BASIS6

Bay Area Scientific Information Symposium


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NAVIGATING CHANGING TIDES

Addressing New Challenges with Effective Science and Management

Tampa Bay Estuary Program

Tampa Bay Regional Planning Council
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BASIS 6

Navigating Changing Tides: Addressing New Challenges with Effective Science & Management

September 28 - 30, 2015
St. Petersburg, Florida

Maya Burke
Editor

FOREWORD

These proceedings contain presentations given at the sixth Tampa Bay Scientific Information Symposium, held September 28 - 30, 2015 in St. Petersburg, Florida. Since its inception in 1982, the BASIS conference series has provided a forum for sharing state-of-the-art research on Tampa Bay and its watershed. The theme of the BASIS 6, *Navigating Changing Tides*, features work that explores the 21st century dimensions of environmental challenges and the innovative and practical strategies devised by regional researchers and resource managers to address them. Presentations are organized around the following session topics: Coastal Connections; Practical Applications of Environmental Management & Policy; Emerging Issues, Technology & Methods; and Climate Change.

More than 200 scientists, resource managers and students from the Tampa Bay area participated in the symposium, which included 75 papers and posters.

ACKNOWLEDGEMENTS

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COASTAL CONNECTIONS

INCORPORATING VALUATION METRICS INTO LONG-TERM RESTORATION GOALS IN TAMPA BAY

Holly Greening, Felicia Burks, Mark Russell, Avera Wynne

ABSTRACT

The establishment of science-based environmental management goals is just the first step in what is typically a decades-long process to restore estuarine and coastal ecosystems. In addition to adequate monitoring and reporting, maintaining public interest, financial support and political will are crucial elements in sustaining progress towards goals. The local government and agency partners participating in the Tampa Bay Estuary Program have established numeric areal extent goals for seagrass, emergent coastal habitats and freshwater wetlands in the watershed, and water quality targets necessary to meet seagrass goals. Progress towards these goals are monitored and reported on a regular basis, and eagerly tracked by local governments, agencies and the environmental community. However, engaging the business community and the general public in understanding the value of restoring habitats and water quality, and encouraging their participation in maintaining forward progress has been challenging. Adding new metrics to convey the value of reaching long-term goals has proven an effective method for reaching previously unengaged elements of the community. Ecosystem services valuation, including nitrogen removal via denitrification, indicate that seagrass extent recovered over the last 20 years now generate nitrogen removal services equivalent to building a new wastewater treatment plant. An economic evaluation indicates that water quality and habitat improvements now support one of every five jobs in the Tampa Bay area and add $22B US per year, or 13% to the local economy. Economic valuation metrics provide important, and relevant, new tools for sustaining the community support necessary for successful attainment of long-term goals.

INTRODUCTION

Tampa Bay, Florida, is a shallow, subtropical estuary that experienced severe cultural eutrophication between the 1940s and 1980s, a period when the human population of its watershed quadrupled. In response, citizen action led to a number of initiatives including the formation of the Tampa Bay Regional Planning Council's Agency on Bay Management, the Southwest Florida Water Management District's Surface Water Improvement and Management program, and the Tampa Bay Estuary Program. Together, these agencies and the public and private partners participating in them adopted management objectives to support the restoration and protection of the bay's living resources. These included numeric chlorophyll *a* and water clarity targets, as well as long-term goals addressing the spatial extent of seagrasses and other selected habitat types, to support estuarine-dependent faunal guilds.

Over the past three decades nitrogen controls involving sources such as municipal wastewater treatment plants, stormwater conveyance systems, fertilizer manufacturing and shipping operations, electrical power stations and residential landscaping have been undertaken to meet these and other management objectives. Cumulatively these controls have resulted in an almost 70% reduction in annual TN loads relative to earlier ‘worse case’ (latter 1970s) conditions. As a result annual water clarity and chlorophyll *a* targets are currently met in most years (Figure 1). Seagrass cover measured in 2014 was higher than that recorded in 1950, and exceeded the long-term restoration goal (Figure 2).

Factors that have contributed to the observed improvements in Tampa Bay over the past several decades are summarized in Greening et al. (2014) and include:

- **Development of numeric, science-based water quality targets** to meet a long-term goal of restoring seagrass acreage to 1950s levels. Empirical and mechanistic models found that annual average chlorophyll *a* concentrations were a primary manageable factor affecting light attenuation. The models also quantified relationships between TN loads, chlorophyll *a* concentrations, light attenuation, and fluctuations in seagrass cover. The availability of long-term monitoring data, and a systematic process for using the data to evaluate the effectiveness of management actions, has allowed managers to track progress and make adaptive changes when needed.
- **Citizen involvement**. The initial reductions in TN loads, which occurred in the late 1970s and early 1980s, were a result of state regulations that were developed in response to citizens’ call for action. Improved water clarity and better fishing and swimming conditions were identified as primary goals by citizens again in the early 1990s, and led to development of numeric water quality targets and seagrass restoration goals. More recent citizen actions, from pet waste campaigns to support of reductions in residential fertilizer use, are important elements of the nitrogen management strategy.

Year	Old Tampa Bay	Hillsborough Bay	Middle Tampa Bay	Lower Tampa Bay
1974	No	No	No	Yes
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
2010	Yes	Yes	Yes	Yes
2011	No	Yes	Yes	Yes
2012	Yes	Yes	Yes	Yes
2013	Yes	Yes	Yes	Yes
2014	Yes	Yes	Yes	Yes

Figure 1. Average annual chlorophyll-a concentration threshold attainment for the four major bay segments,1974-2014. Red (no) indicates years when a bay segment-specific threshold was not attained, while green (yes) indicates years when a threshold was attained (Sherwood 2015). Data source: EPCHC.

- **Collaborative actions.** In addition to numerous other collaborative ventures that have benefitted Tampa Bay, the public/private Nitrogen Management Consortium, which includes more than 45 participating organizations, has implemented 500+ nutrient reduction projects. These projects have addressed stormwater treatment, fertilizer manufacturing and shipping, agricultural practices, reclaimed water use, and atmospheric emissions from local power stations, providing more than 500 tons of TN load reductions since 1995.
- **State and federal regulatory programs.** Regulatory requirements, such as state statutes and rules requiring compliance with advanced wastewater treatment (AWT) standards by municipal sewerage works, have played a key role in Tampa Bay management efforts. The technical basis and implementation plan of the Tampa Bay nitrogen management strategy have been developed in cooperation with state and federal regulatory agencies, and the strategy has been recognized by them as an appropriate tool for meeting water quality standards, including federally-mandated total maximum daily loads (TMDLs) and Numeric Nutrient Criteria.

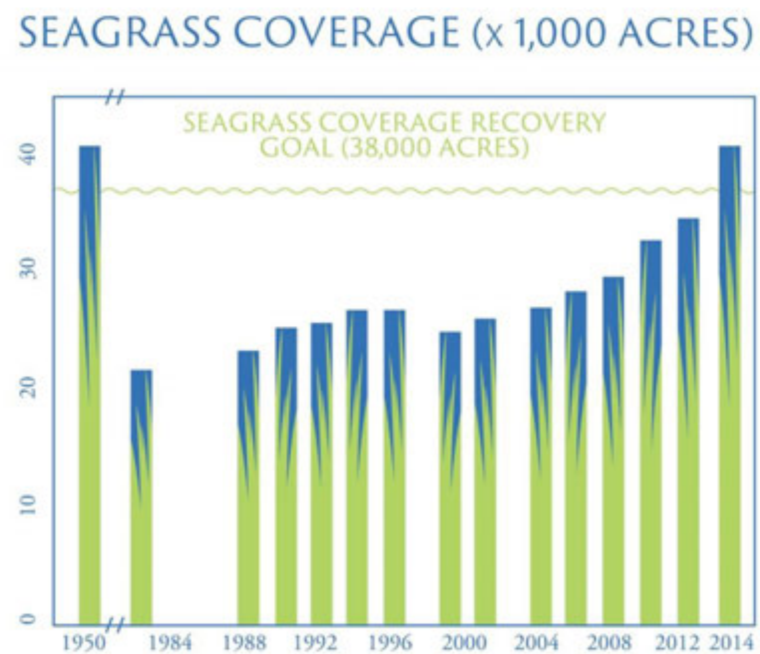

Figure 2. Total seagrass coverage (acres) in Tampa Bay circa 1950 through 2014. Seagrass coverage estimates were derived from photo-interpretation of aerial photographs acquired and analyzed by the SWFWMD. Data sources: SWFWMD (1982-2014); Haddad 1989 (1950).

Subsequent management efforts have focused on maintaining and extending those improvements in Tampa Bay's environmental resources by addressing water and sediment quality and habitat protection and restoration. Implementation of a collaborative, watershed-based management process, driven by an integrated science approach, has played a central role in supporting progress toward the achievement of science-based estuary management goals. These concerted management efforts in Tampa Bay have contributed to significant improvements in water quality and gains, during a time when other estuaries have lost many hectares of valued habitats (Lotze et al. 2006). Tampa Bay habitat gains are widely reported as a management and restoration success (Cloern 2001, Duarte 2009).

Recently, several new initiatives have developed estimates of the economic value of Tampa Bay's recovery to the region. Here, we summarize these initiatives and briefly discuss the benefits of incorporating economic valuation metrics with more traditional measures of environmental improvement and indicators in communicating Tampa Bay's recovery.

ECOSYSTEM SERVICES VALUATION

Restoration and preservation of habitats such as riparian forests, coastal marshes and seagrass meadows provide nutrient removal and other biochemical and physical functions which may preclude, reduce or delay the need for additional water treatment while also protecting human health. Based on an approach piloted by the United States Environmental Protection Agency's (US EPA) Office of Research and Development in Tampa Bay and its watershed, Russell and Greening (2015) examined the ecosystem goods and related potential cost savings for the Tampa Bay community from seagrass expansion, coastal marsh and mangrove restoration/recovery, and habitat that has been maintained or preserved. Ecosystem services related to N removal from seagrass expansion are summarized here.

Measureable biophysical attributes for the ecosystem good of usable clean water include the presence or absence of harmful or noxious algal blooms, the amount of light penetrating to benthic habitats, including seagrass beds, and the various concentrations of dissolved and suspended chemicals. Quantification of the biophysical processes regulating these attributes in seagrass habitats, combined with various valuation methods for estimating the replacement costs for substituting an engineered solution to maintain a specific biophysical attribute state, gives us a way to summarize the avoided costs associated with, and thus the value of, ecosystem restoration efforts.

The biophysical rates for nitrogen removal through denitrification were quantified from previous studies and literature reviews of coastal and bay habitats similar to those being restored in the Tampa Bay area (summarized in Russell and Greening 2015). Rates represent averages from several different studies with various degrees of accuracy and should not be thought of as exact. These biophysical removal rates were combined with estimates of areal extent to estimate the relative quantities of nitrogen removed from the system by seagrass beds.

The total value of denitrification rates for maintaining adequate water clarity for seagrass expansion was estimated for the bay and surrounding coastal region based on seagrass areal extent measured in 2014. Seagrass value here is defined as the rate of denitrification multiplied by the cost to remove nitrogen using engineered solutions. Replacement cost is one way to place a monetary value on the maintenance of a physical quantity of a common water pollutant such as nitrogen. This is equivalent to saying that if the community wants to maintain its amount of usable clean water at a given state without this ecosystem type it would need to pay this amount per year for maintaining its cleanness through removal of nitrogen using wastewater treatment plants which includes building and maintaining diversion infrastructure.

Replacement costs for removing a kilogram of nitrogen from various sources range from $2.71 to as high as $1885 (Table 1). Costs increase as the nitrogen becomes harder to route towards treatment areas and as simpler, more cost efficient mechanisms for removing nitrogen need to be replaced by more centralized advanced waste water treatment facilities. Compton et al. (2011) reviewed the cost of removing nitrogen from a wide range of sources and concluded that costs ranged from $2.71 - $96 kg^{-1} N. Abatement costs of reducing nitrogen from point sources are estimated as $18 kg^{-1} of nitrogen (Birch et al. 2011). We use this cost as our conservative ecosystem replacement value estimate based on using traditional waste water treatment to remove nitrogen from upstream point sources. Several lifecycle estimates, including upgrading and maintaining existing or building additional advanced waste water treatment facilities and drainage structures to remove nitrogen, put the cost as high as $1885 kg^{-1} of nitrogen removed (Roeder 2007). We use this cost as an upper limit ecosystem replacement value to illustrate the potential future value for bay habitats in a scenario of increasing nitrogen removal needs.

TABLE 1. REPLACEMENT COST VALUATION OF DENITRIFICATION

(Russell and Greening 2015)

Value of Denitrification $US / kg N	Denitrification References	Notes
18[1]	(Birch et al. 2011)	Freshwater N Point Source
3 - 96	(Compton et al. 2011)	Agricultural to Urban N Sources
40	(Doering et al. 1999)	Upgrade to AWWTP
11 - 1103	(FDEP 2004)	Upgrade to AWWTP plus new sewer infrastructure
195	(USEPA 1997)	Tampa Bay opportunity cost
1885[2]	(Roeder 2007)	New AWWTP

[1] Value used as conservative replacement cost estimate. [2] Value used as future scenario replacement cost estimate.

Results show that maintaining the baywide seagrass extent goal of 38,000 acres in Tampa Bay provides a conservative estimate of nutrient reductions equivalent to $25 million per year in avoided wastewater treatment plant costs. This translates to the avoided cost of a new medium-sized (40 mgd) WWTP. Future accrual of value associated with maintaining the ecosystem good of usable clean water could increase to as high as ~$3 billion per year when one takes into account the additional costs of water treatment and storm water diversion infrastructure that is likely as the region's population continues to grow (Russell and Greening 2015). The large current and future cost savings for the community surrounding Tampa Bay and additional benefits for the global community speak to the value of maintaining a healthy bay through past and continued restoration and preservation efforts.

THE ECONOMIC VALUE OF A HEALTHY BAY

Tampa Bay is recognized as a valuable asset for waterborne transportation, habitat, recreational uses, power plant heat exchange, ecosystem services, and much more. However, this value has generally gone unqualified. To assist in estimating the economic value of Tampa Bay, the Tampa Bay Regional Planning Council partnered with the Tampa Bay Estuary Program to conduct an economic valuation study of Tampa Bay and its watershed (TBRPC 2014). The primary approach used is a method called counterfactual analysis. Simply stated, the objective is to answer the question "What percentage of the Tampa Bay watershed's economy is dependent on the Bay? Additionally, what percentage of the watershed's economy is dependent upon a healthy Bay?"

A customized econometric model (REMI) is maintained by the Tampa Bay Regional Planning Council. REMI tracks more than 6,000 economic variables that details the economic history of the region and provides a current snapshot of the economy. Economic activity dependent upon the Bay and/or a Healthy Bay for each industrial sector was estimated using targeted expert groups and surveys. The results were used to develop industry-specific coefficients for both Bay influenced (e.g., shipping, underwater piping) and Healthy Bay dependent uses (e.g., boating, aquaculture). Survey results were factored against the current direct employment within the watershed, and then modeled to capture the indirect and induced multipliers within each sector.

Results show that, of the 1.4M people employed within the Tampa Bay Estuary watershed, about 47% (660,000) are influenced by the Bay in some capacity. Furthermore, 1 in 5 jobs within the watershed depends upon a healthy Bay (Figure 3). Within the 6-county area around Tampa Bay, 13% of the economy ($22B) is dependent upon a healthy Bay (TBRPC 2014).

Economic implications for three 'real world' case studies also indicated significant economic value from a healthy Bay. The first focused on the difference in value between a bay-front home and a similar home in the same neighborhood that was not located on the Bay, as compared to the median home price throughout the county. A bay-front home will generate approximately 4 times

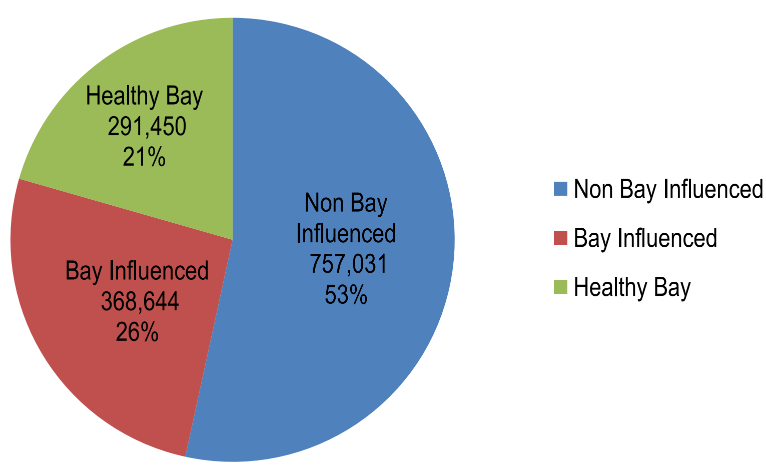

Figure 3. Employment within the Tampa Bay watershed. Red plus green indicate jobs influenced by the Bay; green indicates jobs dependent upon a healthy Bay; blue indicates jobs not influenced by the Bay (TBRPC 2014).

the ad valorem taxes as the median-priced home, and a home located within a quarter-mile of the Bay will generate approximately 2 times that of a median-priced home.

Secondly, comparisons of 3 star and 4 star hotels, depending on their location, yielded similar results. The average 3 star Bay-front hotel commands a 45% increase per night and a 4 star Bay hotel commands a 31% premium per night when compared with similar hotels not located on the Bay.

For the third case study, TBRPC (2014) used the results from Russell and Greening (2015) to estimate the cost savings from avoided wastewater treatment due to the nutrient reduction services provided by seagrass in Tampa Bay. The impacts of an additional $24M saved annually in avoided nutrient reduction costs were analyzed using REMI. For Hillsborough, Pinellas and Pasco Counties, this results in an estimated economic impact of 478 jobs, $223M in personal income, and $206 gross regional product over a ten-year period.

DISCUSSION

Local governments, municipalities and private businesses around the country realize the importance of a healthy watershed and bay environment to the economy of their regions. Many are also facing requirements to meet federal, state and local water quality regulations. In Tampa Bay, local communities and industries developed voluntary water quality goals and nutrient loading targets to support recovery of clear water and underwater seagrasses in the mid-1990s, and have implemented more than 500 projects since 1996 to help meet the nutrient loading targets developed for Tampa Bay. Their collective efforts, starting with significant wastewater point source reductions and continuing with nutrient loading reductions from atmospheric, industrial and community sources, have resulted in a present-day Tampa Bay which looks and functions much like it did in the relatively pre-disturbance 1950s period.

However, engaging the business community and the general public in understanding the value of restoring habitats and water quality, and encouraging their participation in maintaining forward progress has been challenging. Adding new economic metrics to convey the value of reaching long-term goals has proven an effective method for reaching previously unengaged elements of the community. As noted by the Tampa Bay Business Journal (TBBJ 2015), the "environmental health of the Bay has a lot more to do with the health of the local economy than you might imagine."

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CHANGES IN RESIDENCE TIME DUE TO LARGE-SCALE INFRASTRUCTURE IN A COASTAL PLAIN ESTUARY

Mark Luther, Steven D. Meyers and Amanda J. Moss

ABSTRACT

Alteration of bathymetry by the dredging of shipping channels and the construction of bridges and causeways are found to change residence time in a coastal plain estuary. Two identical three-year simulations are performed using realistic numerical circulation models of Tampa Bay that differ only in their bathymetry. The first bathymetry is based on present-day depth measurements and contains the modern infrastructure; the second is based on depth soundings from the pre-construction year 1879. Both models are seeded evenly with over 456,000 passively advected particles at the beginning of three distinct 90-day time periods within the simulations representing low, average, and high fresh water inflow conditions. Two types of Lagrangian residence time are studied: 1) The baywide residence time based on the total number of particles remaining in the bay. 2) The gridscale residence time based on the total number of particles in each model grid cell. The largest change in baywide residence time due to infrastructure is found during a period when the subtidal Eulerian circulation is strongly impacted by the infrastructure. During periods of weak to moderate Eulerian impact the baywide residence time is largely unaffected by infrastructure. At the grid-scale there are significant impacts such as decreased residence time headward of the bridges and decreased residence time in the portion of the bay where relatively deep dredging has occurred.

INTRODUCTION

The flushing of an estuary is driven by several mechanisms (MacCready and Geyer, 2010; Zimmerman, 1986). One mechanism is locally wind-forced volume exchange, principally at the sub-tidal scale (Janzen and Wong, 2002; Wong and Garvine, 1984). Extreme weather events can force an exchange of water between the estuary and larger coastal region in a short time period, as in the case of Hurricane Frances that flushed 40% of the volume in Tampa Bay (TB) in one day (Wilson et al., 2006) or Hurricane Floyd that generated a peak volume influx about 6 times the nominal peak tidal influx in Chesapeake Bay (Valle-Levinson et al., 2002). A second mechanism is tidal mixing, where the incoming ocean water entrains estuarine water through turbulent mixing, and then removes the estuarine water on the outgoing tide (Bilgili et al., 2005; Griffin and LeBlond, 1990). A third mechanism is a build-up of freshwater near the head of the estuary generating a barotropic pressure gradient that drives a mean current u towards the mouth. This is sometimes called “piston” or “plug” flow. The fourth is the sub-tidal residual “exchange” circulation where slow (relative to tidal speeds) but persistent currents are created by a net density gradient between the head and mouth of the estuary (Pritchard, 1956). For further discussion of mixing in estuaries see Fischer et al. (1979) and Geyer and Signell (1992).

Bathymetric changes have the potential to significantly alter residence time within an estuary by impacting the hydromorphology (Elliott and Whitfield, 2011). The details of the impacts are difficult to estimate analytically for individual estuaries where the complexities of wind, bathymetry, coastline, and stratification quickly make the problem intractable. Numerical circulation models are then a useful tool for estimating residence times (Banas and Hickey, 2005; Brooks et al., 1999; Liu et al., 2008; Oliveira and Baptista, 1997).

Meyers et al. (2013) used a finite difference numerical model of TB and found large-scale construction within the bay altered the subtidal circulation and that these changes displayed significant temporal dependence related to the total freshwater discharge and the resulting horizontal salinity gradient. This paper extends their work and examines the effects of those changes in circulation on residence time using passive Lagrangian tracers.

The morphology of TB includes a major shipping channel from the mouth to the upper reaches of Lower Tampa Bay (LTB) and into Middle Tampa Bay (MTB), where it splits into two branches, one entering Old Tampa Bay (OTB) and the other going into Hillsborough Bay (HB) (Fig. 1). Dredging has increased the main channel maximum depths from 10 m to 15 m (Vincent, 2001). The presence of the channel has permitted large vessel traffic into the shallower regions of the bay where the vessel wakes re-suspend sediment (Schoellhamer, 1996). In addition to the dredging, four major bridges and causeways now span the Bay: the Courtney Campbell Causeway (CCC), the Howard Franklin Bridge (HFB), the Gandy Bridge (GB), and the Sunshine Skyway Bridge (SSB). Changes to morphology of TB are associated with changes in sedimentation (Zhang and Yang, 2006).

A three-dimensional numerical ocean model of TB, described in the following Section, is used to simulate the circulation for years 2001-2003 using present day bathymetry. The trajectories of about 450,000 passive Lagrangian particles are generated using the model velocity field in order to examine characteristics of the flushing. Then, an identical simulation is performed using the bathymetry generated from 1879 depth soundings. The same boundary conditions were used in both model scenarios, so differences between the computed circulations are solely due to the effect of infrastructure. In Section 3 the residence times for both scenarios are calculated during three non-overlapping 90-day time periods representing different relative impacts of the bathymetry on the circulation (Table 1). The simple flushing models are shown to compare well to the 3D model results and be a useful aid in diagnosing the impact of infrastructure in spite of the inhomogeneous particle distributions that occur within a few tidal cycles. Section 4 discusses conclusions from these experiments.

MODEL AND METHODS

The numerical model used here is based on the three-dimensional Estuarine and Coastal Ocean Model (ECOM-3D), a variation of the Princeton Ocean Model (Blumberg and Mellor, 1987) and was originally developed for TB by Vincent (2001) from an earlier model (Galperin, 1991). The model is a sectioned horizontally on a finite-difference curvilinear grid of 2248 cells fit to the coastline, with an average horizontal grid cell size of 668 *m*. There are 10 terrain-following “sigma” layers concentrated near the surface and bottom in order to more accurately represent the boundary layers. Boundary conditions are taken from observations. The open boundary at the mouth is forced using hourly tide gauge (#8726347) data and observed monthly surface, middepth and bottom salinities reported by the Environmental Protection Commission of Hillsborough County. River discharge is from multiple United State Geological Survey (USGS) gauged locations and ungauged location interpolated from nearby gauged sites (Meyers et al., 2007). These are adjusted to compensate for missing freshwater sources, ground water in particular (Vincent, 2001). Surface winds are from NOAA station 8726413 in the central bay and precipitation is an average of USGS rain gauges around the coastline. Model output accurately recreates the elevation, velocity and salinity of the bay; model errors are small compared to observed values (Meyers et al., 2013).

To examine the impact of large-scale construction on residence time, two model simulations are performed using identical boundary conditions. The first utilizes a modern bathymetry ("Present"), representing the contemporary circulation. The second model run is identical to the first except that the bathymetry is based on depth soundings from the pre-construction year 1879 ("PreC") (Fig. 2). This is not an attempt to recreate conditions in 1879, but to investigate the impacts of large-scale infrastructure on present day residence time. The Lagrangian algorithm is described elsewhere (Meyers and Luther, 2008a).

To make the large amount of model output more manageable three distinct time periods are examined, selected to represent times when changes in circulation due to bathymetric changes are small, moderate, and large. The details of the selection process and of the Lagrangian scheme are presented elsewhere (Meyers et al., 2016).

Two measures of particle flushing are used. The first is the total number of particles in the bay, obtained from the spatial summation over the three-dimensional domain

$$N(t) = \sum_{xyz} n(x, y, z, t) \tag{1}$$

The model *N(t)* closely resembles a Continuously Stirred Tank Reactor (CSTR) which has been shown to be a practical concept for some estuaries (Beck and Young, 1975; Bilous et al., 1957), wherein:

$$(t) \sim A \exp(-tB) \tag{2}$$

Fitting (2) to model values of *N(t)* using least squares yields a relatively unambiguous measure of residence time $T_R = B^{-1}$. This is referred to as the "baywide residence time".

The second type of residence time used here is at the model grid scale where particle counts are summed over each water column $N_g\ (x, y, t) = \sum_n (x, y, z, t)$. The value of this function at most locations is dominated by tidal signals and does not resemble any theoretical decay function (Meyers and Luther, 2008b). Therefore an empirical definition is used for the "grid-scale residence time": First, N_g is subjected to a temporal low-pass filter (10-d boxcar) to remove high-frequency signals. Then at each (x, y) position the final time during the calculation that the filtered N_g drops below $N_c = N_g\ (x,\ y,\ 0) \exp(-1)$ is defined as the non-local gridscale residence time $T_R^g(x, y)$. The term non-local is used because (x,y,z,t) is defined without regard to particle origin, as opposed to counting only particles originating within a grid cell. The latter yields much lower values of $T_R^g(x, y)$since particles are quickly dispersed out of the small model grid cells. The Lagrangian-based gridscale residence time is defined in analogy to the Eulerian-based Local Residence Time (Abdelrhman, 2005). The $T_R^g(x, y)$ is similar to the 'influence time' (Delhez et al., 2014) as it allows re-entry of particles originating in each cell as well as particles from other locations.

RESULTS

The total number of particles (t) in the bay decreases monotonically during all three time periods (Fig. 3). The rms of $N_{Pres}\,(t) - N_{PreC}\,(t)$ during P1 is 0.013, the smallest difference of the three time periods. For P2 and P3 the rms differences are 0.023 and 0.10 respectively. This is consistent with the δ values in Table 1, with the smallest difference in mean velocity fields is in P1 and the largest in P3.

The longest baywide residence time T_R is found in P1. This time period also has a small relative change in T_R, from 223 *d* in Present scenario to 217 *d* in the PreC scenario. The baywide residence times in the other two time periods are 193/189 and 38/55 d for the P2 and P3mPresent/PreC scenarios respectively. The total number of particles (t) is not an exact mexponential. The difference between (t) and the best fit exponential functions is largest in the m first week or two after the particle release when the rate of loss is greater than that estimated by a one-dimensional advective-diffusion equation (ADE) (Ebbesmeyer et al., 1975; Ippen, 1966; Takeoka, 1984). The rms difference between the model values and the fit are reduced by factors ranging from 7-70% using a hybrid CSTR-piston equation as opposed to the simple CSTR (Fig. 3). This indicates a net movement of particles towards the mouth is an important component of the dynamics in TB.

Relatively large local changes to $T_R^g(x, y)$ are found during P1 even though this time period has small δ and small changes in T_R. North of the CCC in OTB the region of small residence time is larger in the Present scenario than in the PreC scenario. This change is due to a decrease of T_R^g just north of the gap in the CCC (Fig. 5). The effect of the gap in the causeway on Lagrangian transport is analogous to that of a tidal inlet where there is a Lagrangian asymmetry between the ebb and flood tidal phases. The ebb phase has a jet-like seaward flow that generates larger displacement of particles compared to the flood which produces a broader, weaker flow (Kapolnai et al., 1996; Wheless and Valle-Levinson, 1996). In Present central OTB the T_R^g is 20-40 d smaller than in PreC, possibly resulting from an extension of this jet. This remains for more detailed study. In contrast, the eastern portion of OTB has Present T_R^g as much as 50 d longer than in the PreC scenario, particularly between the CCC and the HFB indicating the bridges are restricting exchange. North of the western sections of both the HFB and GB the Present T_R^g increases by ≤10 d, indicating a weak decrease in flushing due to the bridges.

The western portion of HB (west of the spoil islands) shows Present T_R^g is smaller than PreC by10-50 d. Within MTB and LTB most of the changes in T_R^g are relatively small, except for a few localized regions where Present T_R^g is larger by 20-50 d. These regions correspond to locations where the bathymetry has been deepened (Fig. 2) but not deepened more than other regions that do not show large increases in T_R^g. Therefore these localized increases in T_R^g are likely not locally driven but due to integrated changes in the circulation induced by the infrastructure.

The P2 $T_R^g(x, y)$ across the bay (Fig. 6) varies from a few days to 90 days (the limit of computation). Again there is a large Present-PreC decrease in residence time north of the CCC. The T_R^g north of the CCC has an east-west gradient of 10-50 d for the Present run with shorter times on the southern side of the causeway. In the PreC run the area of longer residence time north of the CCC is larger and continuous with the values south of the current-day causeway position. The relatively fast flushing in this area for PreC is confined to the eastern shoreline. The increase in Present T_R^g also appears in regions adjacent to the north and south sides of the HFB and GB where residence time increases by as much as 50 d.

In HB near and to the west of the dredging spoil islands the Present residence time is nominally 50 d, about 40 d shorter than in PreC. Given that the region of decreased residence time overlays and is west of the dredged shipping channel, this indicates that deepening of the channel has led to increased flushing here, thereby reducing residence time. East of the shipping channel changes to T_R^g are weak except for the small domain near East Bay. This is in contrast to the dynamics in MTB and LTB, where most of the change in T_R^g is ≤ 10 d. The notable exception is north of the SSB where Present T_R^g is 10-30 d higher than PreC.

During P3 the T_R^g has a relatively large and consistent Present-PreC change throughout most of TB (Fig. 7). Typical values of the change are < −20 d including north of the CCC, eastern OTB, western HB and much of central MTB. The T_R^g in LTB is again relatively unaffected by the infrastructure. The large change in MTB has two northern branches roughly following the dredging of the shipping channel. The only strong increases in T_R^g are found in the far northern section of the SSB, and in small pockets on either side of the western HFB and south of the GB.

SUMMARY AND DISCUSSION

Estimating the baywide residence time with the CSTR model (2) reveals the largest change in T_R between the Present and PreC scenarios occurs during P3, when δ is large (Fig. 3). A large δ indicates relatively large change in the subtidal circulation due to the infrastructure, meaning the advection of particles will be altered the most during this time period. Using a hybrid model, which adds a "piston" or "plug" flow to the CSTR, increases the agreement with simulated (t) compared to the CSTR alone. Regions where the channel has been greatly deepened (HB in particular) tend to have lower T_R^g. Linear theory of the gravitationally driven exchange circulation shows the scale of the subtidal exchange currents U_g (representative of both inflow and outflow) is proportional to H, where H is the depth of the estuary. See Geyer and MacCready (2014) for a review.

A change in U_g does not directly relate to a change in residence time as the flow is not laminar and effects of mixing are still important as indicated by a relatively large effective diffusivity from the ADE model during P3 in both Present and PreC scenarios compared to the other time periods.

Generally the differences in T_R^g due to the bathymetric changes vary across the model domain and across the time periods examined. However, some features are relatively stable between time periods. The areas adjacent to bridges are consistently associated with increased residence time, though the spatial extent of these varies between time periods. There appears to be a "shadow effect" where the bridges tend to restrict the movement of particles creating regions of higher T_R^g.

Residence times and flushing rates are useful parameters for estimating estuarine vulnerability to ecological disruption by pollutants. There has been a long-term effort to conserve and restore the environment of TB in order to improve water quality and habitability for both aquatic biota and the surrounding human community (Greening and Janicki, 2006). An important variable chosen as an indicator of estuarine health is existence and distribution of nearshore seagrass. There have been documented improvements in seagrass health in TB over the last 30 years, but the restoration efforts in OTB lags most of the other regions (Tomasko, 2000). This may be due, at least in part, to the changes in residual flow and residence time shown here.

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A WEST FLORIDA COASTAL OCEAN CIRCULATION MODEL

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ABSTRACT

Presented is a West Florida Coastal Ocean Model (WFCOM) that downscales from the deep-ocean, across the continental shelf and into the estuaries, plus four applications to environmental matters of societal concern: 1) harmful algal blooms, 2) transit of Deepwater Horizon hydrocarbons to the West Florida Shelf, 3) gag grouper recruitment and 4) how Deepwater Horizon oil arrived on north Florida beaches. Along with these hindcast simulation applications, WFCOM provides daily, automated nowcasts and forecasts that are publically available at http://ocgweb.marine.usf.edu. The WFCOM design follows from the coastal ocean circulation being driven by a combination of deep-ocean and local forcing and the need for increasing resolution at important regions of mass conveyance. As such, WFCOM simulations provide the offshore conditions that affect water properties within Tampa Bay and other west Florida estuaries, and hence may find use in forecasting when harmful substances may enter one of the west Florida estuaries in the event of a future oil spill. Other applications may include the communication of water properties and materials between the Big Bend Nature and Springs Coasts with the Tampa Bay, Charlotte Harbor and Florida Bay regions. Being that water properties and transport routes are full three dimensional, with near bottom currents being of particular importance throughout the west coast of Florida, WFCOM simulations are germane to anything pertaining to the ecosystems services of the west Florida coastal ocean.

INTRODUCTION

Ecosystems services, when applied to the coastal ocean, pertains to the total economic value derived therefrom, including living marine resources, their commercial and recreational exploitation, tourism and its intrinsic economic value through hotels, restaurants and services and the indigenous populations pursuit of enjoyment through what the aesthetics offered by the coastal ocean and its beaches. Moreover, given that Florida is a peninsula, it may be argued that no aspect of the Florida economy goes untouched by the adjacent ocean. Effective management of Florida's coastal ocean and related ecosystems services necessitates an understanding of how the complex coastal ocean system works. That need is the motivation of our coordinated coastal ocean observing and modeling activities on the West Florida Continental Shelf (WFS).

A Coastal Ocean Monitoring and Prediction System (COMPS) was initiated in 1997, and grew through complementary research efforts, including support from the Integrated Ocean Observing System Office presently housed within NOAA. Our COMPS and related activities coordinate observations with models of the coastal ocean circulation to describe and predict how water properties vary along the WFS and how this bears upon various ecological phenomena, either natural, or human-induced. Observations provide the starting point of scientific investigation, but by virtue of the coastal ocean's vastness, these observations are intrinsically sparse, requiring suitably constructed models to help fill observational gaps. But models, even perfect ones (if such could exist), require observations for initialization, boundary conditions and simply to determine if the model bears any resemblance to nature. Hence coastal ocean observations and models are best done in coordination, which is our adopted approach.

Here we report on a relatively recent numerical circulation model referred to as the West Florida Coastal Ocean Model (WFCOM) that downscales from the deep ocean, across the continental shelf and into the estuaries by nesting the Finite Volume Coastal Ocean

Model (FVCOM; e.g., Chen et al., 2003) into the Global Hybrid Coordinate Model (HYCOM; e.g., Chassignet et al., 2009), with the addition of eight principal tidal constituents. WFCOM was introduced by Zheng and Weisberg (2012), where a calendar year 2007 hindcast was used to demonstrate model simulation veracity gauged against available in situ data. Subsequent applications were made to K. brevis Harmful Algal Blooms (HABs) by Weisberg et al (2014a) and to the subsurface transport of Deepwater Horizon hydrocarbons to the WFS by Weisberg et al. (2015a). The WFCOM domain was then expanded westward beyond the Mississippi River Delta to include actual Mississippi River inflows, versus climatology, and this version was used to explain gag grouper recruitment on the WFS (Weisberg et al., 2014b). These four refereed WFCOM publications provide the model details, quantitative comparison with in situ data for establishing model simulation veracity and methods. Here we will summarize these applications and findings, and provide an introduction to publically available nowcasts and forecasts. One new application (Weisberg et al., 2015b; in review) provides an explanation on how Deepwater Horizon oil was transported to the north Florida beaches.

APPLICATIONS

WFCOM in its present configuration has horizontal resolution varying from that of the HYCOM in the nesting region to 150 m in the Tampa Bay and Charlotte Harbor estuaries. It is three-dimensional and density dependent, with 31 terrain following sigma layers in the vertical, and it also includes flooding and drying of adjacent land. Figure 1 shows the WFCOM domain and an example of the surface velocity field superimposed on surface salinity for June 19, 2010 when Deepwater Horizon surface oil was rapidly moving eastward. Such hindcast simulations are available from 2004 through the present time, and we also run daily, automated nowcasts and 3.5 day forecasts that are publically available at http://ocgweb.marine.usf.edu.

2.1 Circulation control of Karenia brevis HABs on the WFS

The WFS is generally described as being oligotrophic (e.g., Steidinger, 1975; Heil et al., 2001; Vargo et al., 2008; Dixon et al., 2014). Yet, it supports robust commercial and recreational fisheries (NOAA NMFS, 2014), and it experiences inter-annual blooms of the harmful alga, *Karenia brevis* (e.g., Heil et al., 2014). The hypothesis on the sequential development of a *K. brevis* bloom by Walsh et al. (2006) provides a nutrient-driven, primary productivity perspective under oligotrophic conditions, lending itself to the possibility that the development of a *K. brevis* bloom may be shut down by too much nutrient injection. Such appears to have been the case in 1998, a year of anomalous upwelling (Weisberg and He, 2003) when only a nominal *K. brevis* bloom occurred (Walsh et al., 2003). Further evidence is provided by the anomalous upwelling conditions of 2010 when no *K. brevis* bloom was observed, which led Weisberg et al. (2014a) to conclude that the circulation physics and the organism biology each provide necessary conditions for bloom development, with neither alone being a sufficient condition. A comparative study between a robust bloom observed in 2012, versus a nearly null event in 2013 provides further evidence for this conclusion (Weisberg et al., 2016b).

Upwelling is required for an offshore originating *K. brevis* bloom (Steidinger, 1975) to manifest along the shoreline (Weisberg et al., 2009), but too much upwelling may result in the introduction of new inorganic nutrients of deeper ocean origin through upwelling across the shelf break. With new inorganic nutrients, the WFS may no longer be oligotrophic, thereby allowing faster growing diatoms to outcompete slower growing dinoflagellates, as shown in the companion papers by Weisberg et al. (2003) on the circulation and Walsh et al. (2003) on the phytoplankton biology for the anomalous conditions of 1998.

Anomalous upwelling through deep-ocean, shelf interactions occurs when the Gulf of Mexico Loop Current comes in prolonged contact with the shelf slope near the Dry Tortugas. The Dry Tortugas is important for two reasons. First, the dynamics of continental shelf waves are such that these waves propagate with shallow water on right in the northern hemisphere (e.g. Gill, 1982). Second, as the western terminus of the Florida Keys chain all isobaths shallower than 25 m must wrap around the Dry Tortugas. By combining these two attributes, it follows that a surface dynamic height high imposed near the Dry Tortugas will result in a pressure gradient force extending across the entire WFS, with an associated southward directed geostrophic current, as suggested by Hetland et al. (1999). The turning to the left of this southward geostrophic current by friction across the bottom Ekman layer results in an upwelling circulation bringing relatively cold, higher nutrient water toward the coast, as demonstrated by Weisberg et al. (2003).

The above scenario occurred from approximately May 20, 2010 through the end of the year when the Loop Current shed an eddy and retreated southward. This is demonstrated in Figure 2 through a series of biweekly snapshots of sea surface height (observed by satellite altimetry) and associated surface geostrophic currents. An example of the WFCOM simulations of both the near surface and near bottom currents superimposed on temperature for July 15, 2010 is shown in Figure 3, where we see the upwelling circulation and cold water in close proximity to the coast. That the WFCOM simulation bears resemblance to nature is demonstrated in Figures 4 and 5, the first of these showing observed water properties from an across shelf glider transect in July 2010 and the second showing a full year (2010) comparison between observed and modeled velocity vectors from one of the COMPS moorings (C10, situated on the 25 m isobath offshore from Sarasota, FL).

Thus we may explain the absence of a *K. brevis* HAB bloom on the WFS in 2010 by the injection of new, inorganic nutrients of deeper ocean origin, caused by anomalously strong and prolonged upwelling. The anomalous and prolonged upwelling was due to Loop Current interaction with the shelf slope near the Dry Tortugas. With the nutrient conditions of the WFS reset by the coastal ocean circulation, diatoms were favored over dinoflagellates, and no *K. brevis* bloom occurred in 2010.

2.2 The transit of Deepwater Horizon hydrocarbons to the WFS

Subsequent to the Deepwater Horizon oil spill was the emergence of anecdotal information regarding skin lesions and other abnormalities in commercial and recreations fish species. These reports, while primarily from the region where oil was prevalent at the surface, were not limited to that region. Reports from the WFS motivated a purposeful scientific study that found skin lesions in reef fish, along with chemical evidence of hydrocarbon exposure (Murawski et al., 2015). Whereas there were no reports of Deepwater Horizon oil on the surface to the east of Cape San Blas (and hence on the WFS), hydrocarbons of Deepwater Horizon origin may have made their way to the WFS sight unseen beneath the surface. This question was addressed by Weisberg et al. (2015a) using the WFCOM.

Surface oil was quite pronounced offshore of the north Florida coastline throughout most of June 2010. If we hypothesize that some of this oil became entrained in the water column via Langmuir circulation or by other means then it would follow that the persistent and prolonged upwelling circulation described in the previous section would have carried this subsurface oil to the WFS. To test this hypothesis we introduced a passive tracer in the WFCOM on June 19, 2010 where satellite imagery (Hu, personal communication, 2014) showed abundant surface oil. The tracer was positioned uniformly over the water column and its initial concentration was normalized so that we could determine the dilution as the tracer was advected and mixed by the evolving flow field. Figure 6 shows the initialization of the tracer and Figure 7 provides the near bottom concentrations on June 30, 2010 and September 30, 2010. The tracer rapidly covered the entire WFS domain following the upwelling induced flow field and eventually exited the WFS near the Dry Tortugas. Normalized concentration values were within 10% of the initial values along the coastline from Tampa Bay to Charlotte Harbor. By making certain assumptions on how much of the surface oil may have permeated the water column, Weisberg et al. (2014c) suggested that actual concentration levels may have been in the 10s of parts per billion, sufficient to have been detrimental to fish. The simulated tracer pattern also aligns reasonable well with where the Murawski et al. (2014) study found fish with skin lesions (Figure 8).

Whereas direct hydrocarbons in the water column evidence does not exist (no samples were taken), indirect evidence through fish lesions and liver chemistry support the inference that Deepwater Horizon hydrocarbons permeated the WFS sight unseen beneath the surface. This inference is consistent with the known aspects of the coastal ocean circulation from June 2010 when surface oil was off the north Florida beaches and subsequently.

