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Tampa Bay estuary: Monitoring long-term recovery through regional partnerships

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ABSTRACT

Historically, significant impacts to Tampa Bay's water quality (e.g. chlorophyll-a concentrations) and ecosystem (e.g. seagrass coverage) have been documented as a result of early coastal development and urban expansion that occurred between the 1950s and 1980s. Since this time, Tampa Bay's estuarine water quality and ecosystems have significantly recovered. A long-term water quality monitoring program, first established by the Environmental Protection Commission of Hillsborough County (EPCHC) in 1972, was instrumental in the development of water quality management targets and regulatory thresholds related to the recovery of seagrass that helped guide restoration activities in the Bay from the 1980s to present. The EPCHC monitoring program has provided over 40 years of consistent and quality assured data that have been used to document Tampa Bay's ecosystem recovery, as well as, guide future research, monitoring, and management actions. Forecasted future pressures of continuing coastal population growth and climate change impacts further necessitate the need to maintain long-term water quality monitoring efforts in the Tampa Bay estuary. Maintenance of a robust estuarine monitoring program will not only help to identify future risks to the important environmental assets represented in the Tampa Bay estuary, but also help to identify potential risks to Tampa Bay's economic vitality that are garnered from maintaining a "healthy" Tampa Bay.

1. Background

Henry B. Plant is credited with initiating modern industrial and commercial development of the Tampa Bay area through the establishment of railroad and steamship transportation networks to and from the region in the 1880s (Simon, 1974). Since that time, port development and shipping interests have benefited from a federally maintained navigation channel also established in the 1880s. Today, Tampa Bay ranks among the U.S.'s most productive port regions (United States Army Corps of Engineers). Establishment and maintenance of the shipping channel (Fig. 1) was one of the first anthropogenic alterations influencing Bay water quality conditions (Meyers et al., 2014; Zhu et al., 2015).

The region continued to expand throughout the 20th century as agriculture, phosphate mining, and industry grew, but it was not until after World War II when indoor air conditioning became readily available to homeowners that widespread suburban and urban development ensued. Population within the region continues to expand, and it is estimated that the region will approach 5M people by mid-century (Tampa Bay Partnership). Significant alterations to fresh and saltwater wetlands, submerged aquatic vegetation, and other natural uplands have been documented throughout Tampa Bay's 20th century coastal development (Robison, 2015; Ries and Scheda, 2015; Yates et al., 2011). Hydrologic alterations to the landscape (e.g. mosquito ditching, creek channelization and ditching, and spoil mound and borrow pit creation), as well as, changes in land use and intensity (e.g., conversion of natural lands to rangeleand to agriculture to suburban and urban development) further influenced bay water quality during this period. In addition, causeway and bridge construction across Old Tampa Bay and Lower Tampa Bay further modified hydrodynamics within the Bay proper (Meyers et al., 2014; Zhu et al., 2015).

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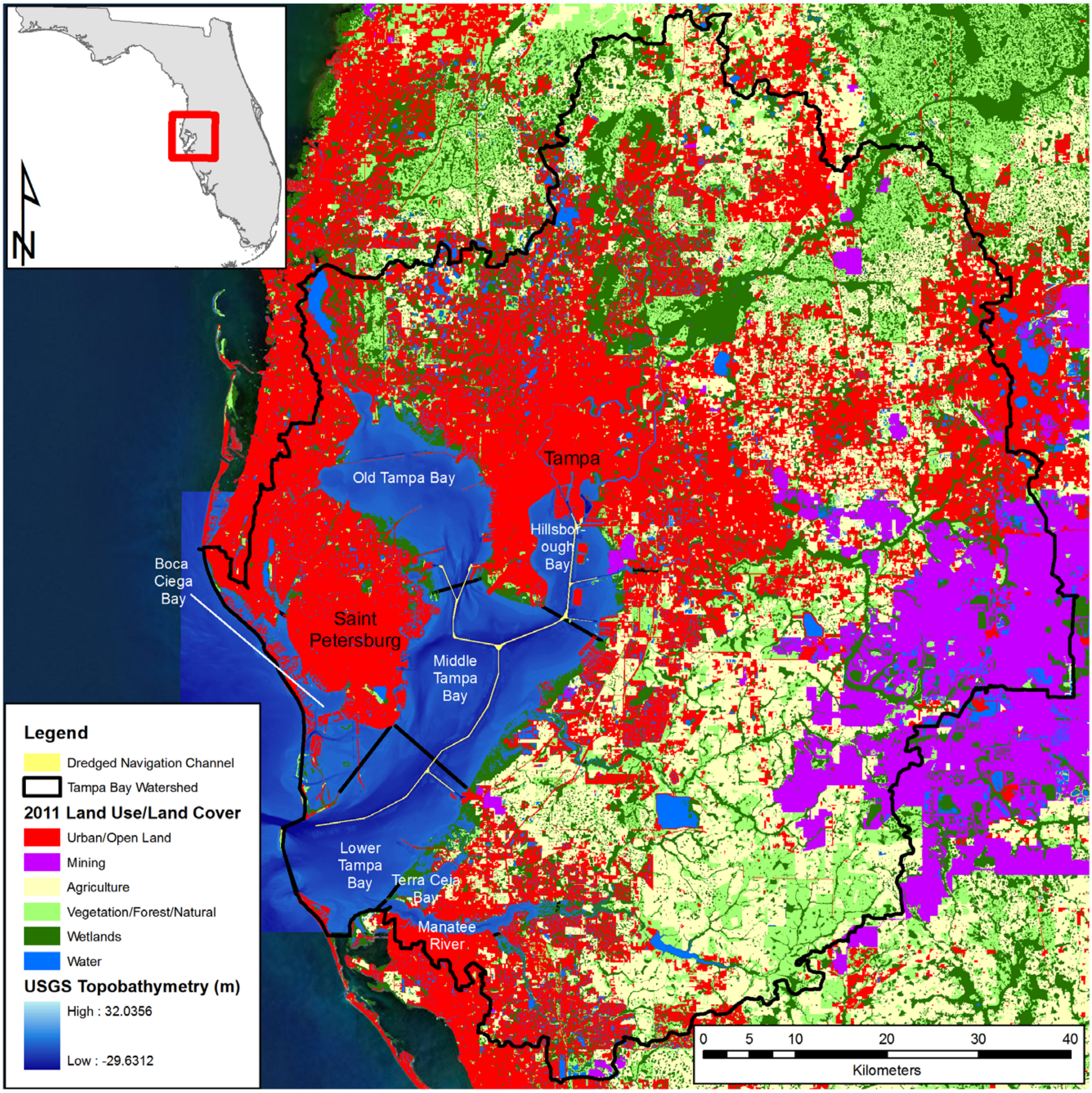

Fig. 1. Tampa Bay overview map highlighting watershed development, dredging alterations to the bathymetry, and management segments (white text labels). Data sources: SWFWMD, TBEP and USGS.

Perhaps the greatest influence on Bay water quality has been the alteration of external nitrogen load inputs to the bay itself (Yates et al., 2011). Regional development between the 1950s–1980s manifested in significant increases in nitrogen loads from municipal wastewater treatment and industrial point sources. During this time, Bay water quality deterioration contributed to significant decline in baywide seagrass coverage (Greening et al., 2015, 2011). Initially led by citizens, a call to action ensued in the 1970s–80s (Johansson and Lewis, 1992; Lewis et al., 1999; Lewis, 2012). After which advanced treatment and/or reuse of domestic wastewater effluent was required prompting an initial kick-start to the Bay's recovery. The bay is now considered a worldwide model for a recovering estuary, and as of 2014, it has met restoration targets related to seagrass coverage (Greening et al., 2015, 2011; Greening and Janicki, 2006; Morrison et al., 2006; Bricker, 2008; Cloern and Jassby, 2009; Duarte et al., 2009; Waycott, 2009; Rabalais, 2010). Significant effort to manage nutrient loading to Tampa Bay began in the 1980s and still continues today through an ad-hoc, public–private partnership termed the Tampa Bay Nitrogen Management Consortium (NMC) (Yates et al., 2011; Greening et al., 2015). Through these regional collaborations, external nitrogen loads have been significantly reduced, and indicators of ecosystem recovery (e.g., reduced chlorophyll-a concentrations, greater seagrass abundance, and enhanced fisheries stocks) are now approaching thresholds documented in the 1950s (Yates et al., 2011; Greening et al., 2015, 2011; Greening and Janicki, 2006). A benchmark period that predates the rapid population growth experienced in the region following World War II.

