others. Petroleum hydrocarbons resulting from oil spills are typically degraded very quickly in tropical marine waters (Botello and Castro-Gessner, 1980). However, PAHs resulting from degradation of hydrocarbons are easily incorporated into underlying sediments that support the growth of wetland plants and submerged vegetation. PAHs are highly mutagenic and cause recessive mutations in the red mangrove species, *Rhizophora mangle L.*, resulting in chlorophyll deficiency, albinism in mangrove propagules, and impaired reproduction (Klekowski and others, 1994). The mutation occurs in the apical meristems of seedlings that become trees. These trees then express the mutation as a 3:1 ratio of normal to albino propagules. This mutation can also be seen in offspring trees whose propagules came from mutated trees. In growing trees that are affected by this mutation later in their life-stage, the mutation may occur in the apical meristem of a single branch. In this case, all of the propagules on secondary stems that grow from that mutated branch will show albinism, but the rest of the tree will appear normal. This mutagenic effect is easily identifiable, making the red mangrove an ideal species for assessing the effects of historic contamination events on mangrove forests (box 7–1, fig. 1).

The USGS (Proffitt and Travis, 2005) compared the frequency of trees exhibiting albino propagules in four historically contaminated sites and 11 uncontaminated sites located throughout Tampa Bay. The four contaminated sites had a known history of contamination by either oil spills or spills and discharges from phosphate plants, and included islands north of Fort Desoto, Eleanore Island area, Simmons Park, and Bishop Harbor. Out of 16,989 counted trees, 97 showed the albino mutation. Highest mutation rates were located near the mouth of Tampa Bay, and lower rates were

Box 7–1, Figure 1. Red mangrove tree (*Rhizophora mangle* L.), showing the mutagenic effect of propagule albinism resulting from contamination by polycyclic aromatic hydrocarbons. Albinism manifests itself in Red Mangrove trees as discolored (off-white to reddish) propagules. Photo by Ed Proffitt, Florida Atlantic University.



Box 7–1, Figure 2. Location of study sites in Tampa Bay, Florida. The diameter of circles is proportional to the mutation rate at that site. Image by Ed Proffitt, Florida Atlantic University.

located in Old Tampa Bay, Middle Tampa Bay, and Hillsborough Bay (box 7–1, fig. 2). Mutations were significantly greater in contaminated, as opposed to uncontaminated, sites. There was, however, no difference in stand reproduction effort or mean rank tree size between contaminated and uncontaminated sites. This baseline dataset can be used to assess before and after effects for future oil spill events as a metric to gage future pollution abatement efforts, and to assist resource managers in the development of wetland restoration projects that require mangrove transplants or a source of mangrove propagules.

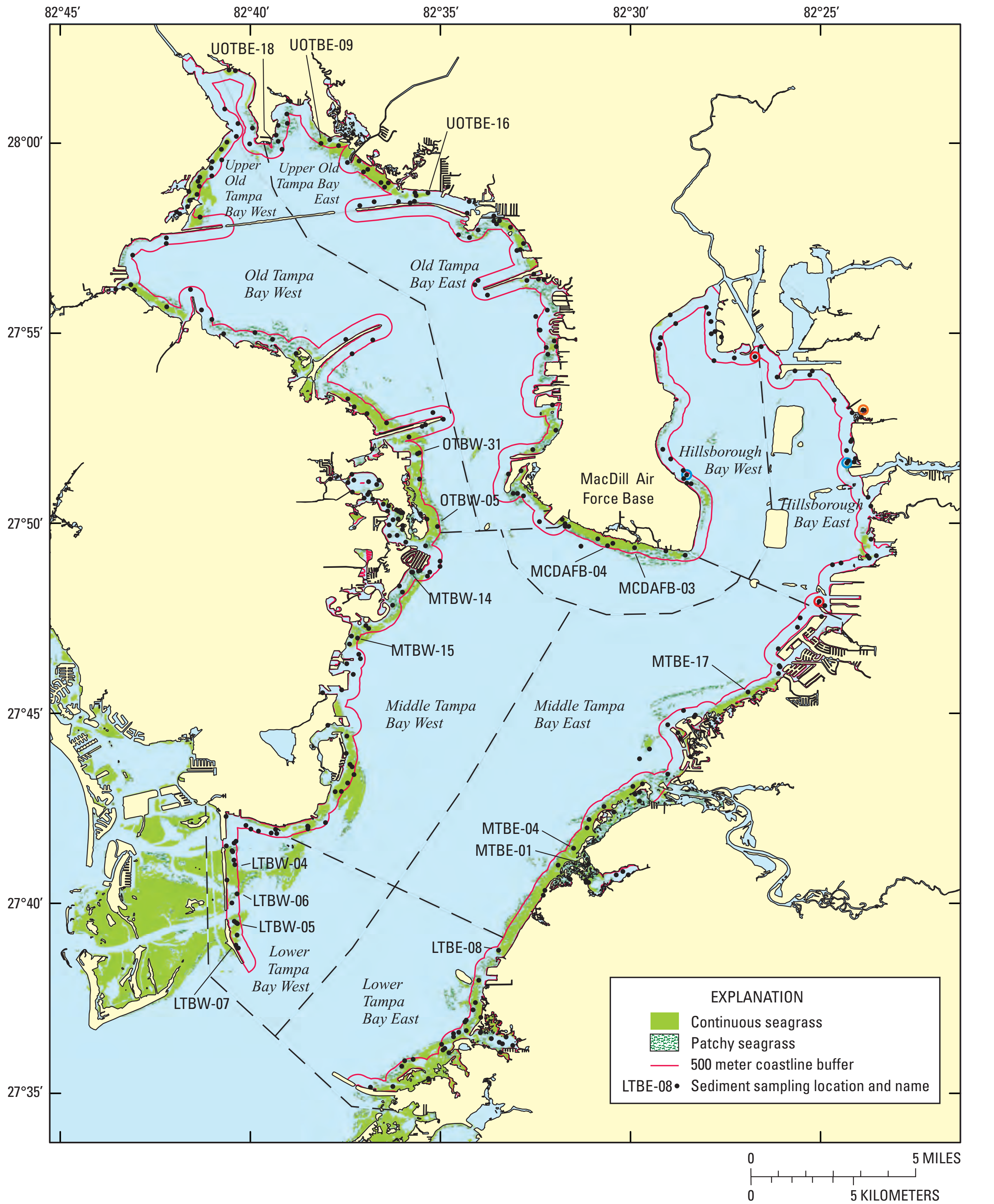
Box 7–2. Bioaccumulation of Select Metals in Seagrass Tissues

By Mario Fernandez, Jr. (U.S. Geological Survey–Tampa, Florida); Kimberly K. Yates (U.S. Geological Survey–St. Petersburg, Florida); and George R. Kish (U.S. Geological Survey–Tampa, Florida)

As noted in Chapter 4, improvements in water quality and implementation of a N management strategy have resulted in the re-growth of seagrasses in Tampa Bay between 1982 and 2008. However, seagrass growth remains limited in some areas within Tampa Bay where N load targets are met and light availability is sufficient. These locations coincide with areas of increased concentrations of metal contaminants. Previous investigations (Nicolaidou and Nott, 1998; Campanella and others, 2001; Fourqurean and Cai, 2001; Macinnis-Ng and Ralph, 2002; Amado and others, 2004; Macinnis-Ng and Ralph, 2004a,b; Whelan and others, 2005) indicate that seagrasses may be influenced by the toxicity of sediment contaminants and the degree to which seagrasses translocate and accumulate contaminants in their vascular tissues. A relation between contaminant uptake and standing biomass could provide an important link between the concentration of contaminants in sediments and in seagrass tissue. Researchers at USGS performed a preliminary investigation on the relation between metal concentrations in sediments and in seagrass tissue from samples collected in Tampa Bay.