2.3 Gag grouper recruitment

Gag are known to spawn in winter to early spring months near the shelf break, with subsequent juvenile settlement occurring some 30-50 days later along the shore (Fitzhugh et al., 2005). Unknown was the mechanism by which the larvae and juveniles transited the shelf from spawning to settlement. This was the topic addressed by Weisberg et al. (2014b). The starting point was a time series of juvenile settlement sampled in May, 2007 at Mullet Key (the southern end of Pinellas County, FL). Winter and spring 2007 showed very good agreement between our WFCOM simulations and observations of velocity made in situ using a WFS array or moorings. Similar to 2010, the Loop Current was in contact with the shelf slope in the vicinity of the Dry Tortugas, and this drove an upwelling circulation in April and May, 2007. We tested two hypotheses, the first being a surface route of transport, the other being a near bottom route. Particles were input to the model along different isobaths and at different times, and their trajectories were then calculated over 45 day intervals. None of the near surface particles made any progress toward the shore, whereas the near bottom particles did result in shore impacts. Examples of these results are provided in Figure 9 (surface) and Figure 10 (near bottom).

The WFCOM particle trajectory analyses were supplemented by both biochemical evidence and the co-location of juveniles on Mullet Key with macro-algae of deep water (mid-shelf to shelf), hard bottom origin. Three conclusions may be drawn. First, the mechanism for gag larvae and juvenile transport from spawning to settlement is the near bottom (Ekman layer) circulation under upwelling favorable conditions. Second, the preferred settlement locations, Tampa Bay to Charlotte Harbor and Apalachicola Bay and westward are consistent with the upwelling circulation necessary to transport the larvae and juveniles to the shore. Third, and as a corollary to the near bottom transport route, inter-annual variability in gag recruitment success is tied to the requirement that an upwelling circulation must last long enough and be in phase with spawning for there to be a successful recruitment.

2.4. How Deepwater Horizon oil arrived on north Florida beaches.

The northern Gulf of Mexico beaches, particularly from the Mississippi River Delta to the Florida Panhandle, were oiled during the Deepwater Horizon oil spill and most notably in June 2010. We (Weisberg et al., 2016, in review) used four different numerical circulation models to track particles at the surface in an attempt to account for the transport of surface oil from the deep ocean to the beaches. These models were the Gulf of Mexico HYCOM and the Global HYCOM, both run by the Naval Research Laboratory and the WFCOM nested into either the Gulf of Mexico HYCOM or the Global HYCOM. Surface particles were initialized on May 24, 2010 using satellite imagery (C. Hu, personal communication, 2014), and new particles were added at the well site on a three hourly basis through July 15, 2010 to mimic the continual input of oil. Tracking was done using a fourth order Runge-Kutta scheme relying on HYCOM fields when particles were positioned in HYCOM and WFCOM fields when particles were positioned in WFCOM. In addition to these ocean circulation fields, we also added wave effects via Stokes drift derived from the SWAN wave model (Zijlema, 2010).

The initial particle positions, as initialized on May 24, 2010, are shown in Figure 11. Particles were generally in deep water and quite distant from the northern Gulf (Mississippi to Florida) beaches at this time. Within two weeks, however, oil was sullying these beaches. Our results in closest agreement with observations were with the WFCOM nested in the Global HYCOM and including Stokes drift. These results, with and without Stokes drift, are shown in Figure 12. A limitation of the Gulf of Mexico HYCOM during this time interval was the appearance of an eddy that shifted many particles too far to the east and inconsistent with observations. A limitation of the Global HYCOM alone was its limited resolution. By nesting the WFCOM in the Global HYCOM we benefitted from the Global HYCOM deep ocean circulation being constrained through data assimilation and from the high resolution afforded by the WFCOM.

Our findings suggest that the ocean circulation brought the surface oil to the vicinity of the beach, and that the Stokes drift then deposited the oil on the beach. This combination of effects is physically sensible because the circulation tends to be parallel to the isobaths and to the beach upon approaching the shoreline, whereas the Stokes drift may be perpendicular to the beach. From these findings it follows that forecasting the beaching of oil requires: 1) adequate initialization of where the oil may be, 2) an accurate deep ocean model suitably constrained by data assimilation, 3) a high resolution coastal ocean model nested in the deep ocean model and inclusive of the barrier islands and estuaries and 4) a wave model.

SUMMARY AND CONCLUSIONS

We introduced a West Florida Coastal Ocean Model (WFCOM) that nests an unstructured grid finite volume model (FVCOM) into an operational data assimilative deep ocean model (either the Gulf of Mexico or the Global HYCOM). The utility of this approach to modeling the coastal ocean circulation was demonstrated using four hindcast simulation examples: 1) K. brevis HABs on the WFS, 2) Deepwater Horizon hydrocarbon transport in explanation of fish lesions on the WFS, 3) gag grouper recruitment and 4) how Deepwater Horizon oil reached the northern Gulf of Mexico beaches. The first three of these examples further demonstrates the multidisciplinary nature of coastal ocean ecology.

Three general conclusions follow. First, coastal ocean environmental stewardship requires a multidisciplinary approach, including observations coordinated with models. Observations alone are too sparse. Models without observations for initialization, boundary values, forcing functions and veracity testing are not very useful. Second, ecology is the sum of all processes necessary for an organism to make a living. As shown for HABs and fish recruitment, the physics of the circulation are as important as the biology of the organism. Third, adapting our science strategy to accommodate the multidisciplinary nature of coastal ocean ecology will provide improved understandings on complex ecological questions that are necessary for facilitating improved environmental stewardship in this coastal ocean region where society meets the sea.

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THE INFLUENCE OF ANTHROPOGENIC AND PHYSICAL EFFECTS ON FISH, ZOOPLANKTON, AND HYPERBENTHOS COMMUNITY STRUCTURE: A COMPARISON OF WEST-CENTRAL FLORIDA ESTUARIES

Brianna C. Michaud, Ernst B. Peebles and Timothy C. MacDonald

ABSTRACT

We compared fish, zooplankton and hyperbenthos communities with a diversity of habitat metrics from 18 estuarine gradients along the west-central Florida coast to determine which habitat metrics correlate with variation in community composition. The objective of this comparison was to develop a model for predicting community-level responses to changes in one or more habitat metrics. The data used in the comparison originated from surveys conducted over a 25-year period by the Southwest Florida Water Management District and public water utilities. We used distance-based redundancy analysis (dbRDA) of Bray-Curtis similarity to ordinate biological communities at 78 locations (zones) within the 18 estuarine gradients, and used principal components analysis (PCA) to ordinate the habitat metrics at the same locations. The PCA analysis included different types and sources of habitat data: (1) salinity, dissolved oxygen, pH, and water temperature measured at the time of the biological collections, (2) chlorophyll a, color, and turbidity obtained from the EPA STORET database, (3) metrics for freshwater-inflow flashiness, water turnover time, and temporal instability in water turnover time, and (4) metrics related to site-specific vegetation, bottom type, and geomorphology. The primary pattern that was observed across all of the multivariate ordinations was the serial community gradient along the longitudinal axis of the estuary. A secondary trend was evident in light-associated habitat metrics and inflow flashiness, which generally corresponded to habitat differences between surface-fed and spring-fed estuarine systems. Water management that considers both inflow flashiness and nutrient loading relationships with estuarine residence time may be effective in encouraging light environments that support the healthy benthic ecosystems that are needed by both benthos- and plankton-oriented species.

INTRODUCTION

Many estuaries have existed in areas of high human density for decades or even centuries and have become some of the most anthropogenically degraded habitats on earth (Edgar et al. 2000). In US states that border the Gulf of Mexico, it is estimated that over 80% of the fisheries catch is either directly dependent on estuaries or is supported by estuarine production (Day et al. 1989). The high secondary production that is characteristic of estuaries can be diminished by changes to the quality and timing of freshwater inflows (Mann and Lazier 1996, Raposa and Oviatt 2000). Understanding how the broad diversity of habitat characteristics interacts with estuarine community structure is necessary for developing estuarine management and restoration approaches.

Estuarine habitat quality is influenced by highly dynamic and highly complex interactions of hydrology, biology, climate, sedimentation, and water quality. One approach for assessing the combined effects of these interactions is to compare community structure among estuaries with diverse habitat characteristics (e.g., Burghart et al. 2013). Estuarine communities include the juveniles of economically important species as well as species that are not directly important economically, yet support coastal food webs (Peebles, 2005). By comparing biotic communities across estuaries that have received varying degrees of anthropogenic impact, we can use space-for-time substitution to isolate the habitat metrics that are most closely tied to undesirable changes in community structure.

Between 1989 and 2014, the Southwest Florida Water Management District surveyed fish, zooplankton and hyperbenthos communities within 18 estuaries in west-central Florida. The surveyed estuaries were: Crystal River, Homosassa River, Halls River, Chassahowitzka

River, Weeki Wachee River, Mud River, Anclote River, McKay Bay, Palm River, Alafia River, Little Manatee River, Manatee River, Braden River, Cowpen Slough, Myakka River, Myakkahatchee Creek, Peace River, and Shell Creek.

These estuaries span a linear distance of 230 km along the coast and include the transition from sub-tropical mangrove-dominated habitat to the south to temperate salt marsh-dominated habitat to the north. The group of estuaries represents different levels of anthropogenic impact (including the presence and absence of water control structures), different water qualities, and different patterns of freshwater input. Freshwater input into some estuaries is dominated by surface runoff, whereas others are dominated by flows from one or more springs. Crystal River, Homosassa River, Halls River, Chassahowitzka River, Weeki Wachee River, and Mud River are primarily spring-fed, and Anclote River, McKay Bay, Palm River, Alafia River, Little Manatee River, Manatee River, Braden River, Cowpen Slough, Myakka River, Myakkahatchee Creek, Peace River, and Shell Creek are all primarily surface-fed. This paper provides an overview of variation in biotic community structure among these 18 estuaries, and initiates an effort to link community variation to habitat metrics that can be managed in the future.

METHODS

Each of the 18 estuaries was divided into 4-8 zones that extended from the receiving basin (large bays or the Gulf of Mexico) upstream to (1) reaches that were normally fresh or (2) water-control structures that had saline water on their downstream side and fresh water on their upstream side. In all cases, zone 1 represents the mouth of the estuary where it entered its receiving basin, and the highest zone number represents the zone farthest up-estuary. Each zone typically contained two, fixed-location sampling stations where plankton tows were conducted monthly during nighttime flood tides. During daytime hours, two shoreline bag-seine hauls and one otter-trawl deployment were typically made within each zone at randomly-selected sites on a monthly basis and under variable tidal conditions. Salinity, temperature, pH, and dissolved oxygen were measured at the surface and at 1 m intervals to the bottom in association with each gear deployment.

The plankton net had a 0.5 m mouth diameter, 500 µm mesh, a 3:1 conical aspect ratio, a three-point nylon bridle, a calibrated flow meter (General Oceanics model 2030R or SeaGear model MF315), a one-liter plastic cod-end jar, and a 9 kg (20 lb) weight. It was deployed in a stepwise-oblique manner (bottom-midwater-surface) with a total duration of 5 min and a typical filtration of 70-80 m^3. The plankton net targeted invertebrate zooplankton, hyperbenthos, and ichthyoplankton. “Invertebrate zooplankton” refers to organisms that cannot swim against currents and whose distribution is largely influenced by hydraulic conditions. “Hyperbenthos” refers to invertebrates that are usually associated with the bottom but migrate into the water column under certain circumstances, particularly at night. The catch from the plankton-net tows was usually dominated by invertebrate zooplankton and hyperbenthos, but also collected larval fish and fish eggs (ichthyoplankton).

Otter trawls and bag seines targeted larger organisms such as juvenile and small adult fishes. The 21.3 m center bag seine had 3.2 mm mesh and bottom leads spaced every 150 mm. The seine net was typically deployed in water <1.8 m deep across an average swept area of approximately 68 m^2 next to the shoreline. The 6.1 m otter trawl had 38 mm stretched mesh with a 3.2 mm mesh liner and tickler chain. The typical area swept by the otter trawl was approximately 720 m^2 in the channel.

Most estuarine surveys were conducted over a period of two or more years. The data from a twelve-month period was selected for each estuary system with as much overlap between time periods as possible. These data were compared with both static and dynamic habitat metrics to determine which metrics had significant influence on variation in community structure among estuaries. These metrics include depth, slope, bottom type, presence of submerged aquatic vegetation (SAV) or benthic algae, shoreline type, salinity, temperature, dissolved oxygen, pH, freshwater flow, freshwater flashiness (Baker et al., 2004), residence time, chlorophyll, color, turbidity, and presence of a water control structure. The biological catch data were converted into relative abundance and then fourth-root transformed to prevent more abundant species from dominating the analysis. The abundance data were then converted into a Bray Curtis similarity matrix (Bray and Curtis 1957) that identified which river zones were most and least similar in terms of community composition. Continuous variables other than residence time were fourth-root transformed and percentages were arcsine transformed. Residence time was Ln-transformed.

Initial analysis of habitat metrics included creation of a Spearman rank correlation matrix. Among highly correlated metrics (e.g., surface pH, average pH, bottom pH), a single metric was chosen (e.g., average pH) to represent others that were excluded from further analysis (e.g., surface pH, bottom pH).

This was followed by multivariate analyses conducted using PRIMER v7 software (PRIMER-E Ltd. [UK]; Clarke and Gorley 2006). Distance-based redundancy analysis (dbRDA) of the Bray-Curtis similarity matrix was used to ordinate individual zones according to similarity in biotic community structure, and also to identify taxa that best correlate with the biotic ordination axes. Taxa were grouped into larger assemblages using similarity profile analysis (SIMPROF).

A similar multivariate approach was taken for the non-catch habitat metrics, which were normalized and ordinated using principle components analysis (PCA). The two different types of ordination plots (for biotic communities and habitat metrics) and the vector plots associated with them were visually compared to identify common patterns in the data.

RESULTS AND DISCUSSION

Biotic communities:

The biotic catch data for the 50 most abundant taxa for each gear type were examined as seriated heatmaps; an example of these is presented in Figures 1 and 2. In general, freshwater taxa such as mosquitofish (*Gambusia holbrooki* in Figure 1) appear at the upper right of the heatmaps, and coastal marine taxa such as pinfish (*Lagodon rhomboides* in Fig. 1) appear at the lower left. Between these groups are taxa that are common in the middle estuary. This pattern was evident in each of the four analyzed organism groups (invertebrate plankton, ichthyoplankton, seine catch, trawl catch). Distinctions among these three general groups of taxa were somewhat confounded by variable freshwater inflow, which caused the freshwater and middle-estuary groups to move or be advected upstream and downstream as inflow varied.

The first dbRDA axis explained 23-32% of the total variation among the biotic catch data, with the seine (32%) and plankton-net invertebrates (30%) have the strongest relationships with the first axis. The first axis coincided very well with distance upriver (zone) in the same manner as observed in the seriated heat maps. In Figures 3 and 4, this trend is evident as cool-colored symbols predominating to the left of the plot, but transitioning to warm-colored symbols to the right. This axis reflects the fundamental role of freshwater flows in creating a serial community gradient along the longitudinal estuarine axis. This serial gradient was also described by Greenwood et al. (2007) and Guenther and MacDonald (2012), and is consistent with the river continuum concept (Vannote et al. 1980) and its derivative concepts (e.g., the serial discontinuity concept, Ward and Stanford 1995).

The second dbRDA axis explained an additional 13-18% of the total variation in the biotic community composition. The second axis coincided with water source; primarily spring-fed systems such as Chassahowitzka plot low on the y-axis, and primarily surface-fed systems such as Hillsborough plot high on the y-axis. Water source was, in turn, associated with the light environment and first-order trophic state (oligotrophic vs. eutrophic, Burghart et al. 2013). Invertebrate indicators for eutrophic systems (Figure 3) were planktonic organisms (copepods Acartia tonsa and Labidocera aestiva), and indicators for oligotrophic systems were benthically associated organisms (the isopod Cassidinidea ovalis, juvenile Americamysis mysids, and gammaridean amphipods). Among the fish catches, Anchoa mitchilli (Bay Anchovy) was indicative of the surface-fed state, and Lucania parva (Rainwater Killifish) was indicative of the spring-fed state. Among spring-fed estuarine systems, Burghart et al. (2013) described Crystal River as having relatively high turbidity, and found its community composition to be more similar to the surface-fed estuaries in their comparison. Similarly, the surface-fed Anclote River had relatively low turbidity for a surface-fed estuary, and its communities plotted closer to the spring-fed estuarine systems. Plankton-net invertebrates appeared to be particularly sensitive to this water-source effect (18% of community variation explained by dbRDA axis 2).

Non-catch habitat metrics:

The Spearman rank correlation (Figure 5) revealed that many habitat metrics were highly correlated. Some of these were obvious relationships (such as surface salinity being highly correlated with bottom salinity). Other relationships reflected important estuarine processes and were therefore not excluded. One such example is the relationship between turbidity, flashiness, and water control structures. Flashiness is characterized by high variability in freshwater input with periods of sudden high flow being immediately followed by periods of low flow (Baker et al. 2004). This type of hydrographic pattern can be expected to introduce nutrients and particulates (turbidity) during high-inflow periods, and the nutrients will encourage phytoplankton blooms, particularly if there is a low inflow period when residence times are long enough to allow phytoplankton to accumulate. Flashiness was also correlated with the presence of water-control structures, suggesting flows from impounded watersheds are flashier than flows from unimpounded watersheds.

The PCA ordination for the habitat metric data was performed independently of the catch data, yet it depicted the same patterns seen in the dbRDA ordinations (Figure 6). The river zones were similarly ordinated according to both position upstream (zone) and according to the water source (spring-fed or surface-fed). The habitat metric indicators for different regions of the ordination can be seen in the vector plot to the right of the figure. The strongest trend in habitat indicators along the first axis (y-axis) is light-related, which is most likely conjoined with eutrophication, as discussed by Bughart et al. (2013). Zones that plot high on the first axis have elevated color, turbidity, and chlorophyll, each of which can be powerful light-attenuating agents. In contrast, positions that plot low on the first axis have more SAV and attached benthic algae, both of which are indicative of more light reaching the bottom.

CONCLUSIONS

A graphical synthesis of the community analyses is presented in Figure 7, which depicts trends that are generally consistent with all of the multivariate observations in this study. The primary pattern that was observed across all of the multivariate ordinations was the serial community gradient along the longitudinal axis of the estuary. The seriated heat plots and SIMPROF analyses showed three main communities emerging; freshwater, marine coastal, and upper estuary. In all four comparisons (invertebrate plankton, ichthyoplankton, seine catch, trawl catch), seriation of zones by organism abundance resulted in ordination by the relative position of the zones, despite the fact that position (the color-coded symbols at the top of Figures 1 and 2) was merely a passive label in this analysis. In other words, the process of seriation resulted in community gradients that have been observed elsewhere (e.g., Mouny & Dauvin 2002, Thiel et al. 1995, Weinstein et al. 1980, Minello 1999).

Although the geographic area covered by the upper-estuary fauna is usually only a few km in length, this community typically includes economically important species (Red Drum, Common Snook, Tarpon, Sand Seatrout) that use the estuary as nursery habitat. The upper-estuary fauna also includes important prey animals such as anchovies and menhaden that form the foundation of coastal food webs, particularly after they move seaward following their juvenile residence within the interiors of tidal rivers.

Light-associated habitat metrics were strongly associated with habitat differences between surface-fed and spring-fed estuarine systems. Surface-fed systems had higher levels of light-attenuating color, turbidity, and chlorophyll. Spring-fed systems had more benthic algae, seagrasses and other SAV, which indicate sufficient light reached the bottom for extended periods of time. The surface-fed systems had more zooplankton and zooplanktivorous fishes, and the spring-fed systems had more benthically associated invertebrates and fishes. Stable-isotope analyses have previously identified the existence of both benthic and planktonic trophic pathways within local tidal rivers (Hollander and Peebles 2004, Hollander et al. 2005). Studies have also shown that, even within primarily planktonic trophic pathways, fauna often rely on more stable benthic resources when planktonic food is scarce (Vander Zanden and Vadeboncoeur 2002, Rooney et al. 2006). Diet analysis of planktivorous fish (juvenile menhaden and anchovies) has confirmed their dependence on benthically associated food items while these fish are within tidal rivers (Peebles and Flannery 1992). Maintaining a healthy benthic community is thus important even in estuaries that tend to be naturally eutrophic and are dominated by planktonic species.

Water management that considers both flashiness (timing of freshwater delivery to the estuary) and nutrient loading relationships with estuarine residence time may be effective in encouraging light environments that support the healthy benthic ecosystems that are needed by both benthos- and plankton-oriented species. While the trends observed in this study are clear, the biotic catch data and the non-catch habitat metrics have yet to be quantitatively related to each other. In the future, further multivariate analysis will be performed with the goal of creating a numerical model that will predict how a given community will change if one or more of the habitat metrics changes.

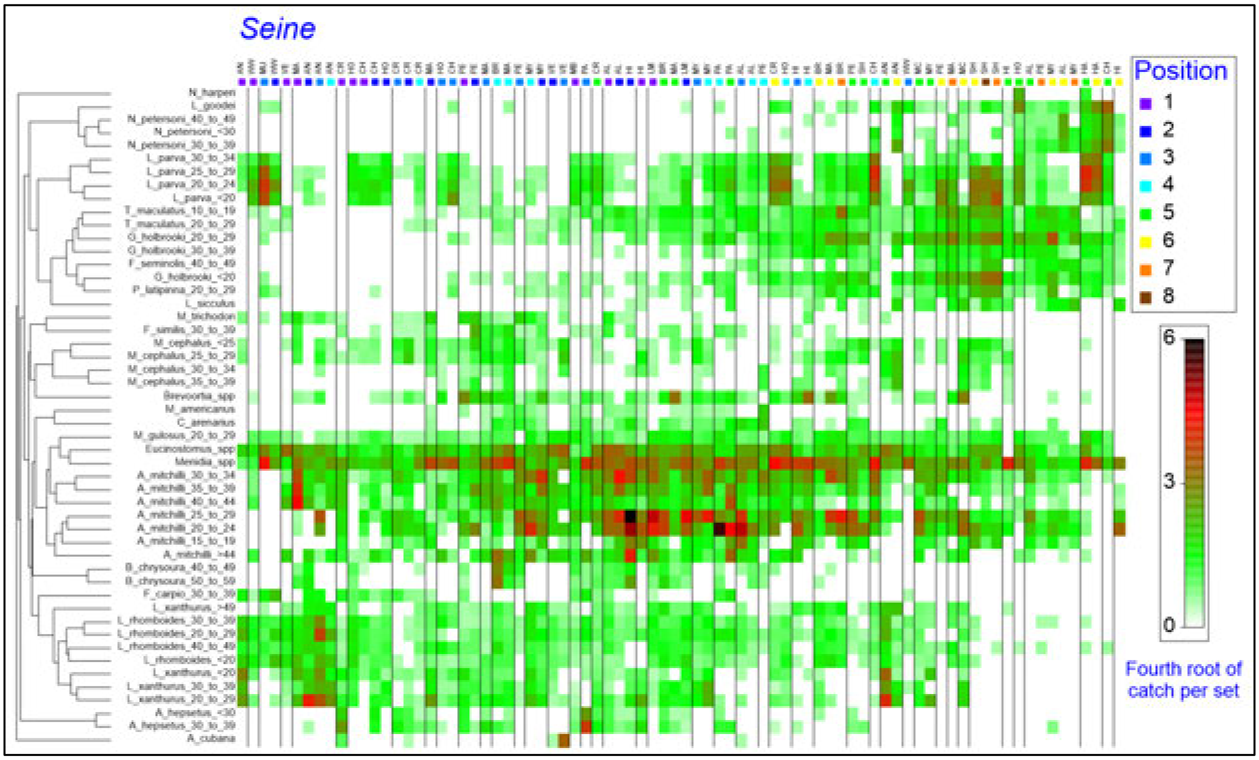

Figure 1. Seriated heatmap for the seine catch; the color scale indicates the fourth root transformation of annual mean abundance. Community associations are indicated by the dendrogram to the left of the y-axis, and seriated river-zone positions are color-coded along the top of the x-axis. The cooler colors along the x-axis indicate zones closer to the mouth of the river and the warmer colors indicate zones farther up-estuary.

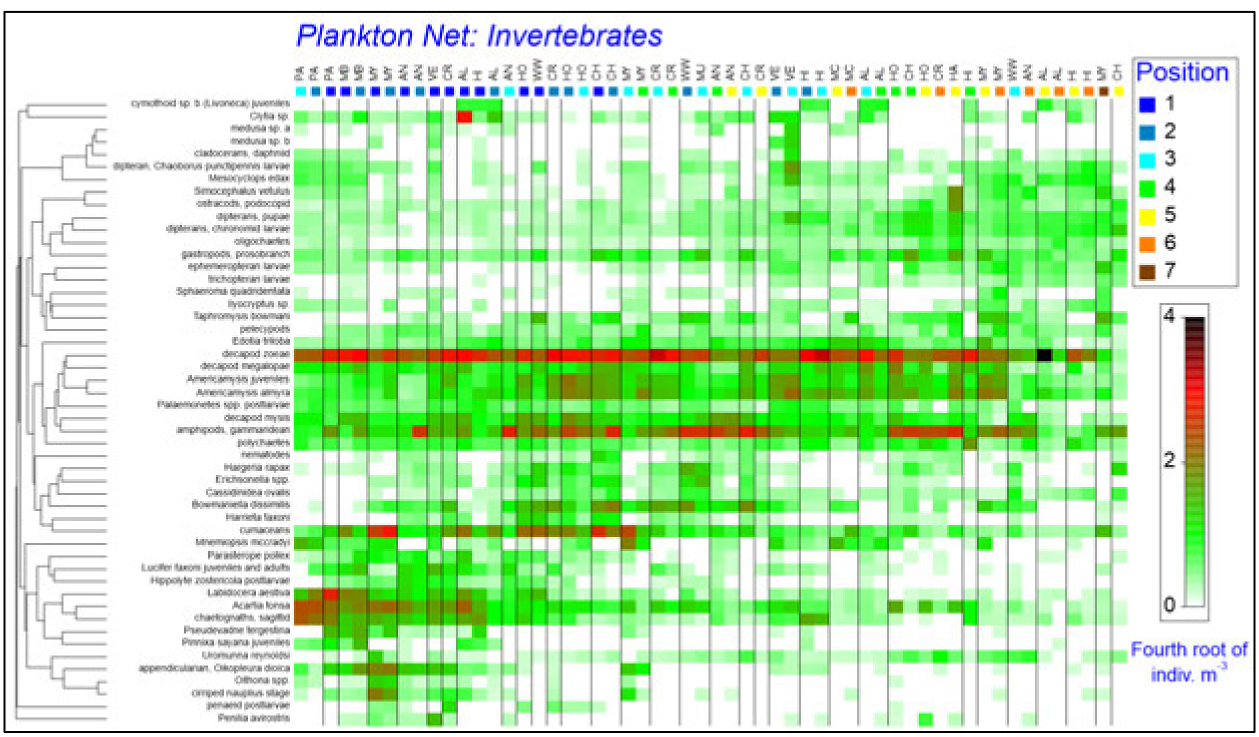

Figure 2. Seriated heatmap for the plankton net invertebrate catch; the color scale indicates the fourth root transformation of annual mean abundance. Community associations are indicated by the dendrogram to the left of the y-axis, and seriated river-zone positions are color-coded along the top of the x-axis. The cooler colors along the x-axis indicate zones closer to the mouth of the river and the warmer colors indicate zones farther up-estuary.

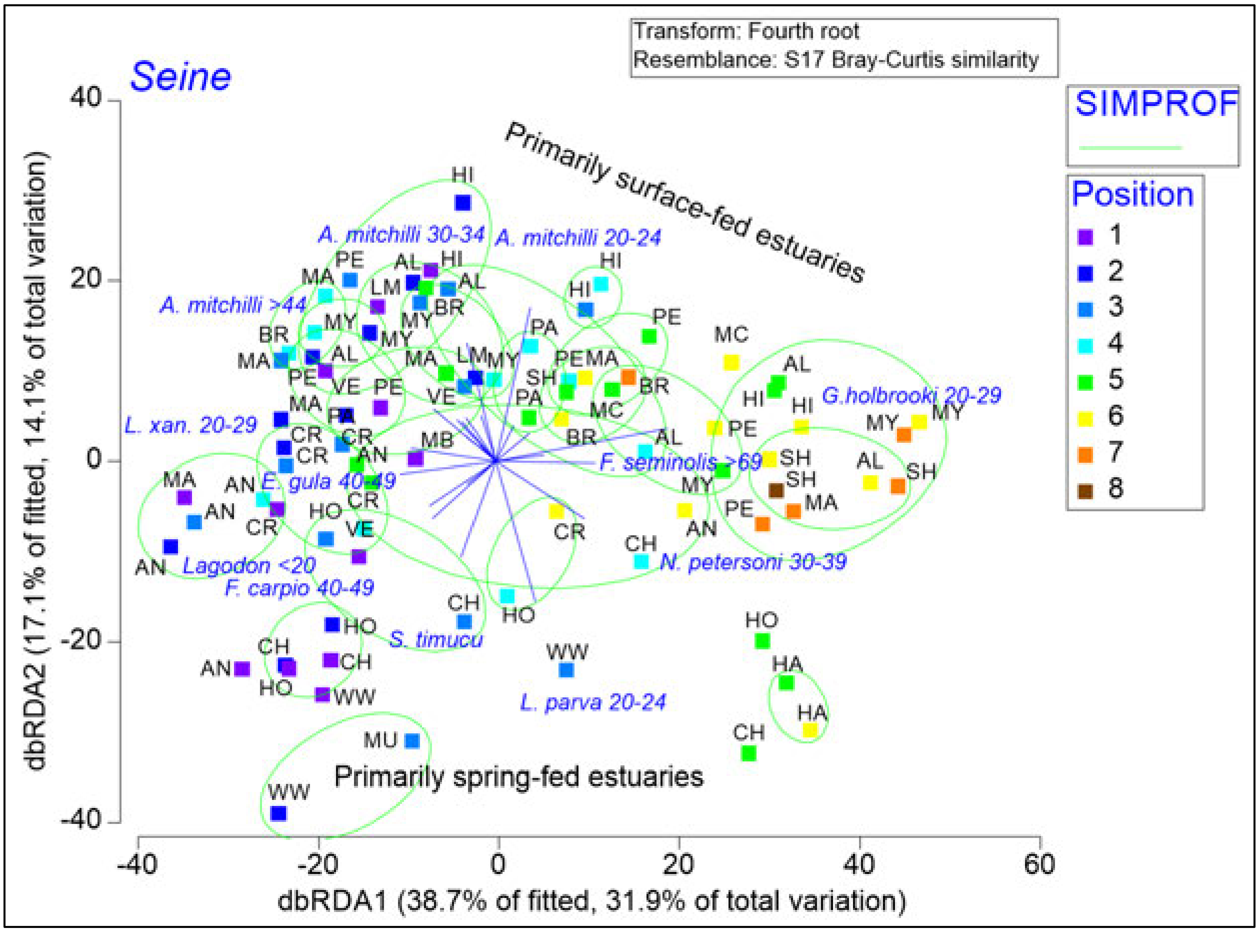

Figure 3. dbRDA analysis of the seine catch. Estuarine positions that plot near each other had annual catches with similar compositions (higher Bray Curtis similarity). Positions within circles are not significantly different (*p* <0.05) according to SIMPROF tests. Relative importance of each indicator taxa is shown by the length of the vectors near the center of the figure.

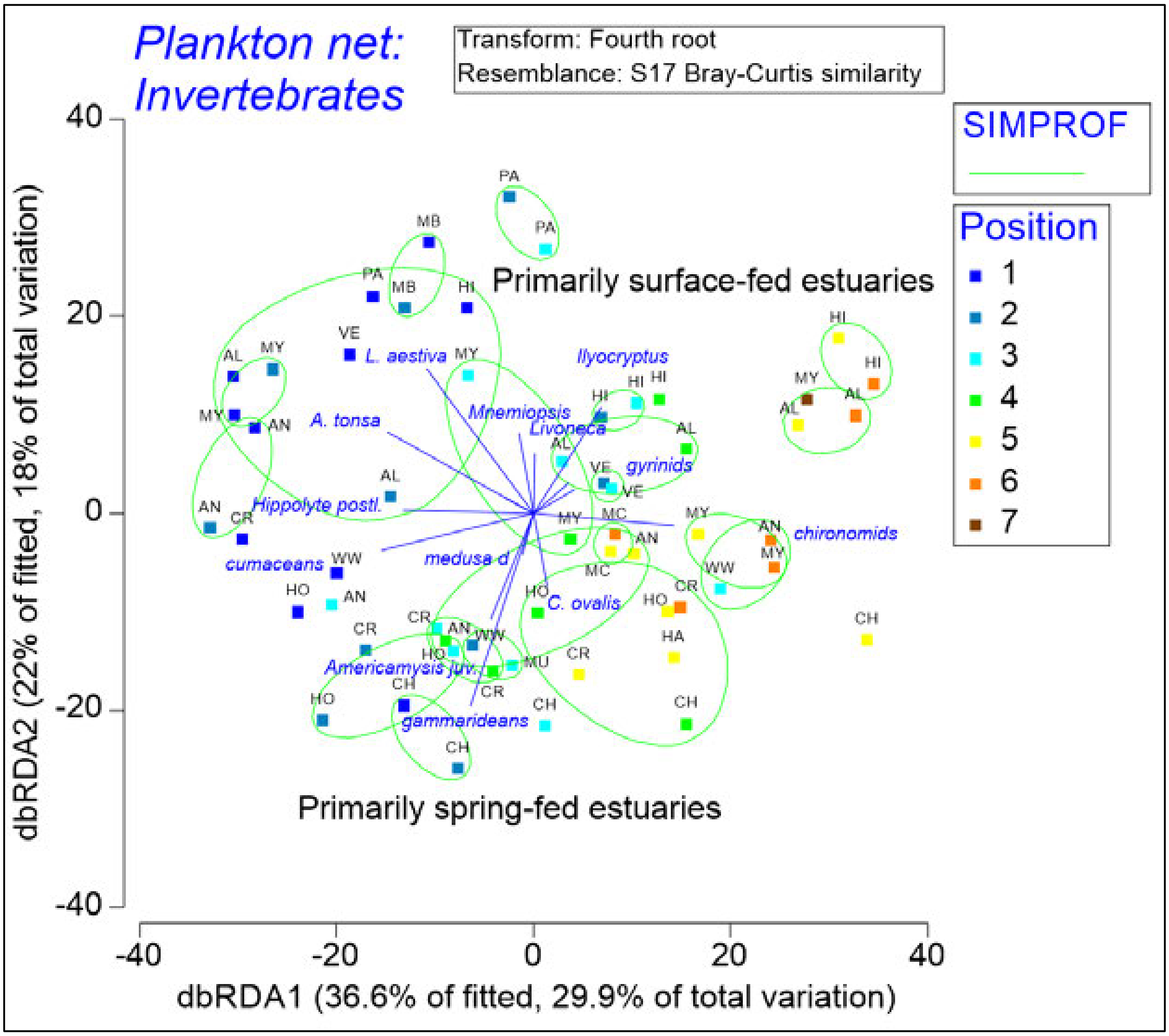

Figure 4. dbRDA analysis of the plankton-net invertebrate catch. Estuarine positions that plot near each other had annual catches with similar compositions (higher Bray Curtis similarity). Positions within circles are not significantly different (p <0.05) according to SIMPROF tests. Relative importance of each indicator taxa is shown by the length of the vectors near the center of the figure.

Figure 5. Correlation matrix used to identify redundant habitat metrics (in red type), where DO is dissolved oxygen.

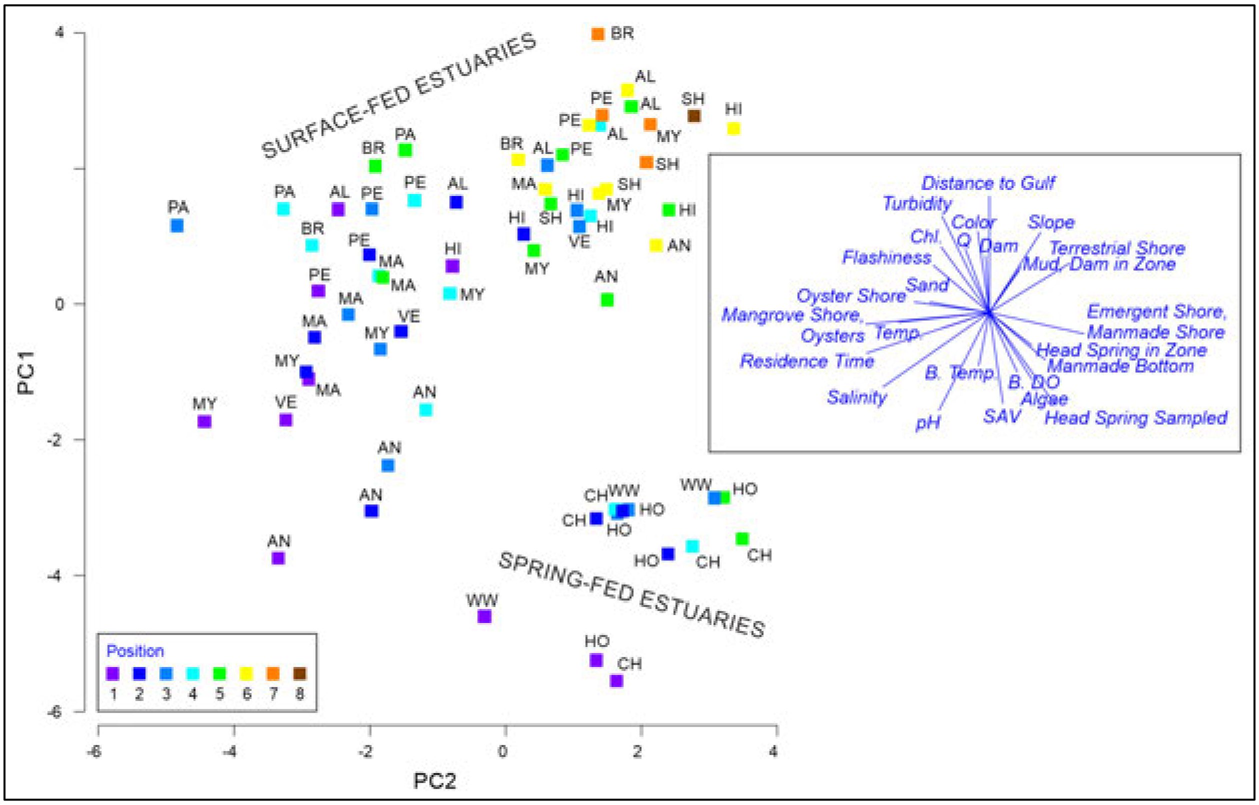

Figure 6. PCA of non-catch habitat metrics. The inset figure depicts the vector plot of habitat metric indicators from the PCA, where Q is average daily freshwater flow, B. DO is bottom dissolved oxygen, B. Temp is bottom water temperature, Temp is average water-column water temperature, and SAV is the presence of submerged aquatic vegetation. This inset figure is simplified and redrawn in Figure 5, where some metrics are renamed to increase clarity.

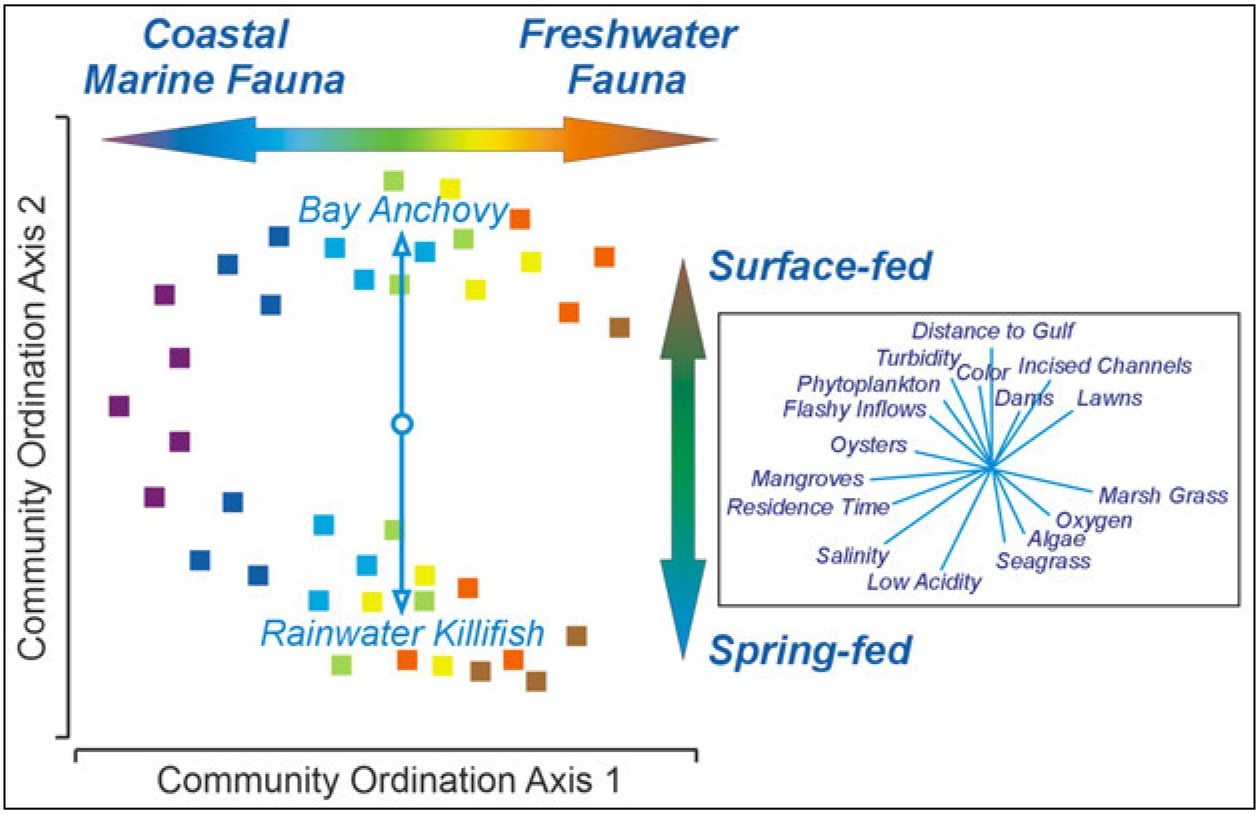

Figure 7. Graphical synthesis of the community-level analyses, with an inset figure depicting habitat metrics that are influential in distinguishing the estuarine positions that were evaluated in the present study.

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COMPARISON OF ISOTOPE-BASED BIOMASS PATHWAYS WITH GROUNDFISH COMMUNITY STRUCTURE IN THE EASTERN GULF OF MEXICO

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ABSTRACT

This study compared traditional community analysis with stable-isotope trophic analysis to define process-based trophic elements of community structure in the eastern Gulf of Mexico, and developed a predictive capability regarding changes to fish community structure that would be expected from increasing eutrophication. Specifically, it used an existing trawl survey program (SEAMAP) to compare invertebrate herbivore (sponge and sea urchin) isotopes with groundfish isotopes, and then compared the resulting spatial patterns with spatial variation in community structure, as identified by cluster analysis. The comparison was applied to seven NMFS survey zones that extended offshore from the Caloosahatchee River, FL northwest to Mobile Bay, AL. Isotopic patterns were consistent with the presence of an oligotrophic-eutrophic spatial gradient in this region. $\delta 15N$ values increased in the northwestward direction in herbivores and in each of the 17 fish species examined. In the southern NMFS survey zones, $\delta 13C$ was elevated in shallow depths for individual fish species, but not in herbivores, indicating a higher proportion of benthically derived biomass contributed to the biomass of fish in the shallow parts of the southern NMFS zones. Fish community analysis using SIMPROF created a similar pattern, with distinct nearshore and offshore communities and also a northwesterly community transition. Among the 17 fish species, five appeared to have obligate dependence on either benthic or planktonic basal resources, while twelve species appeared to have facultative relationships. Impairment of current water-quality (nutrients, turbidity, light transmission, chlorophyll a) is expected to lead to reductions in the abundance of both obligate and facultative benthic-dependent fishes.

INTRODUCTION

Over the last several decades, there have been significant changes to aquatic ecosystems on a global level due to the influences of eutrophication, land-cover changes, and freshwater diversions and impoundments for water supply or hydroelectric power. Many of these changes impact coastal water quality by changing the light environment, in some scenarios by increasing light attenuation within the water column and potentially changing the trophic structure of aquatic communities. Aquatic communities are trophically oriented to the specific types of primary producers that support them (basal resources), with species at lower trophic positions being most strongly linked to planktonic or benthic basal resources and biomass pathways. Small, pelagic consumers tend to rely on plankton-based pathways, benthic consumers tend to rely on benthic pathways, and larger predators tend to exploit both pathways (if both are available) at different times (Vander Zanden and Rasmussen 1999, Vander Zanden and Vadeboncoeur 2002, Rooney et al. 2006, Deines et al. 2015).