Modern record of studies to investigate Tampa Bay's ecology began during the 1950s period prior to the initial boom in coastal development (see Simon, 1974 for review). A US National Marine Fisheries Service laboratory conducted many initial

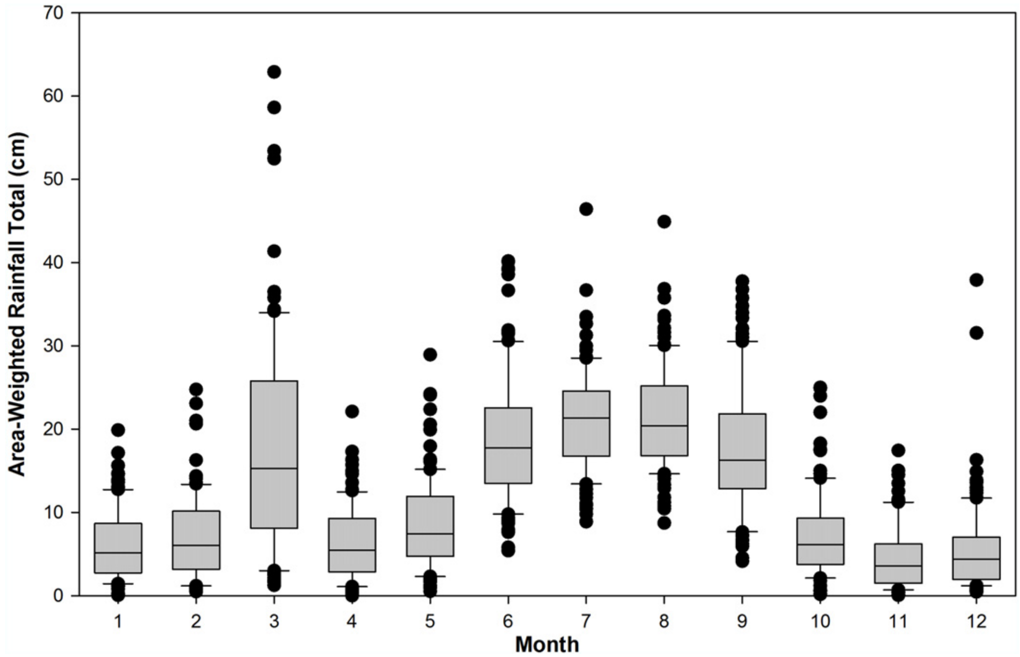

Fig. 2. Box plots of monthly, area-weighted total rainfall (cm) for the Tampa Bay watershed from 1915–2014. Data source: SWFWMD.

investigations into Tampa Bay's water quality and ecology from 1954–1974 (Simon, 1974). Interest in Tampa Bay water quality significantly increased in the 1970s amid burgeoning development impacts related to the increased disposal of sewage treatment plant effluent into the Bay proper and large-scale dredging and filling operations that occurred throughout the region from the 1950s–70s (Simon, 1974). The US Army Corps of Engineers (United States Army Corps of Engineers) commissioned several new studies during the 1970s when deepening of the main shipping channel in the Bay was initiated (Fig. 1).

Due to the poor condition of the Bay leading up to the 1970s, a unique mandate by the Florida Legislature (Laws of Florida, 2015) established the Environmental Protection Commission of Hillsborough County (EPCHC). The EPCHC developed a baywide ambient water quality monitoring program in 1972 and has maintained monthly data collections since that time. Other local water quality programs were initiated in the 1980s (City of Tampa Bay Studies Group and Manatee County) and 1990s (Pinellas County) and have supplemented the baywide data collection effort of the EPCHC (Poe et al., 2006).

In 1992, the Tampa Bay Estuary Program (TBEP) was established, and coordinated Baywide monitoring, assessment, and recovery target-setting was initiated (Tampa Bay Estuary Program, 2006). The TBEP is one of 28 programs administered by the US Environmental Protection Agency (USEPA) under the National Estuary Program. The local water quality monitoring programs were instrumental in supplying information to achieve the management goals set forth by the TBEP, and continue to supply information to support research and regulatory requirements for the estuary (Yates et al., 2011; Greening et al., 2015). Continuous coordination of the local monitoring programs has been accomplished through the Southwest Florida Regional Ambient Monitoring Program (RAMP). The RAMP has become a state model for interlaboratory coordination and calibration for water quality analytes routinely collected and measured within fresh and marine waters in southwest Florida.

This paper will discuss the development of these contemporary local water quality monitoring programs, their application to assess bay management goals and objectives over the 1980–present period, and highlight the 40+ years of long-term water quality monitoring data collected in Tampa Bay. Without the long-term commitment of these local monitoring programs, the recovery of the Tampa Bay estuary would have been left undocumented.

2. Estuary description

Tampa Bay is Florida's largest open water estuary. It is located on Florida's west-central, Gulf of Mexico coast between 27.5° and 28° latitude. The Bay's subtropical climate provides distinct seasonal rainfall patterns with the wet season typically occurring during the June–September months with approximately 55% of the total annual rainfall (∼143.4 cm) occurring during this period (Fig. 2). A cooler dry season occurs from November to March and winter, cold fronts typically originating from the northwest provide sporadic rainfall and freshwater input to the Bay during this period, though with less intensity than during the summer wet season. A warm, spring dry season occurs from late March to June and drought conditions are typically exacerbated during this period. These seasonal climate patterns influence the underlying water quality variability observed in the Bay annually.

The majority of coastal lands within the Bay's watershed are developed (Fig. 1). Approximately 43% of the watershed area has been converted to urban/suburban land uses, about 20% converted to agriculture, and about 5% converted to extractive/mining practices (Southwest Florida Water Management District, 2011). The western portion of the watershed has extensive phosphate deposits ("Bone Valley") and has been mined since the late 1800s (Fig. 1) (Yates et al., 2011). The phosphate-rich soils influence the Bay's downstream water quality, and the Bay itself is considered primarily N-limited (Yates et al., 2011; Greening et al., 2015).

For management purposes, the Bay is divided into 4 mainstem segments: Old Tampa Bay (OTB), Hillsborough Bay (HB), Middle Tampa Bay (MTB), and Lower Tampa Bay (LTB) (Fig. 1).

3. Ambient water quality monitoring programs in Tampa Bay

Regional comparability and consistency in reporting water quality monitoring results has been honed through quarterly, split sample exchanges facilitated through the Southwest Florida RAMP.