Brooks and Doyle (1991) observed that concentrations of metal contaminants in sediments are highest in Old Tampa Bay and west-central Hillsborough Bay. Subsequently, Zarbock and others (1996) concluded that the most contaminated sediments in Tampa Bay were located in upper and middle Hillsborough Bay, parts of Old Tampa Bay, Boca Ciega Bay, and western Middle Tampa Bay. Grabe (1999) found that about 1 percent of sediments in Tampa Bay were subnominal and had a high probability of being toxic, but evidence that metals directly affect seagrasses does not exist.

Seagrass samples and their surrounding sediments were collected from 15 different locations throughout Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay (box 7–2, fig. 1). Seagrass samples were placed in plastic zip-lock bags, and stored at 4 °C. The seagrasses were identified to genus level then thoroughly soaked and rinsed with deionized water. Macroscopic epiphytes were removed from seagrass leaves using a PVC scraper. Samples were subsequently transferred to clean zip-lock bags and shipped in coolers maintained at 4 °C to the National Water Quality Laboratory in Denver, Colorado. Upon arrival at the laboratory, samples were rinsed with ASTM Type I water before digestion. Samples were subjected to microwave-assisted acid digestion EPA method 3052 (USEPA, 1996).



Box 7–2, Figure 1. Map showing location of sampling sites in Tampa Bay.

Extracts were analyzed by cold vapor atomic absorption spectrophotometry (mercury only), inductively coupled plasma-mass spectrometry, or inductively coupled plasma-atomic emission spectrometry (Hoffman, 1996).

Sediment samples were collected from the top 4 to 6 cm of bottom sediments with a Petite Ponar and were prepared for analysis by sieving through a 2-mm nylon sieve to remove large pieces of shell, detritus, and marine seagrass. Samples were placed in labeled bottles and stored in a -24 °C freezer. Prior to chemical analysis, the samples were air dried at room temperature, ground in a mortar and pestle, and dried at 103 °C. A 0.5-gram sample was digested using aqua regia and analyzed by inductively coupled plasma/mass spectroscopy (ICP/MS) Perkin Elmer SCIEX ELAN 6100. International certified reference materials USGS GXR-1, GXR-2, GXR-4, and GXR-6 were analyzed at the beginning and end of each batch of samples. Internal control standards were analyzed every 10 samples and a duplicate was run for every 10 samples. In addition to the internal quality control, 5 samples were analyzed in duplicate.

Results of these analyses (box 7–2, table 1) indicate that concentrations of nickel, copper, and zinc in seagrass tissues exceeded concentrations in surrounding sediment at all 15 sample locations. Concentrations of lead in seagrasses exceeded sediment concentrations in 13 locations, chromium in 12 locations, and arsenic in 6 locations, indicating bioaccumulation of metals at these sites. A total of 80 percent of the seagrass samples and 33 percent

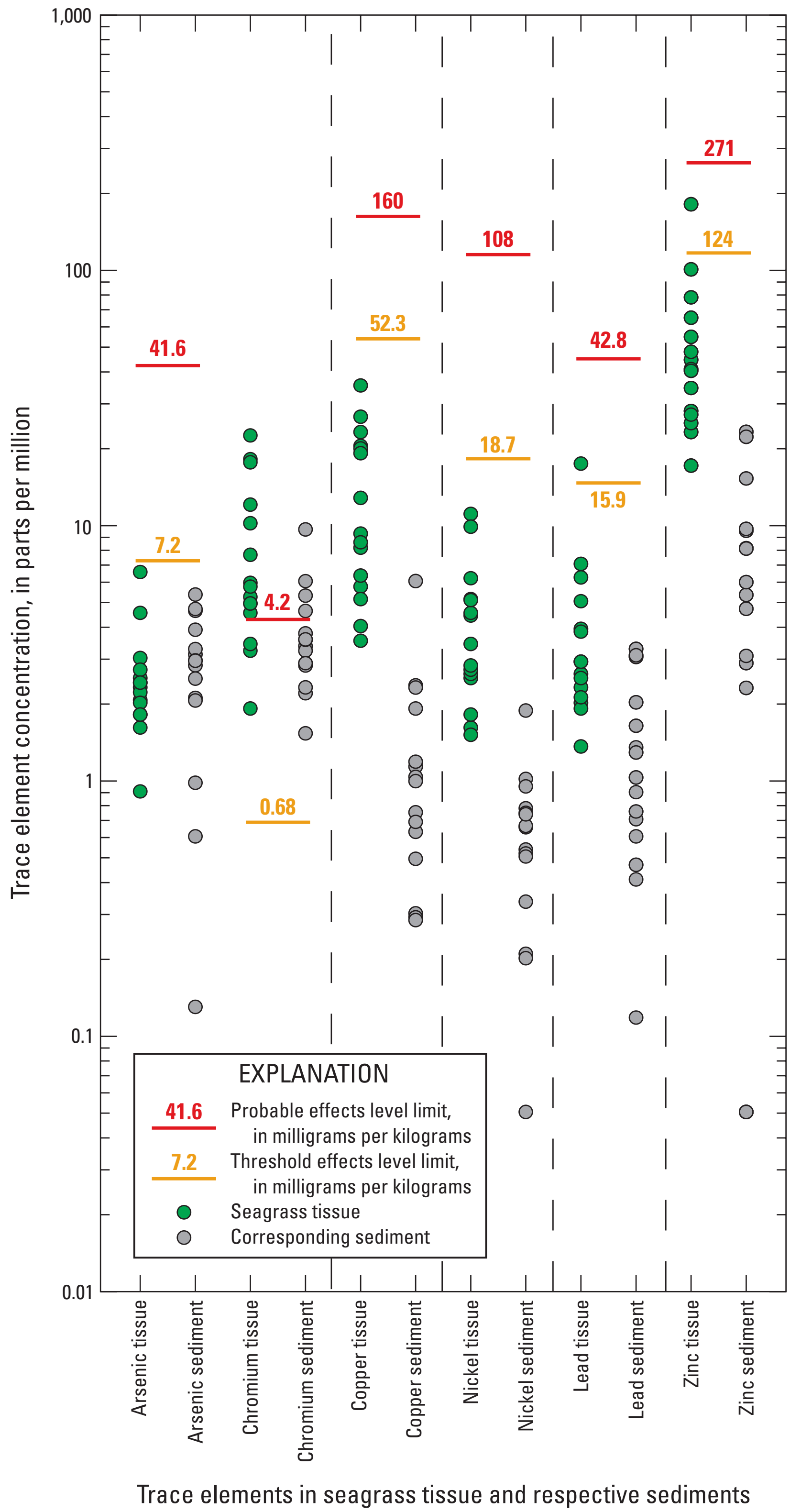
Box 7–2, Table 1. Analysis of six trace elements of seagrass tissue and corresponding sediments, Tampa Bay, Florida, July, 2003.