Coastal water-quality changes, such as changes associated with anthropogenic eutrophication, can alter the ratio of pelagic-to-demersal species in regional fisheries harvests, with demersal species disappearing from catches in the most eutrophic waters (Caddy 1993). Surface plankton blooms that are associated with eutrophication limit light penetration in the water column, reducing benthic algal production even in shallow environments, as sufficient light may no longer reach the ocean floor. This change in basal-resource dependence is evident in the latter half of the 20th century, as global fisheries yields have shifted distinctly towards phytoplankton-dependent species, although some of these observed changes could be due to improved fishing technologies or market demand

(Caddy and Garibaldi 2000). Continual changes in the distribution of available basal resources over time could lead to species redistribution or the overall decline of species with both obligate and facultative basal-resource dependence (Rooney et al. 2006).

The eastern Gulf of Mexico represents a trophic-state gradient, with eutrophic dead zones forming near the mouth of the Mississippi River to the northwest (Rabalais et al. 1996, Rabalais et al. 2009, Wei et al. 2012), and oligotrophic coral reefs occurring in areas such as the Florida Keys to the southeast. The extent of the hypoxic zone depends on Mississippi River flows, with smaller hypoxic areas (<5,000 km^2) occurring during low flows and larger hypoxic areas (>15,000 km^2) occurring during high flows (Rabalais et al. 2007). It is not known if the trophic-state gradient in the eastern Gulf is stable or changing over time; it could be changing at a decadal scale that would be difficult to detect.

In a recent study by Radabaugh et al. (2013), three widely distributed fish species (*Calamus proridens* [Littlehead Porgy], *Synodus foetens* [Inshore Lizardfish], and *Syacium papillosum* [Dusky Flounder]) were selected to create isotopic maps (isoscapes) for fish muscle on the continental shelf of the eastern Gulf of Mexico. Each of the three selected species demonstrated significant isotopic trends, with $\delta^{15}N$ (indicates nutrient sources and organism trophic positions [Minagawa and Wada 1984, Michener and Schell 1994, O'Reilly et al. 2002]) increasing to the north and west and $\delta^{13}C$ (useful for basal resource detection [France 1995, Vander Zanden and Vadeboncoeur 2002, Radabaugh et al. 2014]) increasing in shallow waters near the Florida peninsula. Radabaugh and Peebles (2014) subsequently observed these trends in four additional species (*Diplectrum formosum* [Sand Perch], *Haemulon aurolineatum* [Tomtate], *Haemulon plumierii* [White Grunt], and *Lagodon rhomboides* [Pinfish]). However, it was not clear if these isotopic trends prevail throughout entire fish communities in the area or if they are limited to the selected species.

The present research combines a community-level trophic analysis with conventional, clustering-based community analysis. The trophic analysis is based on stable-isotope comparisons of invertebrate herbivores and predatory fish at the same spatial scale as a conventional community analysis (Davenport and Bax 2002). The following null hypotheses are investigated in this study: (1) gradients in $\delta^{13}C$ or $\delta^{15}N$ are not evident in the eastern Gulf of Mexico when the entire fish community is considered; (2) fish isoscapes result from spatial patterns in the molecular baseline (DIC and DIN) that are reflected at all trophic levels; (3) all fish species in the study area have equal dependence on planktonic and benthic basal resources; (4) fish species found in the eastern Gulf of Mexico form a single community with no differences when location or depth are considered; and (5) patterns in fish isoscapes and fish community structure, if present, do not agree spatially.

METHODS

The eastern Gulf of Mexico has been divided into ten statistical zones by the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS), with zone 1 in the Florida Keys representing more tropical/reef areas and zone 10 in the Florida Panhandle bordering Alabama in more temperate waters (Figure 1). During July 2009, only zones 4-10 were sampled in accordance with the Southeast Area Monitoring and Assessment Program (SEAMAP) requirements for that sampling year. Data were collected during two separate cruises (July 10-19 and July 22-30) in the eastern Gulf of Mexico along the west Florida shelf from Biloxi, Mississippi to waters offshore of the mouth of the Caloosahatchee River as part of shrimp and groundfish trawl surveys. Both cruises were conducted by the R/V *Tommy Munro*. Fish, sponge, and sea urchin samples were obtained from 12.8 m otter trawl deployments

(4.1 cm stretched mesh) that followed standard SEAMAP protocols (SEDAR27-RD-05). Bottom depths ranged from 8 to 96 m among stations.

For stable-isotope sampling and analysis, the objective was to represent species that were numerically dominant from a survey-wide perspective. Total fish lengths ("fish length" = "total length") for each sample were recorded in centimeters, and a lateral muscle-tissue sample (eyed side in flatfishes) between the dorsal and caudal fins of approximately 5-7 cm in length and 2-4 cm in width was collected from three individuals of the three-to-five most abundant species. Sponge tissue (3-6 cm in length and 4-8 cm in width) and sea urchin samples (stomach and contents) were also collected for each trawl whenever possible. All samples were frozen at sea at -20°C until processing was conducted during August and September 2009.

Fish species with at least 20 samples collected (with the exception of *Diplectrum formosum*, n=19) were selected for isotope analysis (totaling 17 species). Using a circular biopsy tool, muscle tissue was separated from skin, avoiding scales and visible blood vessels, in enough quantity to fill a 3 cm glass vial. Tissue was dried in a 55°C oven for at least 48 hours, homogenized into a fine powder with a mortar and pestle, and then weighed and placed in aluminum capsules in approximately one milligram subsamples for analysis.

All samples were analyzed on an Elemental Analyzer (EA Carlo-Erba NA2500 Series II) coupled to a continuous flow Isotopic Ratio Mass Spectrometer (IRMS ThermoFinnigan Delta+XL) to obtain C:N, $^{13}C/^{12}C$, and $^{15}N/^{14}N$ data. Lower quantification limits for C and N were 12 µg. Calibration standards (NIST 8573 and NIST 8574 L-glutamic acid Standard Reference Materials) were loaded approximately every 25 samples to verify the accuracy of the carbon and nitrogen isotopes. Each sample was run in duplicate to measure the precision of the $^{13}C/^{12}C$, and $^{15}N/^{14}N$ measurements. Any samples that were outside the calibration standards or had a high variance between replicates were re-analyzed. The average of the replicates was used for all analyses except when these quality-control procedures indicated a replicate needed to be removed. In those cases, only a single sample was used. $^{13}C/^{12}C$ is reported relative to the Pee Dee Belemnite (PDB) international standard and $^{15}N/^{14}N$ is reported relative to atmospheric N_2 (Air), such that $\delta A(‰) = [(R_{sample} / R_{standard}) - 1] \times 1000$, where δA is either $\delta^{15}N$ or $\delta^{13}C$ and R_{sample} and $R_{standard}$ are the isotopic ratios ($^{13}C/^{12}C$ or $^{15}N/^{14}N$) of the sample and the standard, respectively.

Total catch data by trawl and species was determined from fish catch data provided by the Florida Fish and Wildlife Conservation Commission (FWC) and organized for further analysis in PRIMER 7 (PRIMER-E, Ivybridge, UK). GIS shapefiles for NMFS zones 1-10 were also provided by FWC, and each trawl was assigned to a zone. Similarity profiles (SIMPROF, Clarke et al. 2008) were created using Bray-Curtis similarity of pairwise trawl-catch abundance (individuals caught per species in a standard trawl time of 30 minutes) that had been fourth-root transformed. SIMPROF groups were mapped geographically using starting latitude and longitude of each trawl deployment. Geographic maps were created for SIMPROF groups and for supersets of SIMPROF groups (similarity at 24%, Clarke et al. 2008).

Trawl fishing depths were binned into five, 20 m zones (zone 1: <20.0 m; zone 2: 20.1-40.0 m; zone 3: 40.1-60.0 m; zone 4: 60.1-80.0 m; and zone 5: 80.1-100.0 m). Statistical data analyses were conducted using Statistica (version 12.6, Dell Software). Analysis of covariance (ANCOVA) was used to compare fish isotopes among NMFS zones and depth zones, and was performed on all fish grouped together and for individual species, with either NMFS zone or depth zone serving as the primary factor and fish length serving as a covariate. For invertebrate herbivores, analysis of variance (ANOVA) was used because all individuals are at trophic position 2.0 regardless of individual size. Isotopic variation with depth was also compared within individual NMFS zones for all fish and herbivores combined, as well as for individual species that occurred in more than one depth zone. All multiple sample comparisons were represented graphically by plots of means with 95% confidence intervals. Bonferroni multiple comparisons were used in a post-hoc analysis to identify significant differences among NMFS zones and depth zones.

RESULTS

Fish community analysis

SIMPROF analysis produced 35 community groups, with multiple community groups occurring within each NMFS zone and few apparent spatial trends. Because the initial SIMPROF analysis produced an excessive number of groups (35), a slice was made in the dendrogram at the 24% similarity level, preserving four SIMPROF groups (*a*, *b*, *c* and *f*) and creating two large SIMPROF supersets *d* and *e*. The slice was made immediately above group *b*, which had the lowest significant similarity level among all SIMPROF groups, thereby avoiding subdivision of any SIMPROF group (Clarke et al. 2008).

The 24% community map revealed differences in community groupings for panhandle versus peninsular trawls and also for shallow versus deep trawl depths within each NMFS zone (Figure 2). All NMFS zones had shallow and deep communities; with a single exception in NMFS zone 4, SIMPROF superset *d* consistently occurred on the outer continental shelf within each NMFS zone, where it was distinguished by relatively high abundances of *Pristipomoides aquilonaris* (Wenchman), *Serranus notospilus* (Saddle Bass), and by depth-related replacement of *Prionotus martis* (Barred Searobin) with *Bellator militaris* (Horned Searobin). SIMPROF superset *e* was the largest community in the 24% slice; it dominated a large area of intermediate depths along the Florida peninsula, and was spatially intergraded with SIMPROF group *f* in waters offshore of the panhandle (Figure 2). Superset *e* was distinguished by the reef-dwelling mesopredators *Calamus arctifrons* (Grass Porgy), *H. plumierii*, *C. proridens*, *Lutjanus synagris* (Lane Snapper), and *H. aurolineatum*.

SIMPROF group *f* included the largest number of trawl samples and consisted mainly of abundant species that occupy unstructured bottom (*Diplectrum formosum, Synodus foetens,* and *Syacium papillosum*) and was primarily located at intermediate depths in NMFS zones 7-10 (Figure 2). SIMPROF group *b* had large catches of the zooplanktivores *Chloroscombrus chrysurus* (Atlantic Bumper), *Decapterus punctatus* (Round Scad), and *Sardinella aurita* (Spanish Sardine), and was primarily located in shallow waters of the panhandle (NMFS zones 7-10), but also occurred once within NMFS zones 5 and 6. Group *a* consisted of a single trawl sample that was compositionally similar to group *b*, except for its relatively large catch of *Arius felis* (Hardhead Catfish). Group *c* consisted of two trawl samples from the western panhandle that contained various benthic species that are characteristic of intermediate depths (Figure 2).

Analysis of $\delta^{13}C$

In order to determine which fish species had significant differences among NMFS or depth zones, one-way ANCOVA was used, resulting in significant differences among NMFS and depth zones ($F = 12.1$ and 56.0, respectively, $p < 0.0001$). While fish were sampled in multiple NMFS zones, they may have only been collected from two depth zones. In almost all comparisons, there was a statistically significant difference in $\delta^{13}C$ among NMFS zones, with the exception of two species (*O. chrysoptera* [Pigfish] and *Saurida normani* [Shortjaw Lizardfish]). For all fish species combined, NMFS zones 8 and 9 were significantly lower than 5 and 7 (Bonferroni multiple range test, $p < 0.05$, Figure 3a). There were also significant differences in $\delta^{13}C$ by depth zone, with $\delta^{13}C$ becoming more negative with increasing depth zone when all fish species were combined (Figure 3b). Depth zones 4 and 5 had significantly lower $\delta^{13}C$ values than depth zones 1 and 2 (Bonferroni multiple range test, $p < 0.05$) for all fish combined.

After looking at fish species independently by NMFS zone and by depth zone, ANCOVAs were also used to look for potential $\delta^{13}C$ differences within NMFS zones using depth as a categorical variable. Using data from all fish species combined, analyses were conducted comparing $\delta^{13}C$ over depth zones for each NMFS zone (Figures 5-6). There were differences among depth zones for each of the NMFS zones with the exception of zones 9 and 10 ($p > 0.05$, Figure 5). This comparison indicated that in NMFS zones 4-8, depth zones 5 and 4 had lower $\delta^{13}C$ values and zones 1 and 2 had higher $\delta^{13}C$ values (Bonferroni multiple range test, $p < 0.05$).

For herbivores, in order to determine if there were significant differences among NMFS or depth zones, one-way ANOVA was used, resulting in significant differences among NMFS zones ($F = 6.15$, $p < 0.0001$) but not depth zones ($p > 0.05$). In general, $\delta^{13}C$ values became more negative when moving from NMFS zone 4 to 8 for all herbivores combined (Figure 4a).

As with fish, after looking at herbivore species independently by NMFS zone and by depth zone, ANOVAs were conducted to look for potential differences within NMFS zones using depth as a categorical variable. NMFS zones 9 and 10 did not have enough data for analysis, and the only two NMFS zones that had significant differences between $\delta^{13}C$ and depth were zones 6 and 8 ($F = 2.66$ and 13.6, respectively, $p < 0.05$). However, in NMFS zone 8, depth zones 2 and 5 had higher $\delta^{13}C$ values than depth zone 1, which could be a result of small sample size ($n = 11$).

Analysis of $\delta^{15}N$

As with $\delta^{13}C$, one-way ANCOVAs were used to determine which fish species had significant differences among NMFS or depth zones for $\delta^{15}N$. There were significant differences among NMFS zones ($F = 198$, $p < 0.0001$) but not depth zones ($p > 0.05$) for all fish species combined. All fish species combined and all individual fish species indicated significant differences among NMFS zones, with $\delta^{15}N$ increasing in the northwestward direction from zone 4 to zone 10. However, only three individual fish species (*Diplectrum formosum*, *E. lanceolatus* [Jackknife-fish], and *H. aurolineatum*) had significant differences in $\delta^{15}N$ by depth zones. For all fish species combined, NMFS zone 10 had significantly higher $\delta^{15}N$ than all other zones. While most species followed the pattern of increasing $\delta^{15}N$ from NMFS zone 4 to zone 10, there may have been a slightly different order of NMFS zones based on means for some species.

After looking at fish species independently by NMFS zone and by depth zone, ANCOVA was conducted to look for potential $\delta^{15}N$ differences within NMFS zones using depth as a categorical variable. There were no significant differences in $\delta^{15}N$ among depth zones by NMFS zone, with the exception of NMFS zone 10 ($F = 2.63$, $p = 0.04$). However, when using Bonferroni multiple range test to determine which depth zones were significantly different, there were no differences among depths ($p > 0.05$).

For herbivores one-way ANOVAs were used to look for significant differences among NMFS or depth zones, which resulted in significant differences among NMFS zones ($F = 9.99$, $p < 0.0001$) but not depth zones ($p > 0.05$). Herbivores indicated the general pattern in $\delta^{15}N$ as fish with values increasing when moving to the northwest from NMFS zones 4 to 9 (Figure 8a). All herbivores had the highest $\delta^{15}N$ in zone 9 (Bonferroni multiple range test).

As with fish, after looking at herbivore species independently by NMFS zone and by depth zone, ANOVA was conducted to look for potential differences within NMFS zones using depth as a categorical variable. There were no significant differences in $\delta^{15}N$ among depth zones for all the NMFS zones combined and all but NMFS zone 6 for the individual zone analysis ($p > 0.05$). Using Bonferroni multiple range tests ($p < 0.05$), there were significant differences between depth zone 5 and zones 1-2 with depth zone 5 having higher $\delta^{15}N$ values within NMFS zone 6.

DISCUSSION

Spatial Patterns in invertebrate herbivores and fish

Herbivores had a decrease in $\delta^{13}C$ towards the northwest, as values became more negative with increasing NMFS zone; this agrees with a greater contribution of phytoplankton (perhaps as phytodetritus) to herbivore diets in the northwest direction, and also agrees with the pattern observed by Radabaugh et al. (2013). Average $\delta^{13}C$ values for all herbivores decreased from approximately -18‰ to -20‰ between NMFS zones 4 and 8. However, there were no consistent trends with depth. Based on the location of most of the trawl deployments, with very few occurring within 10 km from shore, it is doubtful that terrestrial carbon influenced the $\delta^{13}C$ values for most of the samples, as Thayer et al. (1983) found that terrestrial carbon only traveled about 30 km offshore. Other causes, such as a shift in $\delta^{13}C$ values of primary producers or a change in basal-resource dependence, are more likely explanations for the gradient in $\delta^{13}C$ observed between NMFS zones 4 and 8. The shallower depth zones (1 and 2) that had potentially higher light penetration tended to have higher $\delta^{13}C$ values for invertebrate herbivores. Radabaugh et al. (2014) concluded that light limitation may be a causative factor in the offset between $\delta^{13}C$ in benthic algae and phytoplankton, with higher light increasing photosynthetic fractionation and reducing $\delta^{13}C$ in phytoplankton. Radabaugh and Peebles (2014) also found that light-related variables were most explanatory in their modeled isoscapes for $\delta^{13}C$ in the SEAMAP survey area.

With data for all fish species combined, there was a general decrease in $\delta^{13}C$ with increasing depth, agreeing with the pattern observed in three species by Radabaugh et al. (2013). Shallow waters tended to have higher $\delta^{13}C$ than the deeper, offshore waters. Additionally, the present study considered depth-related changes in $\delta^{13}C$ within NMFS zones. Fish $\delta^{13}C$ values decreased with increasing depth in most NMFS zones, except in those farthest north and west (NMFS zones 9 and 10). This pattern is consistent with increased dependence on isotopically heavy benthic pathways in the southeastern direction. However, this pattern was not observed in herbivores, indicating a higher proportion of benthically derived biomass contributed to the biomass of predatory fish in these areas. This suggests that the general variation in $\delta^{13}C$ among fish was caused by variation in the relative contributions of planktonic and benthic basal resources, which have inherently different $\delta^{13}C$ values (France 1995, Vander Zanden and Vadeboncoeur 2002, Radabaugh et al. 2014) and not by variable isotopic baselines. Specifically, there appeared to be greater dependence on benthic basal resources in the shallow, clear waters of the southeastern NMFS zones.

In contrast, the spatial gradients in δ^{15}N were universally observed, occurring in invertebrate herbivores as well as fish; in fish this gradient agreed with isoscapes from the three species in the Radabaugh et al. (2013) study. In the present study, the increasing trend in δ^{15}N to the northwest (from NMFS zone 4 to 10) was observed in all 17 species analyzed, including the three considered by Radabaugh et al. (2013). Invertebrate herbivores (a group that mainly consisted of the urchin *Lytechinus variegatus* and sponges) had a similar pattern, with δ^{15}N increasing from approximately 4‰ in the southeast (NMFS zone 4) to 9‰ in the northwest (NMFS zone 9). Because the same pattern was observed in both herbivores and fish, it can be concluded that baseline sources of nitrogen change from the southeast to the northwest. Radabaugh et al. (2013) suggested this δ^{15}N gradient is caused by the mixture of heavy DIN from river inputs to the northwest with light DIN from the oligotrophic southeast, where nitrogen fixation is more prevalent (i.e., the gradient is not caused by variation in trophic level).

Various anthropogenic sources of nitrogen, usually in the form of sewage, livestock manure, and agricultural fertilizer runoff, collectively create a mass-balanced δ^{15}N signature for the DIN in river inputs into coastal and marine waters; this mass-balanced δ^{15}N signature may also be modified by processes such as denitrification (Hansson et al. 1997). On the other hand, nitrogen fixation by *Trichodesmium* spp. can add new, atmosphere-based light nitrogen to oligotrophic waters (Capone et al. 1997). Besides adding new nitrogen to oligotrophic waters, *Trichodesmium* spp. may also contribute its organic carbon to small zooplankton grazers in the Gulf of Mexico (Holl et al. 2007). In a meta-analysis of published data, McMahon et al. (2013) constructed a zooplankton isoscape that depicted low δ^{15}N in the mid-gyre region of the North Atlantic (the Sargasso Sea) and in other low-latitude areas that did not receive fixed nitrogen from terrestrial runoff or upwelling. It is expected that differences in DIN baseline propagate to higher trophic levels (e.g., Macko et al. 1984, McMahon et al. 2013, Radabaugh et al. 2013). Differences in δ^{15}N from south Florida to the northwest Gulf were also observed by Macko et al. (1984) in all sample types analyzed (particulate organic matter [POM], zooplankton, sediment, and shrimp).

Agreement between community structure and biomass pathways

The 24% similarity geographic map (Figure 2) identified the distributions of six fish community groups. Of the five species that dominated SIMPROF group *b*, two were used in isotopic analysis (*Decapterus punctatus* and *Lagodon rhoimboides*). *D. punctatus* had significant differences in δ^{13}C among NMFS zones, with NMFS zone 7 having the lowest δ^{13}C values (-18.5‰), but this species had no significant differences among depth zones, which is expected for a species with relatively low dependence on benthic trophic pathways. *L. rhomboides* had significant differences in δ^{13}C among both NMFS and depth zones, but was also abundant in group *d*, which occupied shallow areas of the southeastern region, where dependence on benthic basal resources was commonly observed. In support of this observation, the more southerly specimens (NMFS zones 4-6) had higher δ^{13}C values indicative of benthic basal resources. Catches of *L. rhomboides* from deeper waters (this species also was common in group *d*, the deep-water community) indicated dependence on planktonic basal resources (Figures 9 and 10). This species thus appears facultative in its basal-resource dependence, although it had considerable dependence on benthic basal resources on average (Figure 11).

The largest community (group *e*) was well-represented in the δ^{13}C and δ^{15}N analysis, but the deep-water community (group *d*) was not well-represented because its strongest indicator species were usually not in the top five most abundant species per trawl (note that the maximum number analyzed per trawl was 20 individuals). Group *d* was present in every NMFS zone and primarily consisted of zoobenthos and nekton consumers (one exception being *Trachurus lathami*, a zooplanktivore). Fish $\delta^{13}C$ was consistently high in depth zones 4 and 5 (>60 m), which is consistent with dependence on planktonic basal resources in deep water where benthic algal growth would be expected to be inhibited; this matches the observed depth-related community transition. More specifically, one species from the deep-water group, *Stenotomus caprinus* (Longspine Porgy), had no significant differences in its relatively low $\delta^{13}C$ values (Figure 11) among NMFS zones 8-10, which is consistent with group dependence on planktonic basal resources. While not significant, this species also had an increase in $\delta^{15}N$ in the westward direction.

The effort to identify species-specific basal-resource dependence is presented in Figure 11, where fish species are ranked by $\delta^{13}C$. Benthic algae are generally enriched in $\delta^{13}C$ by ~5‰ relative to planktonic algae, with mean values near -17 and -22‰, respectively, for coastal marine locations around the world (France 1995). In comparison, mean $\delta^{13}C$ values estimated for the SEAMAP survey area are near -19.3‰ for benthic algae and -23.4‰ for phytoplankton (as particulate organic matter, Radabaugh and Peebles 2014). Assuming a trophic position of 4.0 for the fish and adding a 3.9‰ allowance for trophic fractionation (using $\delta^{13}C$ fractionation of 1.3‰ per trophic step from McCutchan et al. 2003) adjusts the mean values to -15.4 and -19.5‰ (this is an approximation; determining the actual trophic positions and trophic fractionations for the collected fish was not attempted). The midpoint of -17.5‰ between benthic algae and phytoplankton presented by Radabaugh and Peebles (2014) is indicated as a horizontal red line in Figure 11. Fish with $\delta^{13}C$ values that plot above the red line are likely to have a basal-resource bias towards benthic algae, and those with $\delta^{13}C$ values that plot below the red line are likely to have a basal-resource bias towards phytoplankton. Figure 11 suggests that most of the fish in the study has some degree of dependence on benthic algae. The seven species at the left in Figure 11 (benthic-algal dependents) are brightly marked, reef-associated fish that were most abundant within SIMPROF superset *e*, which predominated in the eastern and southeastern part of the survey area (Figure 2). None of the eight species are primarily zooplanktivorous during the life stages collected by the SEAMAP trawls. The only obligate zooplanktivore in Figure 11 is *Decapterus punctatus*. *Rhomboplites aurorubens* (Vermilion Snapper) apparently also has a large amount of zooplankton in its diet, particularly during the juvenile stages collected by the SEAMAP trawls. However, many of the fish in Figure 11 may have been facultative in their dependence on benthic basal resources. The species at the left of Figure 11 would be expected to be impacted most by eutrophication or any other change to water clarity.

Implications for the fish community

In previous research on semi-enclosed seas, eutrophication has been increasing over the last several decades, in turn creating larger and more numerous hypoxic areas (Diaz and Rosenberg 1995, Diaz and Rosenberg 2008). If nutrient loading to coastal environments continues to increase, then the severity of eutrophication and the spread of hypoxic areas would also be expected to increase (Rabalais et al. 2009). In addition to the spatial expansion of hypoxic zones, the increasing duration that hypoxia, which usually occurs during warmer months, can decimate the benthic fauna (Diaz and Rosenberg 2008). In the eastern Gulf of Mexico, if eutrophication or other light-reducing processes expand east and south, then the species toward the left of Figure 11 (*C. proridens*, *Lutjanus synagris*, and *H. plumierii*) appear most likely to be impacted. A similar outcome could result from increased direct nitrogen discharges to coastal waters along the Florida peninsula, as fish communities in this area appear to be particularly dependent on water clarity's effect on benthic primary production.

Shifts in relative basal-resource productivities (benthic to planktonic) will not only affect species with obligate dependence on benthic pathways, but will also affect facultative species that periodically depend on benthic pathways during times when planktonic pathways are unproductive (Rooney et al. 2006, Burghart et al. 2013). Using existing and future SEAMAP trawl surveys, abundance and spatial distribution data for these species could be compared over time to investigate whether basal-resource changes are occurring in the eastern Gulf of Mexico. Fisheries landings in Florida waters could be used to determine whether a change in the pelagic-to-demersal ratio (P/D) is occurring. Changes in P/D are not only directly indicative of fish community change, but higher caches of pelagic species would also indicate a shift from oligotrophic to eutrophic conditions (Caddy 2000, Hondorp et al. 2010). Landings data could be coupled with water clarity data to get an overall picture of the link between fish community change and water quality.

FIGURES

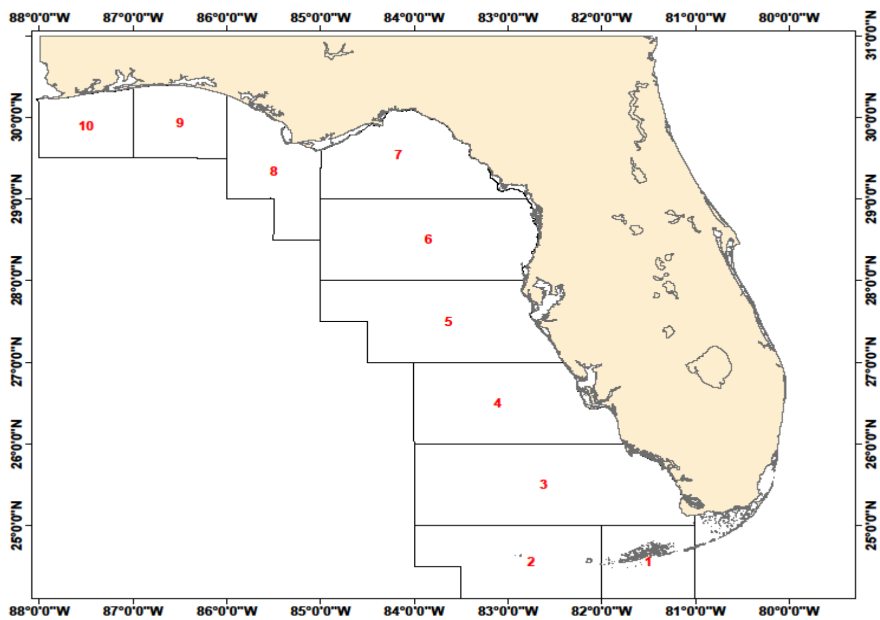

Figure 1. Map of the ten aggregated statistical zones as determined by the NOAA National Marine Fisheries Service (NMFS). Only zones 4-10 were sampled during the July 2009 cruises reported here.

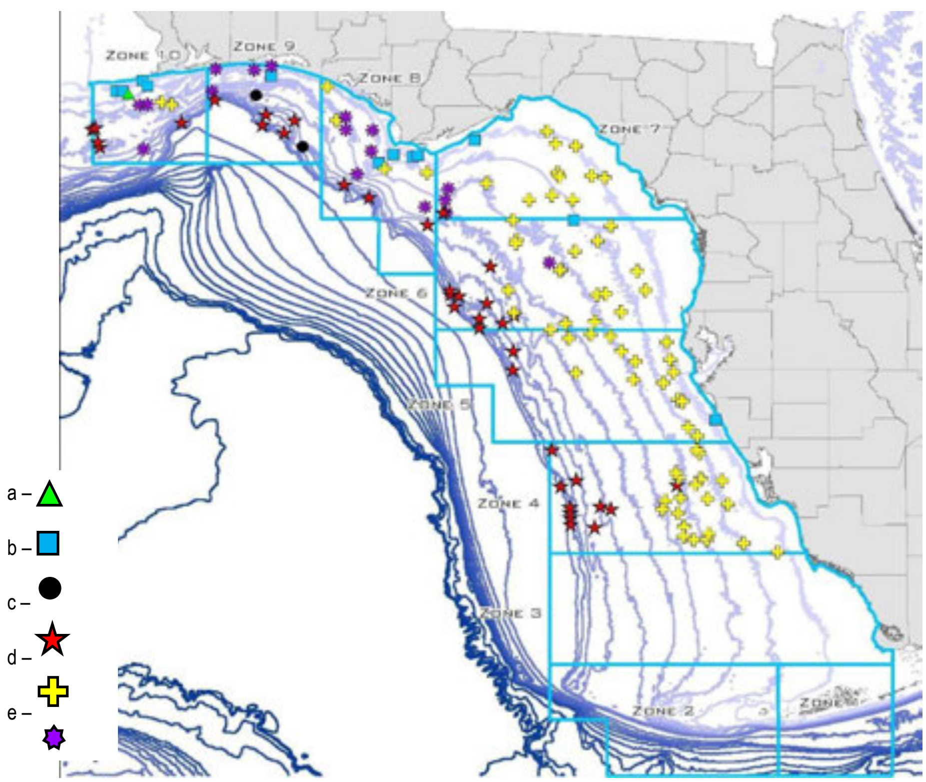

Figure 2. Map of trawl-based communities (SIMPROF groups *a, b, c, f* and supersets *d* and *e*) identified by 24% similarity. Isobaths are in increasing increments (10 m increments inshore to 100 m, 100 m increments to 1000 m, and finally by 500 m increments) and NMFS zones are indicated by polygons.

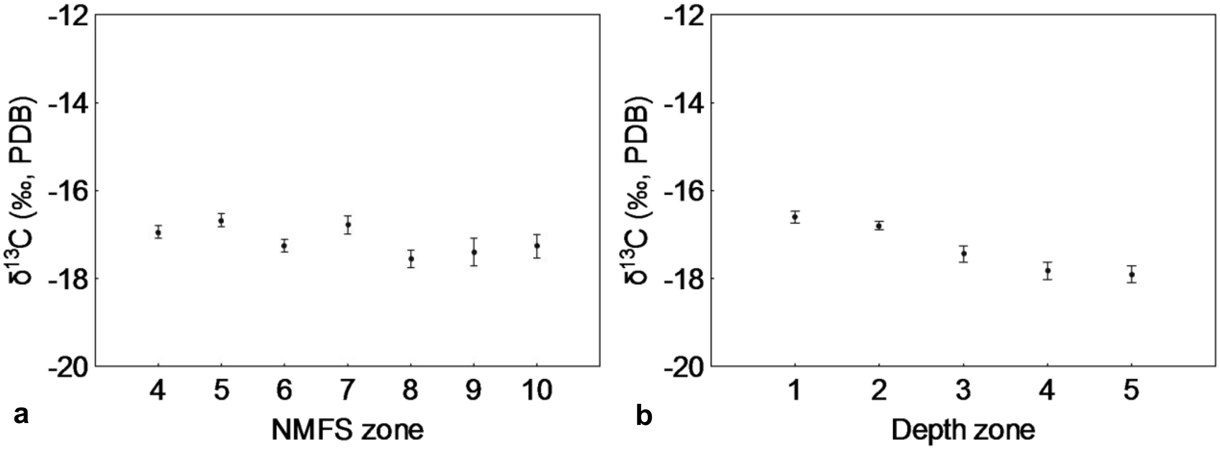

Figure 3. Multiple comparison plot for δ^{13}C and NMFS zone (a) or depth zone (b) for all fish species combined. Central marker represents the mean and bars are 95% confidence intervals.

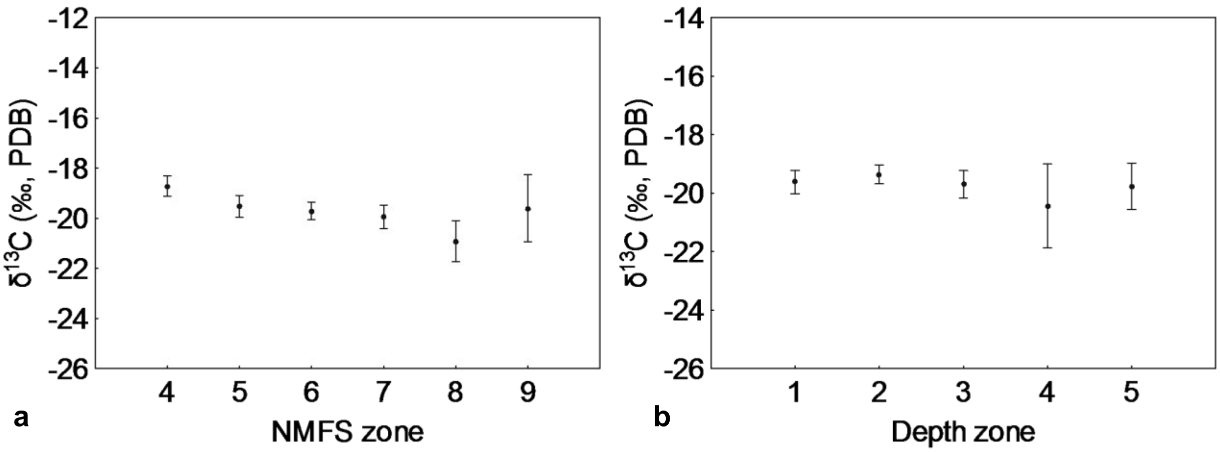

Figure 4. Multiple comparison plot for δ^{13}C and NMFS zones (a) or depth zones (b) for all herbivores combined. Central marker represents the mean and bars are 95% confidence intervals.

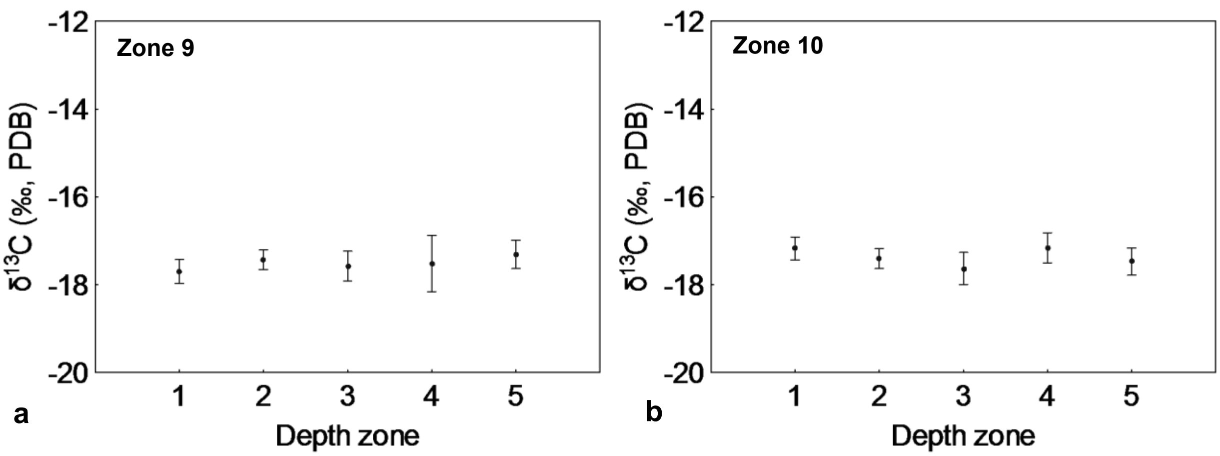

Figure 5. Multiple comparison plot for δ^{13}C and depth zone for all fish combined in NMFS zone 9 (a) and NMFS zone 10 (b). Central marker represents the mean and bars are 95% confidence intervals.

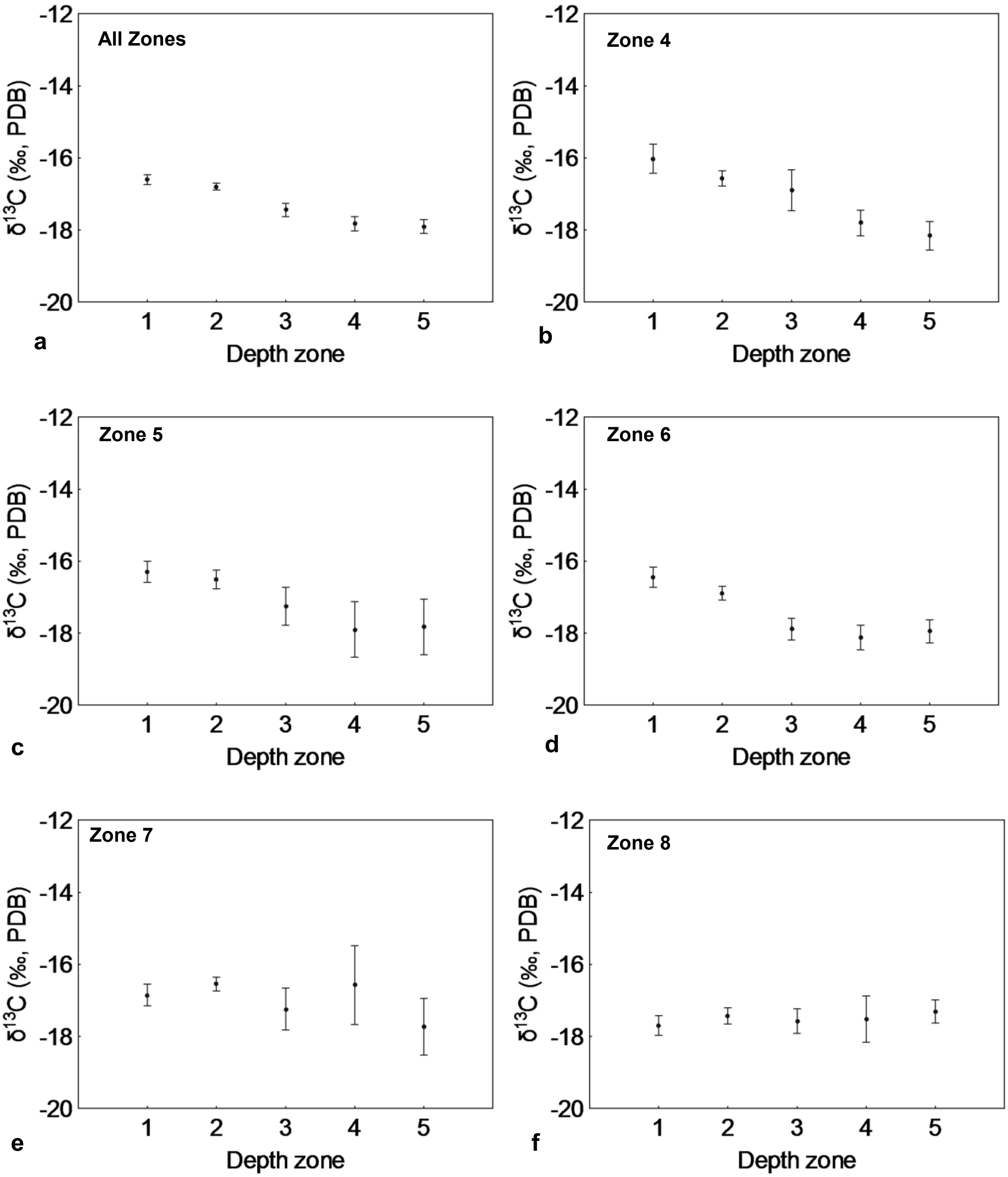

Figure 6. Multiple comparison plot for $\delta^{13}C$ and depth zone for all fish combined across all NMFS zones (a), NMFS zone 4 (b), NMFS zone 5 (c), NMFS zone 6 (d), NMFS zone 7(e), and NMFS zone 8 (f). Central marker represents the mean and bars are 95% confidence intervals.

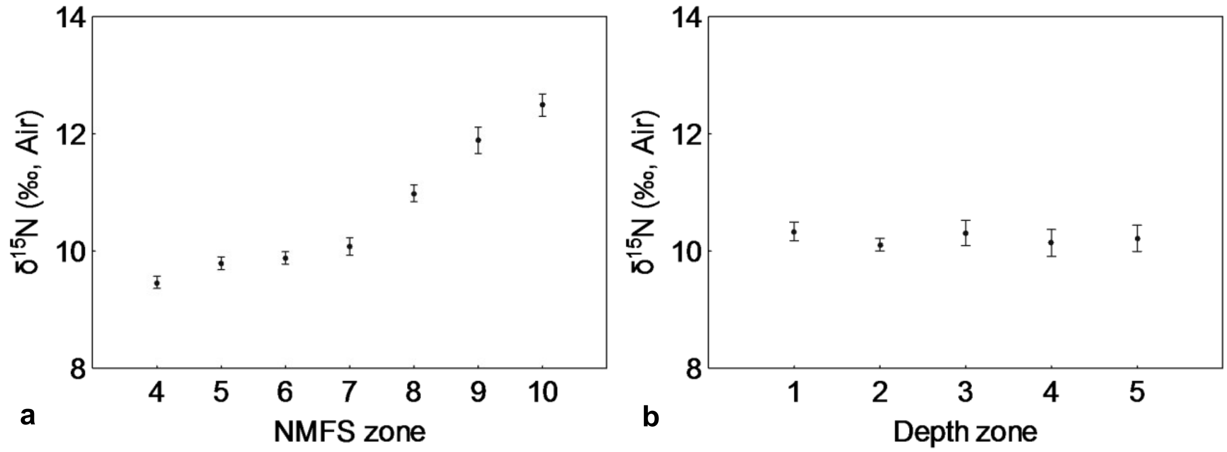

Figure 7. Multiple comparison plot for $\delta^{15}N$ and NMFS zones (a) or depth zones (b) for all fish species combined. Central marker represents the mean and bars are 95% confidence intervals.

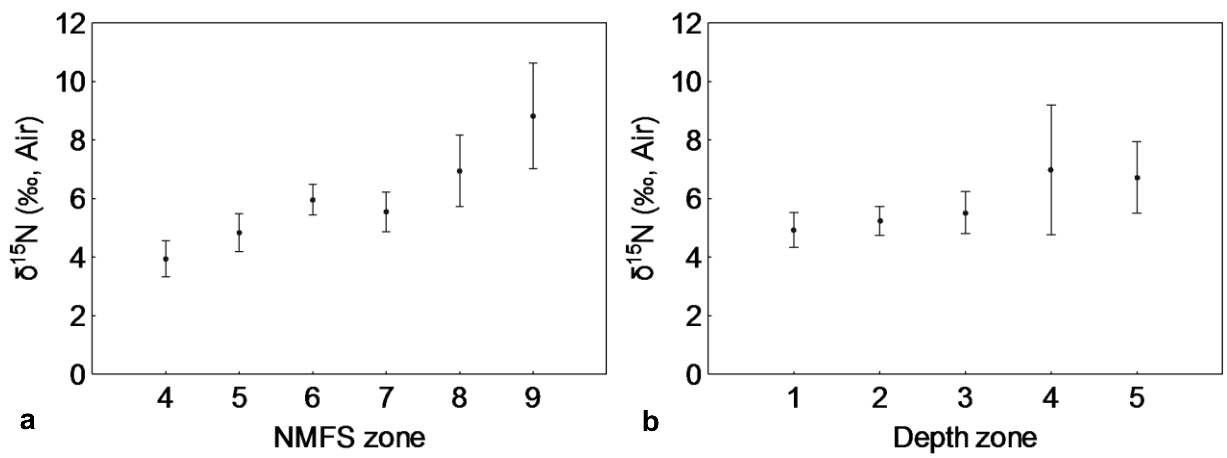

Figure 8. Multiple comparison plot for $\delta^{15}N$ and NMFS zone (a) and depth zone (b) for all herbivores combined. Central marker represents the mean and bars are 95% confidence intervals.