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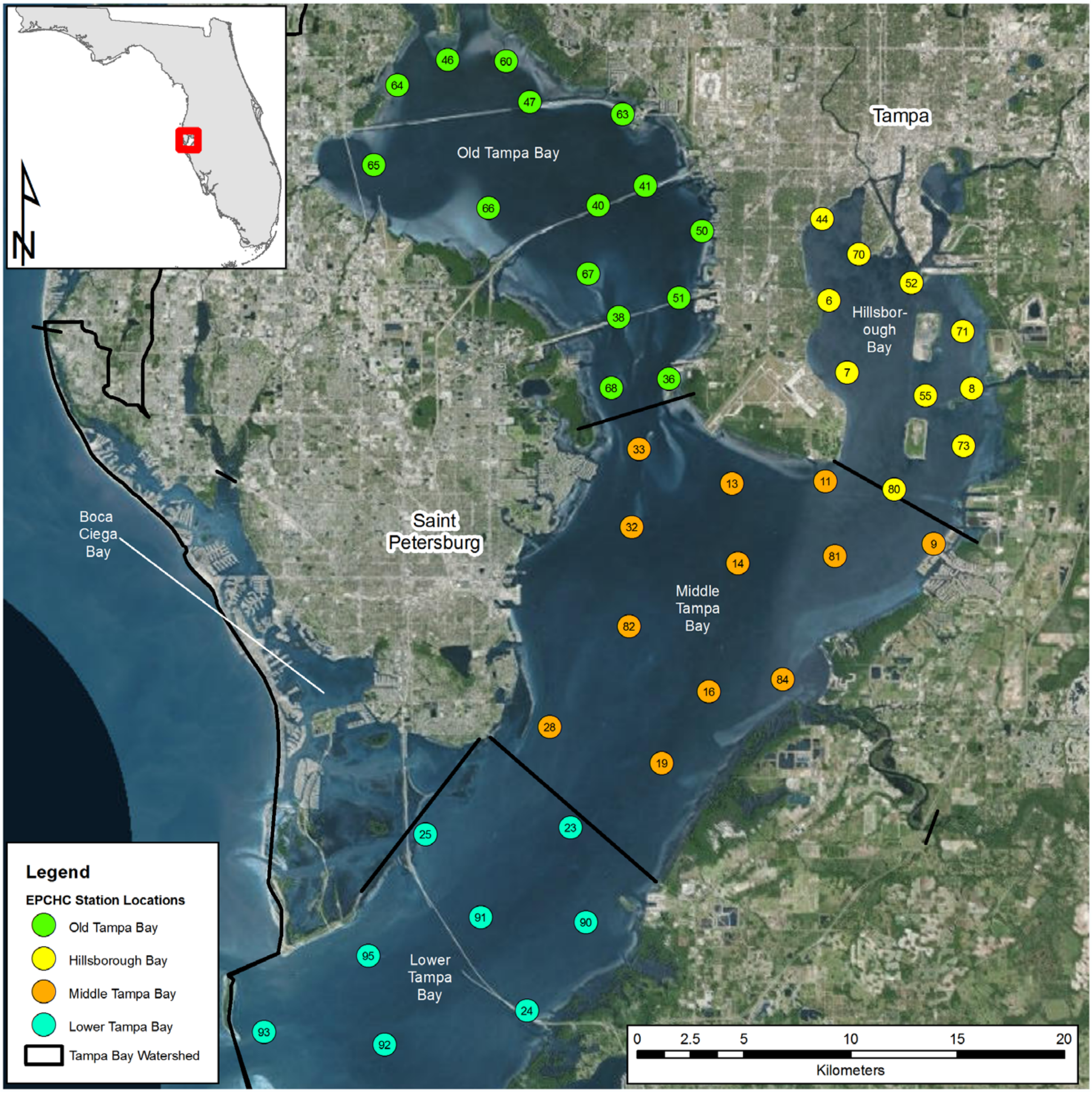


Fig. 3. Locations of long-term monitoring stations sampled monthly by the Environmental Protection Commission of Hillsborough County (EPCHC) from 1972 to present. Data source: EPCHC.

The RAMP was initiated by TBEP in 1992, but it is now coordinated by the local governments that run the monitoring programs throughout the Tampa Bay watershed and larger southwest Florida region. Participants meet quarterly to collect water samples from a common container originating from a freshwater or marine resource within the region. Each participant then has its own laboratory run the samples for a core group of parameters, and the RAMP participants statistically compare their individual results for each event. Typical comparisons include laboratory analytes for nutrients (ammonia, nitrate/nitrites, total kjeldahl nitrogen, total nitrogen, orthophosphate, total phosphorus, and total organic carbon), water clarity (true and apparent color, turbidity, total dissolved and suspended solids), algal abundance (chlorophyll -a, -b, -c, total, and pheophytin) and bacterial abundance (enterococcus and fecal coliform). Semi-regular comparisons of physical field measurements (temperature, pH, specific conductivity, salinity, and photosynthetically-active radiation) are also performed. Statistical analyses utilizing z-scores (e.g. Zar, 1996; Woodworth and Connor, 2003) are used to qualify individual laboratory/parameter results from a particular event and inform participants on their reporting performance relative to other regional laboratories. The Southwest Florida RAMP has served as a model for inter-laboratory, regional monitoring collaborations and similar methods are being implemented at the Gulf of Mexico-wide scale through the Gulf of Mexico Alliance's (GOMA) round robin events (Leary, 2012), as adapted from the RAMP and US Geological Survey (USGS) techniques (Woodworth and Connor, 2003).

3.1. Long-term water quality monitoring program

Since 1972, the EPCHC has consistently monitored 52 fixed stations throughout Tampa Bay (Fig. 3) (Karlen). Surface, mid-depth, and bottom profiles of physical parameters (temperature,

Table 1
Comparison of management targets and regulatory thresholds established for the main-stem bay segments of Tampa Bay utilizing empirical modeling approaches from long-term monitoring datasets (Janicki et al., 2000).

Bay segment	Chlorophyll-a (μg/L)	
	TBEP management target	FDEP adopted regulatory threshold
Old Tampa Bay	8.5	9.3
Hillsborough Bay	13.2	15.0
Middle Tampa Bay	7.4	8.5
Lower Tampa Bay	4.6	5.1

pH, conductivity/salinity, and dissolved oxygen) are taken at each site along with Secchi disk depths. In addition, mid-depth samples are collected for a variety of laboratory analytes (e.g., nutrients panel: ammonia, nitrate/nitrites, total kjeldahl nitrogen, organic nitrogen, orthophosphate, total phosphorus, dissolved silica, and total organic carbon; bacterial indicators: enterococcus and fecal coliform; water clarity: turbidity and true color; algal abundance indicators: chlorophyll-a, -b, -c, total, and pheophytin). Sample collections have followed state and federally-approved standard operating procedures (SOP; e.g. FDEP SOP FS1000, FT1000, FS2110), while all laboratory analyses have been conducted in a NELAC-certified laboratory.

3.2. Complimentary water quality monitoring programs

Several state and federal agencies and other municipalities have also contributed to the collective monitoring data available in Tampa Bay. Several ongoing monitoring programs, including Pinellas and Manatee County-run water quality collections, have focused their efforts within their shallow, jurisdictional waters and compliment the baywide monitoring effort conducted by the EPCHC in deeper Bay waters. The City of Tampa Bay Studies Group had one of the longest worldwide records of phytoplankton production (established circa 1980) as well as other nutrient and water quality datasets, however this program was terminated in 2010 (Cloern, submitted for publication; Johansson, 2010). The USGS (Yates et al., 2011), Florida Department of Environmental Protection (FDEP), and Southwest Florida Water Management District (SWFWMD) (Southwest Florida Water Management District) have conducted several, project specific monitoring programs within portions of Tampa Bay, however none have been sustained over long periods like those implemented by the EPCHC and bordering counties.

4. Monitoring results & Bay management discussion

The long-term monitoring programs in the Tampa Bay estuary have informed a variety of management actions over the 40-yr history in which these local programs have been implemented. Foremost, data from the programs have led to the creation of water quality targets supporting baywide seagrass recovery, support annual assessments to determine baywide compliance with adopted management targets and regulatory thresholds, and inform future monitoring and research efforts within the estuary. A summary for each of these management frameworks follows.

4.1. Quality assurance: RAMP assessments

Approximately 74 inter-laboratory, RAMP assessments have been conducted in the Southwest Florida region since 1992. Both field collection and laboratory analysis techniques have been considered for the interagency comparisons. Based on prior evaluations, RAMP participants have minimized differences in reporting values for chlorophyll-a, total nitrogen, total phosphorus, and total suspended solids, while efforts to reduce reporting variability for other parameters (e.g. color) continues (Fig. 4). As a result, data comparability has improved within the region and integrated assessments that use data available from all providers have become more robust in terms of management decision confidence.

4.2. Establishment of management targets and regulatory thresholds

A primary goal for overall Bay restoration has been to improve water quality in order to support seagrass coverage expansion to levels observed in the 1950s. Reduced water clarity, as a result of excessive nitrogen loads to the bay and resulting light attenuation by phytoplankton responding to these loadings, were the key water quality indicators established by the community to help manage Bay seagrass recovery. Other light attenuating parameters (e.g. non-phytoplankton turbidity and colored dissolved organic material) play a significant role in influencing the underwater light environment for seagrass in Tampa Bay; however, the greatest temporal variability in light attenuation has been attributed to phytoplankton production, as expressed by chlorophyll-a concentrations (Greening et al., 2011, 2015; Greening and Janicki, 2006; Morrison et al., 2006). Consequently, Bay managers viewed chlorophyll-a as the most appropriate, "manageable" water quality parameter as it directly related to nutrient loadings and discharges to the Bay proper. Details on the establishment of management targets for chlorophyll-a and effective light penetration (based on Secchi disk depths) utilizing the EPCHC's long-term monitoring program dataset have been well documented (Yates et al., 2011; Greening et al., 2015, 2011; Greening and Janicki, 2006; Janicki et al., 2000). The management targets (Table 1) are used by local resource managers as early warning signs for potential water quality degradation, as it relates to expected future seagrass expansion and recovery.