[Trace elements in parts per million; sediment trace element concentrations below detection limits are reported as 0.05 ppm]

Sediment site	Arsenic			Chromium			Copper			Nickel			Lead			Zinc		
	Tissue	Sediment	Ratio	Tissue	Sediment	Ratio	Tissue	Sediment	Ratio	Tissue	Sediment	Ratio	Tissue	Sediment	Ratio	Tissue	Sediment	Ratio
LTBE08	2.5	2.1	1.2	12.0	2.3	5.2	19.0	0.29	65.7	6.2	0.5	12.0	2.1	0.41	5.2	179.3	2.3	78.4
LTBW04	2.4	0.1	18.6	1.9	3.5	0.5	23.0	0.99	23.3	1.8	0.7	2.7	1.9	0.89	2.1	39.9	3.1	13.1
LTBW06	2.1	2.8	0.7	3.4	1.5	2.2	19.9	0.28	70.4	5.1	0.05	101.0	1.4	0.12	11.5	25.0	0.05	499.0
LTBW-05	4.5	3.1	1.5	4.5	3.2	1.4	4.0	0.3	13.3	4.5	0.2	22.5	2.5	0.7	3.6	26.9	9.6	2.8
MCDAFB-03	0.9	0.6	1.5	4.9	2.8	1.8	8.5	6	1.4	2.8	0.5	5.6	3.8	0.6	6.3	23.0	0.05	460.0
MTBE01	3.0	3.2	0.9	10.1	5.3	1.9	35.0	2.30	15.2	9.8	0.9	10.4	6.2	1.34	4.6	99.8	8.1	12.4
MTBE04	2.3	4.6	0.5	7.6	3.5	2.1	5.1	0.68	7.5	2.7	0.5	5.1	2.6	1.28	2.0	17.0	5.9	2.9
MTBE17	1.8	2.9	0.6	5.7	2.9	2.0	6.3	0.75	8.4	2.6	0.2	12.5	2.9	0.46	6.3	40.6	22.0	1.8
MTBW14	2.2	2.9	0.8	5.2	2.2	2.4	8.1	0.49	16.5	2.5	0.3	7.5	2.3	3.03	0.8	47.4	23.0	2.1
MTBW15	2.7	4.7	0.6	17.5	3.7	4.7	3.5	1.90	1.8	1.5	0.7	2.3	2.9	3.07	0.9	44.1	15.1	2.9
OTBW05	2.0	5.3	0.4	4.9	2.9	1.7	26.4	1.03	25.7	3.4	0.7	4.6	3.9	0.75	5.2	54.3	4.7	11.6
OTBW31	1.6	3.9	0.4	3.2	3.3	1.0	12.7	1.18	10.8	1.6	0.7	2.2	2.0	1.02	2.0	77.4	2.9	27.1
UOTBE09	2.4	2.0	1.2	18.0	6.0	3.0	20.3	1.13	18.0	5.1	1.0	5.1	7.0	2.01	3.5	64.5	9.4	6.8
UOTBE16	6.5	1.0	6.7	5.9	9.6	0.6	9.2	2.34	3.9	11.0	1.9	5.9	17.3	3.25	5.3	34.2	8.0	4.3
UOTBE18	1.8	2.5	0.7	22.3	4.6	4.9	5.7	0.63	9.1	4.4	0.8	5.7	5.0	1.63	3.1	27.8	5.3	5.3

of the sediment samples exceeded PEL limits for chromium. Highest concentrations of chromium were found in samples from upper Old Tampa Bay and Middle Tampa Bay. Only one seagrass sample from upper Old Tampa Bay and one sample from Lower Tampa Bay east exceeded TEL limits for lead and zinc, respectively (box 7–2, fig. 2). Highest concentrations of lead were found in samples from upper Old Tampa Bay, whereas highest concentrations of zinc were found in Lower Tampa Bay. A Pierson's correlation analysis of metal concentrations in tissues versus sediments for the six metals listed in table 1 indicates a significant correlation between seagrass and sediment concentrations only for lead and nickel. However, results of this analysis may be affected by age of seagrass tissue, which was unaccounted for in this preliminary investigation.

These results indicate that a more in-depth study on the impact of metal contaminants to seagrass growth is warranted. Concentration of metals in seagrass tissue, and the subsequent deterioration of dead seagrass, provide a mechanism for remobilization and transport of contaminant metals throughout Tampa Bay. Additionally, bioaccumulation of metals in seagrass provides a mechanism for direct transport of metal contaminants to higher trophic level animals feeding on seagrass.



Box 7–2, Figure 2. Concentrations of selected trace metals in seagrass tissues and their corresponding sediments from 15 different sites throughout Tampa Bay (see box 7–2, table 1).

Box 8–1. Historic Records Shed Light on Marsh to Mangrove Conversion in Tidal Wetlands

By Kimberly K. Yates and Ellen A. Raabe (U.S. Geological Survey–St. Petersburg, Florida)

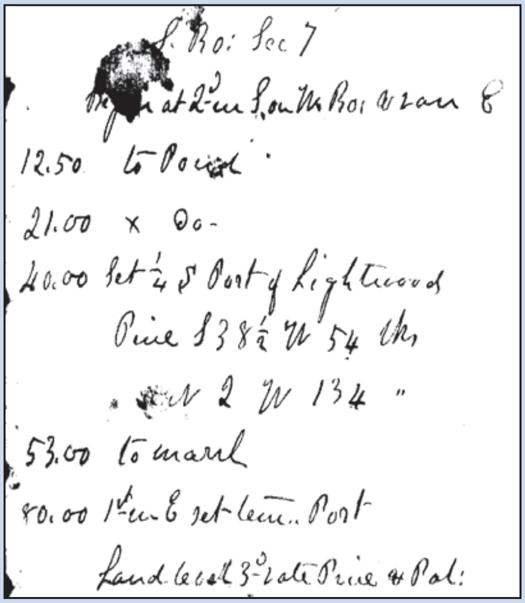
Tampa Bay is located at a climatic boundary characterized by cooler temperatures and temperate conditions to the north, and warmer temperatures and subtropical conditions to the south. This boundary is also the location of a transition zone, with salt marsh predominant to the north, and mangroves predominant to the south. Today, mangrove forests dominate the intertidal zones in Tampa Bay. However, historic surveys from 100 to 150 years ago indicate that emergent wetlands were characterized by a mixture of tidal marsh, mud flats, salt barrens, and fringing mangroves (Raabe and Gauron, 2007). USGS recently completed a quantitative habitat change analysis to compare presettlement and modern distribution of coastal habitats. Raabe and Gauron (2007) georectified, digitized, and analyzed Public Land Surveys and U.S. Coast and Geodetic Surveys from the 1840s to 1870s, and 1999 SWFWMD land cover classifications from four study sites including Upper Old Tampa Bay, Feather Sound, the Alafia River Area, and Terra Ceia (box 8–1, fig. 1). Results of their analysis indicate that 40 to 100 percent of the bay, along north/south and freshwater/saltwater gradients, has experienced conversion of emergent marsh to mangroves. This transition is most pronounced in the southern and western parts of the bay, and least pronounced in the northern bay and near freshwater sources. Changes in percent cover of terrestrial, open water, mangrove, and tidal marsh habitat in each of four areas from the 1870s to 1999 are shown in box 8–1, fig. 2. Percent change for the intertidal zone is summarized in box 8–1, table 1.

Box 8–1, Table 1. Acres of nonmangrove, mangrove, and intertidal area in the 1870s and 1999.