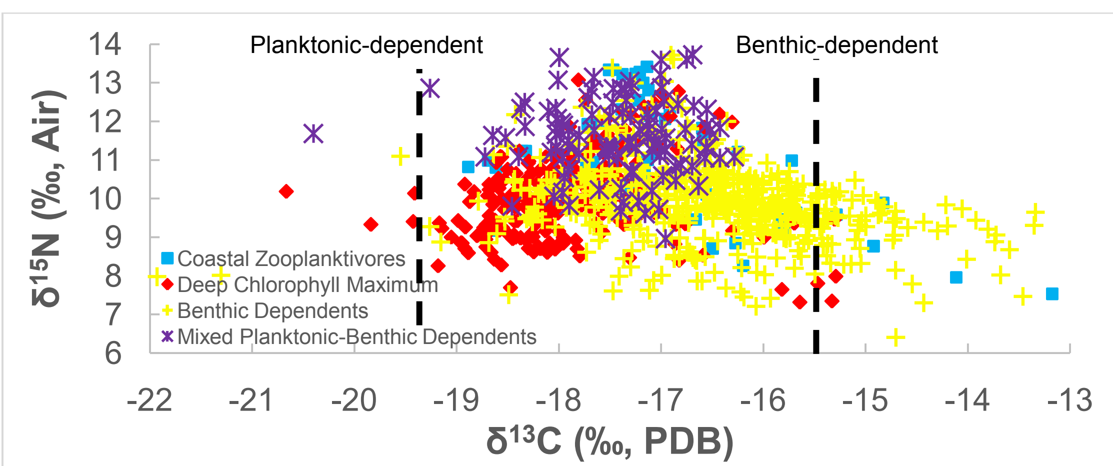

Figure 9. Isotopic comparison of fish samples representing the four largest community groups identified at 24% similarity.

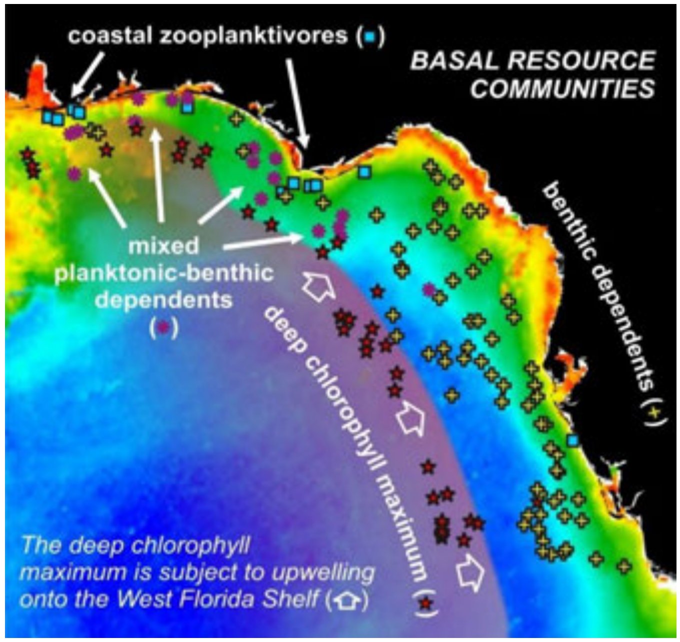

Figure 10. Four main community groups based on community analysis and basal-resource dependence, as indicated by δ^{13}C. Community analysis results (colored symbols) are overlaid on the Aqua MODIS Level-2 surface chlorophyll concentration average for a 14-day period centered on June 15, 2009, with the deep chlorophyll maximum simulated in purple.

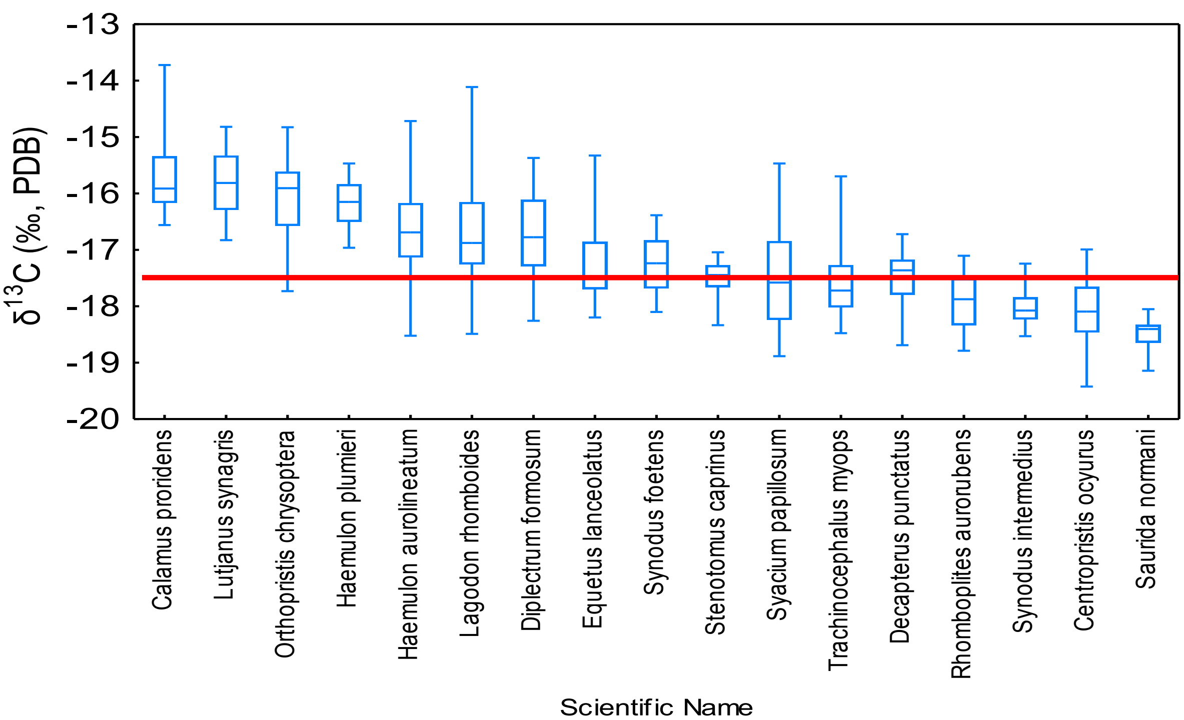

Figure 11. Ranking of median δ^{13}C (‰, PDB) for individual fish species analyzed in July 2009. Box represents 25-75% with centerline median and 5-95% whiskers. The horizontal red line represents the approximate boundary between dependence on phytoplankton (low δ^{13}C) and benthic algae (high δ^{13}C, see text for explanation).

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INNOVATION IN COLLABORATIVE ECOTOURISM

Jennifer Shafer

ABSTRACT

Nature-based tourism on the Gulf Coast has experienced an unprecedented surge in popularity over the past five years, on par with arts-based tourism and far exceeding sports-based tourism. To meet this growing demand while protecting the natural resources that support it, the Science and Environment Council developed ECKO, a collaborative non-profit web-based business platform. It serves as the organizing hub for local ecotourism, providing international marketing and reservations for our unique ecotravel packages as well as ecotours from local guides. The Council offers five exclusive multi-day sustainable ecotours that combine the assets and destinations of member organizations, including "insider knowledge" about where to go and exclusive "behind the scenes" experiences. In parallel, a voluntary locally tailored education program is being developed to provide local guides assistance in implementing sustainable practices for their tours and the opportunity to use the platform to promote them. As a collaboration of leading science-based environmental organizations, the Council has extensive and unparalleled local environmental knowledge and expertise and is the natural organizing hub for sustainable ecotourism. ECKO will uniquely brand our Gulf Coast as an ecotourism destination, promote environmental stewardship and volunteerism, protect our natural and cultural heritage, and support sustainable economic development.

BE FLORIDIAN: USING SOCIAL MARKETING (AND A PLASTIC FLAMINGO) TO REDUCE FERTILIZER USE

Nannette O'Hara and Sara Isaac

ABSTRACT

Residential runoff, including lawn fertilizer, is a significant source of nutrient pollution in Tampa Bay. The Tampa Bay region has the nation's strongest urban fertilizer ordinances, banning use and sale of nitrogen fertilizers in the summer. The "Be Floridian" social marketing campaign was developed to support the ordinances. Be Floridian is a replicable example of using both environmental and social science to identify a priority education need; analyze audiences, attitudes and barriers; and employ proven marketing techniques to address the problem. Be Floridian departs from traditional education and incorporates behavioral determinants, such as perceived social norms, to foster a permanent change in both fertilization practices and cultural attitudes about what constitutes an attractive landscape. 2015 marks the 5th and final year of the Be Floridian campaign, a partnership of Pinellas, Manatee and Sarasota counties, and the city of Tampa. Campaign tools included a website; print, outdoor and digital advertising; social media; and retail and community outreach. More than $350,000 has been invested --excluding staff time– a significant commitment for an education effort funded largely by local governments. Pre-campaign marketing research included focus groups, demographic analysis and message testing. Program evaluation shows measurable changes in behavior regarding fertilizer ordinance knowledge and decreased fertilizer use among target audiences. This presentation will demonstrate how this successful model for non-traditional "government" environmental education can be applied to other environmental issues that could benefit from target audience behavior change.

COASTAL AWARENESS PROGRAM

Kathryn Jeakle

ABSTRACT

The objective of the Coastal Awareness Program was to provide opportunities for students to become more knowledgeable about the environment in which they live. All activities / projects were intentionally designed to develop environmentally educated citizens. During the August 2014-May 2015 time frame, students at Shorecrest Preparatory School spent a total of 25 hours in the field learning about the environment around them. Fieldwork consisted of weeding, transplanting, and recycling Spartina alterniflora, collecting water samples at the 54th Ave Channel to test for pH, salinity, temperature, turbidity, dissolved oxygen, and nitrates, as well as acting as naturalist to identify local plant and animal species. Most of the work was completed on campus but some was completed off campus at Coffee Pot Park and Rocks Pond in Manatee County. In addition to fieldwork, students completed a project of choice: Science Investigation or Marine Issue Project. Working in the field stimulated several students to complete projects such as eradication of Australian Pines leading to the replacement of the invasive species with 450 native plants, an iBook on ocean acidification and iMovies on topics such as plastic in our backyard, sea level rise, and the importance of bay grasses. In total, 83 students were directly part of the program. These 83 students impacted our entire school and the surrounding community by sharing their projects with a guided naturalist tour for kindergarten, reading their stories to different grade levels, and sharing their iBooks and iMovies. Parents as well as friends of students were impacted by the projects as well as by a water bottle challenge that was initiated with the original 83 students but extended to other grade levels as well as families outside of school. The Coastal Awareness Program has been a great success at stimulating students to understand and care about the environment in which they live.

STEWARDSHIP IN ACTION

Martha Gruber and Melinda Spall

ABSTRACT

Tampa Bay Watch's Bay Grasses in Classes program (BGIC) gives students the opportunity to maintain and grow Spartina alterniflora at their school in a Tampa Bay Watch sponsored salt marsh nurseries. The BGIC program has been involved with the Pinellas, Hillsborough, and Manatee County school districts since 1995. This on-going program at Tampa Bay Watch has restored more than 148 acres at more than 30 different sites throughout Tampa Bay, and coordinates over 1,500 students a year to perform this restoration work. The BGIC program has 17 active salt marsh nurseries at 15 middle and high schools in Tampa Bay. Each on-campus nursery provides hands-on opportunities for students to realize the importance of salt marsh vegetation to the estuarine ecosystem. The salt marsh plants are installed along the newly created tidal shoreline similar to natural marsh communities found along the wetland habitats throughout Tampa Bay. The program provides middle and high school students with an educational resource to learn about ecological and agricultural practices, while enhancing the science-based curriculums at their schools. The students see first-hand when they participate in restoration efforts the importance of wetland habitats and the web networks it provides to a variety of species that depend of this type of habitat. Currently, students have participated in salt marsh plantings at the Rock Ponds Ecosystem Restoration project. Partnerships with SWFWMD-SWIM and Hillsborough County have allowed students to play an active role in the bay's problems and solutions.

THE ROCK PONDS ECOSYSTEM RESTORATION PROJECT – A TRUE MOSAIC OF COASTAL HABITATS FOR TAMPA BAY

Brandt F. Henningsen, Nancy T. Norton and Brad E. Young

ABSTRACT

The Rock Ponds Ecosystem Restoration Project is the largest coastal restoration project ever performed for Tampa Bay, a cooperative effort between the Surface Water Improvement and Management (SWIM) Program of the Southwest Florida Water Management District (SWFWMD) and Hillsborough County. This project was identified as part of the Tampa Bay SWIM Plan as well as the Tampa Bay Estuary Program's Comprehensive Conservation and Management Plan for Tampa Bay. Located on three public parcels in the southeastern reaches of Tampa Bay, the project involves sites that historically were coastal pine flatwoods, scattered hardwood hammocks, and various estuarine and freshwater wetlands (Figure 1). Use of the tracts for agricultural purposes and sand/shell mining removed the majority of the historic plant communities and habitat values from these parcels; historic habitats were replaced by open mine pits, ditching/diking, and non-native vegetation (Figure 2). Accordingly, the project involves the restoration/enhancement of approximately 1043 acres of various coastal habitats (habitat mosaics): 645 acres of uplands (pine flatwoods, hardwood hammocks) and 398 acres of various estuarine and freshwater habitats (Figure 3). Estuarine habitats include: open water/lagoons, tidal channels, mud flats, shallow sand flats, deep water refugia ("holes"), low and high intertidal marsh platforms, islands, and natural limestone artificial reefs. Freshwater wetlands include both ephemeral and permanent pool habitats, inclusive of cascading "pool-to-pool" designs, with the final cascade overflowing into intertidal lagoons. In addition, the project helps restore the area's hydrology, improves the bay's water quality via some stormwater polishing, creates fisheries habitats including salinity gradients and low salinity habitats, and supplements important bird nesting and feeding habitats. The project design will help accommodate projected sea level rise, allowing habitat migration upslope. This project complements the SWIM/Hillsborough County Cockroach Bay Ecosystem Restoration Project located on the north side of Cockroach Bay, a multi-phase 500 acre restoration project completed during 2012. Lastly, this project is but one of 96 SWIM coastal restoration projects for Tampa Bay performed with cooperators since 1989 for a cumulative total of 4617 acres (7.2 square miles) of coastal habitats. Other interesting project facts include:

1. The total project footprint of 1043 acres is the equivalent of 1.6 square miles of enhanced/restored coastal habitats for Tampa Bay.
2. Total length of new shorelines for Tampa Bay = 85,590 ft = 16.2 miles (equivalent of a round trip journey on Howard Frankland Bridge from Tampa to St. Petersburg).
3. Total number of upland and wetland plants installed = 972,127.
4. Total volume of dirt moved to enhance/create wetlands = 1.6 million cubic yards, which is: a) the equivalent of stacking dirt 611' high on a football field; b) a dirt pile taller than the tallest building (579') of downtown Tampa; c) a dirt pile taller than the Sunshine Skyway Bridge (430'); d) about 89,000 loaded dump trucks stretching end-to-end for 505 miles.
5. The largest volunteer marsh planting in the history of Tampa Bay (by numbers of plants) was held November 14, 2015, with 289 volunteers installing 40,000 marsh plugs in new intertidal marsh platforms of the Rock Ponds' project (Borrow Pit Restoration Sector) in about two hours.
6. The record-setting volunteer planting was a cooperative effort between the SWIM Program of SWFWMD, Tampa Bay Watch, Florida Fish and Wildlife Commission, and Hillsborough County Conservation and Environmental Lands Management Department.

COMMUNITY-BASED PROGRAM OF SHORELINE STABILIZATION AND RESTORATION AT MACDILL AIR FORCE BASE

Jason Kirkpatrick and Peter Clark

ABSTRACT

MacDill's shoreline stabilization and restoration program is a multi-year project initiated by the Air Force and supported by Federal and local partners as well as hundreds of community volunteers. The project was developed as an alternative to the installation of traditional 'hardened' shoreline protection. This dynamic stabilization approach uses marine-friendly materials to create a 'living' system that restores natural shoreline stabilizers. The creation of a near shore reef allows salt marsh to re-establish along the shoreline further stabilizing the coastal system and also increasing habitat diversity. Considered innovative in 2004, oyster reef shoreline stabilization has proven to be a successful, cost-effective method for stabilizing coastal systems, one which also expands essential fish habitat. But what makes the MacDill project truly special is the community-based approach to construction. The reef-building materials are installed exclusively by volunteers. MacDill AFB partners with Tampa Bay Watch to host community reef building events throughout the year where civilian and military volunteers install the reef building materials. To date more than 600 volunteers have installed 9,300 marine-friendly concrete oyster domes and 18,000 oyster shell bags to create more than a mile of oyster reef along MacDill's southeastern shoreline. Once the reef is in place, students and community volunteers once again step in to plant marsh grass which historically existed along the coastline. The Air Force has contributed $475,000 to support this community-based conservation project, but partnerships with multiple organization including USFWS, NOAA, and others have provided an additional $360,000 in funding to support construction of the reef.

[DISTRIBUTION AND FLUXES OF DISSOLVED ORGANIC CARBON AND TRACE ELEMENTS IN TIDAL RIVERS OF THE TAMPA BAY ESTUARY]

Ryan Moyer, Mike Lizotte, Christina E. Powell, Christopher S. Moore, Ioana Bociu and Kimberly K. Yates

ABSTRACT

The delivery of dissolved constituents, including carbon (C) and trace elements, from rivers to the coastal ocean via estuaries is recognized as an important component of the global biogeochemical budgets. Smaller river systems are often overlooked and unique mixing dynamics associated with estuaries can make interpretations of mixing and fluxes difficult. The seasonal concentration and fluxes of dissolved organic C (DOC) were measured in five tidal rivers and creeks that drain into Tampa Bay. Concentrations of 15 trace elements were also measured in the tidal portion of the Little Manatee River. DOC distributions were highly variable in all river catchments and no significant differences were observed among or between DOC concentrations with respect to river catchment, season, or year of sampling. DOC generally mixed non-conservatively during the wet seasons, and conservatively during the dry seasons, with the estuarine reaches of each river serving as a sink of DOC. Material fluxes were tied to discharge irrespective of season, and the estuaries removed 15-65% of DOC prior to export to Tampa Bay and the Gulf of Mexico. Trace elements were grouped into three distinct mixing patterns: conservative, quasi-conservative, and non-conservative. In addition to geomorphic properties, the role of past, present, and future land cover and other anthropogenic environmental change in the coastal catchments exerts control on the quantity and flux of DOC and trace elements in these systems. The characterization of DOC and trace elements in tidal rivers and estuaries is critical for quantitatively constraining these systems in local-to-regional scale biogeochemical budgets.

OLD TAMPA BAY INTEGRATED MODEL SYSTEM

Anthony Janicki

ABSTRACT

The Tampa Bay estuary has undergone a remarkable ecosystem recovery since the 1980s despite continued population growth within the region. However during this time, the Old Tampa Bay (OTB) segment has lagged behind the rest of the Bay's recovery relative to improvements in overall water quality and seagrass coverage. In 2011, the Tampa Bay Estuary Program, in partnership with the Southwest Florida Water Management District, began development of an integrated set of numerical and empirical modeling approaches to determine the best management actions needed to improve the ecology of the OTB estuarine segment. While two previously developed models (empirical and simple box) have successfully met the management needs they could not provide the desired spatial and temporal scale for predicted responses to various management actions. Thus, the need for a series of models that included watershed, hydrodynamic, water/sediment quality, and ecological models (light and biota) to simulate changes in OTB at the desired spatial and temporal resolution. The proposed management actions included: diverting freshwater input from Lake Tarpon, diverting directly discharged AWT, physically altering causeways that intersect OTB, reducing stormwater nutrient loads, and various combinations of these actions. The integrated model set was used to evaluate net ecological improvements to OTB's water quality, sediment quality, seagrass coverage, and benthos/nekton habitat suitability. Based upon this evaluation, management actions that produced the greatest predicted improvements relative to costs are being considered for future implementation in the OTB segment and watershed.

BASELINE INFORMATION FOR OTOLITH MICROCHEMISTRY OBTAINED FROM PRE-COLUMBIAN MIDDENS

Brock Houston

ABSTRACT

The absence of baseline information prior to the Deepwater Horizon (DWH) oil spill is often cited as an impediment to assessing the spill's impacts. We use data from pre-industrial-age otoliths to compare Red Drum otolith microchemistry between ancient and modern times. Red Drum otoliths were obtained from three sources: (1) Native American middens at Weedon Island and Crystal River in west-central Florida, (2) fish collected from Tampa Bay and other areas on the Florida Gulf Coast, and (3) fish collected from coastal Louisiana soon after the Deepwater Horizon spill. We used laser-ablation ICP-MS to compare concentrations of nine hydrocarbon-associated trace metals (Mg, Cr, Mn, Fe, Ni, Co, Cu, Zn, and Pb) among the three otolith sources. We used SIMPROF analysis to identify a clean reference group of modern specimens (sources 2 and 3) that had low metal concentrations, and found that the best-preserved portion of an ancient Weedon Island otolith was also classified into the clean reference group for modern otoliths, supporting the idea that midden otoliths can be used as a pre-industrial baseline for otolith microchemistry. Specimens with high concentrations of hydrocarbon metals occurred in both Louisiana and Florida, with contamination occurring both before and after the DWH spill. Contaminated portions of poorly preserved midden otoliths were also observed. Because the midden otoliths were removed from contact with seawater >800 years ago, we suggest that their route of contamination with hydrocarbon metals was atmospheric.

HIGH RESOLUTION TAMPA BAY AND VICINITY MODEL

Robert H. Weisberg and Lianyuan Zheng

ABSTRACT

The Tampa Bay estuary is a complex, interconnected region consisting of Tampa Bay, Sarasota Bay, Boca Ciega Bay, the Intra-coastal Waterway and all of the inlets and waterways connecting these with each other and with the adjacent Gulf of Mexico. Modeling this complex requires resolution sufficient to include all of the important conveyances of mass. We present such a model, quantitatively gauged against available observations to demonstrate model veracity for tide, wind and river driven circulations, along with several application examples. Such model is pre-requisite for ecological applications because the circulation is what largely controls the water properties in which organisms reside. We demonstrate this by considering the salt balances and the salt fluxes throughout the bay. The spatial structure for the salt fluxes is indicative of the spatial structures for other important material properties such as nutrients and fish larvae. The model also provides a tool for tracking harmful substances that may be spilled in the bay and how these substances may be carried offshore and into the various inlets, as occurred during the 1993 Tampa Bay oil spill.

High Resolution Tampa Bay and Vicinity Model

UNIVERSITY OF SOUTH FLORIDA

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COLLEGE OF MARINE SCIENCE UNIVERSITY OF SOUTH FLORIDA ST. PETERSBURG

Abstract

A 3D, numerical circulation model, with high resolution (20 m) at important mass conveyances (inlets, channels, bridge causeways, and rivers), is used to diagnose the salt balances and salt fluxes for the partially mixed, Tampa Bay, FL estuary. The analyses are first justified through quantitative comparisons between the model simulation over a three month interval and all available observations for sea level, velocity and salinity. The fully 3D salt flux divergences and fluxes all vary spatially throughout the estuary. On experimental duration (three month) average, the total (horizontal + vertical) advective salt flux divergence (SFD) is balanced primarily by the vertical diffusive (VDIF) salt flux divergence, except near the bottom of the shipping channel where the horizontal diffusive (HDIF) salt flux divergence is also important. Instantaneously, the local rate of salinity change is controlled primarily by the advective salt flux divergence, with a secondary contribution by the vertical diffusive salt flux divergence everywhere and the horizontal diffusive salt flux divergence near the channel bottom.

The role of tidal pumping is examined by decomposing the advective salt fluxes and their divergences into products of the salinity and velocity means, and correlations between the salinity and velocity fluctuations. The horizontal and vertical advective salt flux divergences by the mean quantities are large and counterbalancing (by continuity), with their sum being a small, but significant residual. The horizontal and vertical advective salt flux divergences by tidal pumping are relatively small (when compared with the mean quantities) and counterbalancing; but, when summed, their residual is comparable in magnitude to that by the mean quantities. So whereas the salt fluxes by tidal pumping are of secondary importance to the salt fluxes by the mean quantities, their total flux divergences are of comparable importance. The salt flux components in all three dimensions themselves vary along the Tampa Bay axis, and these findings may be typical of coastal plain estuaries given their geometrical complexities

Model Grid

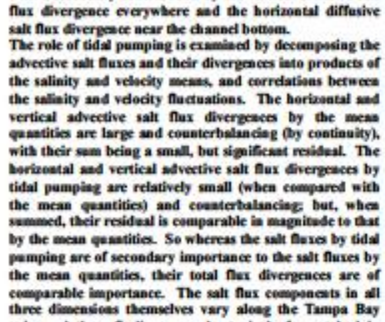

Figure 1. The unstructured (FVCOM) model grid, plus zoomed views of selected sub-regions for the purpose of highlighting the resolution that is achieved. Higher resolution (20 m) grids are located in deep shipping channel, inlets, bridge causeways, and rivers. The lower resolution grids are located near the open boundary.

Model Evaluations

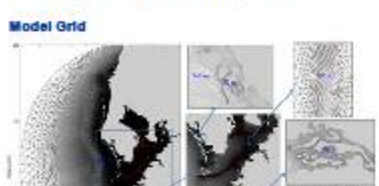

Figure 2. Time-series comparisons for hourly sea levels observed (black) and modeled (red) at the Mckay Bay, Clearwater Beach, Port Manatee, and St. Petersburg stations (from top to bottom). Left (right) panels are for hourly and 36-hour low-pass filtered data, respectively. Root mean square deviations (RMS) and correlation coefficients (CC) are provided.

Table. Comparisons for the M_2, O_1, and K_1 tidal harmonic constants.

Station	Amplitude (cm) Observed	Amplitude (cm) Modeled	ΔH	Phase (°) Observed	Phase (°) Modeled	Δφ
			M_2			
McKay Bay	20.24	19.08	1.17	199.78	200.70	-0.92
Clearwater Beach	23.98	21.80	2.18	122.46	113.61	8.85
Port Manatee	13.60	13.72	-0.12	170.93	170.47	0.46
St. Petersburg	14.28	13.60	0.68	196.78	197.52	-0.74
			O_1			
McKay Bay	15.00	14.81	0.18	39.31	41.18	-1.87
Clearwater Beach	14.76	14.24	0.52	4.15	2.71	1.43
Port Manatee	14.14	14.13	0.01	27.41	27.32	0.09
St. Petersburg	14.38	14.21	0.17	38.43	38.90	-0.46
			K_1			
McKay Bay	16.67	16.43	0.24	28.95	33.69	-4.74
Clearwater Beach	15.29	14.88	0.41	11.34	12.92	-1.58
Port Manatee	13.34	13.18	0.16	39.78	40.32	-0.54
St. Petersburg	13.48	13.47	0.01	30.44	33.21	-2.74

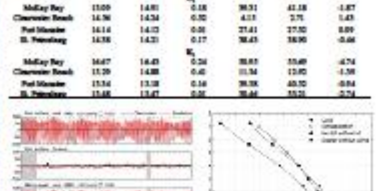

Figure 3. Left: Time-series comparisons for hourly axial and co-axial velocity components observed (black) and modeled (red) at the Sunshine Skyway Bridge ship channel near surface, at mid-depth, and near bottom. Right: Experimental duration (three-months) mean axial velocity component profiles. Solid circles are the observations; open circles are a linear extrapolation of the observations to the surface; triangles are the model simulation with tides, winds and rivers; squares are the model simulation excluding wind forcing.

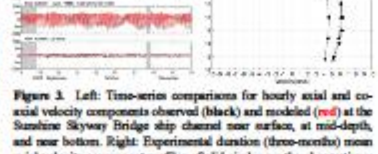

Figure 4. A comparison between modeled and observed surface and bottom salinity at HCEPC observed stations. Modeled values (blue) are averaged over the experimental duration and observed (black) are climatologically averaged over 1998 through 2004. Provided are the correlation coefficient (r), standard deviation (std) and bias (b).

Salt Budgets

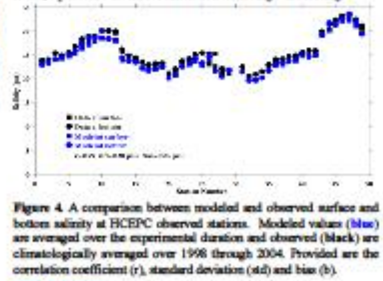

Figure 5. The salt balance terms evaluated at surface (left panels) and bottom (right panels). Clockwise from the upper left are the horizontal (II) and vertical (III) advective SFD and their sum (II+III), followed by the VDIF (V) and HDIF (IV) SFD and local rate of salinity change (I). Note the magnitude differences of the colorbar scales.

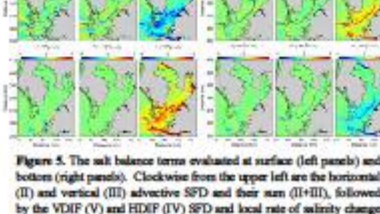

Figure 6. Temporal evolutions of the salt balance terms through nearly one spring-neap tide cycle evaluated across a Tampa Bay mouth cross section. The left and right hand panels are for the surface and the near bottom, respectively.

Figure 7. The advective SFD terms decomposed into mean and tidal pumping contributions at the surface (left panel set) and bottom (right panel set). Upper panels are the horizontal and vertical mean flow terms (VI) and (X) and their sum (VI + X). Lower panels are the horizontal and vertical tidal pumping terms (VII) and (XI) and their sum (VII + XI). Note that the mean flow terms (VI) and (X) are an order of magnitude larger than the tidal pumping terms (VII) and (XI).

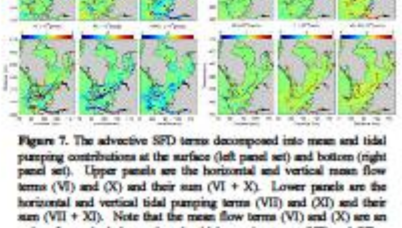

Figure 8. Experimental duration, cross-section normal, mean salt fluxes per unit area by the products of mean values (left column), the tidal pumping (middle column) and their sum (right column), evaluated at three cross-sections: Tampa Bay mouth (upper row), middle Tampa Bay (middle row) and Hillsborough Bay mouth (lower row). Note that the flux distributions vary from section to section and that the tidal pumping terms are an order of magnitude smaller than the mean terms.

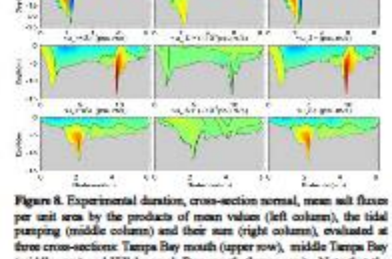

Figure 9. Sequential flow chart for the Tampa Bay salt balance. Hor., Ver., and Adv. are abbreviations for horizontal, vertical, and advection, respectively. The pairs of numbers in brackets are the relative contribution ratios for the corresponding terms in the experimental duration local rate of change of salinity at the surface (number on the left) and near the bottom (number on the right).

Conclusions

1) A high resolution circulation model is used to diagnose the point by point salt balances and salt fluxes for the Tampa Bay, FL estuary.

2) The horizontal and vertical advective SFD by the mean quantities are large and counterbalancing (by continuity), with their sum being a small, but significant residual.

3) The horizontal and vertical advective SFD by tidal pumping are relatively small and counterbalancing, but when summed their residual is comparable in magnitude to that by the mean quantities.

4) Total advective SFD is balanced primarily by vertical diffusion, except near the bottom of the deep channels where the horizontal diffusion also contributes.

5) The instantaneously local rate of salinity change is controlled by the advective SFD, with secondary contributions by vertical diffusion everywhere and horizontal diffusion near the channel bottom.

6) Salt flux per unit area distributions vary along the estuary axis as will all state variable fluxes. Thus our findings apply to all quantities of ecological importance, i.e., nutrients, fish larvae, etc.

Related References

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2) Zhu, J., R.H. Weisberg, L.Y. Zheng, and S. Han, 2014a. Influences of channel deepening and widening on the tidal and non-tidal circulation of Tampa Bay. *Estuaries and Coasts*, doi: 10.1007/s12237-014-9815-4.

3) Zhu, J., R.H. Weisberg, L.Y. Zheng, and S. Han, 2014b. On the flushing of Tampa Bay. *Estuaries and Coasts*, doi: 10.1007/s12237-014-9793-6.

4) Zhu, J., R.H. Weisberg, L.Y. Zheng, and H. Qi, 2015. On the salt balance of Tampa Bay. *Continental Shelf Research, submitted.*

Acknowledgment: This work benefited from the BP/Gulf of Mexico Research Initiative via the Deep-C Consortium led by E. Chassignet at Florida State University.

A COMPARISON OF OTOLITH MICROCHEMISTRY IN GULF OF MEXICO LESIONED AND HEALTHY FISH FOLLOWING THE DEEPWATER HORIZON OIL SPILL

Jennifer E. Granneman, David L. Jones, Steve A. Murawski, Ernst B. Peebles

ABSTRACT

The presence of external skin lesions in Gulf of Mexico (GOM) fishes is known to have declined from 2011 to 2012, following the Deepwater Horizon (DWH) oil disaster. The objective of this study was to compare the otolith element Ahistories of lesioned and healthy GOM fish collected following the DWH oil spill. We analyzed otoliths of the following fish species collected from 2011 to 2013 in the Gulf of Mexico: Red Snapper *Lutjanus campechanus*, Red Grouper *Epinephelus morio*, Yellowedge Grouper *Epinephelus flavolimbatus*, Southern Hake *Urophycis floridana*, and Golden Tilefish *Lopholatilus chamaeleonticeps*. Otoliths were analyzed using laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) for a suite of 9 isotopes found in DWH crude oil: ^{7}Li, ^{23}Na, ^{24}Mg, ^{31}P, ^{43}Ca, ^{45}Sc, ^{51}V, ^{53}Cr, ^{55}Mn, ^{57}Fe, ^{59}Co, ^{60}Ni, ^{63}Cu, ^{64}Zn, ^{65}Cu, ^{72}Ge, ^{85}Rb, ^{88}Sr, ^{89}Y, ^{114}Cd, ^{118}Sn, ^{137}Ba, ^{197}Au, ^{208}Pb, ^{232}Th, and ^{238}U, with ^{43}Ca used as an internal standard. We ablated otoliths along a transect that extended from the primordium to the edge of the otolith, which allowed us to establish baseline otolith microchemistry measurements for fish prior to the DWH oil spill. Averaged both over the lifetime of an individual and for the years preceding, during, and after the DWH oil spill (2009 – 2011), lesioned fish of every species had significantly greater otolith oil-associated trace element concentrations than healthy fish. The elements responsible for the separation between lesioned and healthy groups varied according to species, but ^{60}Ni and ^{64}Zn appeared to be important elements for several species.

A Comparison of Otolith Microchemistry in Gulf of Mexico Lesioned and Non-lesioned Fish Following the Deepwater Horizon Oil Disaster

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ABSTRACT

The presence of external skin lesions in Gulf of Mexico (GOM) fishes is known to have declined from 2011 to 2012 following the Deepwater Horizon (DWH) oil disaster. The objective of the present study was to compare the otolith element histories of lesioned and non-lesioned GOM fish collected following the DWH oil spill. We analyzed otoliths from the following fish species collected from 2011 to 2013 in the GOM: Red Snapper *Lutjanus campechanus*, Red Grouper *Epinephelus morio*, Yellowedge Grouper *Epinephelus flavolimbatus*, Southern Hake *Urophycis floridana*, and Tilefish *Lopholatilus chamaeleonticeps*. Otoliths were analyzed using laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) for a suite of 9 analytes found in DWH crude oil: ^{25}Mg, ^{51}V, ^{53}Cr, ^{57}Fe, ^{59}Co, ^{60}Ni, ^{63}Cu, ^{66}Zn, and ^{208}Pb, with ^{43}Ca used as an internal standard. We ablated otoliths along a transect that extended from the center (primordium) to the outer edge of the otolith, which allowed us to establish baseline otolith microchemistry measurements for fish prior to the DWH oil spill. Lesioned fish of 3 of the 5 species had significantly greater otolith oil-associated trace element concentrations than non-lesioned fish. ^{60}Ni and ^{66}Zn were the elements responsible for the separation between lesioned and non-lesioned groups.

BACKGROUND

Lesioned Fish Prevalence

- The presence of external skin lesions in Gulf of Mexico (GOM) fishes declined in the years following the Deepwater Horizon (DWH) oil disaster (Murawski et al. 2014)
- Did the DWH oil disaster contribute to the prevalence of fish lesions?

Petroleum

- A mixture of hydrocarbon compounds with trace metals concentrated in the heavy fractions

Otoliths

- Ear stones that function in fish hearing and balance
- Contain identifiable daily, seasonal, and annual increments
- Trace elements from the surrounding water and diet are incorporated into the otolith

Fig. 1. Red Snapper (*Lutjanus campechanus*) lesion

Fig. 2. Red Grouper (*Epinephelus morio*) otolith

This project utilizes the ability of fish otoliths to record time and the environmental conditions that a fish has been exposed to throughout its lifetime

OBJECTIVE

Compare the otolith element histories of lesioned and non-lesioned fish collected from the Gulf of Mexico following the DWH oil spill

METHODS

Study Site and Species

- Fish collected from 2011–2013 by collaborators in the C-IMAGE consortium
- Collections made at stations along transects as shown in Figure 3
- Fish were collected at depths of 20–200 m using baited long lines
- Diseased fish were identified during collection by the presence of lesions

Fig. 3. Fish collection locations

Sample Preparation and Processing

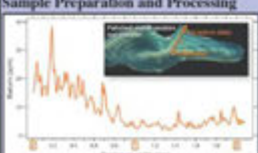


Fig. 4. Graphic depicting how LA-ICP-MS data are obtained

- All preparation procedures took place in a Class 100 metal-free laminar flow bench
- Thin otolith sections were analyzed from the core to the edge through laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS)
- A suite of 9 hydrocarbon associated analytes was measured: ^{25}Mg, ^{51}V, ^{53}Cr, ^{57}Fe, ^{59}Co, ^{60}Ni, ^{63}Cu, ^{66}Zn, ^{88}Sr, ^{208}Pb with ^{43}Ca measured as an internal standard

Table 1. Selected otoliths of the following species were analyzed using LA-ICP-MS

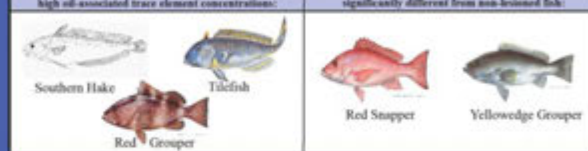
Species	Sample Size	Transect Locations
Red Snapper (*Lutjanus campechanus*)	113	4, 8, 9, 10-15
Red Grouper (*Epinephelus morio*)	10	2, 4, 5, 8
Southern Hake (*Urophycis floridana*)	10	6-9, 13, 14
Yellowedge Grouper (*Epinephelus flavolimbatus*)	35	3, 6-9, 11-15
Tilefish (*Lopholatilus chamaeleonticeps*)	44	7-9, 11, 13-15

Statistical Analysis

- The otolith microchemistry profile was averaged for each year from 2009 – 2011
  - Note: time periods do not correspond to calendar years, but are based on annulus deposition
- Used Similarity Profile (SIMPROF) based cluster analysis to identify significantly different groups within each species
- Nonmetric Multidimensional Scaling (nMDS) plots used to depict SIMPROF groups with *a posteriori* labeling of lesioned and non-lesioned fish
- Seriated heat plots were used to examine patterns of trace element distribution within each SIMPROF group

FIGURES & RESULTS

Fish species for which lesioned fish had relatively high oil-associated trace element concentrations:	Fish species for which lesioned fish were not significantly different from non-lesioned fish:
Southern Hake, Tilefish, Red Grouper	Red Snapper, Yellowedge Grouper



Tilefish Results

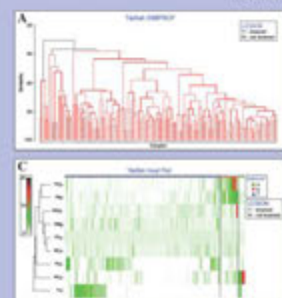


Fig. 5. Tilefish analysis results. A) SIMPROF based cluster analysis identified 3 significantly different groups. B) Only one of the SIMPROF groups (Group b) contains lesioned fish, C) Group b (lesioned fish group) is characterized by high levels of ^{60}Ni and ^{66}Zn compared to the other groups. Groups a and c are relatively "clean" groups, although levels of ^{51}V and ^{63}Cu are high in some individuals of these groups.

Red Grouper Results

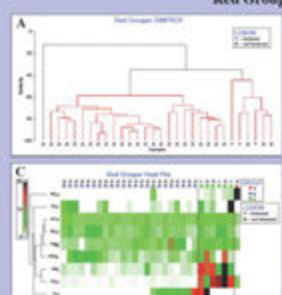


Fig. 6. Red Grouper analysis results. A) SIMPROF based cluster analysis identified 3 significantly different groups. B) Only one of the SIMPROF groups (Group c) contains lesioned fish, C) Group c (lesioned fish group) is characterized by high levels of ^{60}Ni and ^{66}Zn compared to the other groups. Groups b and c are relatively "clean" groups, although levels of ^{51}V and ^{63}Cu are high in some individuals of these groups.

FIGURES & RESULTS (CONTINUED)

Southern Hake Results

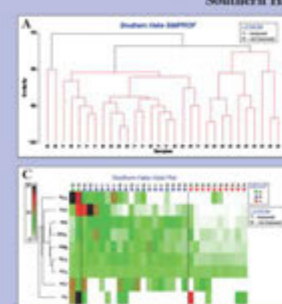
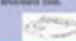


Fig. 7. Southern Hake analysis results. A) SIMPROF based cluster analysis identified 3 significantly different groups. B) Only one of the SIMPROF groups (Group b) contains lesioned fish, C) Group b (lesioned fish group) is characterized by relatively high levels of oil-associated elements compared to the relatively 'clean' Group c. Group a is characterized by the highest concentrations of oil-associated elements observed, although it does not contain lesioned fish.



SUMMARY

- The SIMPROF analysis revealed that the otolith microchemistry of lesioned Tilefish, Red Grouper, and Southern Hake was significantly different than non-lesioned fish
  - This difference was consistently observed before and after the DWH oil disaster (data not shown)
  - The elements that tended to be high in lesioned fish were ^{60}Ni and ^{66}Zn, which were often correlated
  - The DWH oil disaster may have been the proximal cause of lesion formation; however, lesioned fish were apparently exposed to oil-associated elements prior to the disaster
- In the non-lesioned fish, the concentrations of the oil-associated elements were generally low
  - Some individuals without external lesions were grouped with lesioned fish
  - The concentrations of ^{51}V and ^{63}Cu were relatively high in some of the non-lesioned fish; we suspect this may indicate a different source of hydrocarbon metals

In summary, several fish species examined were exposed to oil-associated elements (e.g. ^{60}Ni and ^{66}Zn) before and after the DWH oil disaster. Prior exposure may have made these fish species vulnerable to the DWH oil disaster and caused lesions to form in response to oil exposure.

NEXT STEPS

- Examine the geographic histories of the 3 fish species for which otolith microchemistry of lesioned fish was significantly different than non-lesioned fish
- This information will help us determine where exposure to oil-associated elements may have occurred within the Gulf of Mexico
- Geographic histories will be evaluated using carbon and nitrogen stable-isotopes records within fish eye lenses (see Wallace et al. poster)

FUNDING SOURCES

GOMRI via C-IMAGE consortium
National Fisheries Institute (NFI)
State of Louisiana

TAMPA BAY COMMUNITY-BASED SEAGRASS TRANSPLANTING

Serra Herndon and Peter Clark

ABSTRACT

The primary objective of Tampa Bay Watch's seagrass transplanting program is to enhance and restore seagrass communities in an area where they were historically present at a location off MacDill Air Force Base through the installation of manatee grass (Syringodium filiforme) plots across the estuarine shelf. This project has developed over four phases with Phase I occurring as a "trial" in 2006. The successful monitoring results of the donor site and the transplant site after Phase I were the driving force behind the Phase II in 2009, Phase III in 2010, and Phase IV in 2012.