Bay resource managers have recognized that there may be years in which these targets may be exceeded without causing significant reductions in seagrass cover. This means that there is some allowable amount of variation that should not elicit a significant degradation in water quality and therefore seagrass coverage. This level of variation was defined as two standard errors around the period of record mean annual chlorophyll-a concentrations in each segment (Janicki et al., 2000). Therefore, a distinction is made between a management target (i.e., a desired chlorophyll-a concentration) and a threshold (i.e., a value above which undesirable chlorophyll-a concentrations exist). The chlorophyll-a threshold is the sum of the target and two standard errors around the mean annual chlorophyll-a concentrations in each bay segment (Table 1).

These thresholds have been formally adopted by state regulators (FDEP) as regulatory thresholds to assess annual compliance for allowable external nitrogen loads to each of the major bay segments of Tampa Bay. Tampa Bay is unique in that a federally-recognized total maximum daily load (TMDL) for total nitrogen loads has been previously established by the USEPA (US Environmental Protection Agency, 1998), while state regulators have made a "reasonable assurance" (RA) determination that the nitrogen management strategies developed in the region will support its

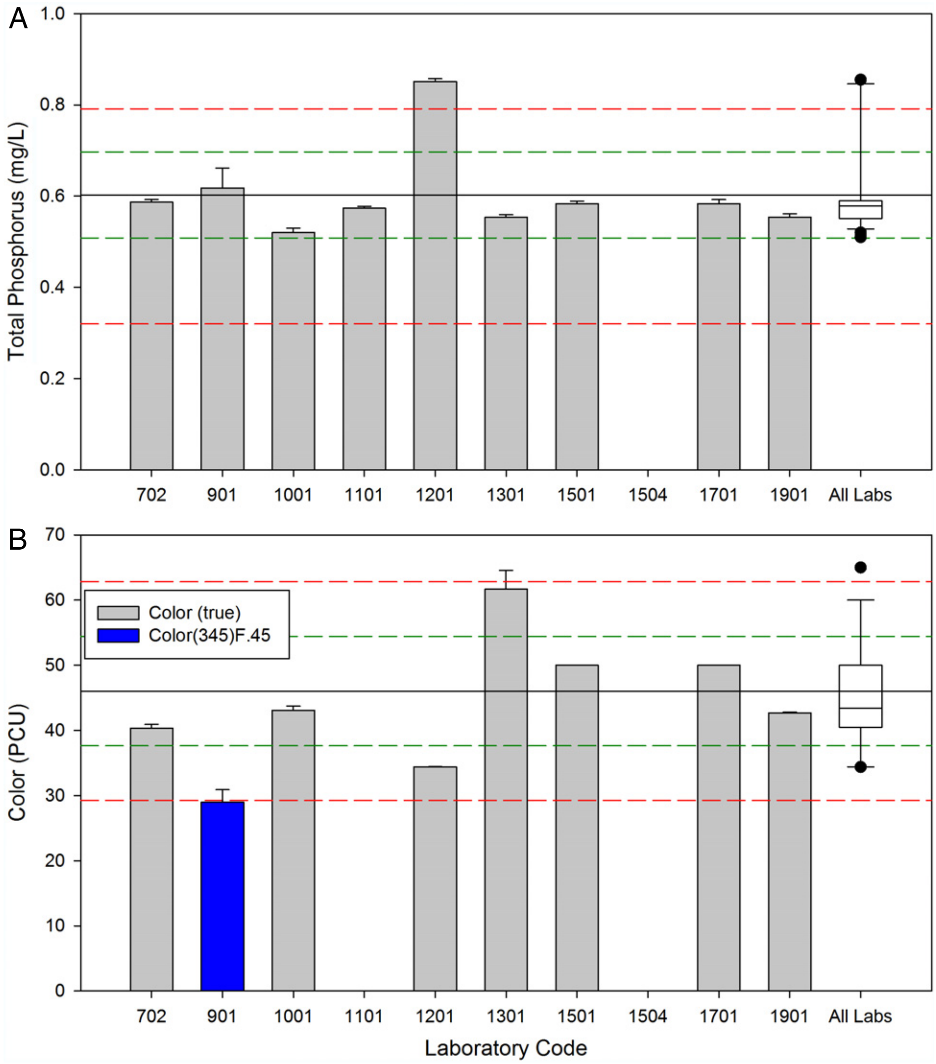


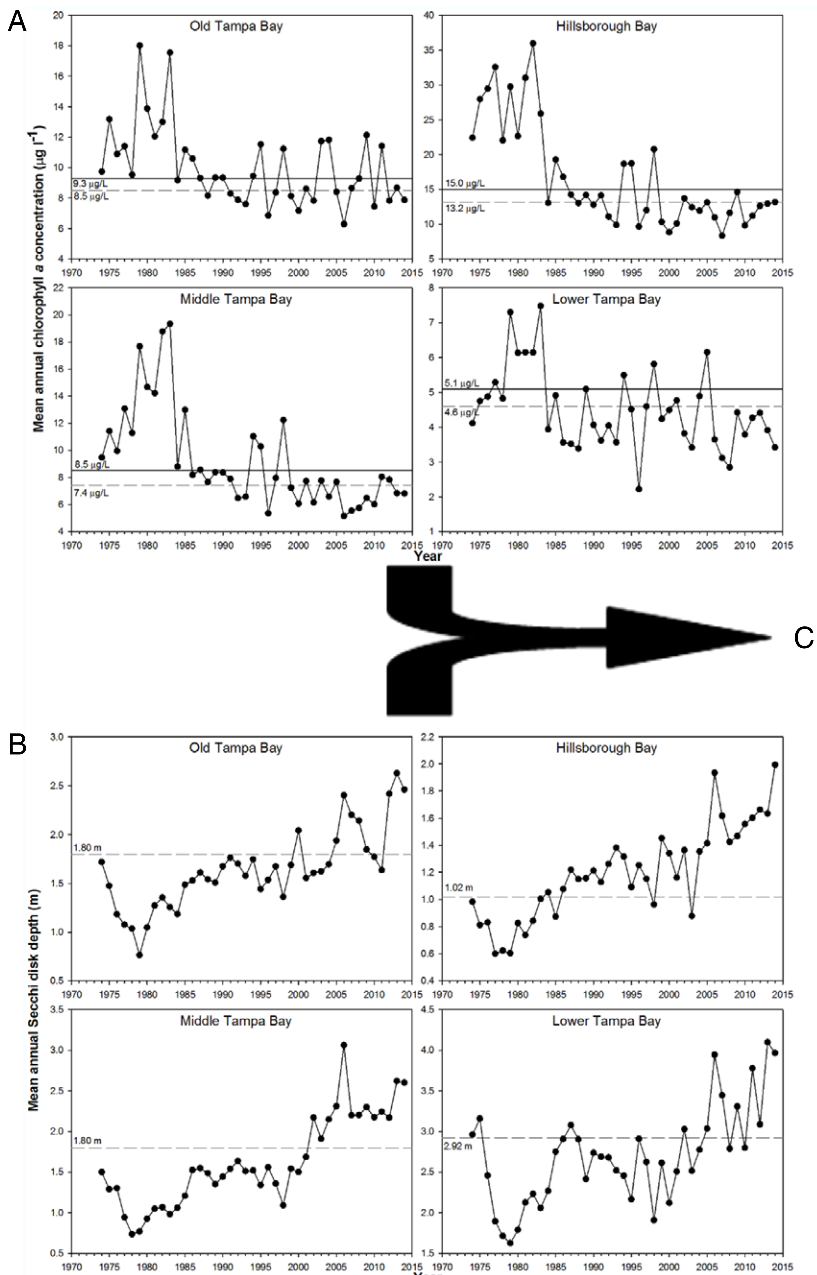
Fig. 4. Examples of inter-laboratory analyte comparisons conducted as part of the Southwest Florida Regional Ambient Monitoring Program (RAMP) for (A) total phosphorus and (B) color. These samples originated from the estuarine portions of the tidal, Alafia River on October 9, 2013 and highlight the relative agreement in reporting of total phosphorus (A) values from the collected samples, while greater variability in reporting is still present from the regional laboratories for water color (B) results. Green and red dashed lines refer to 1 and 2 standard deviations of the grand mean, respectively. Data source: RAMP. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

ecosystem recovery as it relates to nutrient pollution and therefore have not established a state-adopted TMDL. Regardless, both state and federal regulatory agencies have recognized that maintaining chlorophyll-a concentrations below the regulatory thresholds will ensure that continued seagrass recovery will occur in Tampa Bay. Both management target and regulatory threshold development relied upon data generated from the long-term monitoring established in Tampa Bay by the EPCHC (Yates et al., 2011; Greening et al., 2015, 2011; Greening and Janicki, 2006).