[Percent (%) change in acreage from the 1870s to 1999. From Raabe and Gauron, 2007]

Location	Year	Nonmangrove % (acres)	Mangrove % (acres)	Intertidal area (acres) % change
Terra Ceia	1874	59 (950)	41 (659)	(1,609)
	1999	7 (273)	93 (3,422)	(3,695)
				130% Gain
Feather Sound	1875	88 (2,556)	12 (358)	(2,914)
	1999	4 (113)	96 (2,764)	(2,877)
				2% Loss
Alafia River	1876	96 (890)	4 (37)	(927)
	1999	29 (199)	71 (496)	(695)
				25% Loss
Upper Old Tampa Bay	1875	99 (2,089)	1 (6)	(2,095)
	1999	48 (821)	52 (905)	(1,726)
				18% Loss
Total	1870s	86 (6,485)	14 (1,060)	(7,545)
	1999	25 (1,406)	75 (4,165)	(8,993)
Change		78% Loss	290% Gain	(1,448) 19% Gain

Public Land Survey Notes and Interpretation



South Boundary Section 7 (T 30 R 17)
Began at 2nd mile South on West
Boundary and ran East
Distance

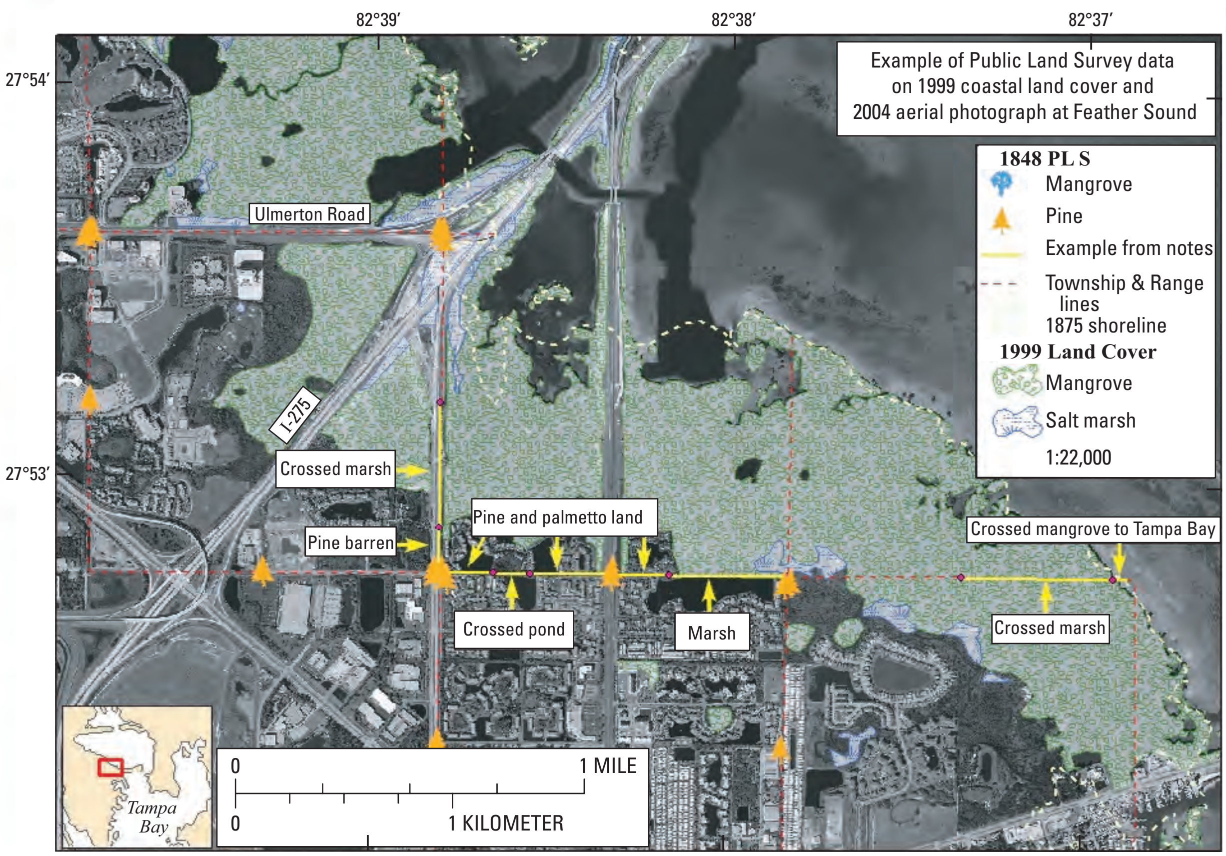
12.50 to pond
21.00 crossing pond
40.00 set 1/2 mile post of Lightwood

Pine South 38 1/2 West 54 links
Pine North 2 West 134 links

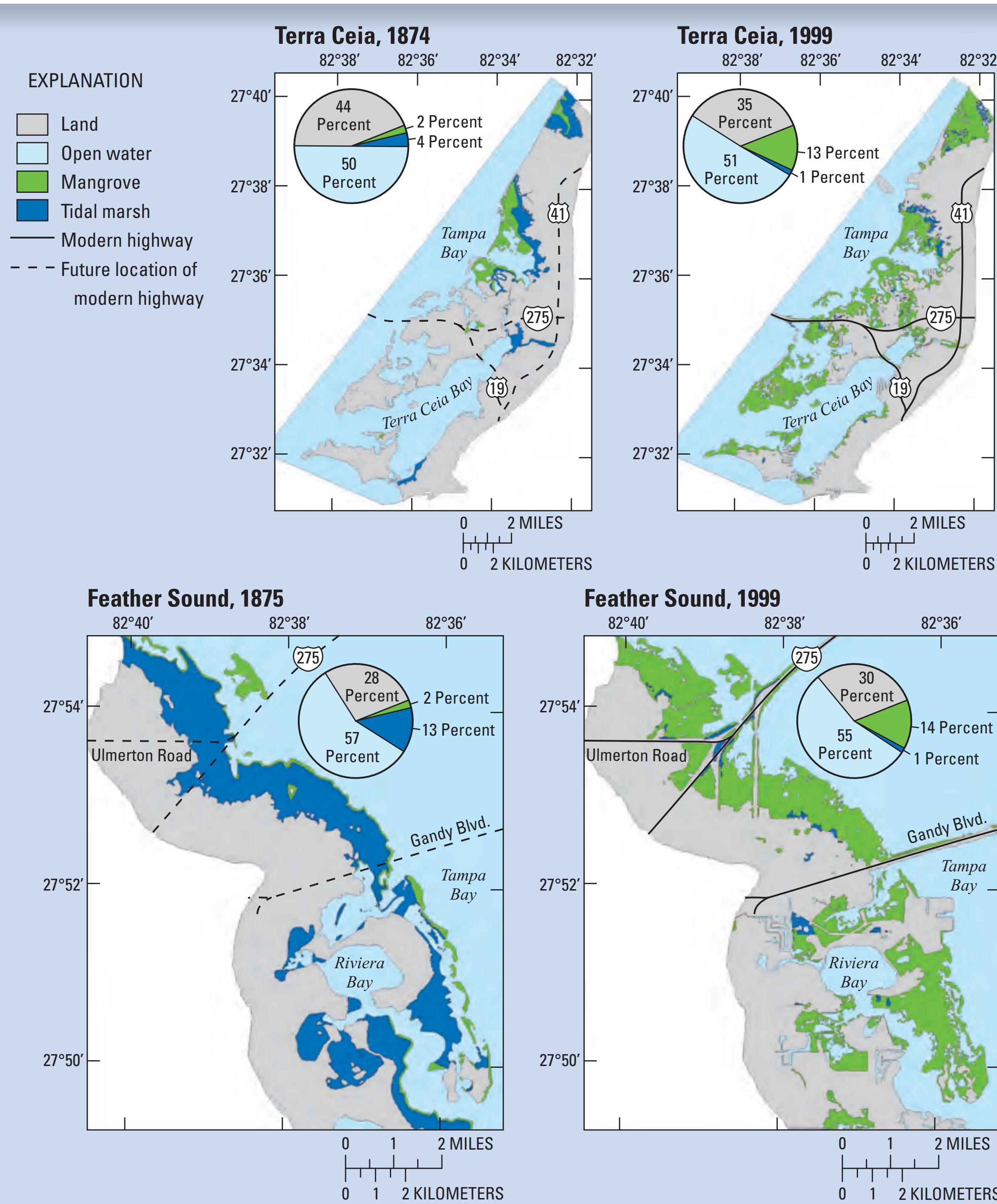
53.00 to marsh
80.00 1st mile East set temporary post