The restored seagrass meadows provide benthic habitat, promote sediment stabilization and enhance water quality. Additionally, these projects rely heavily upon multi-agency collaboration as well as community volunteers. These community-based restoration efforts allow us to encourage greater stewardship of Tampa Bay's natural resources by providing exceptional hands-on field experience in the scientific process and encourage understanding of the importance of Tampa's seagrass communities.

Tampa Bay Community-Based Seagrass Transplanting

Serra Herndon & Peter Clark, Tampa Bay Watch

INTRODUCTION

This project represents the Phase IV of an interagency effort to validate seagrass transplanting techniques with water quality targets and successes of community based planting efforts. Results of the Phase I project in 2006 were utilized to design a second transplanting effort adjacent to the Phase I sites within the elevational zone of the greatest seagrass transplant survival to accelerate recovery and expansion of manatee grass (*Syringodium filiforme)* along the southern MacDill Peninsula shelf. Additionally, the 2006 donor site recovered to background conditions within the first 12 months of monitoring. The donor site and transplant site monitoring results of Phase I were the driving force for the Phase 2 design to transplant a set of six new seagrass plots in the

depth zone of the highest survival and coverage of the Phase I program. Similarly, successes of the Phase II & Phase III (2009 & 2010) efforts were utilized to design this 2012 transplanting effort (Phase IV). The transplanting took place in the area that is directly adjacent to the east to the Phase II & III design on the same elevational plane.

OBJECTIVE

There are two primary objectives of this project: 1) to enhance and restore seagrass in areas of Hillsborough Bay where they have existed historically; and 2) to encourage greater stewardship of Tampa Bay natural resources by providing hands-on educational experiences for community and student volunteers.

PROJECT LOCATION

The *Syringodium filiforme* was harvested from an approved donor area located just south of the Gandy Bridge in Tampa Bay in an area called Westinghouse Flats. The transplant plot locations are south of Broad Creek on the Interbay Peninsula (MacDill AFB). The seagrass plugs were planted in existing bare areas along the shelf in order to help jump-start the growth of *Syringodium filiforme*. The bare areas are located between contiguous beds of *Halodule wrightii*. This method supports our goal of compressed succession of seagrass across the shelf which includes helping to transform a monospecific seagrass bed to an area that includes several types of diverse seagrass species.

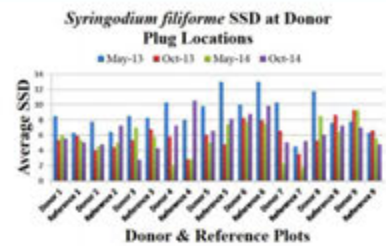
METHODS

Approximately 1,200 20cm x 20cm manatee grass sod units with sediment attached were harvested July thru September 2012 within a permitted donor area located in south-eastern Old Tampa Bay.

The harvested manatee grass was transported by shallow draft boats, kept shaded and wet, and was planted within a few hours of harvesting at the restoration area near the MacDill AFB.

The sod units were carefully removed from the transportation containers and planted level with the surrounding sediment by hand on 1m centers at six bare areas along the peninsula as determined in the Environmental Resource permit. Planting density was designed to install 20cm plug planting units on one meter centers in staggered rows to enhance coalescence of planted seagrass. The result of this planting design is the installation of 200 planting units per plot, for a total of 1,200 plugs. This framework provided an excellent compromise between plot densities, quantity of donor material used, and the ability to construct individual plots on a single day.

RESULTS



The successes of the previous four phases of this project have allowed us to perfect our techniques and methods to provide the highest level of quality and survivability of seagrass plugs. Through the phase four expansion of this project we are able to accelerate seagrass recovery in Tampa Bay through a proven and documented method. First, the donor site monitoring indicated that disturbances caused by harvesting were fully mitigated within the two year study period. This was postulated to occur based on results from other harvesting projects conducted in similar stable and healthy seagrass meadows (Fonseca 1994). Second, about 2,686m^2 of seagrass was established in an area previously devoid of any seagrass species. Third, the per unit area above ground biomass of the recovered manatee grass in most of the donor plots was similar to, or may have exceeded the biomass of the donor grass designated donor grass reference sites. Finally, several of the restored meadows have been actively expanding in area coverage at a rate similar to natural growing manatee grass meadows.

ACKNOWLEDGEMENTS

Tampa Bay Watch would like to thank the Environmental Protection Commission of Hillsborough County, the Tampa Bay Environmental Restoration Fund, Southeast Aquatic Resources Partnership, the Frank E. Duckwall Foundation, City of Tampa- Bay Study Group, Coastal Resources Group, Inc., and the Tampa Bay Estuary Program.

TOWARDS TRASH FREE WATERS IN THE HILLSBOROUGH RIVER WATERSHED

Max J. Krause, Sarah Gustitus, Jeremy Toms, and Timothy G. Townsend

ABSTRACT

There is a growing concern of the magnitude and potential impact of unmanaged municipal solid wastes (MSW) in the marine and aquatic environments. When MSW is discarded inappropriately, it is considered litter. Litter can be transported via wind or rain into a waterbody, where it becomes aquatic trash. Thus, any litter within a watershed can be considered potential aquatic trash (PAT). Reports from local cleanup efforts were used to quantify PAT within the Hillsborough River Watershed (HRW). Cleanup data amounts were geolocated and mapped using ESRI ArcGIS to identify areas of greatest concern and quantify the total PAT within the watershed. Concentrations of PAT were determined based on amounts collected in discrete areas (e.g., parks, schools, etc.). Based on current methodology, HRW, Pasco County and Hillsborough County were estimated to have 4.8, 37, and 4.8 lbs PAT/acre, respectively. The significantly higher PAT concentration within Pasco County is not believed to be from greater littering, but from fewer reported data points with high amounts of collection. No data points were provided within Polk County, for which a portion is within the HRW. The results of this work are the first phase of quantifying and managing PAT within the HRW. This research, in conjunction with the Environmental Protection Agency's (EPA) Trash Free Waters Program will be used to determine metrics for which local groups can use to assess cleanup and educational campaigns with the intent of making the Hillsborough River and other waterbodies within the HRW, Trash Free Waters.

Towards Trash Free Waters
Quantifying Potential Aquatic Trash Recovery in the Hillsborough River Watershed

Max J. Krause, Sarah Gustitus, Jeremy Toms, and Timothy G. Townsend
Environmental Engineering Sciences, University of Florida, Gainesville, FL 32611

Abstract

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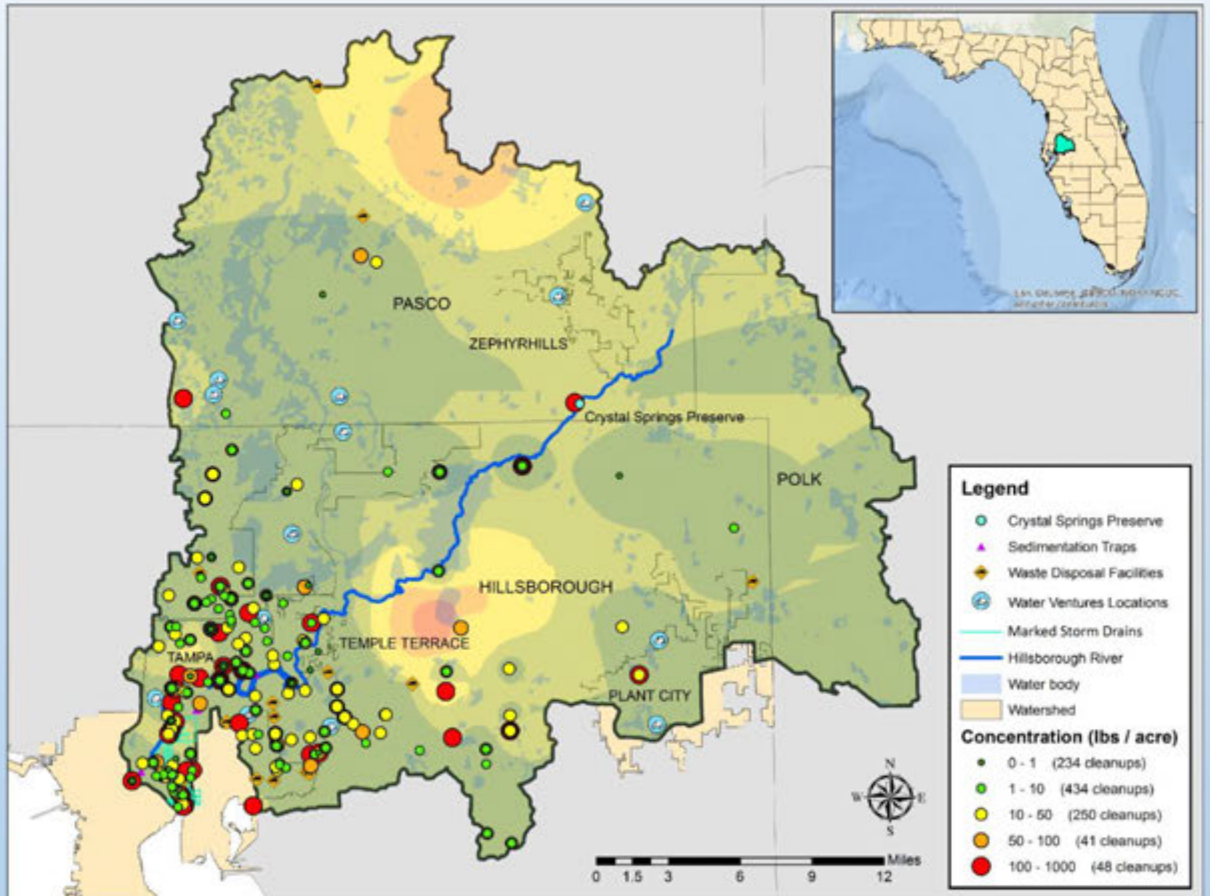
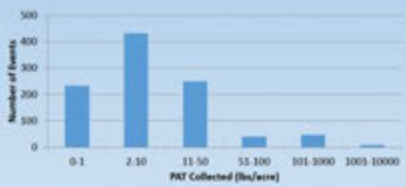
Recovered PAT at various locations within the HRW.



Recovered litter concentrations in the Hillsborough River Watershed (lbs/acre) as reported by local cleanup efforts from 2007 – 2014.



Next Steps

- Make the database available for public use
- Continue to update the PAT database – data submissions by any group are welcome
- Establish metrics to measure efficacy of cleanup efforts
- Establish the Hillsborough River and other water bodies within the HRW as EPA Trash Free Waters.
- Encourage municipalities to proclaim support for TFW efforts

Acknowledgements

Thank you to all groups for volunteering their time and effort. Thank you to Nestlé Waters North America for funding this ongoing research.

UF Solid and Hazardous Waste Management
ENVIRONMENTAL ENGINEERING SCIENCES

WATERSHED AUDIO TOUR

David J. Shafer, PhD and Jennifer L. Shafer, PhD

ABSTRACT

Science and Environment Council's Watershed Audio Tour celebrates our watersheds with highlights, interesting facts and suggestions for easy ways to help protect watersheds. While the 30-stop tour can be accessed free via telephone from anywhere, visiting the featured locations provides listeners an up-close and personal experience. For example, discover why mangroves are so important to our ecosystem while strolling along a mangrove-lined boardwalk. The Watershed Audio Tour is a collaborative project of 18 organizations across Sarasota and Manatee Counties. Representatives from Council member organizations narrate the tour stops about watershed features at their locations. Increased public knowledge and awareness of key watershed issues leads to greater community-based stewardship and support for watershed protection and restoration and the organizations that do this important work. The Watershed Audio Tour is updated with new tour stops and managed by Shafer Consulting for the Science and Environment Council, and was originally funded by the Southwest Florida Water Management District with more recent funding from the Sarasota Bay Estuary Program.

Watershed Audio Tour

watershedtour.org

Dr. Jennifer Shafer + Dr. David Shafer | SHAFER consulting
jennifer@shafer-consulting.org

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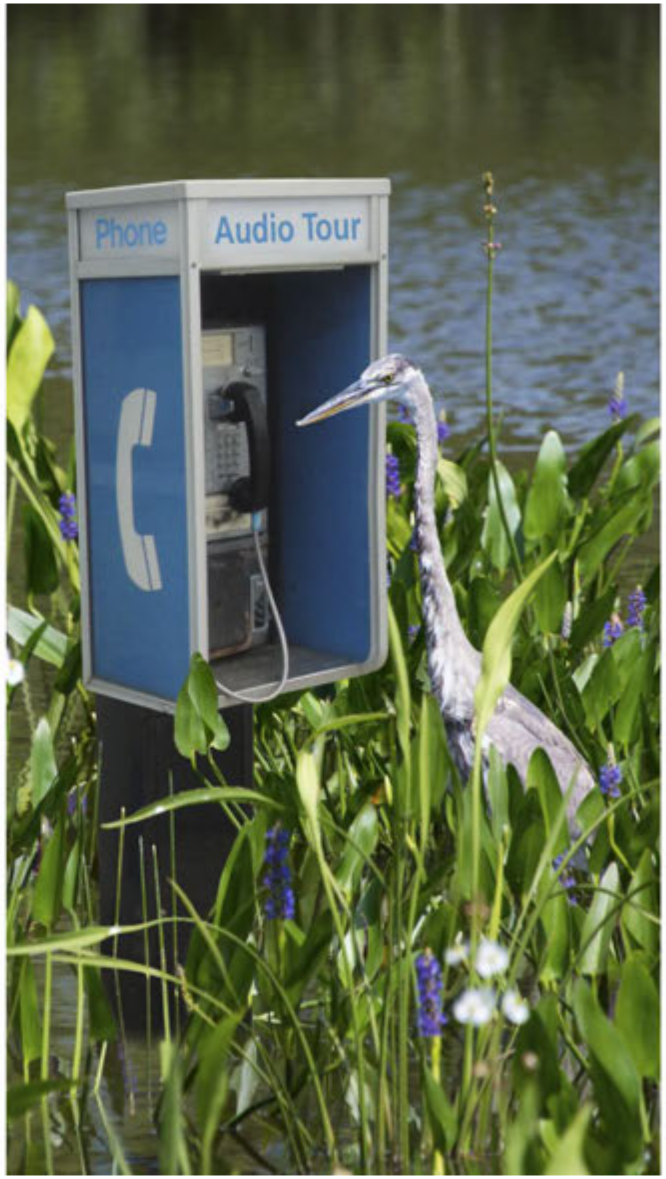
The Science and Environment Council's Watershed Audio Tour was funded by the Southwest Florida Water Management District with more recent funding from the Sarasota Bay Estuary Program.

Science and Environment Council

The Council is a non-profit consortium of the leading science-based environmental non-profit and government organizations working in Sarasota and Manatee Counties. Our mission is to increase science-based environmental understanding, conservation and restoration.

Visit us at ScienceAndEnvironment.org



Dial 941-926-6813

and enter a tour stop number listed below:

1. **Wetlands** — Sarasota County's Celery Fields
2. **Ecosystems** — Crowley Museum and Nature Center
3. **Water Quality** — G. WIZ - The Science Museum
4. **Mangroves** — Historic Spanish Point
5. **Seagrasses** — Sarasota County's Indian Mound Park
6. **Marine Life** — Mote Marine Laboratory and Aquarium
7. **Bay Neighbor Landscaping** — New College of Florida
8. **Tree Canopies** — New College of Florida
9. **Prescribed Burns** — Oscar Scherer State Park
10. **Exotic Plant Removal** — Sarasota County's Phillippi Estate Park
11. **Estuaries** — Sarasota Bay Estuary Program
12. **Land Conservation** — Conservation Foundation of the Gulf Coast
13. **Green Roofs** — Marie Selby Botanical Gardens
14. **Rain Barrels and Cisterns** — Florida House Institute
15. **Water Flow** — Aquarian Quest
16. **Wild and Scenic River** — Myakka River State Park
17. **Water Preservation** — Crowley Museum and Nature Center
18. **Florida Pines** — Myakka River State Forest
19. **Stormwater Retention** — Sarasota County's Celery Fields
20. **Tidal Lagoons** — Marie Selby Botanical Gardens
21. **Rookeries** — Venice Area Audubon Society
22. **Manatee River Manatees** — South Florida Museum
23. **Bay Island Restoration** — Sarasota Bay Watch
24. **Salterns** — Manatee County's Robinson Preserve
25. **Prehistoric Life on Manatee River** — Manatee County's Emerson Point Preserve
26. **Footsteps of the Past** — Manatee County's Neal Preserve
27. **Living Shorelines** — Sarasota Bay Estuary Program
28. **Lemur Land Conservation** — Lemur Conservation Foundation
29. **Red Bug Slough** — Sarasota County's Red Bug Slough Preserve
30. **Coastal Wetlands** — Marie Selby Botanical Gardens

<u>SOCIAL MARKETING: THERE IS NO POOP FAIRY</u>

David J. Shafer, PhD and Jennifer L. Shafer, PhD

ABSTRACT

Pet waste negatively impacts water quality and public health. It can spread harmful bacteria, parasites and nutrients. We developed a social marketing campaign for Sarasota County to encourage pet owners to pick up and properly dispose of pet waste. Messaging was based on a slogan popularized by the Jefferson County, Colorado Sheriff's Office: "There is no poop fairy". Before designing the campaign, we used informal public intercept surveys to catalogue commonly cited barriers, misconceptions and benefits to "picking it up". Results were used to inform messaging strategy. For example, because surveys indicated that men were less likely to "pick it up" than women, we designed a poop fairy to caricaturize that target demographic, and chose a male employee from Sarasota County Water Resources (now famous!) to be our model.

Moon Bikes built a six-foot-tall tricycle, equipped with a large poop fairy billboard for the campaign. We used the monster trike for guerilla marketing at art and music festivals, street fairs, parades and other outdoor events. We created an infographic rack card to communicate the impact and health consequences of pet waste, and handed them out at outreach events and other venues. We also converted elements of the infographic into an interactive poop toss game, which engaged players young and old to shrug off any stigma associated with "picking it up". Players were challenged to pick up and toss poop bags into a can to win a "Poopsie Roll"! The campaign also utilized posters, custom rack card holders featuring a six-foot poop fairy, movie theater screen ads, facebook ads and an online quiz. Shafer Consulting designed and implemented the campaign for the Science and Environment Council and Sarasota County Water Resources. Funding was provided by Sarasota County Water Resources.

Social Marketing: There is No Poop Fairy

Dr. David Shafer + Dr. Jennifer Shafer | SHAFER consulting | david@shafer-consulting.org

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PRACTICAL APPLICATIONS OF ENVIRONMENTAL MANAGEMENT & POLICY

[THE ROLE OF SEEDBEDS IN *PYRODINIUM BAHAMENSE* BLOOM DYNAMICS IN TAMPA BAY]

Cary B. Lopez, Christopher G. Smith, Marci E. Marot, David J. Karlen and Alina A. Corcoran

ABSTRACT

Habitat restoration and water quality improvements in Tampa Bay, FL (USA) provide a success story in estuarine management. An exception to this story is Old Tampa Bay, a sub-estuary of Tampa Bay that has recovered more slowly than other bay segments. This lag, signified by missed water quality targets and declines in seagrass coverage, is due in part to recurring blooms of the dinoflagellate *Pyrodinium bahamense*. In this work, we use historical analysis, field observations, and laboratory experiments to uncover contributing factors to *P. bahamense* blooms. As part of its life cycle, *P. bahamense* produces resting cysts that settle to the seafloor, creating a reservoir that serves to seed future blooms. Sediment core data reveal that *P. bahamense* cysts predate observations of notable blooms -- indicating historical presence of *P. bahamense* at low levels in the phytoplankton community. In a single core collected in 2014, increases in accumulation of fine-grain sediment and organic matter correspond temporally to the emergence of recurring *P. bahamense* blooms. These results suggest that relatively recent physical and(or) environmental changes may have led to conditions that favor bloom formation. Moreover, higher cyst abundance in surface sediments of Old Tampa Bay correlates with finer sediments and is co-located with bloom initiation. Laboratory experiments show that cysts can germinate over a range of conditions present in Tampa Bay, but that changes in environmental parameters, such as temperature, influence germination rates. Together, our results suggest restoration strategies that consider cyst dynamics may improve recovery of Old Tampa Bay through mitigation of nuisance *P. bahamense* blooms.

INTRODUCTION

Since the 1980s, local managers have considerably restored habitats and improved water quality in Tampa Bay, FL (USA). However, the recovery of Old Tampa Bay (OTB), the northwest bay segment, has generally lagged behind other Bay segments. Since 2000, the dinoflagellate *Pyrodinium bahamense* has bloomed nearly annually in OTB, where its high biomass (chlorophyll *a* concentrations often exceeding 20 µg L^{-1}) and cascading effects of low dissolved oxygen, fish kills, and degraded water quality contribute to observed lags in ecosystem recovery. In addition, this alga produces saxitoxins that can accumulate in filter-feeding shellfish, leading to paralytic shellfish poisoning (PSP) in humans if contaminated shellfish are consumed (Rein and Borrone, 1999). Although there are no established shellfish harvesting areas in OTB at present, as shellfish restoration efforts progress, PSP may become a threat in this region.

As part of its life cycle and like many dinoflagellates, *P. bahamense* produces resting cysts (often during bloom decline), which allows the population to remain dormant during conditions unfavorable for vegetative cell growth. The immobile resting cysts settle to the seafloor, creating a cyst bed to seed future blooms. Germination, or excystment, is later triggered when critical internal (e.g., cyst maturation, endogenous cycles) and external (e.g., light, temperature, oxygen) factors optimally align. In OTB, *P. bahamense* bloom initiation is co-located with the greatest densities of cysts in the sediment, supporting the hypothesis that the location and composition of cyst beds are primary predictors of bloom initiation (Karlen and Campbell 2012, C. Lopez unpublished data) and that establishment of cyst beds may be key to bloom recurrence. Here we use historical analysis, field observations, and laboratory experiments to explore the link between resting cyst dynamics and *P. bahamense* blooms in OTB.

METHODS

Sediment cores. In January 2014, we collected sediment cores from a site in OTB, east of Cooper Point (OTB2, Figure 1), using a Wildco KB Core sampler. A single-38-cm core was sectioned at 1-cm intervals and processed for cyst abundance, bulk density, organic matter, sediment texture, and chronology (lead-210 based). We estimated bulk density from the mass lost from a known volume of wet sediment when dried at 60°C for 48 hours. Organic matter content was also measured using mass difference techniques. Mass was recorded before and after sediment exposure at 550°C for 6 hours in a muffle furnace. For bulk density and organic matter content, the pre- and post-masses were differenced and normalized to initial wet volumes and dry sediment mass, respectively. We measured grain size on the inorganic fraction of the sediment using laser diffraction on a Coulter LS-200 Particle Size Analyzer. Organic matter was chemically removed from sediment using a 30% hydrogen peroxide solution with exposure time greater than 8 hours prior to grain size analysis. The activity of lead-210 was measured by isotope dilution alpha spectrometry via its granddaughter isotope polonium-210 and tracer polonium-209. Samples were combusted at 550°C prior to wet chemical extraction and plating of polonium following a modification to the procedure of Robbins and Edgington (1975).

Germination experiments. To define the light and temperature requirements for germination of *P. bahamense,* we conducted experiments across a range of light and temperature conditions characteristic of OTB bottom water. Sediment for germination experiments was collected from the study site in OTB (Figure 1) using a Petite Ponar grab sampler during February 2014 and stored in the dark at 15°C. Prior to experiments, cysts were harvested following Bolch (1997) using sodium polytungstate (1.3 g mL^{-1}) and centrifugation to separate the intact cysts from the sediments. We resuspended harvested cysts in 0.2 μm-filtered seawater and isolated individually into the inner 32 wells of 98-well microplates filled with Tampa Bay water enriched with GSe/20 nutrients (Blackburn 2001). For the light experiments, replicate microplates were maintained at 26° C under 190 µE $m^{-2}s^{-1}$ ("high light") or 40 µE $m^{-2}s^{-1}$ ("low light") on a 12:12 light:dark cycle or in the dark ("dark") for 30 days in the first experiment and only in low light and dark for the second experiment. For temperature experiments, replicate microplates were maintained with an illumination of 40 µE $m^{-2}s^{-1}$ on a 12:12 light:dark cycle at 17°C, 23°C, and 29°C. Microplates were checked daily for germination using an Olympus CK inverted microscope at 200X magnification. For the light experiments, we conducted this work using a red filter over the light source to eliminate light exposure during microscopy. Germination success (% germination) and lag to germination were calculated. ANOVA with post-hoc Tukey tests were used to evaluate differences across light and temperature conditions for the temperature and the first light experiment. A t-test was used for the second light experiment.

RESULTS AND DISCUSSION

Sediment core data from OTB2 reveal that *P. bahamense* cysts in the sediments predate observations of notable blooms (Figure 2). Prior to 2000, blooms were recorded only in 1975, 1977, and 1983 (Karlen and Campbell 2012); however, we found intact cysts at all intervals of the core, including in sediments dated to >100 years old. These findings suggest low levels of *P. bahamense* in the Bay were common historically. Above the 13-cm interval of the core (dated at approximately 1990), a sharp change to finer-grained sediment and a steady increase in organic matter content and cyst abundance correspond temporally to the recent emergence of recurring *P. bahamense* blooms (Figure 2). Peebles et al. (2009) attributed localized increases in fine-grained sediment accumulation in Safety Harbor to internal microalgal production as a result of eutrophication in the Safety Harbor area. Similarly, settling of *P. bahamense* cells and cysts after large blooms could potentially be responsible for observed increases in fine-grained sediments and organic matter at our study site. Alternatively, the changes in sediment texture could signify physical and(or) environmental changes that favor bloom formation and resting cyst retention in OTB. System-wide cyst surveys in surface sediments conducted in multiple years have revealed increases in cyst abundance over time in some locations of OTB (Karlen and Miller 2011, Karlen and Campbell 2012, Karlen et al. 2015), indicating potential expansion of the established *P. bahamense* seed beds as a factor in recurring blooms since 2000. To complement this dataset, we are analyzing sediment cores from other locations in OTB to explore spatial patterns of historical cyst abundance. We are also investigating shorter term (seasonal) variability in cyst abundance to better understand cyst bed dynamics over time.

Experiments revealed that *P. bahamense* can germinate over a range of environmental conditions encountered in OTB. We found that light is not a requirement for germination, but that the lag to germination is slightly longer (~3-4 days) in the dark than in the light (Table 1). There was no significant difference in germination success across the range of temperatures, but the lag to germination at the coldest (i.e., winter) temperature was weeks longer than that at warmer temperatures (Table 1). This finding has important implications for bloom development. Specifically, cysts germinating in wintertime would likely be buried or transported out of the system before germination could be completed. Our findings suggest germination could occur rapidly as temperatures begin to warm during the early spring in OTB, and although light availability is not required for germination, increases in light availability would speed the process of germination. We are currently investigating other factors -- such as cyst maturation, internal cycles, and resuspension events -- that may also be important controls of timing and interannual variability of bloom initiation. Understanding the role of these factors, as well as requirements for vegetative cell growth, will advance efforts to predict and potentially manage *P. bahamense* blooms.

ACKNOWLEDGMENTS

We would like to thank Sue Murasko and Eric Robinson of FWC for their help in the field and Alisha Ellis, Cathryn Wheaton, Scott Adams, and Katie Richwine of the USGS for their help in processing the cores in the laboratory. This work was funded through general revenue through the State of Florida and Federal appropriations through the Coastal and Marine Geology Program of the USGS. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the US government.

FIGURES AND TABLES

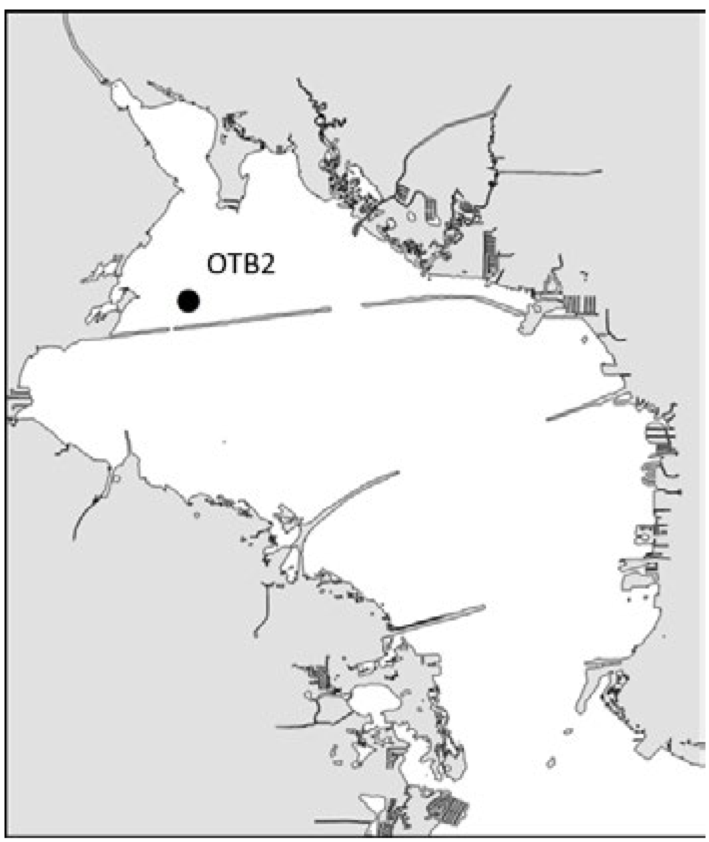

Figure 1. Map of Old Tampa Bay showing site of sediment collection (OTB2).

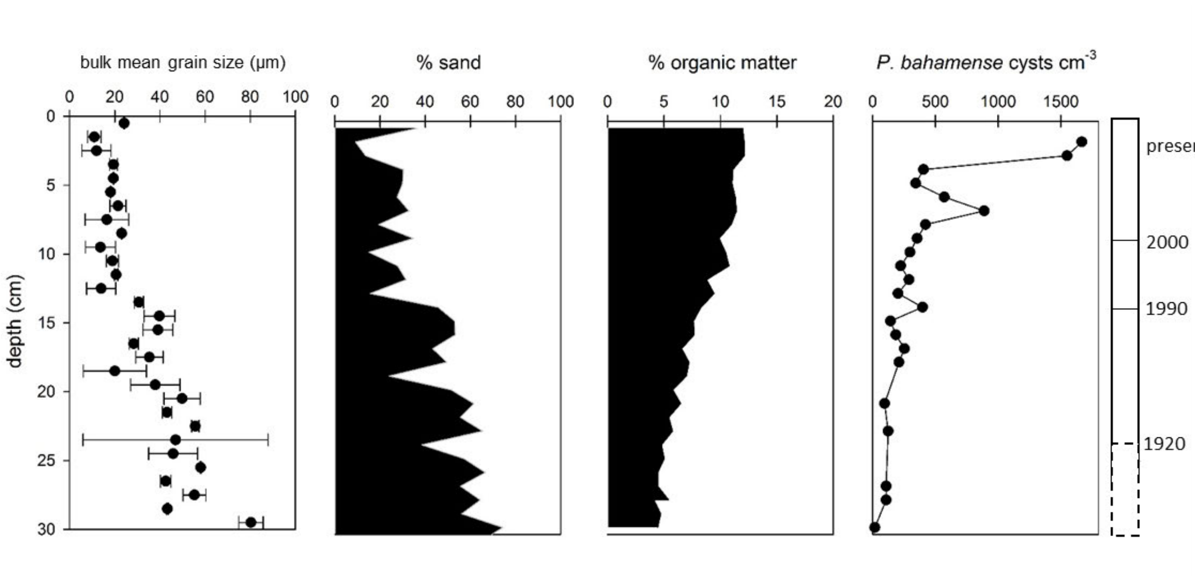

Figure 2. Sediment characteristics and *Pyrodinium bahamense* cyst abundance shown as a function of sediment depth and estimated age of sediment core.

Table 1. Mean (± standard error) germination success and lag time to germination in two light experiments (I and II) and the temperature experiment. Results of ANOVA (df=2) and t-test (df=4) are also presented. Gray shading indicates significant treatment effects and superscript letters indicate differences identified by post-hoc Tukey comparisons.

	Light Experiments				Temperature Experiment			
	High Light	Low Light	Dark	ANOVA	17°C	23°C	29°C	ANOVA
I								
% Germination	20 ± 2.6	24 ± 7.6	38 ± 7.4	F = 2.4, p = 0.174	13 ± 2.5	33 ± 7.9	26 ± 4.8	F = 3.5, p = 0.064
Lag to germination (days)	4 ± 0.8^{A}	4 ± 0.4^{B}	8 ± 0.5^{B}	F = 16.2, p = 0.004	23 ± 0.8^{A}	6 ± 0.2^{B}	4 ± 0.3^{B}	F = 432, p<0.001
				t-test				
II								
% Germination success		30 ± 4.3	40 ± 9.4	t = 0.957, p = 0.393				
Lag to germination (days)		6 ± 0.2	9 ± 0.1	t = 10.5, p < 0.001				

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[LIGHT ABSORPTION PROPERTIES OF ALGAL BLOOMS IN OLD TAMPA BAY: IMPLICATIONS FOR MANAGEMENT]

Jennifer P. Cannizzaro, Alina A. Corcoran, Jennifer L. Wolny, Chuanmin Hu

ABSTRACT

Bio-optical models for estimating phytoplankton absorption coefficients, aph(λ), from chlorophyll-a concentrations, Chl-a, in Old Tampa Bay (OTB) are currently calibrated with data collected during non-bloom conditions from different bay segments. Here, the effect of phytoplankton community shifts on model performance was examined using bio-optical field measurements collected in OTB at nine locations every 1 to 3 weeks between June and December 2013. Chl-a ranged from 2.0 to 330.3 mg m-3, with higher values typically observed in northern-central bay segments from July to September and associated with high Pyrodinium bahamense abundance (>102 cells ml-1). Spatiotemporal shifts in phytoplankton community composition assessed by High-Performance Liquid Chromatography (HPLC) pigment concentrations were found. Blooms dominated by diatoms, dinoflagellates, and chlorophytes were observed. Chlorophyll-specific phytoplankton absorption coefficients at 440nm, a*ph(440), varied four-fold between P. bahamense- and chlorophyte-dominated populations with differences associated with cell size. Future refinements to existing bio-optical models for estimating light attenuation coefficients, Kd(λ), in this region should consider phytoplankton type and size to better estimate light penetration at depth for seagrass monitoring and restoration efforts.

INTRODUCTION

Bio-optical models for estimating light attenuation coefficients, $K_d(\lambda)$, in marine and inland waters require knowledge of light absorption and scattering properties of optically significant constituents (OSCs), including phytoplankton, non-algal detritus, and colored dissolved organic matter (CDOM). For management applications, these parameters are often derived empirically from standard water quality measurements, including chlorophyll-*a* concentrations (Chl-a), turbidity, and color (Gallegos, 2005). Globally tuned power-law functions for estimating phytoplankton absorption coefficients, $a_{ph}(\lambda)$, from Chl-a generally succeed in marine and coastal waters because factors controlling $a_{ph}(\lambda)$, such as pigment composition and pigment packaging, change predictably over space and time (Bricaud et al., 2004; Bricaud et al., 1998; Yentsch and Phinney, 1989). However, regional tuning of these relationships is sometimes necessary in estuarine and inland waters where dynamic hydrographic conditions alter nutrient and light regimes, promoting the dominance of different phytoplankton groups with variable optical properties (Zhang et al., 2012).

In recent years in Old Tampa Bay (OTB; Florida, USA), blooms of the dinoflagellate *Pyrodinium bahamense* have increased in frequency (Badylak et al., 2007; FWC-FWRI and EPC unpublished data). This species, which produces saxitoxin, a neurotoxin that causes Paralytic Shellfish Poisoning (PSP) and Saxitoxin Pufferfish Poisoning, has been responsible for human illnesses associated with consumption of pufferfish harvested from the nearby Indian River Lagoon (Landsberg et al., 2006). Such blooms generally occur in shallow, tropical-subtropical ecosystems with long (> weeks) residence times (Phlips et al., 2006). *P. bahamense* cells are large (>35µm) and heavily pigmented, containing the carotenoid peridinin for harvesting blue-green light. The absorption properties of *P. bahamense* blooms, to our best knowledge, have yet to be reported. However, studies performed on natural populations dominated by larger (>10µm) genera, such as the dinoflagellates *Gonyaulax* and *Prorocentrum*, have shown lower chlorophyll-specific phytoplankton absorption coefficients, $a^*_{ph}(\lambda)$, compared to smaller (<3µm) genera, such as the cyanophytes *Prochlorococcus* and *Synechococcus* (Ciotti et al., 2002). Such differences in absorption properties of individual taxa may affect the accuracy of light absorption models (Zhang et al., 2012) and influence remote sensing applications (Tao et al., 2013).

METHODS

Field sampling in OTB was conducted in coordination with the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute (FWC-FWRI). Temperature and conductivity (salinity) were recorded using a YSI6600 multi-parameter probe and water samples were collected from surface waters (~0.5m) at nine standard stations every 1 to 3 weeks between June and December 2013 (Figure 1).

Phytoplankton were identified to the lowest taxonomic level possible and enumerated using an inverted light microscope (Olympus IX71or Zeiss Axiovert 200) using a settling chamber technique modified from Marshall and Alden (1990). Pigment concentrations were measured by High-Performance Liquid Chromatography (HPLC) (Van Heukelem and Thomas, 2001) and phytoplankton absorption spectra were determined using the quantitative filter technique (Mitchell, 1990; Yentsch, 1962).

Phytoplankton community composition determined from HPLC pigment concentrations used a modified multiple linear regression approach developed originally for Florida Bay by Louda (2008). Zeaxanthin was used as a bio-marker pigment for cyanophytes. Similarly, concentrations of chlorophyll-b, fucoxanthin, peridinin, and alloxanthin were used to estimate contributions by chlorophytes, diatoms, dinoflagellates, and cryptophytes, respectively. Community dominance was defined when certain algal groups (diatoms, dinoflagellates, and cryptophytes) contributed >55% to total algal biomass as represented by Chl-a. A lower threshold (>40%) was used for determining dominance by cyanophytes and chlorophytes. This was because these latter algal groups often co-occurred and at times together contributed >70% to total biomass during blooms.

Dinoflagellate dominance was further divided into two sub-groups: (1) 'DINO-Pb' representing populations with *P. bahamense* concentrations >20 cells ml^{-1} combined with biomass contributions by cyanophytes and chlorophytes <15% and (2) 'DINO-other' representing populations with either *P. bahamense* concentrations <20 cells ml^{-1} or *P.*

bahemense concentrations >20 cells ml^{-1} combined with biomass contributions by cyanophytes and chlorophytes >15%.

RESULTS

Water temperature ranged from 17.1 to 32.1°C with values >25°C observed between June and October and values <25°C in November and December (Fig. 2a). There was little (<2°C) spatial variation in temperature throughout the bay. Salinity varied three-fold (9.4 to 28.5 psu) throughout the sampling period, with lowest values recorded in August in northern portions of OTB (Fig. 2b). Salinity declined bay wide during the wet season (June-September) following rainfall and discharge by local creeks and canals (source: United States Geological Survey).

Chl-a varied over two orders of magnitude (2.0-330.3 mg m^{-3}) (Fig. 2c). Monthly mean Chl-a was lowest (6.9-7.8 mg m^{-3}) during June and December and greatest (20.0-29.0 mg m^{-3}) between July and September. Spatially, mean Chl-a was lowest (7.8-11.8 mg m^{-3}) in the east and far south and greatest (20.5-32.3 mg m^{-3}) in the west and far north. A phytoplankton bloom (Chl-a > 20 mg m^{-3}) associated with high *P. bahamense* abundance (>10^2 cells ml^{-1}) was observed throughout all except the most eastern and southern portions of OTB between mid-July and September (Fig. 2d). Blooms dominated by other taxa were also observed in northern and central OTB between September and November.

Large shifts in phytoplankton community composition were observed with temporal variability largely outweighing spatial variability (Fig. 3). Diatoms dominated the community in June and July followed by dinoflagellates (Type 'DINO-Pb') between July and September. Both of these algal groups often contributed >80% to total algal biomass. Contributions by cyanophyte and chlorophyte populations increased in September and October, during the decline of the *P. bahamense* bloom. These populations often co-occurred, attaining bloom status in mid-September in northern and central OTB. Light microscopy revealed high numerical abundances (>10^7 cells l^{-1}) of picoplankton (<3µm) in this bloom, indicating that this bloom was largely dominated by cyanophytes and chlorophyll-b containing picoeukaryotes (Vaulot et al., 2008). Blooms containing mixed assemblages of other large (>20µm) dinoflagellates (*Ceratium hircus*, *Scrippsiella trochoidea*, and *Akashiwo sanguinea*) (Type 'DINO-other') occurred in October and November in northern and central portions of OTB. Cryptophytes dominated in December during the dry season only, but never reached high biomass.

Compared to published power-law relationships between Chl-a and $a_{ph}(440)$ in oceanic, coastal, and estuarine waters (r^2>0.92) (Bricaud et al., 2004; Cannizzaro et al., 2008; Dixon, 2014; Le et al., 2013), a weaker correlation (r^2=0.67) was observed for OTB (Fig. 4). This result was largely caused by the low $a^*_{ph}(440)$ (0.012±0.003 m^2 mg^{-1}) associated with dinoflagellates belonging to the DINO-Pb sub-group (Table 1). In contrast, $a^*_{ph}(440)$ for populations dominated by diatoms, dinoflagellates in the 'DINO-other' sub-group, and cryptophytes (0.023-0.032 m^2 mg^{-1}) generally agreed with previously reported relationships, and $a^*_{ph}(440)$ for cyanophyte- and chlorophyte-dominated populations (0.045-0.049 m^2 mg^{-1}) often exceeded these relationships.

Differences in pigmentation and pigment packaging between algal groups were examined to determine the source of the variability in the relationship between Chl-a and $a_{ph}(440)$. Pigment composition varied highly depending on the dominant algal group/subgroup present (Table 2). Populations dominated by diatoms and dinoflagellates exhibited relatively high Chl-c/Chl-a and photosynthetic carotenoid (PSC)/Chl-a and low Chl-b/Chl-a and photoprotective carotenoid (PPC)/Chl-a as is typical of most chromophytic algae (Jeffrey et al., 2011). PPC/Chl-a was relatively high for cyanophyte-dominated populations, reflecting high contributions by zeaxanthin. Accessory chlorophyll/Chl-a and PSC/Chl-a were relatively low for cyanophyte- and cryptophyte-dominated populations as the main light-harvesting accessory pigments for these algal groups are water-soluble phycobiliproteins not quantified by HPLC. Chlorophyte-dominated populations also exhibited relatively low Chl-c/Chl-a and PSC/Chl-a. Mean Chl-b/Chl-a for these populations was high both in this study and compared to previous reports for eutrophic waters in coastal and upwelling environments (Bricaud et al., 2004; Matsuoka et al., 2011; Sathyendranath et al., 2005).

To examine how pigment variability affected the relationship between Chl-a and $a_{ph}(440)$, absorption spectra due to pigments, $a_{pig}(\lambda)$, were reconstructed based on knowledge of individual pigment concentrations and spectral weight-specific pigment absorption coefficients according to Bricaud et al. (2004). The four-fold lower $a^*_{ph}(440)$ exhibited by dinoflagellates belonging to the DINO-Pb sub-group compared to chlorophytes for Chl-a ~20-30 mg m^{-3} was not caused by differences in pigmentation (Table 1; Fig. 5a,b). $a^*_{pig}(440)$ for DINO-Pb dinoflagellates was ~8% higher than for the chlorophyte bloom when it would have been lower had pigments been the source of this variability. This was likely because the weight-specific pigment absorption coefficient for Chl-c is twice as high compared to Chl-b at 440nm (Johnsen et al., 1994). Instead, the lower $a^*_{ph}(440)$ for the *P. bahamense* bloom was caused by strong pigment packaging, as evidenced by a three-fold lower mean pigment packaging index, $Q^*_a(440)$, for DINO-Pb dinoflagellates (0.15±0.02) compared to that for the chlorophyte bloom (0.47±0.06) (Fig. 5c).

DISCUSSION

Global models for estimating $a_{ph}(\lambda)$ from Chl-a often succeed in aquatic environments where nutrient enrichment is linked to enhanced turbulence (Margalef, 1978). Under these conditions, microplankton (>20μm) have the tendency to dominate in eutrophic waters and picoplankton in oligotrophic waters. This paradigm breaks down, though, in more hydrodynamically complex systems, including estuarine and inland environments (Phlips et al., 2014; Phlips et al., 1999). In these systems, additional factors (e.g. freshwater discharge, wind-driven resuspension, and tidal circulation) may cause alterations in nutrient and light regimes, resulting in diverse phytoplankton populations with variable optical properties (Wang et al., 2014).