4.3. Regional report card: annual Bay water quality assessments

Annual assessments of Bay water quality management targets have been used by resource managers to guide decisions related to nitrogen management in each of the four major bay segments (Yates et al., 2011; Greening et al., 2015; Janicki et al., 2000). These assessments, termed the annual "decision matrix", have shown that the bay segment water quality targets (mean annual chlorophyll-a concentrations and effective light penetration based on Secchi disk depths) developed by the TBEP have been largely met and that a general improvement in Bay water clarity has been observed since the early 1990s (Fig. 5). Consequently, seagrass coverage in Tampa Bay continues to increase over time and now exceeds the 1950s seagrass recovery goal for the Bay (Fig. 6) (Greening et al., 2015, 2011).

Periodically, annual assessments have revealed that water quality conditions have not met management targets for one or both indicators (chlorophyll-a concentrations and/or light attenuation, as estimated from Secchi disk depths) (Fig. 5). In particular, the OTB segment has lagged behind others in terms of adequate water quality to support the recovery of seagrass (Fig. 5). As a result, bay managers have focused additional research, monitoring and modeling efforts within this Tampa Bay region. Currently, the TBEP and SWFWMD are developing an integrated ecosystem model that will link watershed, hydrodynamic, water/sediment quality, and ecological models (light and biota) to simulate changes in OTB ecology in response to potential future implementation of large-scale management actions (Sherwood, in press). For example these potential actions could include (1) completely diverting stormwater/freshwater input from a portion of the OTB subwatershed that historically drained to the Gulf of Mexico, (2) diverting 100% of the directly discharged advanced wastewater treatment effluent to OTB from the subwatershed, (3) physically altering causeways along road expanses that intersect OTB, (4) reducing stormwater



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
2010	Green	Green	Green	Green
2011	Red	Green	Yellow	Green
2012	Green	Green	Green	Green
2013	Green	Green	Green	Green
2014	Green	Green	Green	Green

Fig. 5. Mean annual (A) chlorophyll-a (µg/L) concentrations and (B) Secchi disk depths (m) in relation to TBEP management targets (dashed lines) and regulatory thresholds (solid line) in each bay segment from 1974–2014. Corresponding management response (C) based on water quality indicator attainment in a given year. Green = Continue planned projects. Report data via annual progress reports; Yellow = Review monitoring data and nitrogen loading estimates. Begin/continue development of specific management recommendations; Red = Finalize development and implement appropriate management actions to get Bay water quality back on track. Data Source: EPCHC and TBEP. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

nutrient loads by 25% throughout the subwatershed, and (5) various combinations of these actions. Data collected from the EPCHC, as well as, the other ongoing monitoring programs in the region have been used extensively in this model development process.

4.4. Meeting regulatory requirements: annual compliance assessments

The Tampa Bay NMC, an ad-hoc public/private partnership between governmental partners and key industry stakeholders, has accepted responsibility to maintain nitrogen loads at levels supportive of seagrass recovery in Tampa Bay (Yates et al., 2011; Greening et al., 2015). As part of the state's RA determination, and to comply with the federally-recognized TMDL established for total nitrogen in Tampa Bay, an annual compliance assessment framework has been established to assess the region's efforts to reduce nutrient pollution in the Bay. The compliance framework takes into account the frequency and duration of exceeding the regulatory thresholds established for chlorophyll-a concentrations in each of the Bay's segments (Table 1; Fig. 7) (Tampa Bay Estuary Program and Janicki Environmental, Inc.). If the chlorophyll-a regulatory threshold for a particular bay segment is exceeded in two consecutive years of a 5-year period and the federally-recognized TMDL has not been exceeded (based on a compilation of all source loading information), then a re-evaluation of the nitrogen load targets established as the federally-recognized TMDL for Tampa Bay for that particular bay segment would be conducted (Tampa Bay Estuary Program and Janicki Environmental, Inc.).

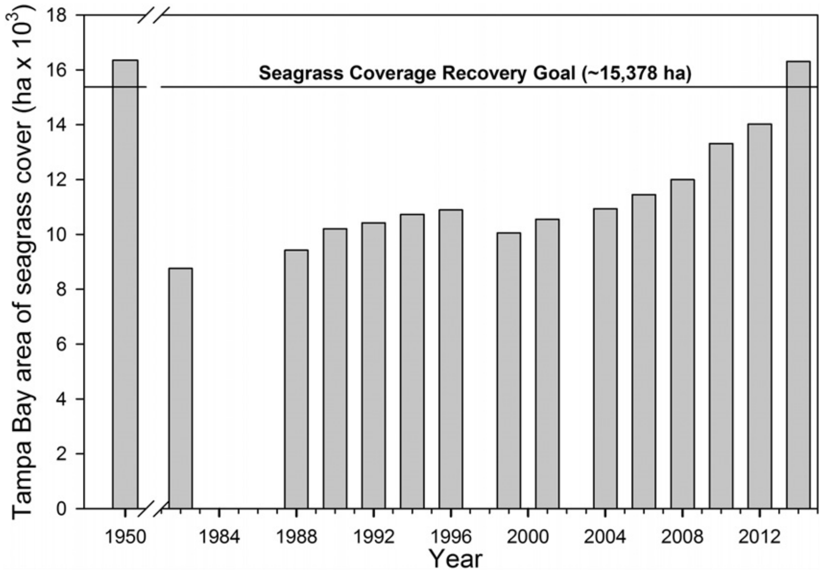
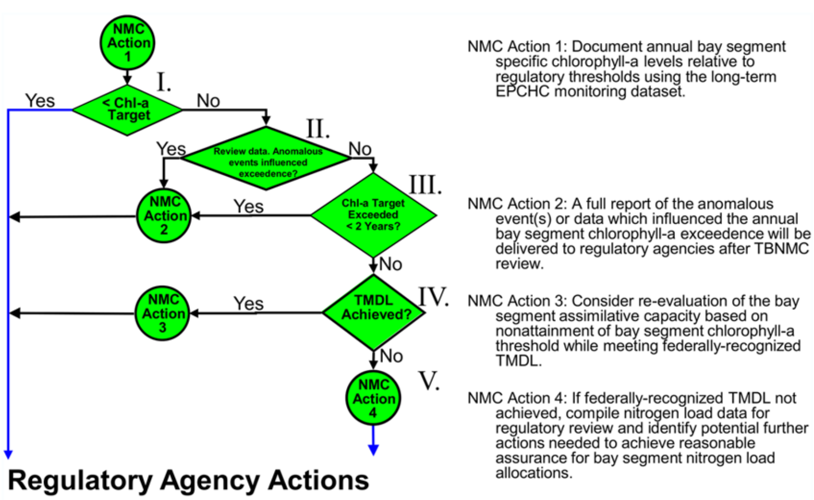


Fig. 6. Total seagrass coverage (ha) in Tampa Bay circa 1950 through 2014. In 2014, Tampa Bay exceeded the seagrass recovery goal set by bay managers in 1995. The baywide seagrass recovery goal was set to 95% of the estimated coverage of the 1950s, a benchmark period prior to rapid and widespread development in the region (Greening et al., 2015). Data Source: SWFWMD.



Assessment Step Linked to Roman Numerals of Figure Above	Result	Action
I. Determine annual bay segment specific chlorophyll-a regulatory threshold attainment.	Yes	NMC Action 1
	No	NMC Action 1
II. Review data and determine if an anomalous event(s) influenced non-attainment of the bay segment specific chlorophyll-a threshold.	Yes	NMC Action 2
	No	Go to III.
III. Determine if the chlorophyll-a thresholds have been exceeded for <2 consecutive years.	Yes	NMC Action 2
	No	Go to IV.
IV. Determine if the bay segment specific federally-recognized TMDL has been achieved.	Yes	NMC Action 3
	No	Go to V.
V. For a given year or for multiple years, compile and report entity-specific combined source loads in comparison to source allocations.	Compile & Report	NMC Action 4

Fig. 7. Overview of annual compliance assessment steps undertaken by the Tampa Bay Nitrogen Management Consortium (NMC) to comply with state and federal regulatory actions to address nutrient management in the Tampa Bay estuary (Tampa Bay Estuary Program and Janicki Environmental, Inc.). Initial assessment steps rely on observed water quality conditions in each of the major bay segments as monitored by the Environmental Protection Commission of Hillsborough County (EPCHC).