Land level 3rd rate pine and palmetto

Interpreted notes overlaid on 1999 Coastal Land Cover Map and 2004 aerial photograph of Feather Sound

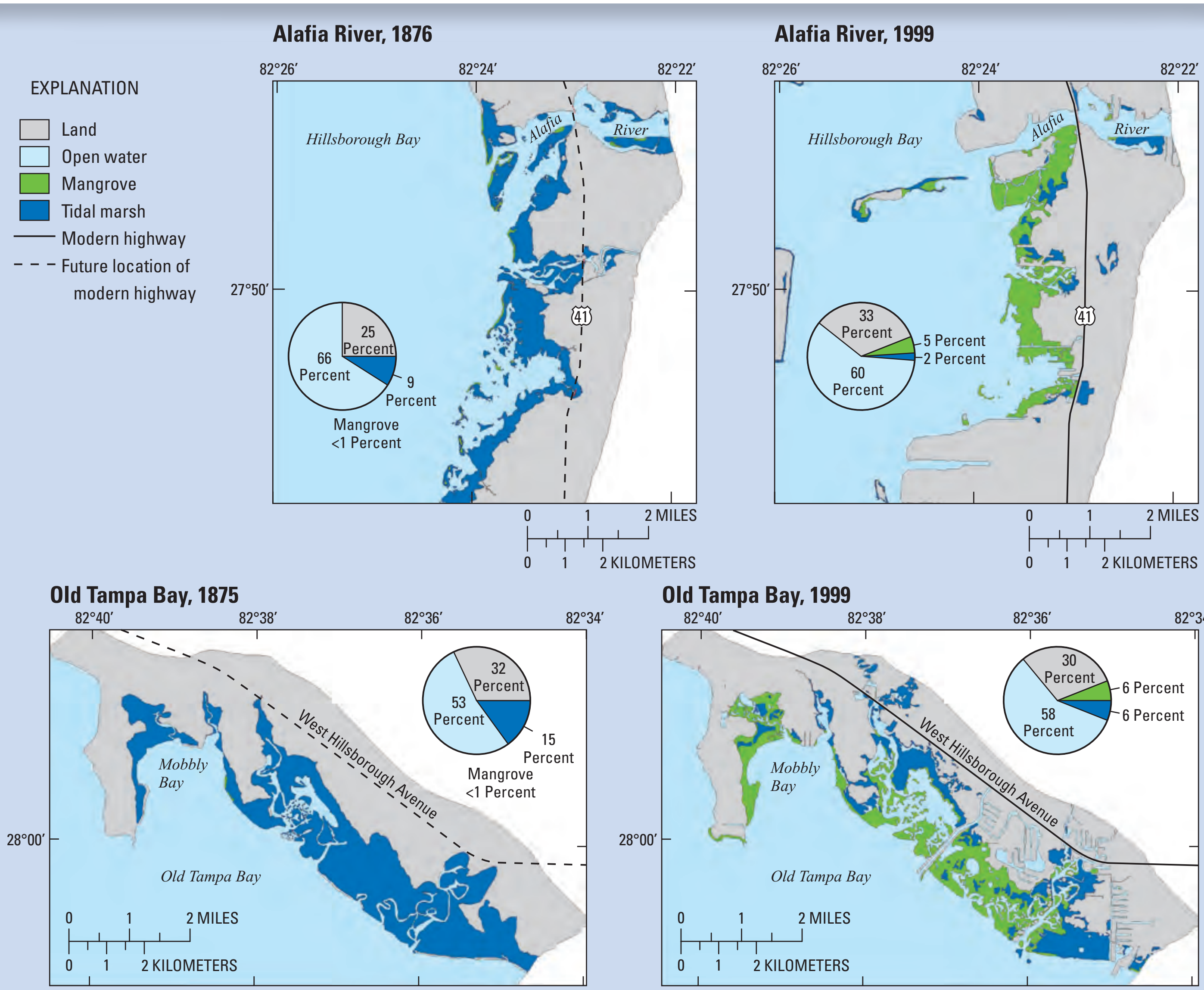


Box 8–1, Figure 1. Example of original Public Land Survey notes and interpretation and overlay of Public Land Survey data on 1999 aerial photography. Image by Ellen Raabe, U.S. Geological Survey.



Box 8–1, Figure 2. Changes in percent cover of terrestrial, open water, mangrove, and tidal marsh habitat from the 1870s to 1999 for Terra Ceia Bay, Feather Sound, Alafia River, and Old Tampa Bay. Data from Ellen Raabe, U.S. Geological Survey.

Raabe and Gauron (2007) attribute this conversion to a complex interplay of climate change, river discharge, and urbanization impacts. Sea-level records from St. Petersburg indicate a sea-level rise of about 2.36 to 2.67 mm/year (Zervas, 2001; *http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8726520*). Assuming a constant rate, sea-level rise from 1870 to 1999 was about 30 cm. Rising sea-level can result in loss of intertidal area as the shoreline boundary migrates inland, and the movement of the landward intertidal boundary is blocked by urban development (PBS&J, 2009). Temperature records from Tampa (GISS NASA *http://data.giss.nasa.gov/gistemp/graphs/*) indicate that annual mean temperatures and summer temperatures have increased from 1890 to 2007. As temperatures



become warmer, fewer winter freeze events occur, allowing mangroves to spread to more northern locations in Tampa Bay. Freshwater discharge records for the Hillsborough and Alafia Rivers (Stoker and others, 1996) indicate significant decreases in freshwater flow to the bay from 1939 to 1992. Additionally, mosquito ditching in the 1950s connected freshwater ponds to the bay, thereby increasing tidal flow into low-lying coastal landscape. The alteration of salinity and hydrological regimes in wetland areas of Tampa Bay may have promoted mangrove growth where marsh grasses were more dominant.

Results of this study support the qualitative observations of the SWFWMD emergent tidal wetland change analysis (PBS&J, 2009), indicating that about 31 percent of salt marsh and salt barren communities in Tampa Bay appear to be in transition to mangrove dominated communities. More detailed investigations of historical coastal ecology are required to better understand the magnitude of impact to wetland ecosystems resulting from multiple forcing factors.

Box 8–1, Figure 2. Changes in percent cover of terrestrial, open water, mangrove, and tidal marsh habitat from the 1870s to 1999 for Terra Ceia Bay, Feather Sound, Alafia River, and Old Tampa Bay. Data from Ellen Raabe, U.S. Geological Survey.—Continued

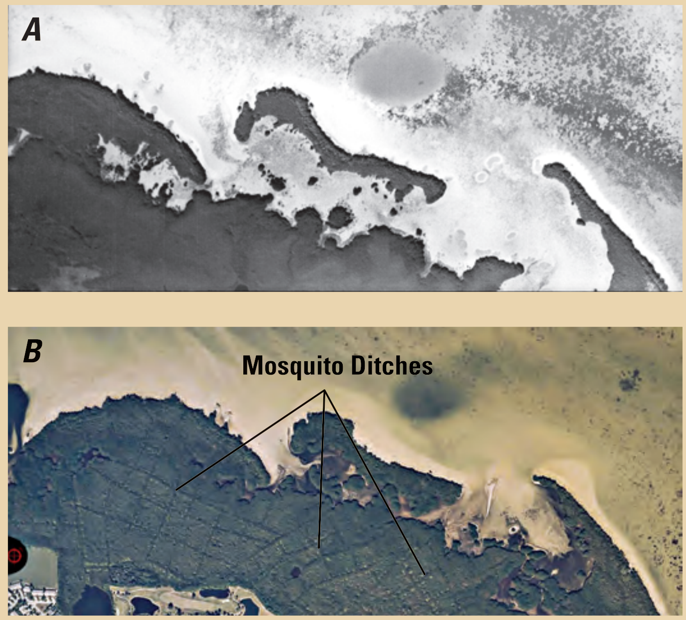
Box 8–2. Mosquito Ditching of Mangrove Forests

By Kimberly K. Yates, Thomas J. Smith, III, and Carole McIvor (U.S. Geological Survey–St. Petersburg, Florida)

During the 1950s and 1960s, many mangrove forests along the coast of Tampa Bay were dredged to create a network of intertidal ditches in a checkerboard pattern (box 8–2, fig. 1*A*, *B*). The intention of this "mosquito ditching" was to allow tidal waters (with fish) to penetrate the inland reaches of the intertidal zone to enhance tidal flooding and minimize the amount of infrequently flooded but continuously damp sediments suitable for mosquito breeding. Such reduction of mosquito-breeding habitat would reduce the numbers of nuisance mosquitoes in nearby residential communities.