Previous studies have shown that the various sub-basins in Tampa Bay support different phytoplankton assemblages with diatoms typically dominating algal biomass in Lower Tampa Bay and dinoflagellates, represented mainly by *P. bahamense*, dominating in OTB (Badylak et al., 2007; Phlips et al., 2006). The results of this study confirm the relative importance of *P. bahamense* in OTB and the successional pattern from diatoms to *P. bahamense* to picoplankton observed previously during 2002-2003. However, several important differences were noted between studies. While picoplankton dominated numerically and contributed only minimally to algal biomass following the 2002-2003 *P. bahamense* bloom, picoplankton dominated numerically and in terms of biomass briefly during the demise of the 2013 bloom. Also, while previous reports of picoplankton populations consisted mainly of cyanophytes, chemotaxonomic analyses revealed the importance of both cyanophytes and chlorophyll-b containing picoeukaryotes (chlorophytes) to picoplankton assemblages in this study. Picoeukaryote populations are commonly underestimated by light microscopy because of difficulties pertaining to cell preservation and lack of distinctive morphological features (Breton et al., 2000; Zapata, 2005). Blooms of small diatoms and other potentially nuisance and/or harmful dinoflagellate species (*Ceratium hircus*, *Scrippsiella trochoidea*, and *Akashiwo sanguinea*) were also observed in late-2013, but not in 2002-2003.

The $a_{ph}(\lambda)$ model currently being utilized by local management agencies for modeling light penetration as part of seagrass monitoring and restoration efforts in OTB was calibrated using data collected south of OTB under non-bloom conditions (Chl-a < 20 mg m^{-3}) (Dixon, 2014). Results here indicate that $a_{ph}(440)$ estimated during blooms of *P. bahamense* with Chl-a ~20-30 mg m^{-3} will be overestimated by ~60% with this model because of the low $a^*_{ph}(440)$ exhibited by this species. Conversely, $a_{ph}(440)$ estimated during picoplankton blooms will be underestimated by ~45% because of higher $a^*_{ph}(440)$. The order of magnitude difference in mean cell size between these bloom types was the likely source of differences in $a^*_{ph}(440)$, contributing to a >3-fold change in the pigment packaging index.

The results of this study agree with previous findings that the variability about trends in Chl-a and $a_{ph}(\lambda)$ contain important information on the pigmentation and size structure of algal communities (Bricaud et al., 2004; Babin et al., 2003; Ciotti et al., 2002). The relative significance of the observed differences in $a^*_{ph}(440)$ between bloom types on $K_d(\lambda)$ models, though, still needs to be assessed, especially in light of large optical contributions often made by co-occurring non-algal OSCs (e.g. CDOM and suspended sediments) for this optically complex estuary (Le et al., 2013). Future refinements to $a_{ph}(\lambda)$ models may need to consider algal type, especially if blooms dominated by organisms of variable cell size, like *P. bahamense* and picoplankton, continue to increase in prevalence in OTB and for other estuarine regions (Phlips et al., 2014; Phlips et al., 1999; Walsh et al., 2011).

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Table 1. Mean (±standard deviation) water temperature, salinity, *P. bahamense* abundance, chlorophyll-*a* concentrations, chlorophyll-specific phytoplankton absorption coefficients at 440nm ($a^*_{ph}(440)$), and pigment packaging index at 440 ($Q^*_a(440)$) associated with populations dominated by specific algal groups/subgroups.

Group/ Subgroup	n	Temp. (°C)	Salinity (psu)	*P. bahamense* (cells ml^{-1})	Chl-a (mg m^{-3})	$a^*_{ph}(440)$ (m^2 mg^{-1})	$Q^*_a(440)$
DIATOM	28	28.9 (3.3)	23.2 (2.4)	4 (9)	11.5 (5.1)	0.024 (0.005)	0.283 (0.052)
DINO							
DINO-Pb	22	29.6 (1.4)	19.4 (2.1)	647 (1,139)	55.7 (66.6)	0.012 (0.003)	0.150 (0.031)
DINO-other	15	27.7 (3.6)	16.6 (2.3)	78 (109)	25.3 (12.9)	0.023 (0.004)	0.277 (0.048)
CYANO	3	28.0 (2.1)	17.5 (0.7)	2 (1)	10.4 (3.8)	0.049 (0.003)	0.559 (0.036)
CHLORO	7	24.3 (5.9)	18.9 (3.5)	25 (31)	15.6 (11.1)	0.045 (0.014)	0.534 (0.155)
CRYPTO	3	18.4 (0.1)	20.5 (1.1)	0 (0)	8.0 (1.6)	0.032 (0.008)	0.381 (0.085)

Table 2. Mean pigment ratios (scaled to Chl-*a*) for populations dominated by specific algal groups/ subgroups.

Group/ Subgroup	n	Chl-b	Chl-c	PSC*	PPC**
DIATOM	28	0.013	0.122	0.418	0.211
DINO					
DINO-Pb	22	0.008	0.182	0.409	0.227
DINO-other	15	0.039	0.154	0.331	0.242
CYANO	3	0.075	0.050	0.131	0.418
CHLORO	7	0.208	0.049	0.089	0.266
CRYPTO	3	0.044	0.093	0.057	0.281

*Photosynthetic carotenoids (PSC) include 19'-butanoyloxyfucoxanthin, fucoxanthin, 19'-hexanoyloxyfucoxanthin, and peridinin.

**Photoprotective carotenoids (PPC) include alloxanthin, carotenes, diadinoxanthin, diatoxanthin, and zeaxanthin.

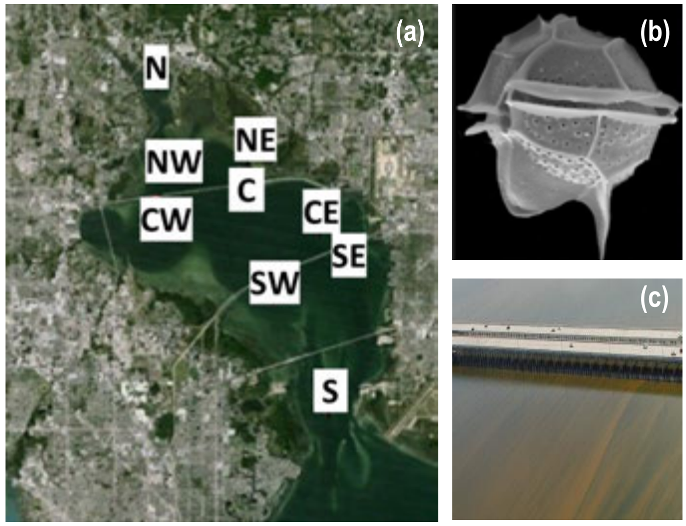

Figure 1. (a) Locations of routine sampling stations in Old Tampa Bay (Florida, USA) between June and December 2013. (b) Scanning electron micrograph of *Pyrodinium bahamense*. (c) Aerial photograph of a *P. bahamense* bloom in Tampa Bay (credit: Dorian Aerial Photographics).

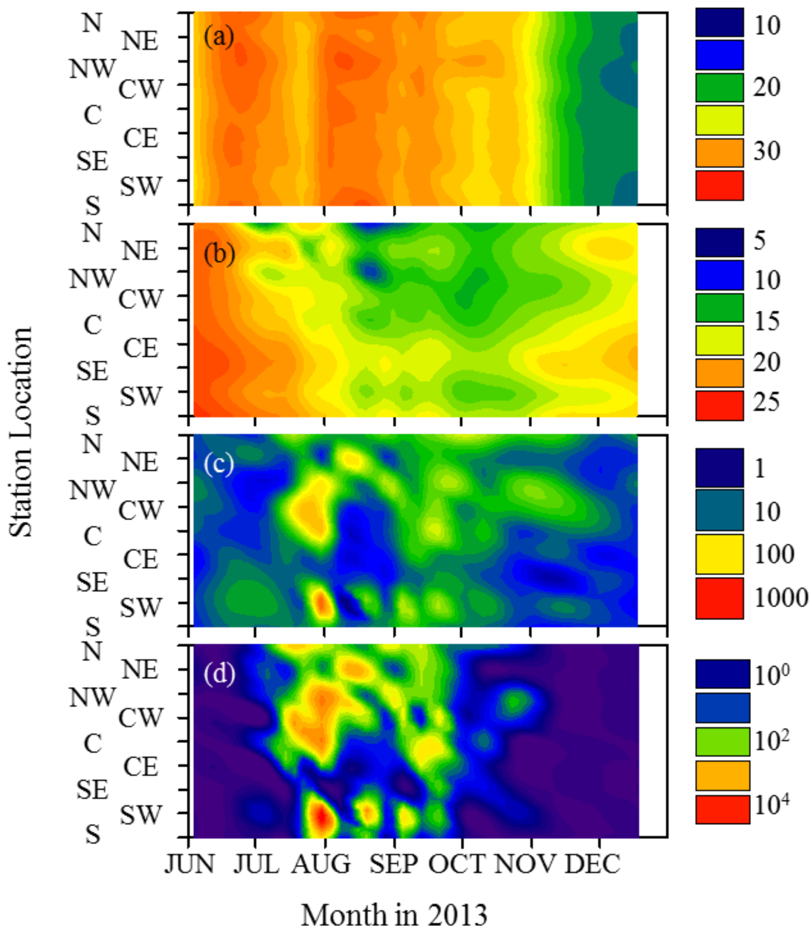

Figure 2. Spatiotemporal variability of (a) water temperature (°C), (b) salinity (psu), (c) Chl-a (mg m^{-3}), and (d) *Pyrodinium bahamense* abundance (cells ml^{-1}).

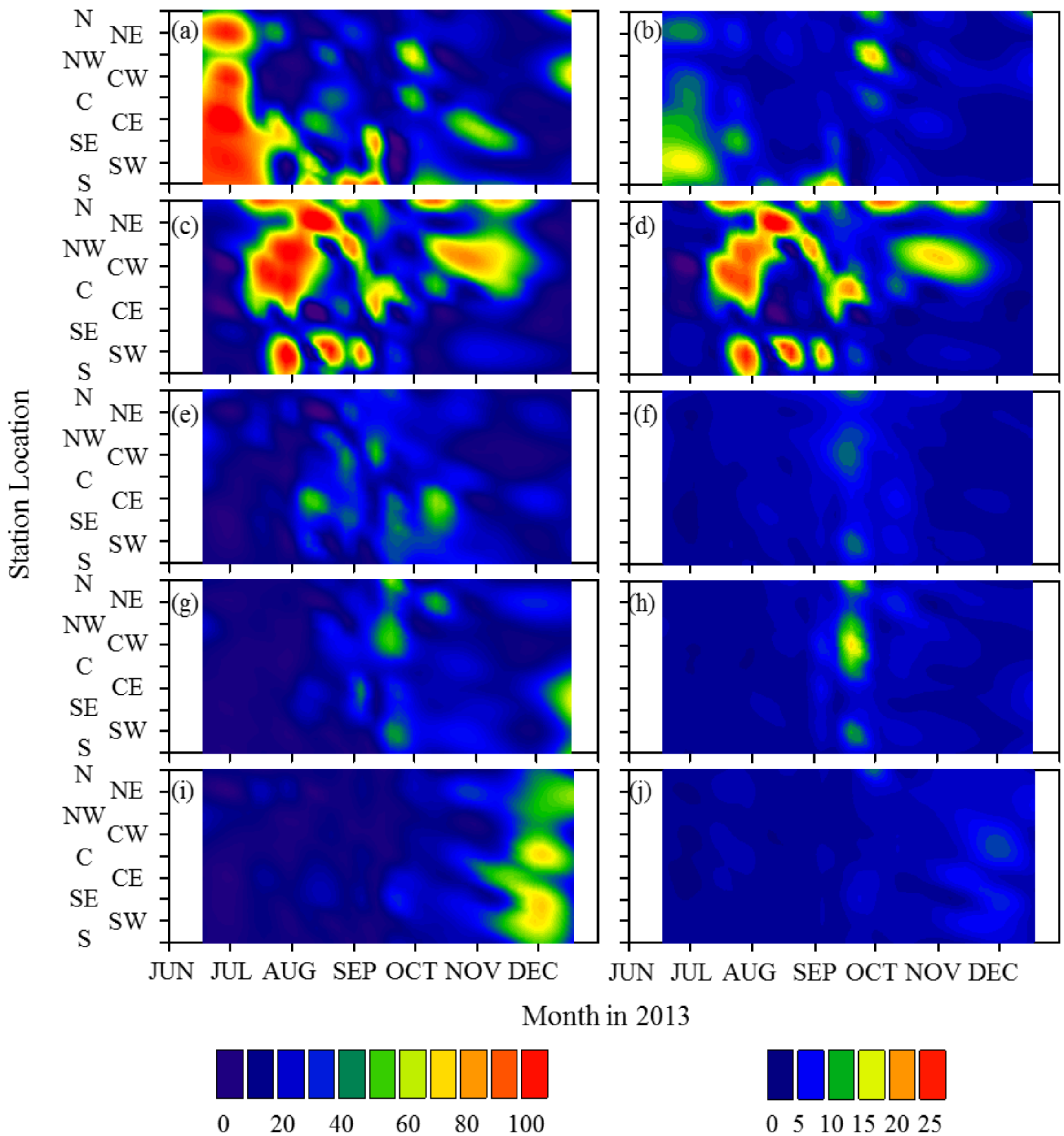

Figure 3. Percentage contribution of total Chl-a (left column) and group-specific Chl-a (mg m^{-3}) (right column) for (a,b) diatoms, (c,d) dinoflagellates, (e,f) cyanophytes, (g,h) chlorophytes, and (i,j) cryptophytes.

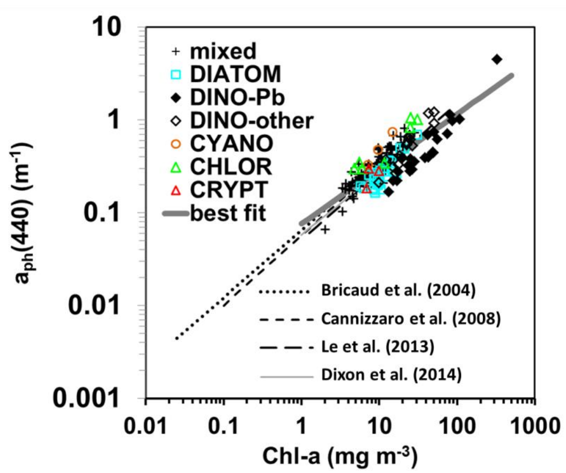

Figure 4. Relationship between Chl-a and $a_{ph}(440)$ with data sorted based on the dominant algal group/subgroup present. Mixed populations (+) represent situations when no single algal group/subgroup dominated. The thick solid gray line represents the best-fit power law relationship determined on log-transformed data: $a_{ph}(440)$=0.079 Chl-$a^{0.586}$ (r^2=0.67, n=152). Previously determined relationships are also shown for comparison (Bricaud et al., 2004; Cannizzaro et al., 2008; Dixon, 2014; Le et al., 2013).

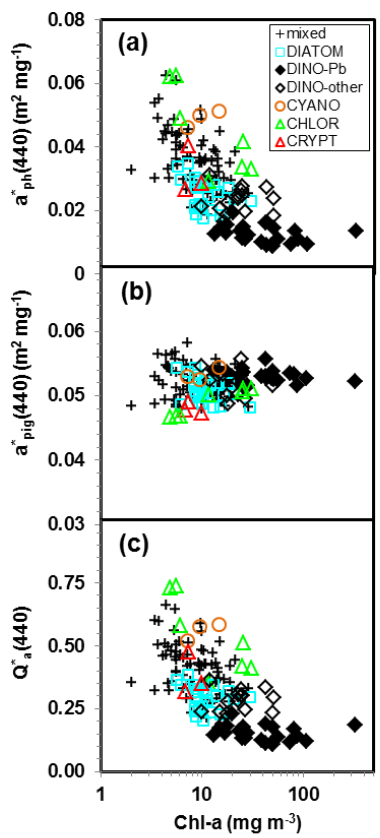

Figure 5. Relationships between Chl-a and (a) $a^*_{ph}(440)$, (b) $a^*_{pig}(440)$, and (c) pigment packaging index at 440nm, $Q^*_a(440)$, determined according to Bricaud et al. (2004). Data were sorted based on the dominant algal group/subgroup present. Mixed populations (+) represent situations when no single algal group/subgroup dominated.

LONG-TERM UNDERWATER LIGHT CLIMATE VARIATION AND SUBMERGED SEAGRASS TRENDS IN TAMPA BAY, FLORIDA

Roger Johansson

ABSTRACT

Seagrasses have successfully existed in the submerged environment over the last 100 million years. The Tampa Bay basin has had a relatively stable sea level over the recent 3,000 years; allowing its seagrass to adapt to local underwater light conditions to ensure sustained growth. A rapid change of underwater light climate that accompanied human influenced water quality degradation during the early 80 years of the 20th century likely exceeded the seagrasses ability to adjust, thus providing cause for large seagrass losses. Water quality and the under-water light climate improved in the early and mid 1980s following substantial reductions in nutrient pollution; and seagrass losses climaxed soon after the improvements. Thus, a foundation had been created for a remarkable recovery of Tampa Bay, indicated by ongoing water quality improvements and a near continuous increase in seagrass acreage. In a historical perspective, the current Tampa Bay underwater light climate is now likely more similar to conditions that the seagrass community adapted to during the several millennia prior to the period of eutrophication, as evidenced by long-term trends in field measured optically important water quality parameters and spectral-specific optical model predictions reported herein. Results indicate that the long-term changes in chlorophyll has substantially affected light climate changes in all bay segments, specifically in wavelength ranges essential for sustained seagrass growth. Thus, the reduction of phytoplankton biomass during the recent 30 years has been an important cause of the ongoing Tampa Bay seagrass recovery.

INTRODUCTION

Seagrasses have adapted to thrive in the underwater environment over the last 100 million years (Orth et al. 2006). Further, the area today recognized as the Tampa Bay basin has had a relatively stable sea level elevation over the recent 3,000 years following the last glacial retreat (late Holocene period; Donahue et al. 2003; Maul 2015). Thus, Tampa Bay seagrass communities have had several thousand years to genetically adjust to underwater light conditions specific to this system to ensure survival and healthy growth.

Periodic variations in the underwater light climate, and accompanied seagrass adaptation likely occurred throughout this geological period. However, the rapid rate of change associated with human influenced water quality impacts during the first 70 to 80 years of the 20th century most likely exceeded the seagrass community's ability to adapt (see Orth et al. 2006; Ralph et al. 2007). Thus, the rapid degradation of water quality and underwater light climate provides a reasonable scenario and cause to the major portion of the large Tampa Bay seagrass losses that occurred during this period (Lewis et al. 1985; Johansson and Greening 2000; Greening et al. 2011; 2014).

However, additional seagrass losses were caused by extensive creation of land acreage through dredge-and-fill projects that accompanied the period of increasing eutrophication (Lewis 1977; Goodwin 1987). Further, the large areal losses of seagrass cover, particularly in the upper bay portions, may have contributed to more severe and persistent sediment resuspension events, thus further degrading the underwater light climate (see Carstensen et al. 2013).

Water quality degradation climaxed during the late 1970s and early 1980s as a result of aggressive water quality management specifically aimed at reducing anthropogenic inputs of nitrogen (Johansson and Lewis 1992; Greening and Janicki 2006; Greening et al. 2014). The subsequent reduction in eutrophication has created a underwater light climate that has become more similar to the conditions the Tampa Bay seagrass community adapted to during the extended pre-eutrophic period. These improvements have resulted in a distinct seagrass recovery, evidenced by a bay-wide near consistently increasing seagrass abundance (Greening et al. 2014).

The documented changes to the Tampa Bay system following the reduced nitrogen loadings appear intuitively reasonable and have been supported through analyses of empirical water quality information and various model scenarios (Johansson 1991; Janicki and Wade 1996; Morrison et al. 1997; Wang et al. 1999). This report seeks to build on those earlier studies by providing a detailed optically derived understanding of historical and current variations in underwater light properties. It specifically aims to examine the light climate as it relates to long-term variations in phytoplankton biomass and how those changes have influenced Tampa Bay seagrass abundance.

Further, it has recently been substantiated that a dynamic link exits between phytoplankton and colored dissolved organic matter (CDOM) concentrations in productive aquatic systems (see Keith et al. 2002; Rochelle-Newall and Fisher 2002; Yamashita and Tanoue 2004; Zhang et al. 2009). In situ generated CDOM by the phytoplankton may be an important source of CDOM in systems similar to Tampa Bay. An account of this source is needed to fully understand the impact of phytoplankton biomass on the underwater light climate, specifically in systems where management approaches use phytoplankton biomass (chlorophyll) as the primary driver to achieve protection and restoration of submerged aquatic vegetation, such as Tampa Bay. A preliminary evaluation of this CDOM source in Tampa Bay is discussed.

METHODS

Selected study periods

Two recent distinct phases of Tampa Bay eutrophic state were selected for detailed evaluations of variations in the underwater light climate. The selection was primarily based on the long-term Tampa Bay records of phytoplankton biomass and seagrass abundance. The five year period 1978-1982 (Peak Eutrophic period) was characterized by highly degraded water quality conditions accompanied by peak phytoplankton biomass and low, or in some bay segments near absent, submerged seagrass abundance. The recent five year period 2006-2010 (Recent Recovery period) represents current conditions characterized by substantially improved water quality conditions, relatively low phytoplankton biomass and near consistently increasing seagrass abundance.

Records of the three water quality parameters required for optical model prediction (chlorophyll, CDOM and turbidity) were primarily selected, or derived, from the long-term measurements of the Environmental Protection Commission of Hillsborough County (EPCHC) and the City of Tampa Bay Study Group (COT-BSG).

Temporal variations of estimated seagrass abundance were taken from the Tampa Bay Estuary Program's adopted seagrass scenario (modified from Yates et al. 2011). The scenario describes abundance estimates spanning from the late 19th century to the current.

Optical model used

The underwater light climate was evaluated using a Tampa Bay specific spectral optical model developed by Dr. Charles Gallegos (see Biber et al. 2008; Johansson 2012). The model was constructed from water quality information and optical inherent properties (IOPs) collected in Tampa Bay during the recent period of recovering conditions (see Anastasiou 2009; Johansson 2012). A similar optical model has also been developed and used by Dixon (2014) for evaluations of current optical conditions in Tampa Bay waters.

Measurements of the three required water quality parameters needed for model predictions are available for both study periods; however, directly measured parameter specific absorbance and scattering coefficients (IPOs) are not available for the period of peak eutrophication. It is presumed that those coefficients, as well as absorption by water, have remained relatively constant during the period of study.

Regarding the use of turbidity (NTU) to evaluate light losses due to non-algal suspended matter

Recent studies of long-term optical changes in estuaries in response to altered trophic state have been conducted in Chesapeake Bay by Gallegos et al. (2011) and in Denmark's Roskilde Estuary by Pedersen et al. (2014). Both studies show that a change in trophic status may be accompanied by alterations in particulate matter composition; suggesting that the optical model coefficients governing scatter-to-absorbance ratios may not remain constant as trophic change occurs. The potential for such change in Tampa Bay was examined to the extent possible, using past and current total suspended sediment (TSS) and total organic carbon from the EPCHC water quality data base (see Johansson 2015).

The evaluation indicated that qualitative changes likely have occurred in the composition of the suspended matter in Tampa Bay over time. Specifically, a relative increase in the organic fraction has occurred as a result of study period reductions in TSS. These findings are similar to those from the Danish fjord, which similar to Tampa Bay has undergone reduced eutrophication (see Pedersen et al. 2014).

Conveniently, it was decided during the development of the Tampa Bay optical model to use turbidity (NTU) instead of TSS concentrations as input variable for light losses due to non-algal particles, partly because NTU generally gives a better account of optical effects by particles than TSS (Gallegos 1994; Gallegos and Kenworthy 1996; Biber et al.

2008; also see Kirk 1994). Therefore, despite the suggested long-term changes in Tampa Bay particle composition, the use of NTU for estimates of light losses due to suspended matter should most likely produce a fair comparison of such losses during the two study periods.

Optical model applications

The underwater light conditions during the two study periods were evaluated by major Tampa Bay segments (Fig. 1), in three model applications: 1. estimates of broad band light attenuation over the total photosynthetically available radiation spectrum (Kd[PAR]); 2. estimates of light attenuation for defined specific wavelength ranges of three color bands (blue: 400-490nm; green: 530-600nm; and red: 640-690nm) of the PAR spectrum (Kd[band]); and 3. estimates of the fraction of total Kd(PAR) accountable for by each of the three optically important water quality parameters.

The first application provides an understanding of study period variations in broad band PAR light attenuation. This information can be used to estimate the PAR light quantity reaching the seagrass meadows, and is hence an important tool in seagrass restoration efforts. A selected light target, set to ensure adequate seagrass protection and restoration, can be compared to the calculated light availability. Management actions can then follow to ensure that the light target is met (e.g. the Tampa Bay seagrass management approach; TBEP 2006).

The second application gives information on study period variations in spectral specific light quality available for seagrass photosynthesis. The spectral ranges of blue and red light include absorbance peaks of the two primary seagrass light absorbing pigments, chlorophyll a and b (see Kirk 1994; Zimmerman 2005). Absorption of green light by seagrass pigments is considered relatively low, but it is not inconsequential (see Kirk 1994; Zimmerman 2003). The phytoplankton community also absorbs light in the blue and red color bands and therefore reduces the amount of usable light reaching the seagrass meadows. In addition, CDOM and turbidity also cause substantial light losses primarily in the blue band. Because both seagrass and phytoplankton have similar spectral requirements, the color band information is of importance in resource protection aiming to improve the underwater light conditions by the control of phytoplankton biomass, as the case is for the seagrass protection and restoration plan implemented by the Tampa Bay Estuary Program (TBEP 2006).

The third application also gives important information to management efforts that strive to control a specific, or combination of, water quality parameters for the purpose to improve underwater light availability (see Biber et al. 2008; Gallegos et al. 2009). These calculations included an annual mean estimated correction of the chlorophyll contributed light losses to account for covariation with turbidity and CDOM (see Biber et al. 2008; Johansson 2012; 2015; and the discussion section herein). The estimated light attenuation by CDOM and NTU were both reduced by 20%, and those fractions were added to the chlorophyll attenuation.

RESULTS

Historical seagrass trends in Tampa Bay

The Tampa Bay climax of seagrass loss likely occurred during the late 1970s and early 1980s following a near 80 year period of continuously increasing water quality degradation and seagrass losses (Fig. 2). By the mid 1980s sporadic seagrass recovery was observed in upper portions of the bay (Johansson and Lewis 1992). The initial patchy recolonization has progressed, and has become a substantial and near consistent increase. The 2014 acreage of about 13,500ha equals the 1950 estimate which in 1996 was set as a goal by the TBEP to indicate successful water quality management and seagrass restoration (TBEP 2006).

Historical trends of water quality parameters used in the optical model predictions

Monthly measurements by the EPCHC of turbidity and color for the period 1974 through 2010 were averaged as annual means by major Tampa Bay segments; and a similar compilation was done for chlorophyll measurements from 1952 through 2010 (Fig. 3). The chlorophyll record prior to the late 1980s, however, is from several Tampa Bay studies. These include primarily monthly, but also less frequent measurements from various bay locations by: Marshall (1956); US Fish and Wildlife Serv. (various reports 1962-1972); Hagan (1969); Turner and Hopkins 1974; EPCHC (various reports 1972-2010); and COT-BSG (various reports 1978-2010). Further, the chlorophyll record from 1978 through the early 1990s, primarily for Hillsborough Bay (HB) and Middle Tampa Bay (MTB), is from monthly or more frequent measurements from the COT-BSG program.

The Tampa Bay chlorophyll record clearly illustrates a rapid progression of eutrophication that occurred from the mid 1960s to the climax during the late 1970s and early 1980s. Further, the decrease in chlorophyll concentrations that followed early reductions in nutrient inputs to the bay from major discharge sources is a nearly unique worldwide occurrence (see Cloern 2015). The lessened eutrophication has resulted in profound ecosystem changes, which includes a large reduction in primary production as reported by Johansson (2005), Greening et al. (2014) and Cloern 2015). During the last several decades, chlorophyll concentrations have remained relatively stable and generally followed patterns in rainfall.

The trend in turbidity is dominated by a four year period of highly elevated values between 1988 and 1992. Those values appear suspect and may be due to instrument issues (see Johansson 2015). Disregarding that period, the turbidity record indicates a near steady decreasing trend in all bay segments.

The color record also suggests an overall steady decreasing trend for all bay segments except Lower Tampa Bay (LTB). Color concentrations in LTB have been quite stable during the period of record.

Study period changes in total PAR light attenuation

Calculations of total PAR light attenuation provide a measure of overall variations in light climate changes during the period of study (Fig. 4 and Table 1). Hillsborough Bay had by far the greatest light attenuation during the eutrophic period and LTB had the lowest, 1.44m^{-1} and 0.85m^{-1}, respectively; and MTB and Old Tampa Bay (OTB) had equal levels at 1.05m^{-1}.

Improvements in total Kd(PAR) availability during the study period were greatest in HB (0.52m^{-1}) and followed by MTB (0.39 m^{-1}); the percent increased light availability at those bay segments was near 36%. Old Tampa Bay and LTB had similar but smaller increases of 0.29m^{-1} and 0.28m^{-1}, respectively. Further, OTB had the least percent improvement in light conditions of the four bay segments. A general down-bay trend of decreasing light attenuation for the three main-stem segments (HB, MTB and LTB) is evident.

Changes in light attenuation during the study period suggest that the potential depth for seagrass colonization has increased in all bay segments during the study period; which is confirmed by field observations and photographic surveys. A review of estimated maximum depths of the current Tampa Bay seagrass meadows is included in the discussion section (also see Johansson 2012).

Color band specific light attenuation

Color band specific light attenuation was evaluated as the average Kd(band) variation of the selected wavelength ranges of blue, green and red light (Fig. 5 and Table 2). Color band attenuation by bay segment and study period was consistently highest for blue light; especially high attenuation occurred in HB during the eutrophic period (near 3.3m^{-1}). Red light attenuation was consistently of secondary magnitude.

Long-term improvements in blue light availability were by far the greatest of the three color bands in all bay segments. Blue light improvement decreased in a general down-bay trend from 1.6m^{-1} in HB to 0.5m^{-1} in LTB; corresponding to percent improvements of 48% and 38%, respectively. Improvements in green light attenuation coefficients were of secondary importance and considerably lower than those of the blue band; and improvements in red light were constantly the lowest. Finally, HB or MTB had the highest percent improvements in all three color bands, and OTB generally had the lowest.

Both phytoplankton pigments and CDOM absorb strongly in the blue band, indicating that long-term reductions of those constituents and the resulting increased availability of blue light at depth, likely has benefited seagrass growth in deeper areas of the bay. An examination of spectral light availability at the current estimated maximum seagrass depths is included in the discussion section.

Partial contributions to total PAR light attenuation by chlorophyll, turbidity and color

The partial contribution to total Kd(PAR) by each of the three water quality parameters required for model predictions was consistently dominated by turbidity irrespective of study period or bay segment (Figure 6 and Table 3). Chlorophyll was of secondary importance and CDOM consistently contributed the least.

Improvements in total Kd(PAR) during the study period were greatly affected by chlorophyll and turbidity in HB and MTB, with reductions in attenuation coefficients between $0.30m^{-1}$ and $0.20m^{-1}$. The chlorophyll contribution in those segments had the greatest percent decrease, 41% and 39%, respectively, with corresponding turbidity decreases of 33% and 35%. In OTB, increased light availability also resulted to a large degree from reductions in both chlorophyll and turbidity attenuation; percent reductions were 30% and 29%, respectively. In LTB, turbidity dominated percent improvements, near 38%, followed by chlorophyll at 24%. CDOM attenuation had a relative low influence on total Kd(PAR) in all bay segments. Improvements in CDOM and chlorophyll attenuation decreased in a general down-bay trend, with the range of improvement in CDOM attenuation being especially large; e.g. HB had a near 5 times greater improvement than LTB.

These results support the study premise that reductions in phytoplankton biomass has had a strong influence on the improving water column light conditions, especially in HB and MTB. However, attenuation by turbidity was also reduced substantially in those segments. In contrast, reductions of chlorophyll attenuation in OTB and LTB were considerably lower, with turbidity having a proportional larger impact on light improvements. The finding that turbidity in addition to chlorophyll has a large influence on partial light attenuation is supported in other Tampa Bay optical studies (McPhersen and Miller1994: Johansson 2012; Le et al. (2013); Johansson and Cross in prep.). However, numerous estuarine turbidity generating processes are beyond mans direct control, thus making efforts to influence turbidity levels complex and generally unsuitable in system-wide management of underwater light conditions.

DISCUSSION

The unique Tampa Bay eutrophication scenario

The long-term comparison of the Tampa Bay seagrass record and that of ambient water quality and light conditions is limited to the period from the mid 20th century to the recent. Measured water quality has not been located for the bay prior to 1952. Therefore, Tampa Bay seagrass losses that likely occurred during the first 50 years of the 20th century (Lewis et al. 1985) cannot be directly related to measured changes in water quality. However, it is reasonable to assume that water quality conditions progressively degraded during the first half of the 20th century due to mans increased influence on bay conditions; and that this influence also caused losses of seagrass abundance.

An accelerated degradation of Tampa Bay water quality conditions took place during the last 40 years of the 20th century as a result of increased population growth and commercial fertilizer production. Discharges from the City of

Tampa's wastewater treatment plant into the upper reach of HB increased substantially during this period; this effluent contained high concentrations of nutrients and suspended matter (see Garrity et al. 1985; Johansson 1991). Further, the mining and production of phosphoric fertilizer increased steadily during the early decades of the 20th century (see Fehring 1985; Johansson and Lewis 1992), and from near 1950 and on, the production also included nitrogen containing products.

Tampa Bay was uniquely impacted by fertilizer pollution as a result of having within its watershed the extensive fertilizer mining operations, production facilities, and shipping and rail terminals. Nutrient impacts from these sources occurred in addition to those resulting from agricultural fertilizer applications, as discussed by Nixon (1995).

The large reductions in nutrient pollution resulting from improvements in sewage treatment and fertilizer operations during the late 1970s to the early 1990s created a foundation for the recovery of Tampa Bay. Additional, and more recent nutrient controls by legislated and management encouraged voluntary capping of nitrogen discharges from a wide range of sources, both governmental and private, have also contributed to the ongoing water quality improvements and the near continuous seagrass expansion (see Greening and DeGrove 2001).

Potential contribution by phytoplankton to the Tampa Bay CDOM pool

Previous Tampa Bay optical model calculations have, with some exceptions, used uncorrected water quality observations derived from concurrent, or near concurrent, collections of the three optically important constituents. However, covariation exists between the parameters; and it has been demonstrated elsewhere that degrading phytoplankton products add CDOM to the overall background CDOM pool. Thus, both living and decomposing phytoplankton cells exert a continuous, and at times of high abundance, a substantial drain on specifically blue light availability.

The phytoplankton contribution of CDOM has been recognized and accounted for in previous studies of estuarine light conditions (Biber et al. 2008; Harding et al. 2014). It has also been clearly documented in laboratory controlled degradation experiments generally employing dense algae concentrations (Zhang et al. 2009; 2010; 2013: Romera-Castillo et al. 2010); and it has been observed in field studies of highly productive lakes (Zhang et al. 2009) and less productive marine systems (Keith et al. 2002; Rochelle-Newall and Fisher 2002; Yamashita and Tanoue 2004). Further, laboratory measured CDOM generation rates have been used to estimate the phytoplankton contribution to the CDOM pool in at least two aquatic systems (Romera-Castillo et al. 2010; Zhang et al. 2013). The estimated CDOM contribution in these studies ranges from about 15% to 25%. These studies suggest that the phytoplankton generated CDOM is an important source of CDOM which needs to be accounted for in aquatic studies. In productive systems, not dissimilar to the upper segments of Tampa Bay, it may at times exceed CDOM added to the system through land drainage (see Zhang et al. 2013).

Both phytoplankton pigments and CDOM strongly absorb high energy blue light (Kirk 1994). Because control of phytoplankton biomass through the management of nutrient reduction often is selected as the primary path to successful estuarine seagrass restoration (e.g. Tampa Bay; TBEP 2006), a need exists to understand the full influence of the phytoplankton population on ambient light conditions; including the influence by both living and decomposing cells.

A first attempt to account for the Tampa Bay CDOM fraction likely due to phytoplankton degradation products is described in Johansson (2015). An interim estimate of this fraction suggests an annual averaged contribution of 20% to the total CDOM pool. This value was primarily based on findings by studies conducted elsewhere (referenced above). However, indirect support of the estimate was also derived from high frequency measurements of surface water conditions collected by the Florida Marine Research Institute in OTB in 2013 (see Johansson 2014; 2015).

Phytoplankton biomass reductions in Tampa Bay and ensuing seagrass recovery

As demonstrated, the overall light climate improvement in all Tampa Bay segments has produced favorable conditions for seagrass growth, which without doubt has been the most important cause to the ongoing expansion of seagrass meadows. The increased availability of blue light at depth has most likely resulted in the observed migration of seagrass meadows to deeper areas, specifically in the upper portions of the bay. It is well well-known that adequate availability of blue light is important for efficient seagrass photosynthesis (Kirk 1994).

Actively growing seagrass and phytoplankton populations have similar spectral light requirements; thus the phytoplankton reduce the photosynthetically usable light reaching the seagrass meadows. Further, the recognition that decomposing phytoplankton cells also exert important water column light losses by their CDOM contribution, adds importance to the Tampa Bay phytoplankton reduction and its impact on seagrass abundance. These findings provide a strong scientific ground for the seagrass restoration and protection strategy adopted by the Tampa Bay Estuary Program, which aims to control phytoplankton biomass through nutrient management (see Greening et al. 2011).

Light availability at current Tampa Bay seagrass colonization depths

The demonstrated long-term improvements in light quantity and quality during the study period imply that the potential depth for seagrass colonization has increased in all bay segments. The following discussion will evaluate the temporal changes in light availability at the currently observed maximum seagrass depths in Tampa Bay (see Johansson 2012).

Calculations using current estimates of maximum seagrass depths and total PAR light attenuation, result in light availability at depth (%Io[PAR]) ranging from 51% of just below surface incident radiation in HB to near 33% in LTB (Table 4). Further, because high energy blue light is important to sustained seagrass photosynthesis, the availability of this light at the deep meadows was compared to that of the commonly used total PAR light (Table 4). The comparison found near constant ratios, ranging from 1.7 to 1.8, of blue light to total PAR light availability for the three main stem bay segments, HB, MTB and LTB (Fig. 7); suggesting that spectral conditions at the deep meadows, as related to the blue light fraction of total PAR light, are similar in these segments with quite diverse ambient water quality. The spectral similarity is also supported by near constant red and green light to total PAR light relationships (not shown).

Old Tampa Bay had relatively lower blue light availability (Table 4; Fig. 7) at depth, suggesting that the deepest seagrass meadows in this bay segment are nearly 20% deficient in blue light in comparison to the other segments. This shortage appears limited to blue light, because the relationships of red and green light to total PAR light were also near constant in this bay segment (not shown). The relative scarcity of blue light at the deep OTB meadows may initially suggest that the blue light requirement of these meadows is substantially lower than that of the other segments, specifically relative to MTB, which currently has similar maximum seagrass depths as OTB (Table 4). However, a comparison of OTB and MTB water quality and light conditions (Figs. 3-6; Tables 1-3) indicates that light quality and quantity were nearly identical in those bay segments during the period of peak eutrophication; and that the maximum depth of seagrass meadows were also similar at near 2.0m in ca.1950 (see Janicki et al. 1995; Janicki and Wade 1996). Thus, the historical records do not provide support for substantially different blue light requirements of the seagrass in OTB and MTB.

The cause of the current relatively low blue light availability in OTB is evident from a comparison of past and current OTB and MTB water quality and light conditions. As discussed above, those conditions were likely similar in the two segments during the peak eutrophic period; however, the recent bay-wide improvements have progressed more slowly in OTB than in MTB (Figs. 3-6; Tables 1-3). The lesser improvements, of specifically chlorophyll and CDOM concentrations, have apparently created the more limited current blue light availability in OTB. Albeit the current deep seagrass meadows in OTB and MTB reach near equal depths (Table 4), the more limited blue light availability in OTB suggests that its meadows may approach a maximum depth distribution sooner than the MTB meadows.

CONCLUSIONS

The current Tampa Bay underwater light climate now likely better resembles the conditions the Tampa Bay seagrass community adapted to during several millennia prior to the relatively brief but severe period of eutrophication that climaxed near 30 years ago. This conclusion is supported by recent trends in optically important water quality parameters and the ongoing recovery of seagrass abundance.

The substantial bay-wide reduction of phytoplankton biomass during the last 30 years, with reductions in other water quality parameters as well, have notably improved the current water column light quality and quantity in all bay segments. These improvements have in turn allowed for bay-wide increases in seagrass abundance and the migration of meadows to deeper depths.

The similar spectral light requirements of actively growing seagrass and phytoplankton populations, and the recognition that decomposing phytoplankton cells also likely exert important water column light losses, provides strong scientific grounds for the seagrass restoration and protection strategy adopted by the Tampa Bay Estuary Program, which aims to control phytoplankton biomass through nutrient management.

CLOSING THOUGHTS

Water quality and biological conditions in Tampa Bay were grim during the peak of eutrophication some 30-40 years ago, near the time of the first Basis in 1982 (Fig. 8). It has taken an immense amount of effort and cost to achieve the recovery of the bay we now are privileged to observe and enjoy.

We should forever remember the difficult lesson learned of nutrient pollution and its harmful effect on the bay ecosystem. It may be difficult to forecast future bay conditions due to anticipated and unknown hardships that lie ahead, such as population growth and impacts from climate change. However, we must do our outmost to not repeat the earlier mistakes, and instead continue and build on efforts which will ensure a healthy and productive Tampa Bay for generations to follow.

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NOTE

This report is an edited version of a report submitted to the TBEP on August 28, 2015. That report resides on the TBEP technical website: http://www.tbeptech.org/TBEP_TECH_PUBS/2015/TBEP_06_15_Long-Term_Light_Climate_09082015.pdf

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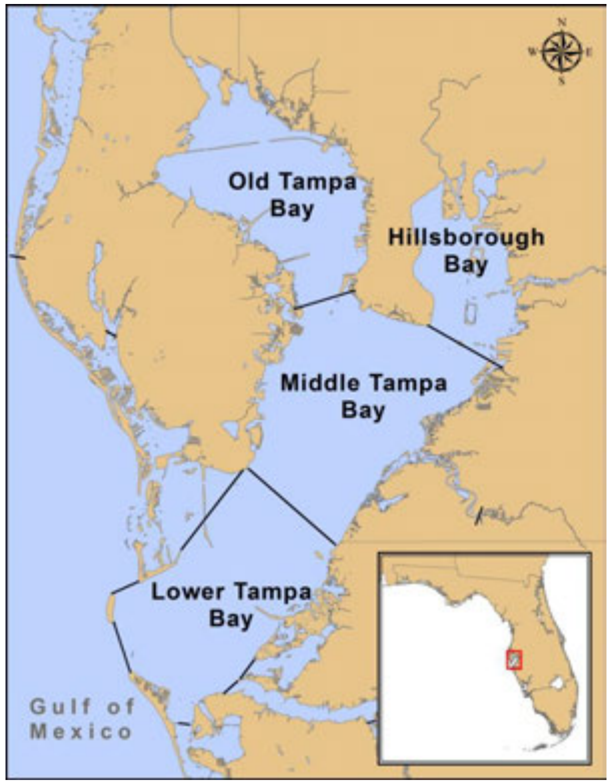

Figure 2. Tampa Bay with the four major bay segments identified.