Conversely, if the federally-recognized TMDL is exceeded, then the re-evaluation may require adjustments of nitrogen load targets (allocations) developed for all major sources discharging to that particular bay segment, as represented by the entities participating in the TBNMC. A hypothetical example of the assessment steps for a particular bay segment is highlighted in Table 2. In this hypothetical example, the bay segment chlorophyll-a target (10 mg/L) was exceeded in 2 consecutive years, and the combined total nitrogen loadings from all sources (1100 tons/yr) exceeded the TMDL target loading (1000 tons/yr) for the bay segment in the second year of assessment (Table 2). Further investigation of entity and source — specific loads indicate that Entity A's domestic point source year 2 loadings (380 tons) and nonpoint source loads (38%, expressed as a percentage of

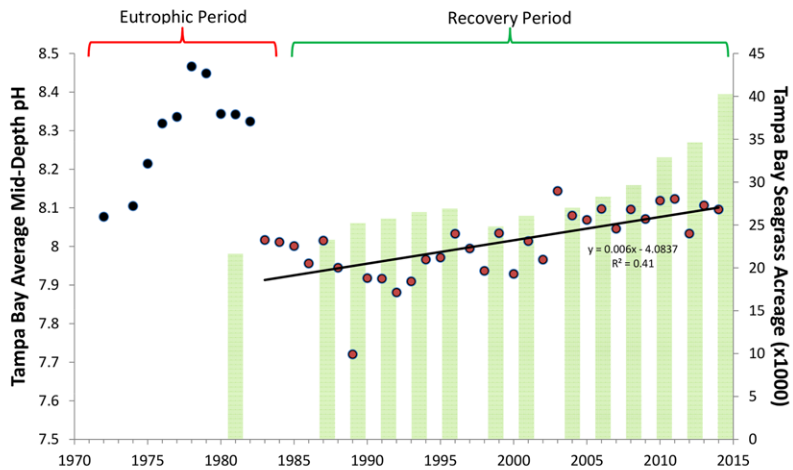


Fig. 8. Recent linear trend in average, daytime mid-depth pH (dots) from long-term water quality monitoring stations established in Tampa Bay since 1972 by the Environmental Protection Commission of Hillsborough County relative to baywide seagrass coverage estimates (bars). Recent pH increases have coincided with increasing seagrass coverage within the estuary which may offer some future buffering capacity to global ocean acidification processes in the future, if seagrass persist in the face of climate change and sea level rise impacts. Data source: EPCHC.

the remaining load to the bay segment, see Tampa Bay Estuary Program and Janicki Environmental, Inc.) exceeded the entity's regulatory permitted allocation (300 tons and 30%, respectively) (Table 2). These compliance assessment steps are performed annually by the Tampa Bay NMC and are predicated on the Bay's ecological response to nutrient loadings (as observed chlorophyll-a concentrations).

Since adoption of this compliance assessment framework in 2009, exceedance of the established chlorophyll-a regulatory thresholds (Table 1) has not occurred in two consecutive years for any bay segment of Tampa Bay. Therefore, extraneous management and regulatory oversight have not been necessary in Tampa Bay in relation to eutrophication-related processes. To date, ongoing actions of the NMC participants continue to reduce nutrient loads to the bay and maintain nitrogen load allocations at historic levels. This steadfast commitment by bay resource managers, governments, and key industries surrounding Tampa Bay have led to documented water quality and ecosystem improvements (Figs. 5 and 6) (Yates et al., 2011; Greening et al., 2015, 2011; Greening and Janicki, 2006). Included in these commitments has been the maintenance of a long-term water quality monitoring program in the Tampa Bay estuary, without which these ecosystem improvements would have not been observed in any rigorous fashion.

4.5. *Future efforts to monitor the benefits of a recovering estuary*

Establishment of the long-term water quality monitoring programs in Tampa Bay has also revealed additional ecosystem benefits that may arise from the continued recovery of seagrass resources. Tampa Bay pH conditions have closely tracked the biologically-mediated, carbonate system (Yates et al., 2007) of the Bay since monitoring began in the early 1970s (Fig. 8). During the period of increased phytoplankton production/blooms and minimal baywide seagrass coverage (late 1970s–early 1980s, Greening et al., 2015; Greening and Janicki, 2006; Bricker, 2008; Cloern and Jassby, 2009; Tampa Bay Estuary Program and Janicki Environmental, Inc., 2015), maximum average annual daytime pH values were observed. This period highlighted Tampa Bay's eutrophic state (Fig. 8). The initial "kick-start" phase of Tampa Bay's recovery (early-mid 1980s) followed large reductions in domestic wastewater treatment inputs of nitrogen. During this phase, phytoplankton production/blooms were reduced and pH values dropped. Since this time, pH has steadily risen in Tampa Bay as increased seagrass coverage and production has replaced the eutrophic, phytoplankton production conditions of the early 1980s decreased from approximately 1970 to the early 1980s (Fig. 8) (Yates et al., 2011; Greening et al., 2015). Whether these trends will continue into the future remains to be seen, as future climate change and sea level rise impacts might modify coastal ocean pH conditions and potentially reduce seagrass coverage within the Bay. However, recent studies have suggested that seagrasses: (1) are projected to benefit from elevated atmospheric pCO_2 in the future (Kleypas and Yates, 2009), (2) are capable of increasing seawater pH and carbonate mineral saturation states through photosynthesis (Unsworth et al., 2012), and (3) may help provide protection to organisms living in close association with seagrass beds (Manzello, 2012).

Seagrass recovery in Tampa Bay has recently been hypothesized to potentially buffer against the chemical impacts of ocean acidification (OA) based on the observed pH trends from the long-term monitoring programs, and as a result may confer some resiliency to important estuarine organisms (particularly shellfish and other economically important fish species that are particularly sensitive to OA). As such, if the Bay's recovered seagrass persist into the future, this habitat may serve as an important, regional OA refugia for important estuarine resources. To further examine this hypothesis, the TBEP, USGS and local monitoring partners are developing an OA monitoring program in Tampa Bay that would supplement EPCHC's existing long-term, monthly water quality monitoring program. The enhanced sampling program proposes measurements of carbon system parameters that would create a new long-term record of key parameters such as water column carbonate mineral saturation state, pCO_2, distribution of carbonate species, and validation of pH measurements using best practice methods (Riebesell et al., 2010; Pfister, 2014). It is hoped that investment into this new, long-term monitoring program will aid future management decisions related to global climate change and continued ecosystem recovery in Tampa Bay.

Lastly, the Tampa Bay region is also poised to integrate new technologies into the long-term monitoring and management of the estuary in the future. Methods to remotely-sense water quality parameters, such as colored dissolved organic material (CDOM) (Le et al., 2013), nutrients (Chang et al., 2012, 2013), chlorophyll-a (Le et al., 2013a,b,c) and other parameters (Hu et al., 2014), are now being developed in the region. These products may offer greater spatiotemporal coverage in determining the water quality state of the estuary over traditional *in situ* collection methods,

Table 2
Example of annual compliance assessment steps for a hypothetical bay segment in Tampa Bay. Green and yellow squares indicate outcomes of decision points outlined in the Tampa Bay Nitrogen Management Consortium's (NMC) reasonable assurance assessment framework (Tampa Bay Estuary Program and Janicki Environmental, Inc.). Purple cells represent entity/source/facility exceedances of nitrogen load allocations for a single year, as determined from nitrogen loads calculations that would be completed under NMC Action 4 for point source (PS) and nonpoint source (NPS) permitted loads.