The mosquito ditching process involved dredging a network of ditches through the wetland and side-casting the resulting spoil alongside the ditches in the mangrove forest (box 8–2, fig. 2). Mosquito ditching had unintended side effects, including: (1) conversion of high intertidal salt marshes and salterns to mangrove forests; (2) creation of "spoil mound" habitat well-suited to colonization by undesirable exotic plants (Brazilian pepper); and (3) creation of new but relatively short-lived channel habitat — the ditches themselves.

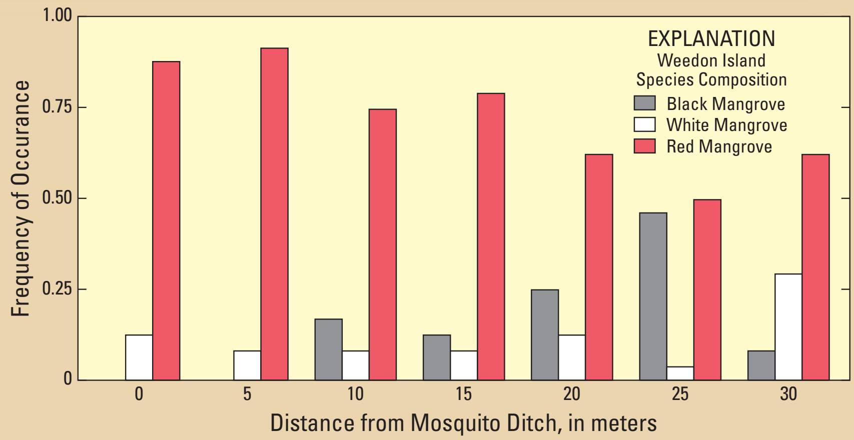
The ditches are reliant on tidal flushing to keep them free of accumulating fine sediments. After 50 to 60 years, many of the poorly flushed ditches farthest from major tidal creeks or bay shorelines are infilling and being converted to wet depressions. Today, many of the wetland restoration efforts in Tampa Bay focus on whether or not to level the spoil mounds and fill the ditches to restore natural hydrodynamic flow conditions to wetland areas. The impact of these ditches on wetland sediments, intertidal vegetation, and fish communities was largely unknown until recently, making it difficult for resource managers to predict how restoration efforts might affect plant and animal communities. USGS scientists performed a series of field investigations to: (1) determine how mosquito ditching affected the composition and distribution of wetland vegetation; (2) identify whether mosquito ditches provide small fishes habitat equivalent to that in natural tidal creeks; and (3) examine a new technique for restoration. Study sites for these investigations included Weedon Island Preserve, Terra Ceia Aquatic Preserve and Buffer, Mobbly Bayou Wilderness Preserve, and Gateway Restoration Tract.



Box 8–2, Figure 1. Photographs of mangrove forest habitat near Feather Sound in Old Tampa Bay *A*, in 1952, prior to mosquito ditching, and *B*, in 2002, showing the checkerboard pattern created by mosquito ditching. Digital photos courtesy of U.S. Geological Survey.

Box 8–2, Figure 2. Example of mosquito ditch adjacent to Tampa Bay. Photo by Carole McIvor, U.S. Geological Survey.

Smith (2004) used permanent vegetation plots and point center quarter transects to characterize vegetation along transects perpendicular to, and moving away from, mosquito ditches and spoil mounds. Results show a transition from primarily red mangroves with a smaller number of white mangroves nearest the mosquito ditches, to a mixture of red, white, and black mangroves further from mosquito ditches (box 8–2, fig. 3).



Box 8–2, Figure 3. Transition in mangrove tree species along a transect perpendicular to a mosquito ditch at Weedon Island in Old Tampa Bay. From Thomas J. Smith III, U.S. Geological Survey.

Krebs and others (2007) sampled nekton (fish, shrimp, and crabs) from natural tidal creeks and well-flushed mosquito ditches to quantify overall community composition and densities of forage and economically valuable species (box 8–2, fig. 4). Their results indicate that a rich community of 76 species, including economically valuable common snook, striped mullet, spot, red drum, and blue crab, occur in both kinds of tidal channels. Differences in distribution occurred between species; juvenile blue crabs were most abundant in some mosquito ditches (Yeager and others, 2007), whereas juvenile snook were found in similar abundance in natural tidal creeks and some mosquito ditches. Results further indicate that environmental conditions (salinity, current velocity, and shoreline vegetation) may provide a more useful indication of habitat "value" for nekton than simply whether or not the habitat has been altered.

Box 8–2, Figure 4. Sampling of fish in mangrove forest creeks in Tampa Bay. Photo by Carole McIvor, U.S. Geological Survey.

Restoration of mangrove wetlands to remove spoil mounds and ditches traditionally involves using heavy equipment, which could cause additional damage to some wetland areas. Smith and others (2007) assessed the efficacy of an alternative technique, hydroleveling, involving the use of a relatively small pump that directs a stream of high pressure water to blast sediments from spoil mounds into adjacent forests (box 8–2, fig. 5). Field testing indicated that this technique was problematic, because there was incomplete restoration of elevation grades on spoil mounds, resulting in poor colonization by native species. In addition, sediment burial of aerial roots of mangroves adjacent to mounds resulted in localized mangrove mortality. Resource managers are currently using results from these studies and other USGS research to assess how physical changes in wetland areas have affected vegetation and habitat use, and to better plan and implement restoration projects in wetlands altered by mosquito ditching and other forms of coastal development.

Box 8–2, Figure 5. Hydroleveling of spoil mounds created by mosquito ditching of mangrove forests in Tampa Bay. Photo by Thomas J. Smith III, U.S. Geological Survey.

Box 8–3. Tampa Bay Tidal Tributaries Initiative

By Edward Sherwood (Tampa Bay Estuary Program)