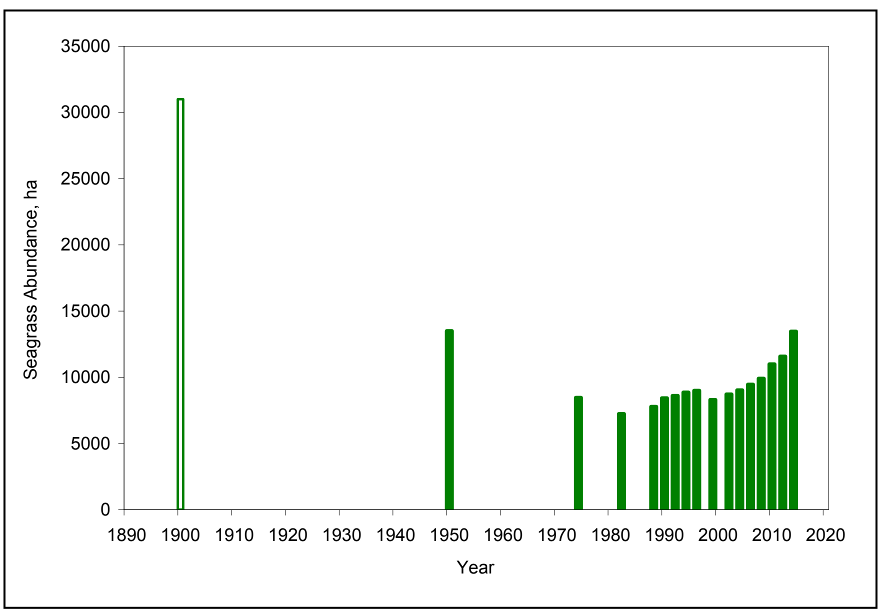

Figure 1. Past and current trends in Tampa Bay seagrass abundance. Sources include: Simon 1974, Lewis et al. 1985, Haddad 1989 and the Southwest Florida Water Management District (various years). The abundance ca.1900 is uncertain due to a lack of reliable records.

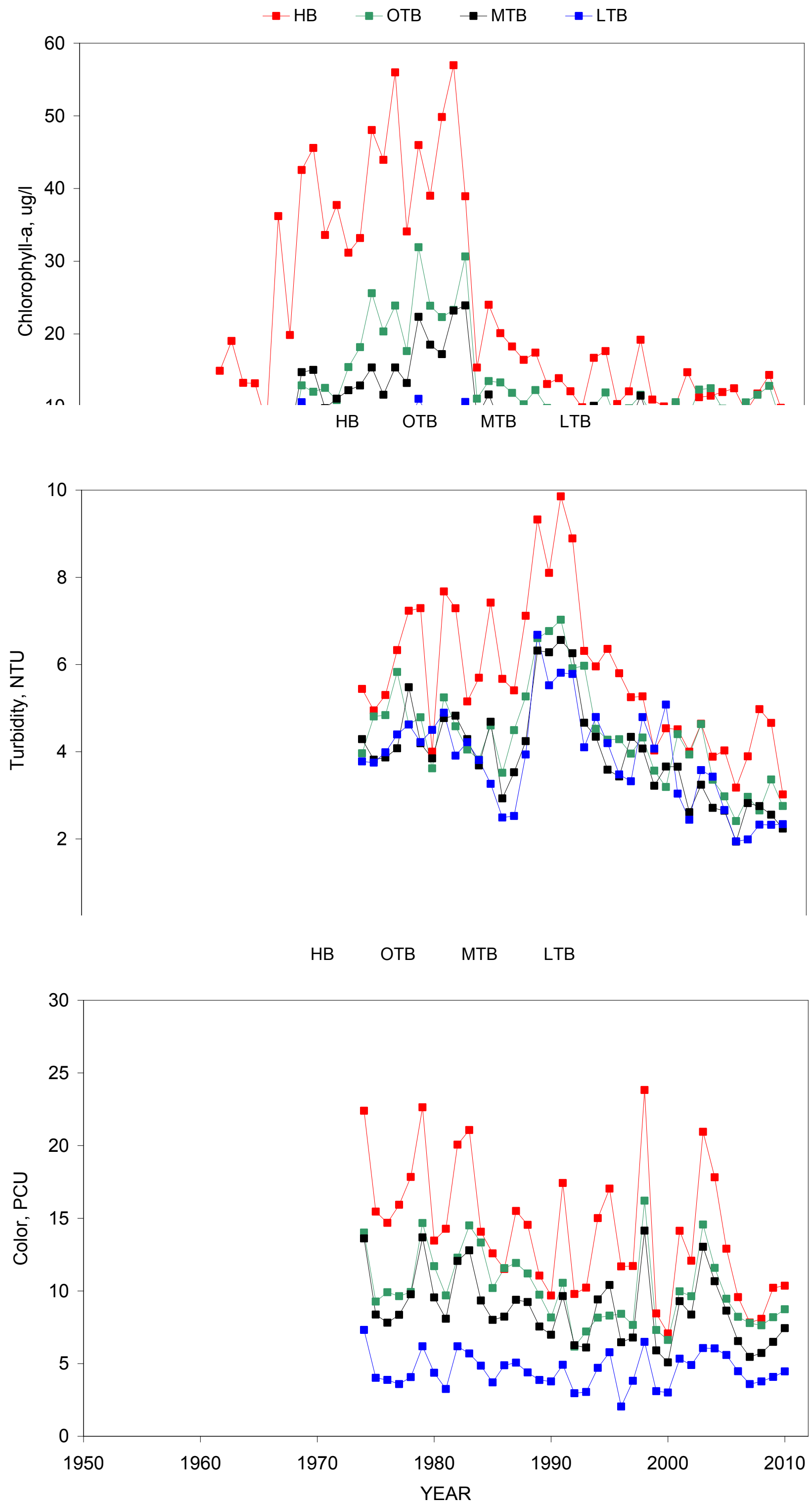

Figure 3. Average annual levels by major Tampa Bay segment of chlorophyll a, turbidity (NTU) and color. The chlorophyll record prior to 1978 includes primarily monthly, but also less frequent measurements from numerous sources (see text); the record from 1978 and on is primarily from EPCHC and COT-BSG measurements. The turbidity and color records are from monthly measurements by the EPCHC.

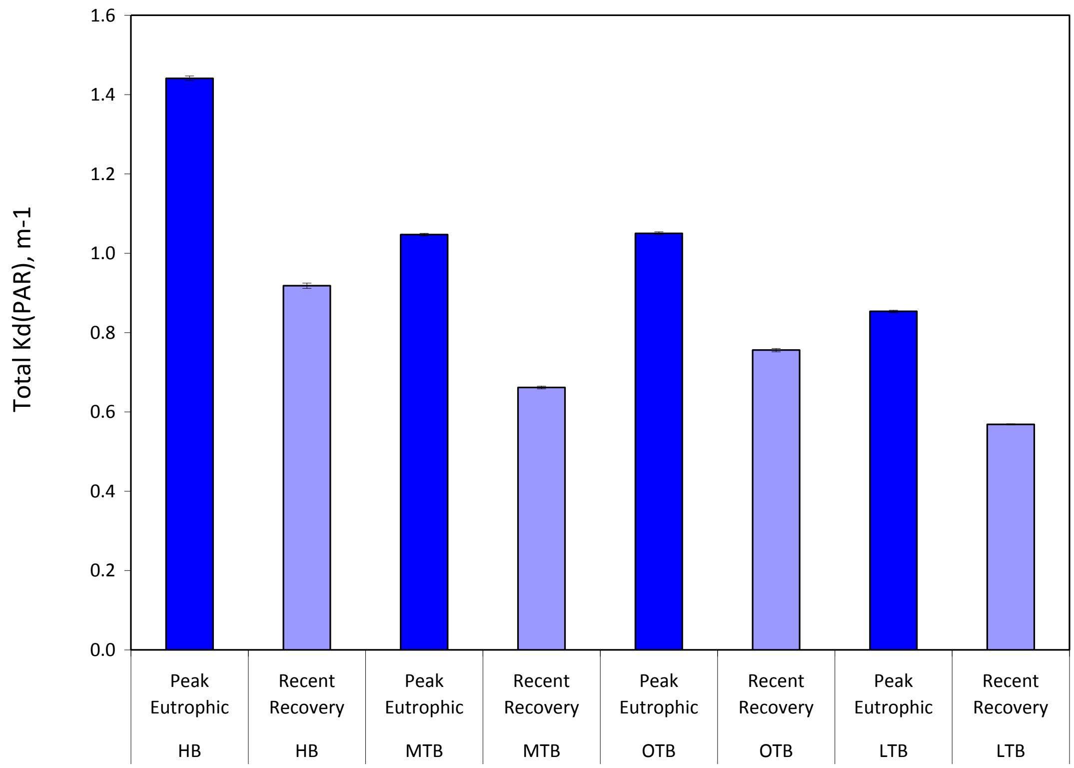

Figure 4. Comparison of total Kd(PAR) by major Tampa Bay segment for the Peak Eutrophic (1978-1982) and Recent Recovery (2006-2010) periods by bay segments. Error bars are ±1 SEM.

Table 1. Comparison of total Kd(PAR) by major Tampa Bay segment for the two study periods, Peak Eutrophic (1978-1982) and Recent Recovery (2006- 2010). Error estimates (±1 SEM) of total Kd(PAR) estimates for respective bay segment and period are shown in Fig. 4.

Bay Segment	Period	Total Kd(PAR) m-1	Difference m-1	Decrease %
HB	Peak Eutrophic	1.44		
	Recent Recovery	0.92	-0.52	-36.3
MTB	Peak Eutrophic	1.05		
	Recent Recovery	0.66	-0.39	-36.8
OTB	Peak Eutrophic	1.05		
	Recent Recovery	0.76	-0.29	-28.0
LTB	Peak Eutrophic	0.85		
	Recent Recovery	0.57	-0.28	-33.4

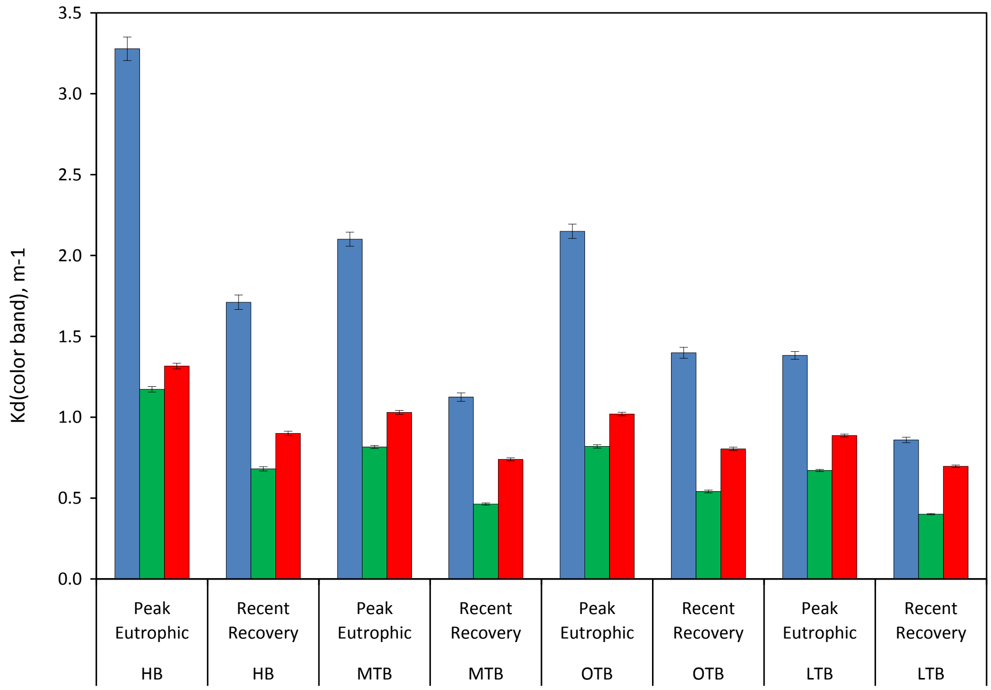

Figure 5. Average estimated light attenuation (Kd) by color band (blue, green and red) for the Peak Eutrophic (1978-1982) and Recent Recovery (2006-2010) periods for each of the four major Tampa Bay segments. Error bars are ±1 SEM.

Table 2. Average estimated light attenuation (Kd) for the three color bands (blue 400-490nm; green 530-600nm; red 640-690nm) for the Peak Eutrophic (1978-1982) and Recent Recovery (2006- 2010) periods and the four major Tampa Bay segments. Error estimates (±1 SEM) of color band Kd(PAR) estimates for respective color band, bay segment and period are shown in Fig. 5.

Bay Segment	Period	Kd(Blue) m-1	Difference m-1	Decrease %	Kd(Green) m-1	Difference m-1	Decrease %	Kd(Red) m-1	Difference m-1	Decrease %
HB	Peak Eutrophic	3.28			1.17			1.32		
	Recent Recovery	1.71	1.57	47.8	0.68	0.49	41.9	0.90	0.42	31.6
MTB	Peak Eutrophic	2.10			0.82			1.03		
	Recent Recovery	1.12	0.98	46.5	0.46	0.35	43.2	0.74	0.29	28.2
OTB	Peak Eutrophic	2.15			0.82			1.02		
	Recent Recovery	1.40	0.75	34.9	0.54	0.28	34.1	0.80	0.22	21.6
LTB	Peak Eutrophic	1.38			0.67			0.89		
	Recent Recovery	0.86	0.52	37.8	0.40	0.27	40.3	0.70	0.19	21.5

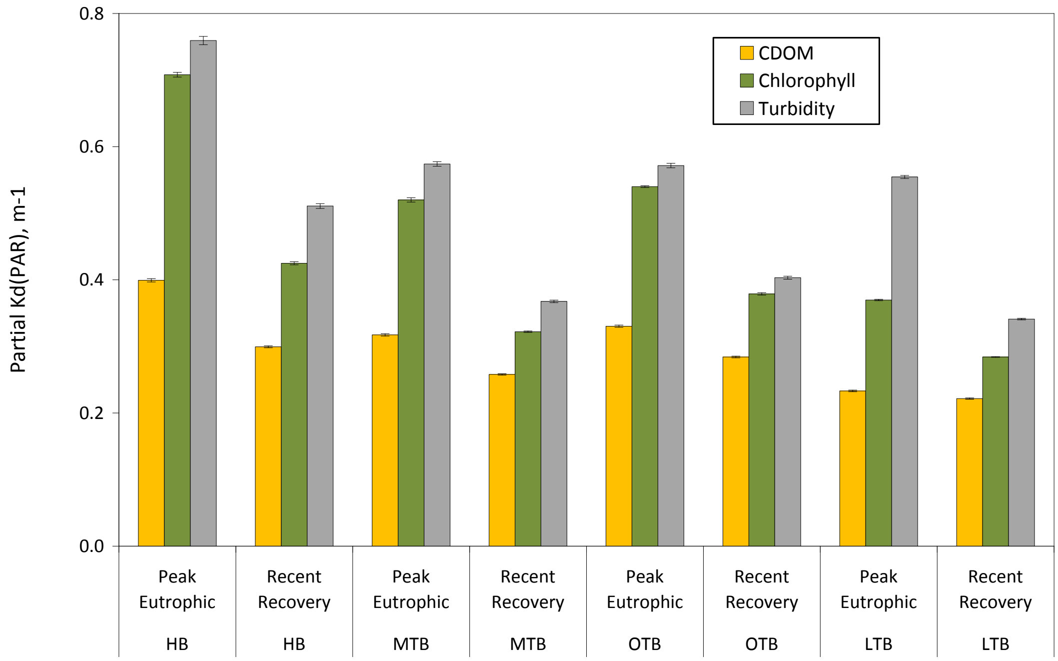

Figure 6. Average estimated parameter contributions by CDOM, turbidity and chlorophyll-a to total Kd(PAR) for the Peak Eutrophic (1978-1982) and Recent Recovery (2006-2010) periods for each of the four major Tampa Bay segments. Error bars are ±1 SEM.

Table 3. Comparison of estimated total Kd(PAR) contributions by CDOM, chlorophyll-a and turbidity by major Tampa Bay segments for the two study periods, Peak Eutrophic (1978-1982) and Recent Recovery (2006- 2010). Error estimates (±1 SEM) of partial Kd(PAR) for respective water quality parameter, bay segment and period are shown in Fig. 6.

Bay Segment	Period	Kd(PARCDOM) m-1	Difference m-1	Decrease %	Kd(PARChl) m-1	Difference m-1	Decrease %	Kd(PARTurb) m-1	Difference m-1	Decrease %
HB	Peak Eutrophic	0.40			0.71			0.76		
	Recent Recovery	0.30	0.10	25.0	0.42	0.29	40.8	0.51	0.25	32.6
MTB	Peak Eutrophic	0.32			0.52			0.57		
	Recent Recovery	0.26	0.06	18.8	0.32	0.20	38.5	0.37	0.20	34.9
OTB	Peak Eutrophic	0.33			0.54			0.57		
	Recent Recovery	0.28	0.05	15.2	0.38	0.16	29.6	0.40	0.16	28.7
LTB	Peak Eutrophic	0.23			0.37			0.55		
	Recent Recovery	0.22	0.01	4.3	0.28	0.09	24.3	0.34	0.21	38.2

Table 4. A comparison of total PAR light (400-700nm) and blue light (400-490nm) light attenuation coefficients and light availability at maximum seagrass colonization depths (deep edge) by major Tampa Bay segments during the recent recovery period.

Bay Segment	Deep Edge m	Kd(400-700) m-1	Kd(400-490) m-1	%Io(PAR) 400-700nm	%Io(Blue Light) 400-490nm
HB	0.73	0.92	1.71	51.2	28.7
MTB	1.20	0.66	1.12	45.2	25.9
OTB	1.17	0.76	1.40	41.3	19.5
LTB	1.97	0.57	0.86	32.6	18.4

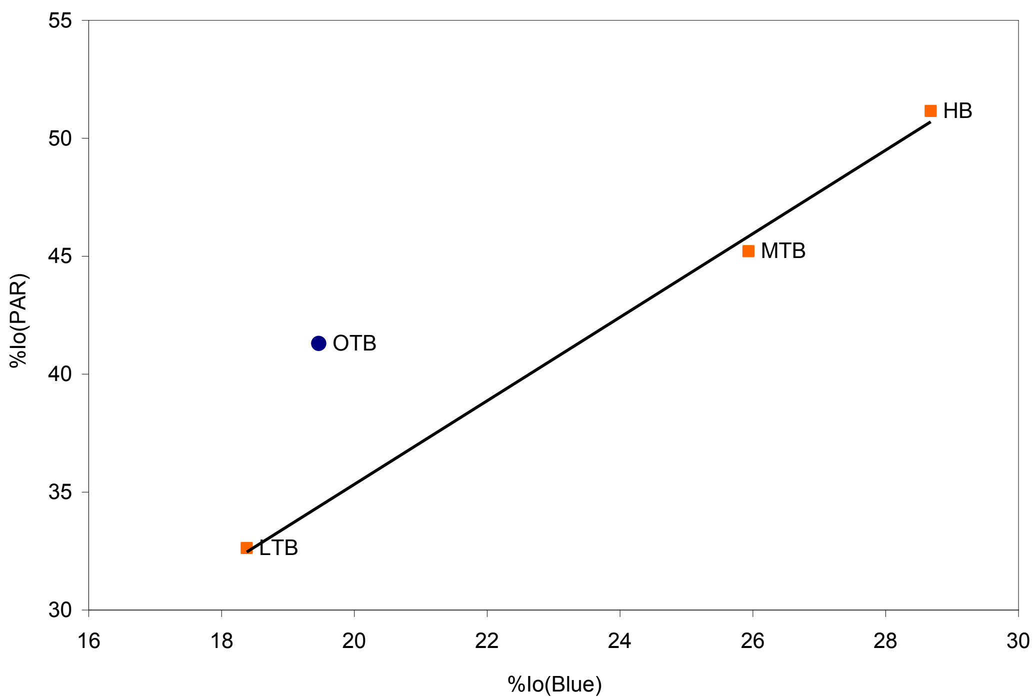

Figure 7. Regression relationship of total PAR (400-700nm) and blue(400-490nm) light availability during the recent recovery period at maximum seagrass colonization depths for the three TB main stem segments (blue squares). Also shown is the corresponding PAR/blue light availability relationship in OTB (blue circle).

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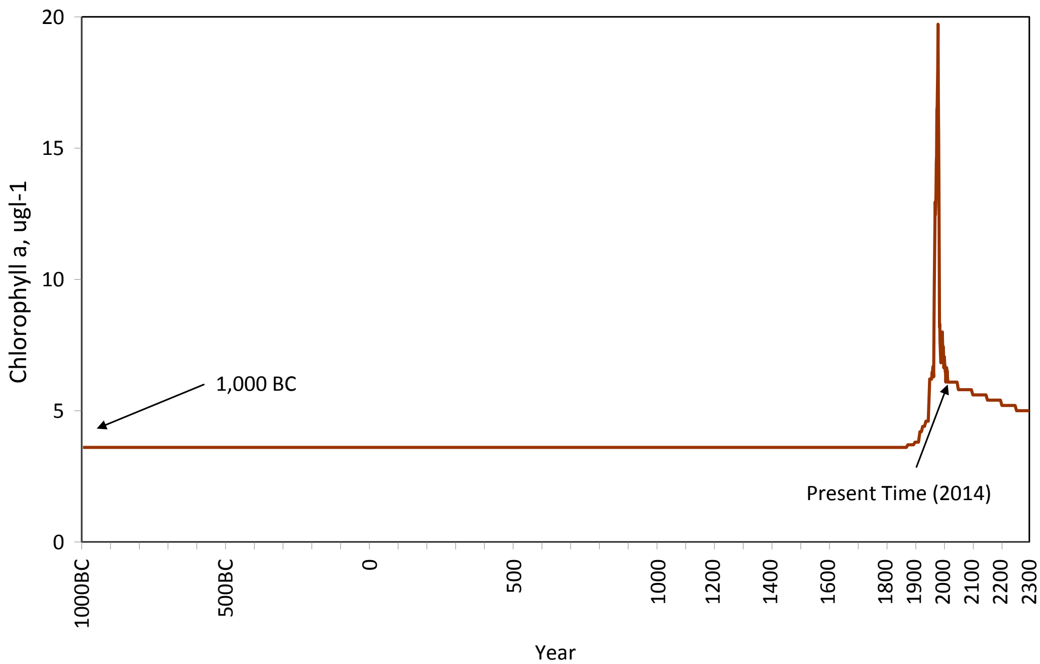

Figure 8. Presumed and measured annual averaged chlorophyll concentration in Tampa Bay during the period of likely seagrass presence (some 3000 years). Chlorophyll concentrations prior to the early 1900s are assumed to have been similar to those currently found in near-shore Gulf of Mexico waters. Values from 1950 to 2014 are averaged Tampa Bay concentrations based on field measurements. Forecasted concentrations for the period past the present represent a hopeful trend of future chlorophyll concentrations**.**

SEAGRASS RESTORATION SUCCESS IN TAMPA BAY AND NEKTON COMMUNITY STRUCTURE: BUILD IT AND THE FISH WILL COME

K. Fischer, K.E. Flaherty-Walia & R.E. Matheson Jr.

ABSTRACT

Seagrass growth and distribution are influenced by many interrelated factors, including light penetration, nutrient levels, salinity, freshwater inflow, turbidity, and substrate. Studies have indicated that seagrass-bed architecture, seagrass species composition, salinity, and freshwater inflow can affect nekton use of seagrass habitats. After decades of declining seagrass coverage in Tampa Bay (from 153.778 km^2 in 1950 to 101.170 km^2 in 1995), the Tampa Bay Estuary Program set the goal of restoring seagrass coverage to levels found in the estuary in the 1950s. This restoration goal was surpassed in 2014 with a record 163.065 km^2 of seagrass observed. We analyzed fisheries-independent monitoring data collected using 21.3-m seines (N = 4,730 hauls) in Tampa Bay during this restoration period (1996–2014) to document patterns of spatiotemporal distribution and abundance of small-bodied nekton and to determine changes in the nekton community associated with increasing seagrass coverage and varying levels of freshwater input. The bay-wide increase in seagrass coverage was not directly associated with nekton community structure, but site-specific seagrass coverage was correlated with observed community differences. Nekton community structure also had a strong seasonal component and was influenced by the presence or absence of seagrass and by the species composition of the beds. Most nekton species were more abundant at sites containing bottom vegetation, and distinct assemblages, driven by lower numbers of nearly all species, were identified over unvegetated sites. A future study to build on these findings should focus on nekton community structure and relative abundance of seagrass-associated species on a regional scale in the bay, focusing particularly on those areas with the greatest increase in seagrass coverage during the restoration period.

INTRODUCTION

Seagrass beds are known to provide refuge and feeding areas for various nekton species, and several studies have indicated that seagrass species composition, bed location, and water quality can affect the value of seagrass as habitat (Bell et al. 1987, 1988; Robbins and Bell 1994). Increasing seagrass canopy cover can also indicate greater protection for fish from predators in these environments (Orth et al. 1984). Furthermore, water quality parameters, such as salinity and turbidity, may also affect seagrass-associated fish communities either directly through species' tolerances and preferences or indirectly through effects on seagrass habitat (Blaber and Blaber 1980; Tomasko et al. 2005). In Tampa Bay, the distribution and abundance of fish species and overall nekton community structure have been correlated with the density of seagrass cover and levels of freshwater inflow (Rydene and Matheson 2003; Flaherty et al. 2010; Flaherty-Walia et al. 2015). Therefore, increases in seagrass habitat due to restoration and favorable water regimes may be reflected in shifts in nekton community structure and increases in the abundance of some species.

Coastal development and urbanization between the 1950s and 1980s significantly diminished seagrass coverage and water quality in Tampa Bay (Lewis and Estevez 1988; Johansson 2005; Crane and Xian 2006; Greening and Janicki 2006; Morrison et al. 2006; Sherwood et al. 2015). Rapid expansion of the human population from less than 0.5 million in 1950 to 1.5 million in 1980, and subsequent increase in development and nutrient inputs, led to eutrophication of the bay (Greening et al. 2014). The effects of these large nutrient inputs were especially pronounced in the 1970s and 1980s, with frequent phytoplankton and algal blooms, reduced water clarity, low dissolved oxygen, and ensuing seagrass die-offs. Considerable public pressure for increased management eventually led to the establishment of the Tampa Bay Estuary Program (TBEP) in 1991 to help local governments and stakeholders plot a course for the recovery of Tampa Bay. In 1996, TBEP and its partners, including the Environmental Protection Commission of Hillsborough County, with long-term water quality monitoring data originating in 1974, implemented a management plan that included goals of restoring bay water quality by focusing largely on regulatory and voluntary reductions in nutrient loadings from point, atmospheric, and nonpoint sources. Target nitrogen-loading rates were determined through empirical models (Janicki and Wade 1996) and designed to improve water clarity and ensure that 20.5% of the sunlight penetrating the water's surface reaches the bottom on an average annual basis, which supports healthy growth of seagrasses (Dixon 2000a, 2000b). A concomitant goal of restoring water quality and water clarity was the recovery of bay-wide seagrass coverage to levels observed in the 1950s (approximately 153 km^2). The seagrass restoration goal was surpassed in 2014, with a record 163.065 km^2 of seagrass observed in the Tampa Bay estuary.

Whereas reaching these long-term restoration targets through regional partnerships is a remarkable achievement, the effects of the increased seagrass coverage on the community structure and abundance of nekton in Tampa Bay have not been documented. The objective of this study was to evaluate the association between long-term trends in nekton diversity and community structure and increasing bay-wide seagrass coverage and varying levels of freshwater inflow.

METHODS

Study Area

All samples were collected in Tampa Bay, located on the west coast of Florida (Figure 1). Tampa Bay is Florida's largest open-water estuary, covering more than 1,000 km^2 (Lewis and Estevez 1988). The bay's subtropical climate creates a relatively wet season during the summer and fall (June–October) and a relatively dry season during winter and spring (November–May). This climate pattern influences seasonality of freshwater flow into the bay as well as seasonal variability of other water quality parameters.

Nekton Collection and Habitat Measures

Nekton data were collected by biologists in the Fisheries-Independent Monitoring (FIM) program of the Fish and Wildlife Research Institute of the Florida Fish and Wildlife Conservation Commission. Nekton sites were selected in a stratified-random manner throughout the study, as detailed by McMichael (2015). Samples were collected monthly, from 1996 through 2014, with a 21.3-m, 3-mm-mesh, center-bag seine. Seines were set and retrieved more than 5-m from shore using a 15.5-m line between seine poles to maintain a consistent width for the net opening. Seines were pulled over a standard distance of 9.1 m and sampled an approximate area of 140 m^2. For each haul all nekton (fish and selected macroinvertebrates) were identified and counted. Some specimens were returned to the laboratory for identification quality control.

For each seine sample, location, water depth, water quality, and habitat descriptions were recorded. Temperature (°C), dissolved oxygen (mg/l), and salinity (ppt) were recorded at the surface, bottom, and at 1-m increments between surface and bottom. The types of submerged aquatic vegetation (SAV; seagrass or macroalgae) were identified for each sampling site. Total percentage of SAV cover was estimated visually, but if turbidity prevented visual estimation of percentage cover or type of SAV, a tactile approach, physically using hands or feet, was used for estimating these parameters at 10 standardized points within the sampling area. For the purposes of analysis, SAV type was defined as one of the three most prevalent seagrass species in Tampa Bay (*Halodule wrightii, Thalassia testudinum,* and *Syringodium filiforme*) or "algae" (attached macroalgae), if they accounted for at least 60% of the bottom vegetation. If multiple SAV types were present but none contributed at least 60% of the bottom vegetation, the SAV type was labeled generically as "grass". Sites with no SAV present were labeled as "none."

Levels of annual freshwater input into Tampa Bay from 1996 through 2014 were estimated using discharge data collected by water-stage recorders at two locations, the Alafia River at Lithia and the Little Manatee River at Wimauma (USGS 2015). Years were categorized into those with above average, average, or below average freshwater input by using 95% confidence intervals of mean inflow for the study period.

Bay-wide seagrass coverage was measured periodically by the TBEP based on photointerpretation of aerial imagery from mapping surveys conducted by the Southwest Florida Water Management District (Greening et al. 2014). Consistent methods of assessing the areal extent of seagrasses in Tampa Bay were established in the early 1980s and have since been used. Mapping was conducted approximately every two years, depending on funding availability. Seagrass mapping methods are presented in detail by Tomasko et al. (2005).

Statistical Analyses

Species diversity was calculated for each sampling site using the Shannon-Wiener diversity index (Shannon 1948). Diversity was averaged by year and qualitatively compared to annual average daily river inflow and periodic seagrass coverage data provided by the TBEP. A principal component analysis (PCA) was conducted to describe trends in correlated environmental variables (temperature, salinity, dissolved oxygen, and SAV cover) measured at each nekton collection site.

Comparisons of nekton community structure by year, season, and SAV type were conducted using PRIMER v6 software (Plymouth Routines in Multivariate Ecological Research; Clarke and Warwick 2001). Catch per unit effort (CPUE, expressed as individuals per haul) was calculated for each fish or macroinvertebrate taxon within each sample and fourth root–transformed to reduce the influence of exceptionally large catches. Differences in community structure associated with season and year and season and SAV type were tested with a two-way analysis of similarities (ANOSIM), a nonparametric permutation test applied to the Bray-Curtis similarity matrix (Bray and Curtis 1957). To test the null hypothesis that community structure was not associated with these factors, the value of the test statistic R (adjusted to range from 0 to 1) was initially calculated for the observed data based upon ranked similarities within groups and ranked similarities between groups. Next, a series of permutations (n = 999) was conducted under the null hypothesis. The observed value of R was then compared with the resulting permuted distribution to calculate a probability value. Nonmetric multidimensional scaling (MDS) plots, based on Bray-Curtis similarities averaged by season and SAV type, were used to graphically depict unique nekton assemblages. Assemblages were delineated with boundaries around groups whose species compositions were at least 70% similar (CLUSTER analysis). The contribution of each taxon to observed group differences was then calculated using similarity percentages analysis (SIMPER). The BEST routine was used to determine which environmental variable (temperature, dissolved oxygen, salinity, and % SAV cover) or combination of variables best explained the observed patterns in the biological data (Clarke and Warwick 2001).

RESULTS

From 1996 through 2014, 4,730 sites were sampled with the 21.3-m center-bag seine in Tampa Bay, and effort over various SAV types was spatially distributed throughout the bay (Figure 1A-1D). Sites dominated by *T. testudinum* and *S. filiforme* were typically localized in the more saline middle and lower portions of the bay, and sites dominated by *H. wrightii*, although common throughout the bay, were more heavily concentrated in the relatively less saline upper and middle portions of the bay. The majority of sites throughout the study period that contained SAV were dominated by *H. wrightii*, followed by *T. testudinum*, a combination of SAV types (“grass”), and *S. filiforme* (Figure 2). Relatively few sites were dominated by attached macroalgae. Annual percent composition of SAV types fluctuated very little throughout the study period.

The PCA of environmental data collected at nekton sampling sites identified two major axes (principal components, eigenvalues >1) explaining 64.3% of the environmental variability (Table 1). The first principal component had positive loadings for temperature and negative loadings for dissolved oxygen, indicating a strong seasonal trend, and the second principal component had positive loadings for salinity and SAV cover, indicating an increasing gradient in SAV cover from fresh to more saline waters.

Nekton collected included 1,360,002 individuals representing 167 fish taxa and 15 macroinvertebrate taxa. Annual nekton diversity declined from 1996 through1998, remained relatively stable from 1999 through 2004, plummeted in 2005, and increased in 2006 to lower but stable levels that continued through 2014. These trends in nekton diversity did not appear to be associated with increasing bay-wide seagrass coverage (Figure 3) or annual mean daily freshwater inflow from the Alafia and Little Manatee rivers (Figure 4). Similarly, nekton community structure did not differ significantly by year (R = 0.06). Therefore, all subsequent multivariate analyses concentrated on nekton community differences associated with season and SAV type.

Nekton community structure differed significantly by season and SAV type (R = 0.624, p = 0.001 and R = 0.5, p = 0.001, respectively; Figure 5) and had the highest correlation with temperature and total percentage of SAV coverage (BEST = 0.471). Post hoc tests for season indicated that summer and winter nekton communities were the most distinct (R = 0.869), but nekton assemblages at unvegetated sites were distinctly separated from SAV sites in every season. Nekton community structure among all SAV types was similar in spring and summer, except for a unique summer assemblage identified over algae-dominated sites. Unique assemblages were also identified in sites dominated by *H. wrightii* and algae in fall and winter. Post hoc pairwise comparisons of nekton communities among SAV types indicated that assemblages over completely unvegetated bottom (SAV type = none) were distinctly different from those collected over any other SAV type (R = 0.748 − 0.965; Figure 6). Nekton assemblages associated with *H. wrightii* and algae-dominated bottom were also moderately different from communities found over all other SAV types. The significance of season and SAV type and the correlation with temperature and total percentage of SAV cover indicate a strong seasonal component to community structure as well as a complex relationship with SAV.

The contribution of individual nekton taxa to the observed group differences was calculated using similarity percentages analysis (SIMPER). Resident species such as *Anchoa mitchilli*, *Bairdiella chrysoura, Cynoscion nebulosus*, *Microgobius gulosus*, and *Lucania parva* were most abundant in the summer and strongly contributed to differences between summer and winter nekton assemblages. Estuarine recruitment of juveniles of transient species such as *Eucinostomus* spp. and *Farfantepenaeus duorarum* in the summer and *Leiostomus xanthurus* and *Lagodon* *rhomboides* in the winter also strongly contributed to seasonal differences. Many species, such as *L. rhomboides*, *Eucinostomus* spp., and *A. mitchilli,* were more abundant in sites where SAV was present (Figure 7). Specifically, *L. rhomboides* and *Orthopristis chrysoptera* were more dominant over *T. testudinum*–dominated bottoms, whereas *A. mitchilli*, *M. gulosus,* and *F. duorarum* were more abundant over *H. wrightii*–dominated bottoms (Figure 8).

DISCUSSION

Despite the large increase in bay-wide seagrass coverage since the early 1980s, we did not observe associated annual changes in SAV composition of vegetated sites sampled, nekton diversity, or nekton community structure from long-term fisheries independent monitoring data. The proportionality of SAV types sampled during nekton monitoring remained relatively stable between 1996 and 2014, and as previously documented, most sampling sites were dominated by *H. wrightii* (Flaherty et al. 2010). A study in another south Florida estuary showed that decreased SAV coverage, particularly associated with massive seagrass die-offs, reduced the abundance of canopy-dwelling nekton, while the abundance of benthic species less dependent on seagrass cover increased (Matheson et al. 1999). In our study, nekton diversity showed no relationship with seagrass recovery, and nekton community structure was more distinctly defined by seasonal trends and site-specific factors such as percent SAV cover and type. These results are not necessarily surprising considering that the composition of the ichthyofauna of Tampa Bay has been relatively stable since the 1950s (Matheson et al. 2010). However, the large variation in nekton community structure between vegetated and unvegetated sites indicates that an increase in overall seagrass cover may lead to an increase in absolute abundance of species associated with vegetated sites.

Annual nekton diversity for the entire bay may have been too broad a metric to reveal associated trends with freshwater inflow and bay-wide seagrass coverage. Generally, the decline in diversity after 1996–1998 and the relatively stable periods from 1999–2004 and 2006–2014 were not related to freshwater inflow or increases in bay-wide seagrass coverage, whereas the sharp decline in 2005 can be attributed to a large-scale red tide event (Flaherty and Landsberg 2011). Many studies have shown that salinity differences associated with freshwater inflow affect community structure of fish and invertebrates and that communities tend to separate along salinity gradients (Rakocinski et al. 1992; Sklar and Browder 1998; Ley et al. 1999; Gelwick et al. 2001; Paperno and Brodie 2004; Flaherty et al. 2013). However, the effects of freshwater input and increasing seagrass coverage throughout the restoration period were likely localized to specific regions of the bay, and associated trends in nekton diversity may have been masked by using bay-wide averages. In future research, the regional effects of freshwater input and seagrass coverage on nekton diversity could be further evaluated by partitioning the bay into regions that match the TBEP seagrass monitoring program (Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay, Lower Tampa Bay, Boca Ceiga Bay, and Terra Ceia Bay). The need for finer regional resolution is supported by Bell et al. (1988), who showed that the location of a seagrass bed in the estuary had a significant effect on the abundance of decapods and juvenile fish there. In addition, nekton diversity varies regionally in Tampa Bay, with the greater diversity in Lower Tampa Bay (Flaherty and Landsberg 2011). Since the usefulness of bay-wide diversity measures in assessing changes over time can be limited, especially since they do not incorporate species-specific differences, multivariate methods that incorporate abundance were also used to look at differences in community structure and the species responsible for driving those trends.

Seasonal variation in the distribution and abundance of nekton in Tampa Bay was significant in both SAV and non-SAV habitats. Seasonality has a large impact on the community structure of estuarine fish (Potter et al. 1986; Tremain and Adams 1995; Lazzari et al. 1999; Tsou and Matheson 2002; Paperno and Brodie 2004) and is usually correlated with changes in such environmental conditions as temperature and salinity. In this study, differences in nekton community structure were most pronounced between summer and winter, and resident species were generally more abundant in the summer, when there are typically higher water temperatures and greater freshwater input. Differences in community structure were also driven by recruitment of juveniles of particular species. For example, juvenile *Lagodon rhomboides* and *Leiostomus xanthurus* recruit to demersal habitats in winter and spring, whereas *B. chrysoura*, *C. nebulosus*, and *F. duorarum* recruit in summer (Allen and Barker 1990; Nelson 2002; Idelberger and Greenwood 2005; Flaherty-Walia et al. 2015). Seasonal changes are distinct and have strong effects on community structure, but future research will be necessary to reveal whether the seasonal abundance of seagrass-associated species increased throughout the seagrass restoration period.

Due to the critical nursery and refuge habitat that SAV provides, nekton communities in areas with SAV are typically more diverse and have more fish and macroinvertebrates than areas without SAV (Heck and Orth 1980; Orth et al. 1984; Worthington et al. 1991; Snodgrass 1992; Rydene and Matheson 2003; Bloomfield and Gillanders 2005). In this study, most species were more abundant in sites containing SAV than in unvegetated sites. The abundance of fish and macroinvertebrates is positively associated with both the presence of SAV and with increasing surface area and biomass of SAV per unit area of bottom (Heck and Orth 1980; Orth et al. 1984; Bell et al. 1987; Worthington et al. 1991). Increased SAV cover, density, and biomass provide more structure, lowering the vulnerability of resident species to predators (Nelson 1979; Heck and Thoman 1981) and increasing the number of fish that can utilize that habitat. Heck and Orth (1980) suggested that fish density would increase along with SAV density until the habitat reaches its carrying capacity. The minimum coverage and density of SAV needed to provide sufficient refuge for nekton has not been determined and is likely species-specific, but at least one study has indicated that few fish larvae will settle in seagrass beds with densities of less than 25 leaves per square meter (Worthington et al. 1991). Although the influence of SAV presence on nekton community structure and abundance has been widely documented, density, biomass, and surface area are also important determinants of the suitability of SAV as habitat, and these intricate relationships should be researched further for individual fish species.

As previously documented (Rydene and Matheson 2003; Flaherty et al. 2010), we found that seagrass species composition had a strong effect on nekton community structure. The structure of the grass itself may play an important role in species-specific habitat selection. For example, Stoner (1980) showed that *T. testudinum* had a greater biomass but smaller surface area than did the same number of shoots of *H. wrightii.* The salinity tolerance of SAV species affects their distribution (Doering et al. 2002) and possibly the influence of SAV species composition on nekton community structure. A short-term synoptic study in Tampa Bay suggested that SAV biomass in areas highly influenced by freshwater was lower and might provide less cover than in areas not influenced by freshwater inflow (Flaherty et al. 2010). Even though less cover may be available, some species, such as *C. nebulosus, A. mitchilli*, *M. gulosus,* and *F. duorarum*, were more abundant in *H. wrightii*–dominated beds in areas with more variation in salinity (Flaherty et al. 2010). In contrast, *T. testudinum* and *S. filiforme*–dominated sites were typically found in the more saline, lower portions of the bay, and the nekton communities were characterized by high abundances of *L. rhomboides* and *O. chrysoptera*. A more thorough investigation of proximity to freshwater input as well as the habitat complexity of SAV present, particularly comparing regions of the bay with the greatest increase in seagrass coverage to regions that changed little during the restoration period, may reveal differences in nekton community structure associated with the bay-wide increase in seagrass coverage.

The interrelatedness of bed location, freshwater input, and SAV type and density complicates the interpretation of their effects on nekton diversity and community structure. In this study, sites with SAV had greater abundance of nearly all species compared with unvegetated sites, reinforcing the knowledge that SAV plays a crucial role as habitat in Tampa Bay (Rydene and Matheson 2003; Flaherty et al. 2010; Flaherty-Walia et al. 2015). We would expect to see a seasonal component to nekton community structure, but the type of SAV at a particular seagrass bed and the site-specific SAV coverage were also highly correlated with observed differences and demonstrate that not all seagrass beds provide the same quality of nursery and refuge habitat. Differences in nekton community structure were significant between sites with and without SAV, but, as might be expected considering the relative stability of nekton diversity over time, seagrass-associated nekton communities did not differ temporally throughout the restoration period. Testing whether the absolute abundances of seagrass-associated species are directly correlated to the bay-wide increase in seagrass coverage may be a better approach, but this metric is difficult to assess. A more feasible approach is to compare relative abundances and community structure of seagrass-associated species over time on a defined regional scale, especially in those regions that saw the greatest increase in seagrass coverage during the restoration period. This approach would also allow for more definitive modeling of local seagrass characteristics, freshwater input, and other contributing environmental factors.

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Table 1. Results of principal components analysis examining the interrelatedness of four environmental metrics quantified during nekton sampling with the 21.3-m center-bag seine in Tampa Bay (1996–2014).

Variable	PC1	PC2	PC3
Temperature (°C)	0.674	0.234	0.071
Salinity (ppt)	−0.221	0.658	−0.717
Dissolved oxygen (mg/l)	−0.688	−0.141	0.146
SAV cover (%)	−0.156	0.701	0.678
Variance explained	1.42	1.15	0.834
Proportion of variance explained	0.354	0.288	0.209
Cumulative variance explained	0.354	0.643	0.851

Figure 1. Distribution of sampling sites in Tampa Bay (TB), 1996–2014, by SAV type; A) *Halodule wrightii,* B) *Thalassia testudinum,* C) *Syringodium filiforme*, D) algae, grass, and none.