Bay segment reasonable assurance assessment steps			Example data used to assess interim reasonable assurance					Comment
			Year 1	Year 2	Year 3	Year 4	Year 5	
NMC action 1: determine if observed chlorophyll-*a* exceeds hypothetical regulatory threshold of 10.0 μg/L			12.0 μg/L (Yes)	14.0 μg/L (Yes)				Chlorophyll-a exceedances occurred during first 2 years of assessment period necessitating further NMC actions
NMC action 2: determine if any observed chlorophyll-a exceedances occurred for 2 consecutive years			No	Yes				Year 2 triggers additional NMC Action 3
NMC action 3: determine if observed hydrologically-normalized total load exceeds hypothetical federally-recognized total maximum daily load (TMDL) of 1000 tons/year			900 tons/yr (No)	1100 tons/yr (Yes)				Year 2 exceeds the TMDL after accounting for hydrology, NMC performs NMC Actions 4–5
NMC actions 4–5: determine if any entity/source/facility specific exceedances of 5-yr average allocation occurred during implementation period								At end of 5-year period, facility/source-specific exceedances listed in this column ↓
Entity	Source	Allocation	Example data used to assess interim reasonable assurance					
			Year 1	Year 2	Year 3	Year 4	Year 5	5-Yr average
Entity A	Set allocation — domestic PS A	300 tons	290 tons	380 tons				
	NPS % contribution (normalized tons)	30.0%	29.0%	38.0%				
Entity B	Set allocation — domestic PS B	200 tons	180 tons	190 tons				
	NPS % contribution (normalized tons)	50.0%	48.0%	49.0%				
Entity C	Set allocation — industrial PS C	50 tons	45 tons	48 tons				
	NPS % contribution (normalized tons)	20.0%	23.0%	13.0%				

and provide earlier warning signs for degradation or enhance indicators of continued ecosystem recovery. Although some of these methods are still in early development (Le et al., 2013b,c), their potential use in rapidly assessing and conferring reliable information to resource managers is being considered within the TBEP's existing management frameworks (Le et al., 2013a). Nevertheless, continued future reliance and maintenance of the *in situ*, long-term water quality monitoring program established by the EPCHC will be necessary to further develop and validate these remotely sensed products in later years.

5. Significance of long-term water quality monitoring in Tampa Bay

The Tampa Bay region has been fortunate to have a consistent and reliable source of information regarding its water quality and ecosystem responses within the estuary since at least 1972. Greater than $0.5B has been invested within the region since the 1990s to help improve water quality conditions to support seagrass and ecosystem recovery. These investments have proven their worth based on the long-term data record within the region that shows positive trajectories of ecosystem improvement. As such, investment in the long-term monitoring of the Tampa Bay estuary has also proven its worth. Without a clear measure of progress, as reflected by the long-term monitoring record, the political and societal will to continue to invest in actions to restore Bay water quality would likely falter.

Maintaining the positive trajectory of ecosystem recovery in Tampa Bay will be a challenge in the future. Population within the Tampa Bay metropolitan region will continue to grow, and new pressures related to climate change, ocean acidification and sea level rise will exert influence on Tampa Bay's current water quality and ecosystem condition. Continued investment in the long-term water quality monitoring programs in the estuary are imperative in light of these forecasted pressures and just makes common sense from a resource management perspective. The benefits of a "healthy" Tampa Bay have been translated to economic terms, and it is now estimated that 1 in 5 jobs are dependent on the bay maintaining its current healthy condition (Tampa Bay Estuary Program and Tampa Bay Regional Planning Council). Continued monitoring will ensure that any risks to both the environmental and economic assets provided by the Tampa Bay estuary will be readily detected and appropriate management actions can be implemented in time to overcome any future ecosystem risks.

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References

Bricker, S.B., et al., 2008. Effects of nutrient enrichment in the nation's estuaries: A decade of change. Harmful Algae 8, 21–32. http://dx.doi.org/10.1016/j.hal.2008.08.028.
Chang, N., Xuan, Z., Wimberly, B., 2012. Remote sensing spatiotemporal assessment of nitrogen concentrations in Tampa Bay, Florida due to a drought. Terr. Atmos. Ocean. Sci. 23, 467–479. http://dx.doi.org/10.3319/TAO.2012.04.10.01(WMH).

Chang, N., Xuan, Z., Yang, Y.J., 2013. Exploring spatiotemporal patterns of phosphorus concentrations in a coastal bay with MODIS images and machine learning models. Remote Sens. Environ. 134, 100–110. http://dx.doi.org/10.1016/j.rse.2013.03.002.

Cloern, J.E., et al., 2015. Fast-paced change where land and sea meet. Global Change Biol. (submitted for publication).

Cloern, J.E., Jassby, A.D., 2009. Patterns and scales of phytoplankton variability in estuarine–coastal ecosystems. Estuaries and Coasts 33, 1559–2731. http://dx.doi.org/10.1007/s12237-009-9195-3.

Duarte, C.M., Conley, D.J., Carstensen, J., Sánchez-Camacho, M., 2009. Return to Neverland: Shifting baselines affect eutrophication restoration targets. Estuaries and Coasts 32, 29–36. http://dx.doi.org/10.1007/s12237-008-9111-2.

Greening, H.S., Cross, L.M., Sherwood, E.T., 2011. A multiscale approach to seagrass recovery in Tampa Bay, Florida. Ecol. Restor. 29, 82–93. http://dx.doi.org/10.3368/er.29.1-2.82.

Greening, H.S., Janicki, A., 2006. Toward reversal of eutrophic conditions in a subtropical estuary: Water quality and seagrass response to nitrogen loading reductions in Tampa Bay, Florida, USA. Environ. Manag. 38, 163–178. http://dx.doi.org/10.1007/s00267-005-0079-4.

Greening, H., Janicki, A., Sherwood, E.T., Pribble, R., Johansson, J.O.R., 2015. Ecosystem responses to long-term nutrient management in an urban estuary: Tampa Bay, FL, USA. Estuarine Coastal Shelf Sci. 151, A1–A16. http://dx.doi.org/10.1016/j.ecss.2014.10.003.

Hu, C., Barnes, B.B., Murch, B., Carlson, P., 2014. Satellite-based virtual buoy system to monitor coastal water quality. Opt. Eng. 53. http://dx.doi.org/10.1117/1.OE.53.5.051402.

Janicki, A., Wade, D., Pribble, J.R., 2000. Developing and Establishing a Process to Track the Status of Chlorophyll-a Concentrations and Light Attenuation to Support Seagrass Restoration Goals in Tampa Bay, Tampa Bay Estuary Program Technical Report #04-00. https://www.tbeptech.org/TBEP_TECH_PUBS/2000/TBEP_04_00Chlor-A.pdf. Accessed February 2015.

Johansson, J.O.R., 2010. Long-term and seasonal trends in phytoplankton production and biomass in Tampa Bay, Florida. In: S.T. Cooper (Ed.), Proceedings, Tampa Bay Area Scientific Information Symposium, BASIS 5: 20–23 October 2009, St. Petersburg, Florida, pp. 73–94. http://www.tbeptech.org/BASIS/BASIS5/BASIS5.pdf. Accessed March 2015.

Johansson, J.O.R., Lewis, R.R., 1992. Recent improvements of water quality and biological indicators in Hillsborough Bay, a highly impacted subdivision of Tampa Bay, Florida, USA. In: Vollenweider, R.A., Marchetti, R., Viviana, R. (Eds.), Marine Coastal Eutrophication. Elsevier, Amsterdam, Netherlands, pp. 1199–1215.

Karlen, D.J., Surface Water Quality 2001-2010 Hillsborough County, Florida, Environmental Protection Commission of Hillsborough County, Tampa, Florida, 144p. http://www.epchc.org/DocumentCenter/View/1275. Accessed March 2015.

Kleypas, J.A., Yates, K.K., 2009. Coral reefs and ocean acidification. Oceanography 22, 108–117. http://dx.doi.org/10.5670/oceanog.2009.101.

Laws of Florida, Chapter 84-446, Special Act, http://www.epchc.org/DocumentCenter/Home/View/351. Accessed January 2015.

Le, C., Hu, C., Cannizzaro, J., English, D., Kovach, C., 2013a. Climate-driven chlorophyll a changes in a turbid estuary: Observation from satellites and implications for management. Remote Sens. Environ. 130, 11–24. http://dx.doi.org/10.1016/j.rse.2012.11.011.

Le, C., Hu, C., Cannizzaro, J., English, D., Muller-Karger, F., Lee, Z., 2013c. Evaluation of chlorophyll-a remote sensing algorithms for an optically complex estuary. Remote Sens. Environ. 129, 75–89. http://dx.doi.org/10.1016/j.rse.2012.11.001.

Le, C., Hu, C., English, D., Cannizzaro, J., Chen, Z., Feng, L., Boler, R., Kovach, C., 2013b. Towards a long-term chlorophyll-a data record in a turbid estuary using MODIS observations. Prog. Oceanogr. 109, 90–103. http://dx.doi.org/10.1016/j.pocean.2012.10.002.