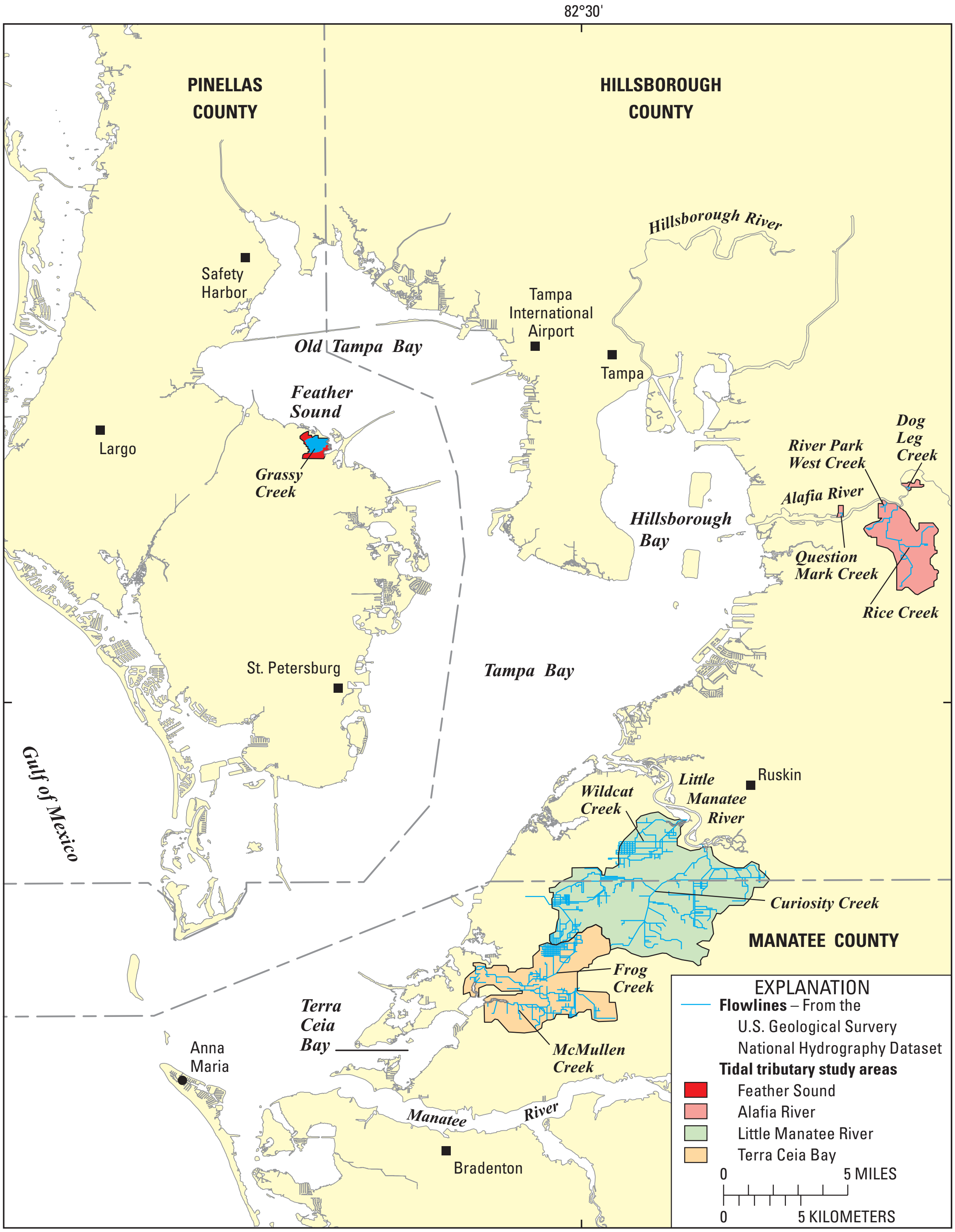
More than 300 named and unnamed creeks and other small tributaries have been identified in the Tampa Bay watershed, including more than 150 that are tidally influenced. Tidal tributaries occur in all areas of the bay (see Chapter 2, fig. 2–5). Land use in their catchments includes urban, residential, agricultural and some relatively unaltered drainage areas.

Tidal creeks have major influence on the productivity and diversity of natural resources in many estuarine systems (Holland and others, 2004). Relatively small, tidally influenced coastal and riverine creeks with and without direct freshwater input, dredged inlets, and other "backwater" areas are subject to a range of anthropogenic impacts (Clark, 1991; Morrison and Boler, 2005). Small tidal creeks are important nursery habitat for many species of fish (Krebs and others, 2007; Yeager and others, 2007; TBTTRT, 2008). A 1986 assessment of 30 representative tidal tributaries around Tampa Bay found that 60 percent were either natural or in restorable condition (Clark, 1991). Until recently, however, few formal studies of the ecology of these systems have occurred. In order to provide more information on these important habitat areas, a tidal tributary habitat initiative (TBTTRT, 2008) was initiated with the objectives of:

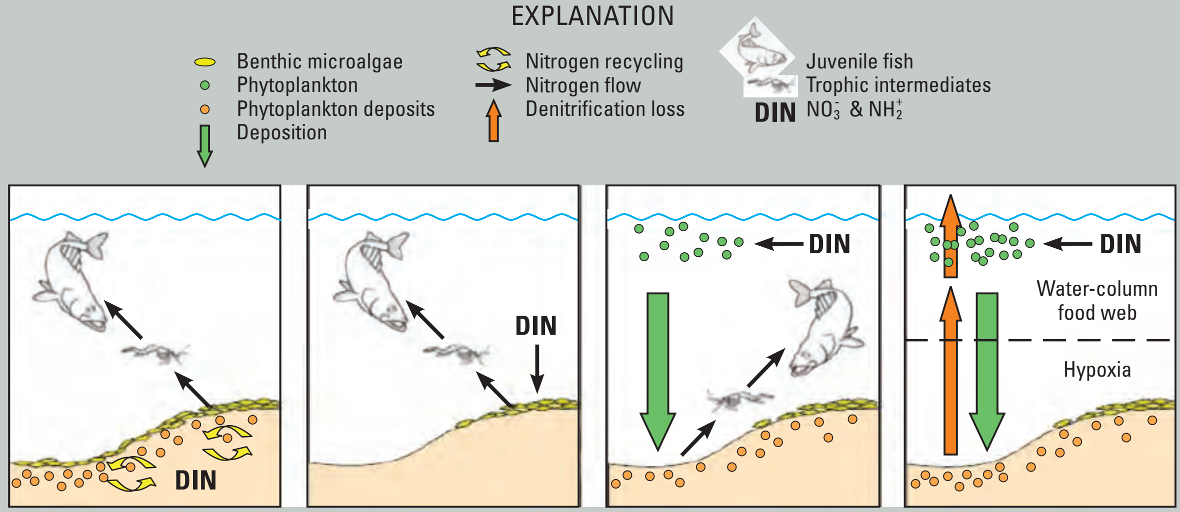
- Characterizing the fisheries resources of Tampa Bay tidal tributaries,
- Determining the effects of watershed condition, water quality, and structural habitat on their fisheries resources;
- Developing measurable goals, management recommendations, and a tidal tributary management strategy based on study results; and
- Communicating findings to resource managers and the public to support informed decisionmaking regarding the management of tidal tributary habitats.

Assessments of small, tidally influenced creek systems and their adjacent riverine and bay habitats were conducted in several parts of the estuary (box 8–3, fig.1). Study areas were chosen such that tidal tributary watersheds exhibiting relatively high and relatively low levels of anthropogenic alteration (based on the local knowledge of the project team) would be represented. The preliminary working hypotheses were that: (A) tidal tributaries are important habitats for fish and invertebrates within the Tampa Bay ecosystem; and (B) water and sediment quality, and biological resources in tidal tributaries with watersheds that have been more heavily modified by human activities, will be degraded relative to those with less altered watersheds.

The 2-year study demonstrated that tidal tributaries are important to estuarine-dependent fish populations, providing both habitat and food resources (TBTTRT, 2008). The study areas were found to provide a location for the production



Box 8–3, Figure 1. Locations of study sites used in tidal tributaries assessment project. From Tampa Bay Tidal Tributary Research Team (2008).



Scenario 1. Benthic microalgal community (BMAC). Scenatio is dependent on benthic normoxia and nitrogen from benthic recycling (e.g., middle estuary during dry season).

Scenario 2. Benthic microalgal community (BMAC). Scenatio is dependent on benthic normoxia and nitrogen from the water column. Assumes CDOM shading at depth (e.g., upper estuary during wet season).

Scenario 3. Phytoplankton based benthic community (PBBC). Requires water-column nutrients, a depositional environment and benthic normoxia (e.g., middle estuary during wet season).

Scenario 4. Phytoplankton based water-column community (PBWC). Requires water-column nutrients, causes benthic hypoxia (e.g., near river mouth during floods). Some nitrogen is removed via denitrification.

Box 8–3, Figure 2. Schematic illustrating four nitrogen (N) pathway scenarios for tidally influenced systems in Tampa Bay. From Tampa Bay Tidal Tributary Research Team (2008).

of benthic microalgae and trophic intermediates including benthic macroinvertebrates (for example amphipods and mysids) that ultimately reached higher trophic levels and influenced production of juvenile estuarine fish (summarized schematically in box 8–3, fig. 2).

Many fish species are known to use a continuum of habitat types at different life stages, including tidal creeks, their tributaries, adjacent larger tidal rivers, small embayments, open bays, and in some cases, open ocean or gulf waters. Differences in the abiotic and biotic conditions governing fish use were more pronounced between the small, tidally influenced systems than between these systems and the larger waterbodies to which they drained. For common snook, an economically important fisheries species, low-salinity tidal tributaries and backwater habitats were shown to provide a critically, unique nursery habitat along the “estuarine continuum” (TBTTRT, 2008).

A major driving force of higher trophic processes in these tidal tributaries appeared to be the delivery pattern of freshwater inflow they experienced. Inflow from the contributing watershed can regulate productivity in small tidal tributaries by governing the flux of watershed-derived nutrients and constituents that decrease water clarity. Benthic microalgae, major sources of primary production in the less-eutrophic study areas, require adequate light for photosynthesis. Due to their relative shallowness, tidal tributaries provide optimal areas for benthic microalgae growth when hydrologic and physico-chemical conditions are favorable. Sudden peak inflows or runoff can “flush out” juvenile nekton and sediments, scour channels, and introduce unsuitable water-quality conditions within the tributaries, thereby reducing or eliminating benthic microalgae production and altering biotic communities (TBTTRT, 2008).

Similarly, low or no freshwater flow can increase concentrations of water column algae and promote hypoxic conditions (low or no DO) due to increased water residence times. These factors can, in turn, reduce the production of benthic microalgae, causing a cascading effect to benthic trophic intermediates and ultimately fishery resources. In terms of sustained ecological production, study results indicated that Tampa Bay tidal tributaries with minimally altered, natural flow regimes exhibit the greatest estuarine value to fisheries resources through sustained benthic microalgae production and N cycling (TBTTRT, 2008).

Furthermore, undeveloped watersheds, and the natural riparian vegetation associated with them, provide a buffer that controls water flow rates to tidal tributaries, retaining rainfall in wetlands and watershed soils during the wet season (thus reducing "flashiness") and gradually releasing water as sustained baseflow to these tidally influenced systems during the dry season. In developed watersheds with greater amounts of impervious surface, rainfall is not as effectively retained in the watershed but can run off quickly and at higher volumes, causing rapid, "flashy" increases in flow. The study found a statistical relationship between degraded water and benthic quality conditions in tidal tributaries with higher levels of landscape development along their banks. Results suggested that the degree of landscape alteration can have an impact on in-situ abiotic conditions (TBTTRT, 2008).

Recommended management actions from the tidal tributary habitat initiative include the following:

- Maintaining connectivity between open bay waters, tidal rivers and smaller, tidal tributaries to allow fish movement, water flow and nutrient flux. Fish require a mosaic of habitats throughout their life cycle, and the most effective management would be based on a system-wide scale. This concept is important in terms of the landscape's connectivity to the surface waters, as well as instream processes that promote desirable conditions within the tributaries for nekton.
- Reducing the "flashiness" of water flow to tidal tributaries would promote more natural hydrologic regimes and foster productivity of benthic microalgae and trophic intermediates. Maintaining and restoring natural wetlands, marshes and riparian corridors in tidal tributary watersheds, as well as considering additional methods of enhancing water retention and gradual release as baseflow, would be of primary importance.
- Tracking physical parameters, water chemistry and quality of nursery habitats of Tampa Bay tidal tributaries by monitoring freshwater inflow, watershed development, water-quality indicators and nekton habitat use. This would improve managers' understanding of the ecological roles of small tidal tributaries within the larger habitat mosaic.
- Improving public education and stewardship of tidal tributaries by promoting an Adopt-a-Creek Program. Tidal tributaries are often overlooked as environmental management priorities, and increased appreciation of their importance as nursery habitats could improve that situation.

Box 8–4. Avifaunal Populations in Tampa Bay

By A.B. Hodgson (Audubon of Florida, Florida Coastal Islands Sanctuaries)

The viability of coastal bird populations in Tampa Bay is dependent upon the preservation of coastal habitats. These populations depend upon freshwater and tidal wetlands and the estuary as feeding grounds, and on bay islands and other coastal areas as nesting locations. Many coastal species' populations have declined in the past 30 years, particularly those that forage primarily in freshwater wetlands. These declines are likely attributable to regional urbanization and loss of both breeding and foraging habitats. Populations of a few species (Roseate Spoonbill, American Oystercatcher, and Caspian, Royal and Sandwich Terns) appear to be increasing (Hodgson and others, 2006).

The Tampa Bay system supports 29 nesting species of water-associated birds, including beach-nesting birds and their allies. Of these, 14 species are State or federally listed due to population trends or rarity. Total numbers in recent years have ranged from about 30,000 to 52,000 breeding pairs and their young, or nearly 200,000 individuals, making this one of the largest and most diverse waterbird communities within Florida outside the Everglades. Among these species, pelicans, herons, egrets, ibis, gulls, terns, and skimmers are particularly useful as ecological indicators because their large size (box 8–4, fig. 1*A–I*) and colonial habits allow them to be fairly easily censused. Audubon of Florida's Coastal Islands Sanctuaries Program

A

C

D

B

Box 8–4, Figure 1. Waterbirds that nest in the Tampa Bay area include *A,* Reddish Egret (shown here is the rare white morph); *B,* White Ibis in breeding phase; *C,* Brown Pelican juveniles at the Coffeepot Bayou Island colony; *D,* Great Egret in courtship display; *E,* Sandwich Tern; *F,* American Oystercatcher; *G,* Black Skimmer; *H,* Snowy Egret; *I,* Roseate Spoonbill. Photos by Gerold Morrison, AMEC-BCI.

E

F

annually locates and censuses all known coastal and inland nesting colonies in Tampa Bay. Between 1994 and 2006, White Ibis and Laughing Gulls accounted for 60 to 70 percent of all individuals in most years (Hodgson and others, 2006).

Most of the nesting colonies within Tampa Bay are located on islands in the estuary or in lakes. The Richard T. Paul Alafia Bank Bird Sanctuary is among the most diverse bird colonies in the United States, with 16 to 20 species nesting here annually. Predation, primarily from raccoons, is an ongoing problem at many bird colony nesting sites. Proper management includes removal of mammalian predators to sustain the breeding bird populations. Posting and patrol of nesting sites to deter human disturbance, remove discarded fishing line, and provide public education and outreach (especially for boaters and fishermen) are also critical management activities. Direct human disturbance of the nesting birds, the continued loss of coastal wetland and estuarine foraging habitats, and entanglement in discarded fishing line contribute to management concerns in the protection of the bay's avifaunal species. The numerous land acquisition programs in the region have not kept pace with the rapid urban and suburban development and consequent loss of critically important habitats. Coastal freshwater wetlands and tidal marshes have been lost or negatively impacted by hydrologic alterations and pollution inputs, reducing wetland biomass productivity and affecting forage availability for birds. This fact has been recognized by the regional land management community, and the restoration of coastal freshwater and estuarine systems is a priority of restoration projects surrounding Tampa Bay. All effective strategies must be considered to protect and sustain the region's colonial waterbird populations (Hodgson and others, 2006).

H

G

I