Le, C., Hu, C., English, D., Cannizzaro, J., Chen, Z., Kovach, C., Anastasiou, C.J., Zhao, J., Carder, K.L., 2013. Inherent and apparent optical properties of the complex estuarine waters of Tampa Bay: What controls light? Estuarine Coastal Shelf Sci. 117, 54–69. http://dx.doi.org/10.1016/j.ecss.2012.09.017.

Leary, R.E., 2012. Statistical Analyses and Summary of Analytical Round Robin #8 – a Data Comparability Study, Gulf of Mexico Alliance Report. http://www.gulfofmexicoalliance.org/working/waterquality/round_robin/ARR_8_Final%20Report.pdf. Accessed February 2015.

Lewis, R.R., 2012. Comments on: A multiscale approach to seagrass recovery in Tampa Bay, Florida, Greening "etal 2011. Ecological Restoration 29, 82–93. Ecological Restoration 30, 7–8. http://dx.doi.org/10.3368/er.30.1.7.

Lewis, R.R., Clark, P.A., Fehring, W.K., Greening, H.S., Johansson, J.O.R., Paul, R.T., 1999. The rehabilitation of the Tampa Bay estuary, Florida, USA, as an example of successful integrated coastal management. Marine Pollution Bulletin 37, 468–473. http://dx.doi.org/10.1016/S0025-326X(99)00139-3.

Manzello, D.P., et al., 2012. Ocean acidification refugia of the Florida Reef Tract. PLoS ONE 7, e41715. http://dx.doi.org/10.1371/journal.pone.0041715.

Meyers, S.D., Linville, A.J., Luther, M.E., 2014. Alteration of residual circulation due to large-scale infrastructure in a coastal plain estuary. Estuaries and Coasts 37, 493–507. http://dx.doi.org/10.1007/s12237-013-9691-3.

Morrison, G., Sherwood, E.T., Boler, R., Barron, J., 2006. Variations in water clarity and chlorophyll a in Tampa Bay, Florida, in response to annual rainfall, 1985–2004. Estuaries and Coasts 29, 926–931. http://dx.doi.org/10.1007/BF02798652.

Pfister, C.A., et al., 2014. Detecting the unexpected: A research framework for ocean acidification. Environmental Science and Technology 48, 9982–9994. http://dx.doi.org/10.1021/es501936p.

Poe, A., Janicki, A.J., Greening, H., 2006. Baywide Environmental Monitoring Report, 2002-2005, Tampa Bay Estuary Program Technical Report #06-06. Accessed January 2015 https://www.tbeptech.org/TBEP_TECH_PUBS/2006/TBEP_06_06_BEMRFinal.pdf.

Rabalais, N.N., et al., 2010. Dynamics and distribution of natural and human-caused coastal hypoxia. Biogeosciences 7, 585–619. http://dx.doi.org/10.5194/bg-7-585-2010.

Riebesell, U., Fabry, V.J., Hansson, L., Gattuso, J.-P. (Eds.), 2010. Guide to best practices for ocean acidification research and data reporting. Publications Office of the European Union, Luxembourg, p. 260.

Ries, T., Scheda, S., 2014. Master Plan for the Protection and Restoration of Freshwater Wetlands in the Tampa Bay Watershed, Florida, Tampa Bay Estuary Program Technical Report #05-14. http://www.tbeptech.org/TBEP_TECH_PUBS/2014/TBEP_05_15_Freshwater_Wetland_Master_Plan.pdf. Accessed January 2015.

Robison, D., 2010. Tampa Bay Estuary Program Habitat Master Plan Update, Tampa Bay Estuary Program Technical Report #06-09. p. 368. https://www.tbeptech.org/TBEP_TECH_PUBS/2009/TBEP_06_09_Habitat_Master_Plan_Update_Report_July_2010.pdf. Accessed January 2015.

Sherwood, E.T., et al., Development of an Integrated Ecosystem Model to Determine Effectiveness of Potential Watershed Management Projects on Improving Old Tampa Bay, Proceedings of the 5th Interagency Conference on Research I the Watersheds, March 2–5, 2015, Charleston, S.C., US Forest Service General Technical Report, Southern Research Station, Asheville, N.C., (in press).

Simon, J.L., 1974. Tampa Bay estuarine system – A synopsis. Florida Scientist 37, 217–244.

Southwest Florida Water Management District, 2011. Land Use/Cover GIS Shapefiles, http://www.swfwmd.state.fl.us/data/gis/layer_library/category/physical_dense. Accessed January 2015.

Southwest Florida Water Management District, SWIM Section, Tampa Bay: Surface Water Improvement and Management Plan, Tampa, Florida, 108p. http://www.swfwmd.state.fl.us/files/database/site_file_sets/34/tampabay.pdf. Accessed March 2015.

Tampa Bay Estuary Program, 2006. Charting the Course: The Comprehensive Conservation & Management Plan for Tampa Bay, St. Petersburg, FL. http://www.tbep.org/about_the_tampa_bay_estuary_program-charting_the_course_management_plan-download_charting_the_course.html. Accessed January 2015.

Tampa Bay Estuary Program and Janicki Environmental, Inc., Final: 2009 Reasonable Assurance Addendum: Allocation and Assessment Report, Prepared for the Florida Department of Environmental Protection, St. Petersburg, Florida, 441pp. https://www.tbeptech.org/attachments/article/50/FINAL_NMC_APPROVED_2009_RA_Addendum_Addressing_FDEP_Comments_01222010.pdf. Accessed March 2015.

Tampa Bay Estuary Program and Tampa Bay Regional Planning Council, Economic Valuation of Tampa Bay. TBEP Technical Publication #04-14, St. Petersburg, Florida, 91p. https://www.tbeptech.org/TBEP_TECH_PUBS/2014/TBEP_04_14_%20FinalReport_Economic_Valuation_of_Tampa_Bay_Estuary.pdf. Accessed March 2015.

Tampa Bay Partnership, Tampa Bay Demographics based on 2015 Nielsen estimates, http://www.tampabay.org/site-selection/tampa-bay-demographics. Accessed March 2015.

United States Army Corps of Engineers, Final Environmental Impact Statement – Tampa Harbor Project, Jacksonville District, 297 pages.

United States Army Corps of Engineers, Waterborne commerce of the United States, Part 5—National Summaries, http://www.navigationdatacenter.us/wcsc/wcsc.htm. Accessed January 2015.

Unsworth, R.K.F., Collier, C.J., Henderson, G.M., McKenzie, L.J., 2012. Tropical seagrass meadows modify seawater carbon chemistry: implications for coral reefs impacted by ocean acidification. Environmental Research Letters 7, 1–9. http://dx.doi.org/10.1088/1748-9326/7/2/024026.

US Environmental Protection Agency, 1998. Decision Document for Technical Approval/Disapproval of TMDL submittal for Tampa Bay, Florida (Nitrogen). http://www.epa.gov/waters/tmdldocs/1180_FINAL%20TMDL%20FL%201180.pdf. Accessed March 2015.

Waycott, M., et al., 2009. Accelerating loss of seagrass across the globe threatens coastal ecosystems. Proc. Natl. Acad. Sci. 106, 12377–12381. http://dx.doi.org/10.1073/pnas.0905620106.

Woodworth, M.T., Connor, B.F., 2003. Results of the U.S. Geological Survey's Analytical Evaluation Program for Standard Reference Samples Distributed in March 2003, U.S. Geological Survey open-File Report 03-261. https://bqs.usgs.gov/srs/Report_Spr03.pdf. Accessed June 2015.

Yates, K.K., Dufore, C., Smiley, N., Jackson, C., Halley, R.B., 2007. Diurnal variation of oxygen and carbonate system parameters in Tampa Bay and Florida Bay. Marine Chemistry 104, 110–124. http://dx.doi.org/10.1016/j.marchem.2006.12.008.

Yates, K.K., Greening, H., Morrison, G., 2011. Integrating Science and Resource Management in Tampa Bay, Florida, United States Geological Survey Circular 1348. http://pubs.usgs.gov/circ/1348. Accessed January 2015.

Zar, J.H., 1996. Biostatistical Analysis, 3rd Edition. Prentice Hall, Inc, Upper Saddle River, New Jersey.

Zhu, J., Weisberg, R.H., Zheng, L., Han, S., 2015. Influences of channel deepening and widening on the tidal and nontidal circulations of Tampa Bay. Estuaries and Coasts 38, 132–150. http://dx.doi.org/10.1007/s12237-014-9815-4.