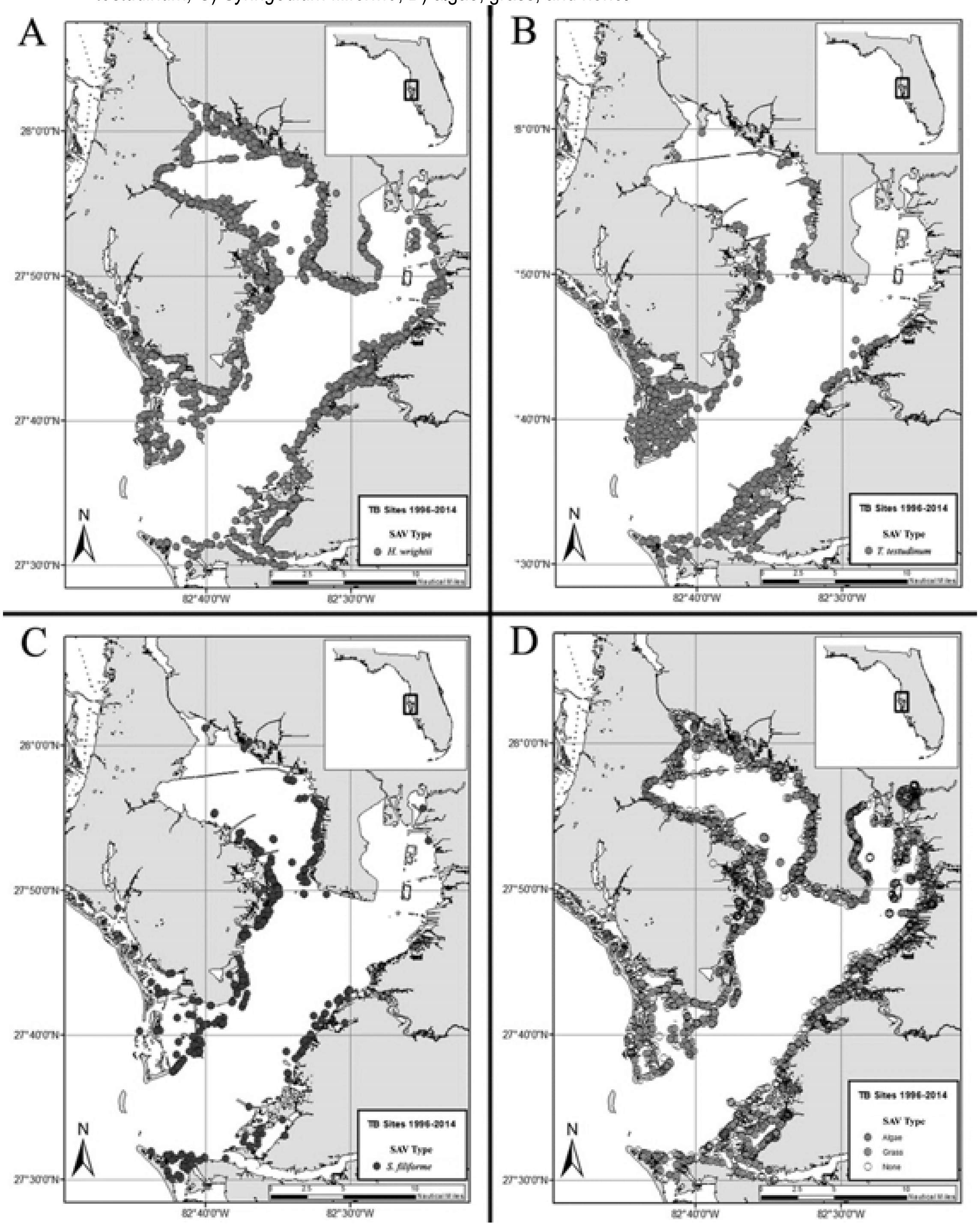


Figure 2. Annual percentage of vegetated sites characterized by each SAV type in Tampa Bay (1996–2014). n = total number of sites for each SAV type.

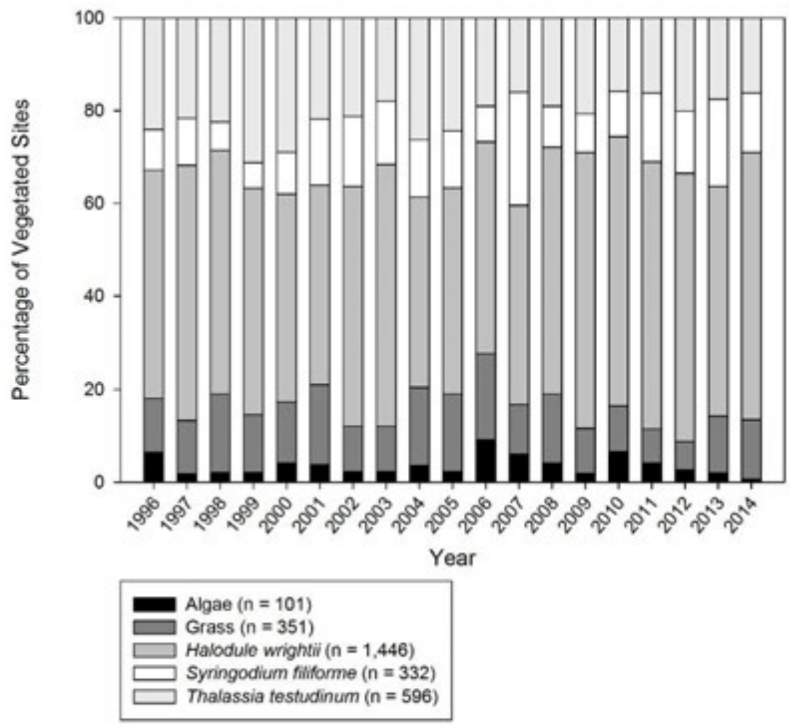


Figure 3. Mean annual nekton diversity and estimated bay-wide seagrass coverage by year. Circles represent mean nekton diversity, error bars represent the standard error of the mean, and diamonds represent years in which seagrass coverage was assessed.

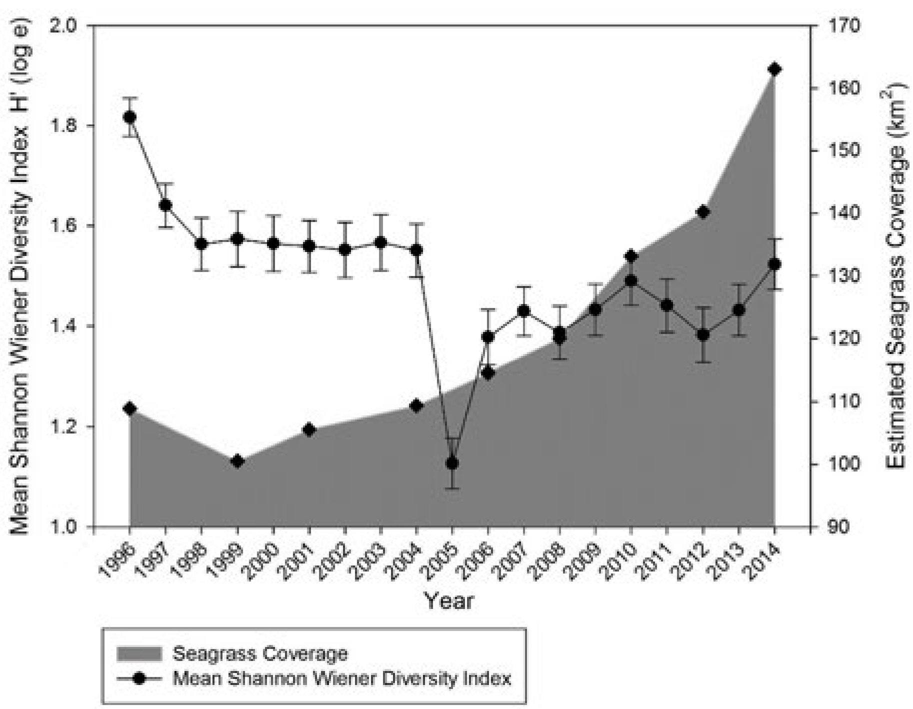


Figure 4. Mean annual nekton diversity compared with mean daily freshwater inflow from the Alafia and Little Manatee rivers, Tampa Bay (1996–2014).

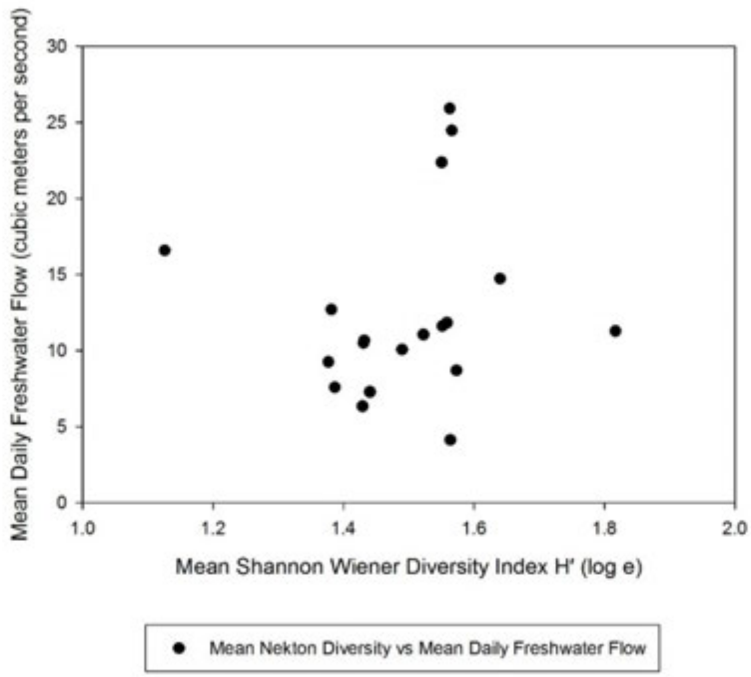


Figure 5. Nonmetric multidimensional scaling plot of nekton community data by season (symbols) and SAV type (labels). Labels for seagrass species are indicated by their genus (*Halodule, Thalassia,* or *Syringodium*). Ellipses represent groups with at least 70% similiarity (CLUSTER analysis).

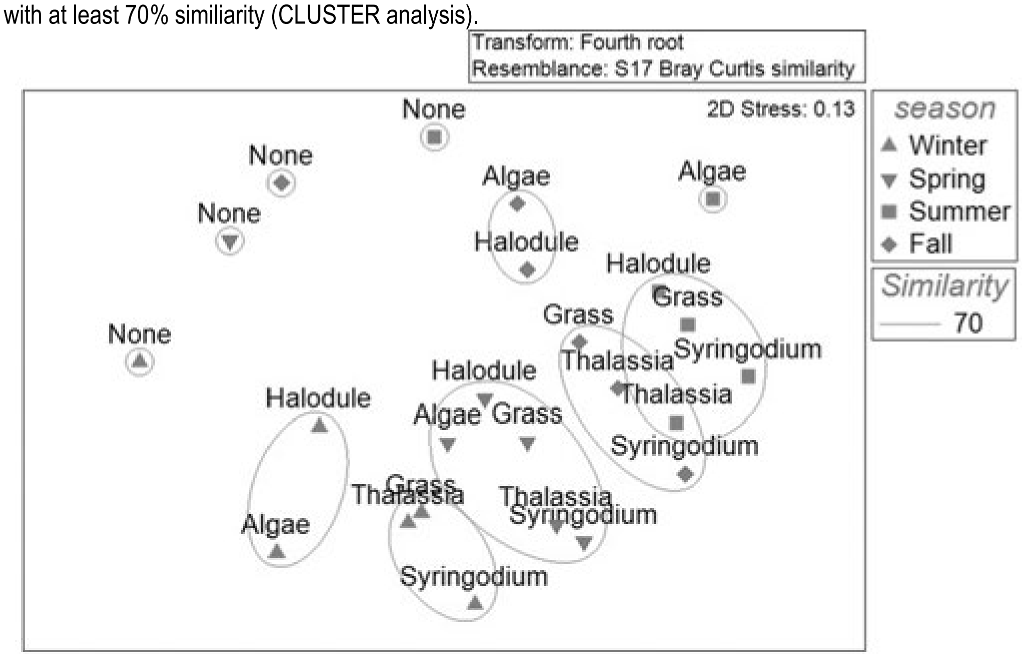


Figure 6. Post hoc pairwise comparisons (ANOSIM) of nekton community structure across SAV types. Colors indicate groups that were well separated (black; R > 0.75), clearly separated but overlapping (dark gray; 0.75 ≥ R > 0.5), moderately separated (light gray; 0.5 ≥ R > 0.25), or barely separated (white; R ≤ 0.25) (Clarke and Warwick 2001).

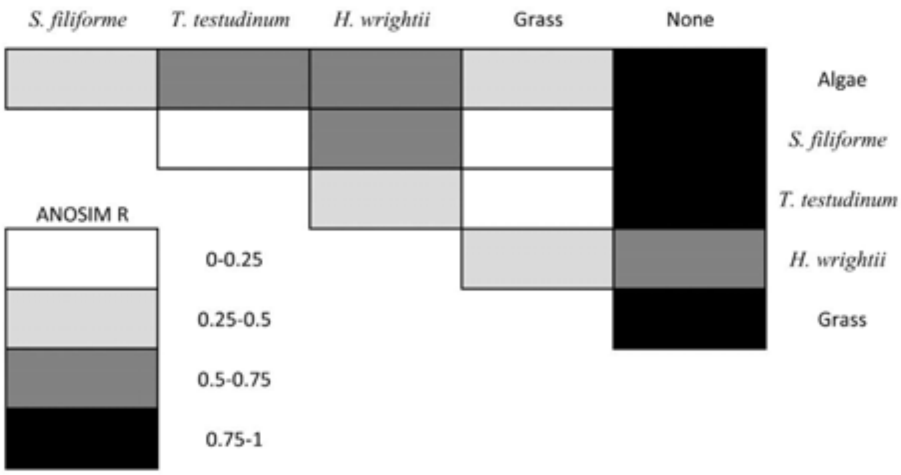


Figure 7. Catch per unit effort of the top 15 species contributing 59.73% to differences in nekton community structure between sites with and without SAV in Tampa Bay, 1996–2014.

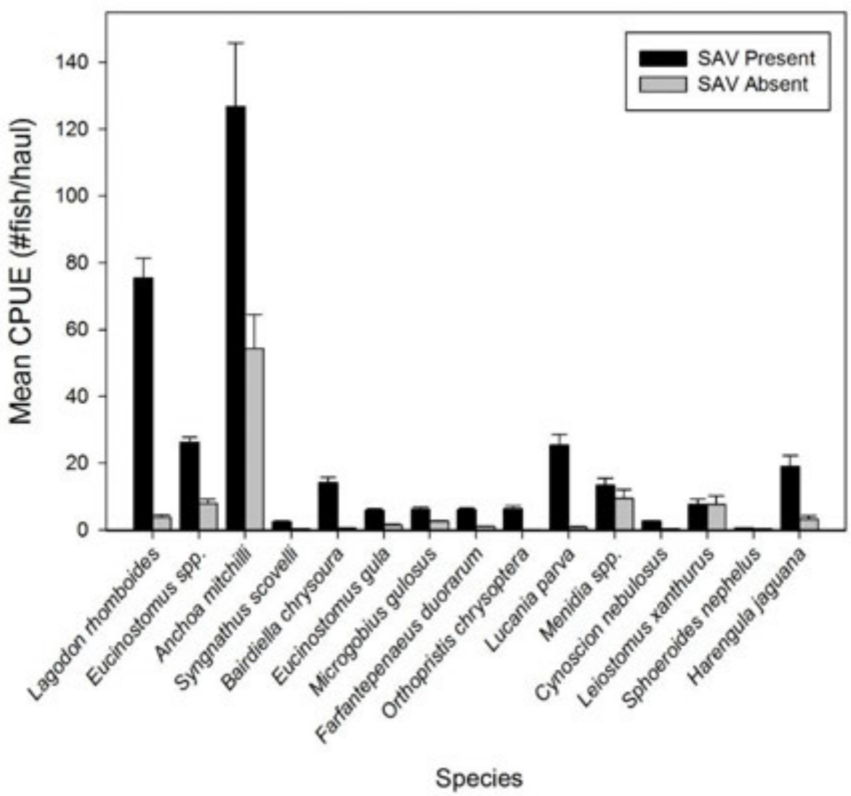
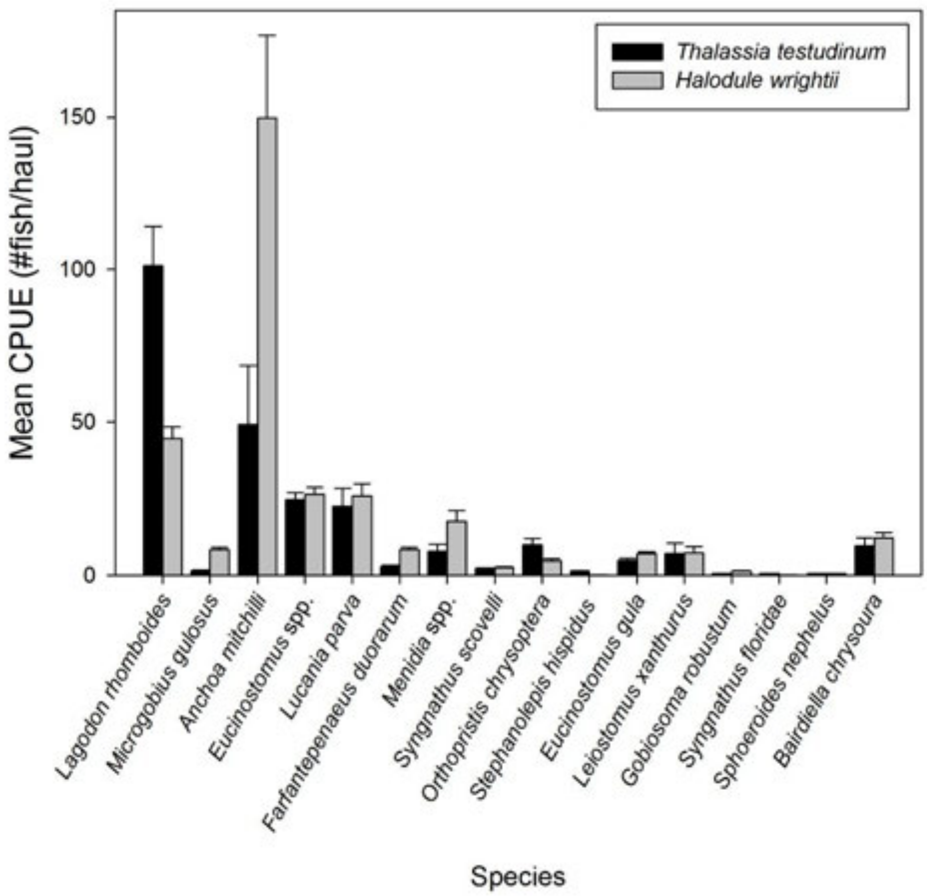


Figure 8. Catch per unit effort of the top 16 species contributing 56.52% to differences in nekton community structure between *Halodule wrightii*– and *Thalassia testudinum*–dominated sites in Tampa Bay, 1996–2014.



SALTERN RESTORATION VIA HYDRO-BLASTING TECHNIQUES

Thomas F. Ries

ABSTRACT

The Tampa Bay Estuary Program's "Restore the Balance" paradigm for Tampa Bay's estuarine systems identified saltern habitat as being disproportionally impacted. There has been a concerted effort by the various restoration practitioners to restore this unique habitat. This paper summarizes the various restoration techniques (creation, restoration, and enhancement) and their subsequent results. Nine saltern restoration projects were examined (Mangrove Bay Golf Course, MacDill AFB Demo Project, Weedon Island, Gateway Tract, Lost River Preserve, Newman Branch Creek Phase I, Feather Sound Preserve, MacDill AFB, and Newman Branch Phase II Expansion). The various restoration techniques are evaluated by cost, temporary construction impacts, and the documented results. Creation costs ranged from $32K to $36K/acre; enhancement costs ranged from $5K/acre to $26K/acre, and restoration costs ranged from $0.5K to $2K/acre. The associated temporal construction impacts and related recovery times varied from moderate impacts with a 3-year recovery for traditional heavy equipment construction, to minimal site impacts and weeks for recovery for hydro-blasting methods. The effectiveness of the various restoration techniques can be difficult to discern, however, the early indications are that these rare habitats can be successfully restored. Finally, the use of the hydro-blasting process to eliminate spoil mounds and to strategically block ditches is discussed and analyzed to assess whether it is as an effective habitat restoration tool. Recommendations for future Tampa Bay saltern restoration endeavors are also provided.

INTRODUCTION

Saltern habitats are defined as hyper saline areas which usually contain high concentrations of halophilic microorganisms including algae and bacteria. Saltern communities typically exist in the upper transitional zone where the extreme high tides or "king" tide water reach occasionally. These flat areas exhibit poor drainage which results in the evaporation of the water, leaving the salt behind. Over time these salt concentrations increase and result in hyper saline conditions, from greater than 45 ppt up to 170 ppt (Hoffman, 1997). In Florida, saltern communities exhibit a variety of forms; the most common expression consists of large white sandy areas with interspersed pockets of algae covered zones.

Saltern environs are very harsh settings with limited plant growth due to the hyper saline conditions; in areas where the salinities are below 45 ppt, there are a few plants that can exist within these extreme conditions, inclusive of glasswort (*Salicornia virginica*) and key west grass (*Spartina spartinae*). Even though the un-vegetated areas within the saltern appear lifeless, they are utilized by nesting birds and fiddler crabs (Reinsel, 2004). The ecologically most productive period for a saltern is during the abnormally high tide events when these areas are flooded. During these peak tides fish can and do enter the saltern areas and can be trapped during the outgoing tides, it is at these times that the saltern areas become extremely important as foraging areas for wading birds (Ries, 2008).

Figure 1. Representative saltern (left) and algae dominated saltern (right).

The Tampa Bay Estuary Program (TBEP) commissioned a report in 1996, on the health and extent of the estuarine ecotones within the Bay. This report, known as the "Restoring the Balance" report detailed that, of all the estuarine habitats within Tampa Bay, saltern communities are the most critical due to the disproportional impacts to this habitat since the 1950s (TBEP, Restoring the Balance, 1996). Since that report was published, restoration practitioners have been prioritizing the protection and restoration of these saltern communities. To re-attain the proper balance of estuarine habitats, over 500 acres of saltern communities would need to be restored. This paper investigated the results of those restoration attempts, inclusive of costs and the various restoration methods, by examining eight sites within the Tampa Bay watershed.

METHODS

To assess the various sites, the projects were categorized by the type of activities that were performed. For consistency purposes, the three primary saltern restorative activities are defined for this assessment purposes: Saltern Creation (SC) - altered uplands transformed into saltern habitat; Saltern Enhancement (SE) - removal of spoil mounds within an existing saltern; and Saltern Restoration (SR) - ditch blocks/hydrologic improvements within an existing saltern.

Saltern Creation (SC) consists of transforming altered uplands to create the appropriate elevations and slopes which are conducive for saltern formation. This is accomplished via traditional heavy construction equipment, bulldozers or grading equipment.

Saltern Enhancement (SE) consists of the removal of spoil mounds, typically associated with historic mosquito ditching activities. The removal of these mounds results in improved sheet flows across the terrain and restores the saltern habitat. Formerly this was accomplished with heavy equipment; however the heavy equipment itself also impacted the very saltern community that was being restored. In the past ten years an innovative alternative technique has been gaining popularity; hydro-blasting, consists of utilizing small pumps to create high pressure water which can be directed to "blast" spoil material from the saltern. If this is performed in a circular (360°) fashion the spoil material is evenly spread around the area. For typical mounds (~30 feet in diameter and ~4 feet in height) this produces less than 1 inch of spoil material, which is easily washed away during the next rain event without any detrimental affects to the surrounding ecosystem.

Figure 2. Hydroblasting

Saltern Restoration (SR) consists of improving the hydrological conditions within an existing saltern community. In the Tampa Bay region, many of the saltern communities were negatively impacted by the creation of mosquito ditches. These ditches deliver tidal waters into the saltern communities on a daily basis which drastically alters the salinities within the saltern and results in a shift of the vegetative community types. To restore the natural tidal patterns, these ditches can be strategically blocked to still allow the extreme high tide events to deliver saline waters onto the saltern and then delay the release of the salt water, as it historically had so the hyper saline conditions can restored. The adjacent spoil mounds can be hydro-blasted directly into the targeted ditch (with silt screen material) to block the receding waters and restore the normal tidal flow patterns.

Nine estuarine restoration projects which included saltern communities were selected around Tampa Bay, they included the following locations:

Project	**Type**	**Location**
Mangrove Bay Golf Course	SC	Pinellas County
Weedon Island Preserve	SE	Pinellas County
Gateway Tract	SE	Pinellas County
Feather Sound Tract	SR	Pinellas County
MacDill AFB Demo Site	SC	Hillsborough County
Lost River Preserve	SR	Hillsborough County
Newman Brand Phase 1	SR	Hillsborough County
MacDill AFB Phases I & II	SE	Hillsborough County
Newman Branch Phase II (Exp)	SR	Hillsborough County

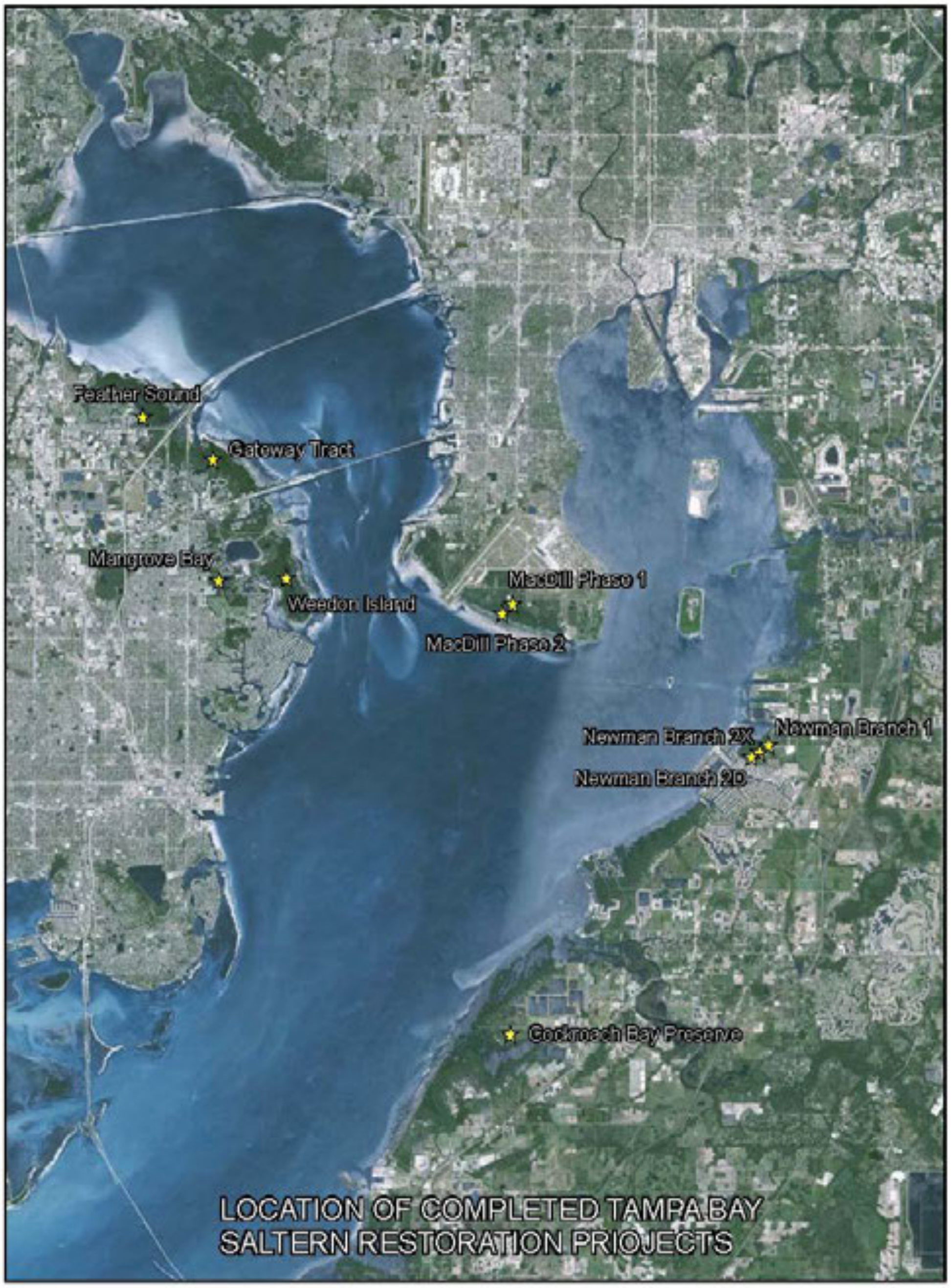


Figure 3. Location map of completed saltern restoration projects in Tampa Bay, Florida.

All of these locations (**Figure 3**) had various saltern improvement components included as part of the project objectives. These sites ranged in age from 1 year (2015 completion) to 24 years old (1992 completion). The resultant saltern restoration acreage ranged from less than 1 acre to more than 14 acres. Each project is unique in the amount of existing habitat and the form of restorative activities that were performed onsite.

RESULTS

The cost of each of the noted restoration projects were categorized into the three noted categories (SC, SE and SR). The range of costs for each category was then averaged to assess the costs to implement the various restorative processes. Also, the construction impacts and resultant saltern improvements were also assessed.

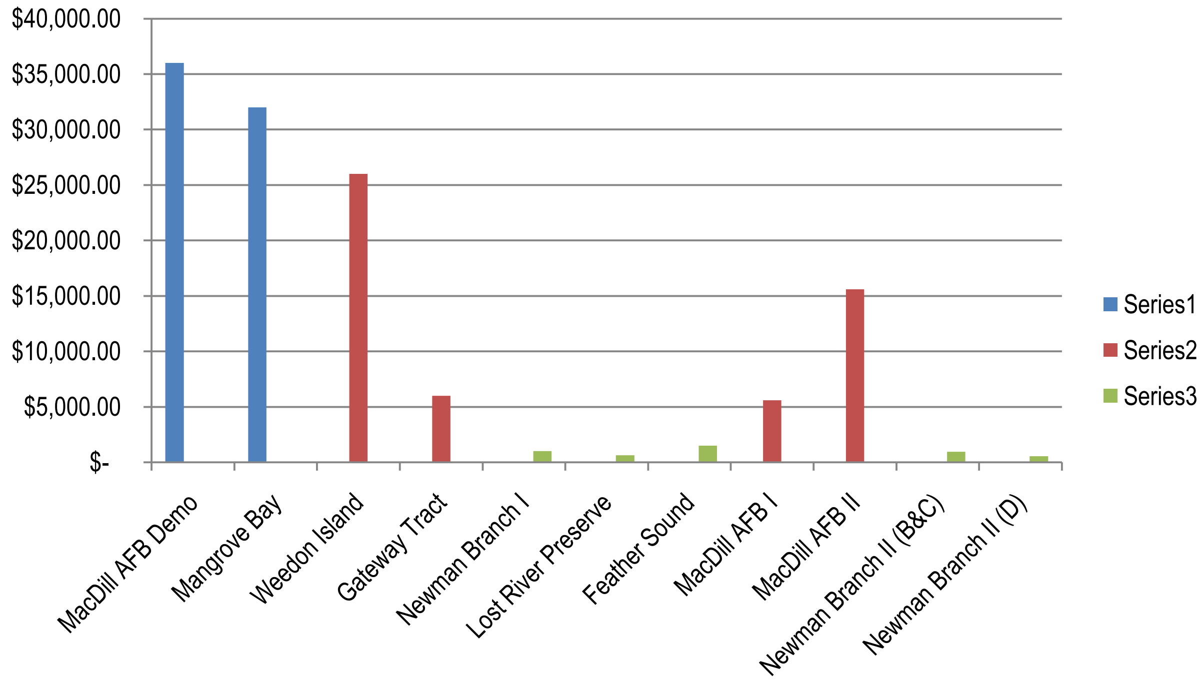


Figure 4. Comparison of restoration costs, by activity type (Series 1 - Creation; Series 2 – Enhancement; Series 3 – Restoration)

The cost range to create saltern habitat, from disturbed uplands, varied from $32K - $36K/acre, with a median of $34K/acre. These costs include the design, permitting and construction of the saltern habitat for that site. The resultant saltern area was successfully achieved at the Mangrove Bay site; for this creation effort the area was designed for a finished grade elevation 1.8' National Geodetic Vertical Datum (1929) and an associated minimum of 60-foot width to achieve the saltern characteristics. The actual construction impacts are extensive and the time to achieve the saltern functions took more than five years. However, it did achieve the saltern habitat and resulted in an acre of new saltern community.

The cost range to enhance existing or remnant saltern habitat varied from $5K - $26K/acre, with a median of $10.8K/acre. This range reflects two distinct methods of removing the spoil mounds associated with the historic mosquito ditching operations; traditional heavy equipment (Weedon Island and MacDill Demo Site) verses the hydro-blasting technique (Gateway and MacDill Phases I & II). The use of heavy equipment is costly and reflects the high end of the cost range. Also, the construction impacts associated with the use of heavy equipment was extensive and it took over three years for the site to recover from those temporary impacts; however the resultant effort did enhance the remnant saltern communities, as anticipated. The second method (hydro-blasting technique) represents the lower end of the cost range. It also results in minimal impacts to the surrounding wetland communities. In fact, since this can be accomplished with two laborers and a high-pressure pump, there are no temporary impacts and thus the recovery time is minimal.

Table 1. *Saltern Restoration Costs (per acre)*

Project	Creation	Enhancement	Restoration
Mangrove Bay	$32K		
MacDill AFB Demo Site	$36K		
Weedon Island		$26K	
Gateway Tract		$6K	
Newman Branch I			$1.0K
Lost River Preserve			$0.642K
Feather Sound			$1.5K
MacDill AFB I		$ 5.6K	
MacDill AFB II		$15.6K	
Newman Branch II (B&C)			$0.945
Newman Branch II (D)			$0.560K

The associated cost to restore saltern habitat ranged from $0.5K - $2K/acre, with a median of $0.945K/acre (**Table 1**). These costs are a fraction of what it costs to create or even enhance saltern communities. Again, since it involves the hydro-blasting method, the impacts are very minimal and the resultant cost per acre is very affordable. The saltern communities can restored via this methodology, although it does take time for the saltern characteristics to naturally return. The older sites (Newman Branch Phase I and Lost River Preserve) are already showing transforming back into a functional saltern community; although it did take approximately 5-6 years for the salinities to reach the minimum of 45 ppt.

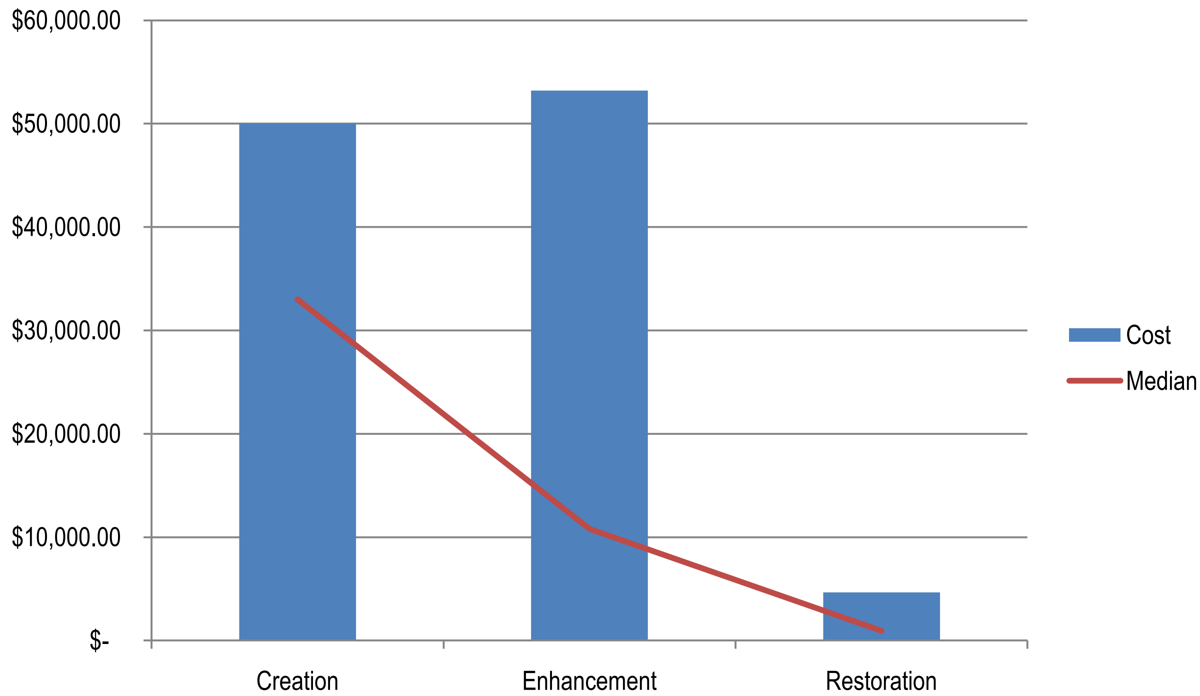


Figure 5. Median cost of various restorative activities.

DISCUSSION

All three saltern restorative processes did yield net saltern acreage. However the costs associated with each technique differed. Saltern creation (SC) is by far the most expensive method to achieving new saltern acreage. However, if performed properly, this is a means to quickly create the conditions for a saltern community to form over time. The saltern enhancement (SE) efforts are much less expensive than the creation method especially if the work is performed via the hydro-blasting technique, it will result in improving the saltern areas, as envisioned. Although it should be noted, that the hydro-blasting technique is labor intensive and hard work especially in the summer months. However, the resultant benefits, restored saltern communities are worth exploring this technique further. A secondary outcome is that each mound that is hydro-blasted out results in new wetland acreage (upland mound transformed into saltern or wetland elevations); although this new acreage is small, a typical mound is 30 feet in diameter, thus only yielding approximately 480 square feet of wetland per mound. Thus this aspect is a very expensive method of wetland creation. Finally the saltern restoration, via the strategic filling or blocking of the mosquito ditches is the least expensive method and it also immediately resorts the saltern hydrology. The transformation of the saltern community does take time; however, it has proven to be an effective means of restoring the functions to the altered saltern community.

Per the results of this analysis, it appears that saltern restoration is achievable and depending upon the site and restorative restoration strategy, it can be cost effective. The hydro-blasting technique appears to the best option due the lowered associated costs and due to the fact that it has the least environmental impacts during the implementation process. Also, the strategic blocking of the upper sections of the mosquito ditches, which bisect historic saltern communities, may be the most effective strategy to restore these crucial habitats within Tampa Bay. Although there are literally tens of thousands of spoil mounds scattered around the Bay, it would be cost prohibitive to try and remove all of them. Also, although the associated mosquito ditches are anthropogenic in nature, they do provide fish spawning habitat and thus should not be totally filled (Krebs, 2009). However, if these ditches are affecting saltern communities then the strategic plugging of these ditches should be considered. To achieve the TBEP's goal of 500 acres of saltern restoration, all mosquito ditched saltern communities should be targeted for investigation, and as appropriate, restorative actions should be implemented.

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LESSONS LEARNED DURING RESTORATION OF DIVERSE NATIVE GROUND COVER AT UPLANDS HABITATS OF TWO COASTAL PRESERVES IN MANATEE COUNTY

Damon Moore

ABSTRACT

Two coastal preserves in Manatee County, Ungarelli Preserve and Perico Preserve, contain upland habitats that have successfully undergone a restoration of groundcover composition from a condition of being dominated by nuisance and exotic vegetation to establishment of a diverse assemblage of desirable native vegetation. Coastal properties in the Tampa Bay area that are acquired for habitat restoration and enhancement typically contain upland habitats that are highly disturbed with a high level of nuisance and exotic vegetation as a result of prior land uses, typically agriculture. These land uses lead to a condition in which vegetative cover is dominated by weedy exotic vegetation and a seedbank of native species is largely absent. This makes restoration of the groundcover stratum to levels of diversity approaching un-impacted habitats a very challenging undertaking. Successful restoration of groundcover was achieved on Perico Preserve and Ungarelli Preserve utilizing a restoration strategy that involved soil inversion, an intensive weed management and monitoring program, native groundcover seeding, out planting of a wide array of native plants, and habitat establishment period adaptive management. This was accomplished using a diversity of funding and labor sources. Through this groundcover restoration process, lessons were learned that could be applied to other habitat improvement projects.

INTRODUCTION

Manatee County Parks and Natural Resources Department has undertaken two recent projects that included upland habitat restoration with a focus on re-establishing a diversity of native groundcover plants as typically found in well managed natural areas that have not been subject to un-natural disturbances of the land surface. The subject properties are Perico Preserve (27.496694, -82.677609) and Ungarelli Preserve (27.463445, -82.648708). Both of these properties are located in western Manatee County and include a combination of coastal wetland and upland habitats. On both sites, the upland habitats were subject to historical disturbances that effectively destroyed the former natural upland habitats. In restoring ecological function to these properties, some established restoration methods were confirmed and some new techniques were applied. There were some abject failures and some notable successes, but overall the upland habitats on both preserves are vastly improved over their pre-restoration condition. The aim of this paper is to share the lessons learned so far on these properties so that the knowledge gained may be applied to future restoration projects. This is done by sharing the most important observations and opinions of the Author, a habitat restoration practitioner with the intended audience being restoration scientists, other practitioners and project designers practicing in coastal southwest Florida, and looking to improve the outcome of future projects. Some points are certainly applicable outside of this area. The lessons learned are presented in three major categories; planning, implementation, and adaptive management.

PLANNING

The most important question posed (in the Author's opinion) and the most influential aspect on the design and implementation plan of both of these projects was; "Are the proposed improvements sustainable with existing and future land management resources?" or "Can we maintain the habitat targets we're aiming for?"

Different habitats require varying levels of effort to maintain the initial gains made with the restoration project. For instance, low salt marsh (or mangrove habitat as marshes convert over time) is a relatively harsh environment with low plant diversity and very little future management requirements. Currently there are not exotic invasive species in the Tampa Bay region that will compete with salt loving native marsh grasses and mangroves used to establish these habitats. (We need to keep an eye out for two exotic mangroves currently in south Florida, *Bruguiera gymnorrhiza and Lumnitzera racemosa.)* If there are little to no future resources for ongoing management, decision makers/project designers should consider converting upland areas to salt influenced wetland habitats. In creating salt water influenced habitats, it's usually a situation where if the correct elevations and salt water exchange regime is achieved, the likelihood of success is high and future management needs are very low.

On the other end of that spectrum are the highly complex native upland systems like coastal pine flatwoods, which is better defined as a savanna or grassland that contains scattered pine trees. The real defining characteristic of flatwoods habitat is not the pine trees as much as it is the high diversity of plants found in the ground cover stratum. So, LOTS of different kinds of plants, it's not just planting pine trees in a flat area. Further complicating matters with flatwoods systems is that they exist above that magic elevation where high salinity severely limits competition from exotic and native weedy species. So, weeds are a big problem. If that weren't enough of a challenge, add to the equation the fact that pine flatwoods require recurring fires every 2 to 5 years to maintain their vigor, and to prevent succession to oak forest or as is often the case in the Tampa Bay Region of upland coastal sites, succession into exotic hardwood forests, dominated by lead trees (*Leucaena leucocephla*), carrotwood (*Cupaniopsis anacardioides*), Brazilian pepper trees (*Schinus terebinthifolia*) and Australian pine trees (*Casuarina equisetifolia*) .

When you look at the two extreme ends of the "what could we do with this area" conundrum as described above, it's very easy to lean towards the saltmarsh/mangrove option, especially given typical resource limitations and everyone's desire for the project to reach its restoration goals. There are certainly values in both extremes, but the route taken will usually be to re-establish a combination of habitat types that meet the goals and limiting parameters of the project. At both Perico and Ungarelli Preserves, the County chose a combination of the less challenging route (creation of salt influenced habitats) and the more challenging restoration goal of re-establishing pine flatwoods and coastal scrub.

The primary reason for choosing the challenging path of restoring flatwoods and scrub at Perico Preserve was the consideration made by project designers for this question; “Of the natural habitats in the coastal areas of Manatee County which are the most under-represented?” The local restoration community is well versed in the historical losses of mangroves, salt-terns, seagrass beds and other wetland habitats, but the coastal upland communities, in a healthy natural condition, i.e. intact healthy pine flatwoods, and coastal scrub are practically non-existent in the coastal areas of Manatee County and very rare in the region. These uplands were prime areas for agriculture, being near the coast and less prone to freezes than more inland areas. A review of the 1940s and 50s aerials gives a good indication of how much coastal areas were valued as agricultural lands. A large amount of these agricultural use areas were later, and continue to be, converted to residential uses, as the population increased in the following decades. Fortunately as development pressures increased the value of wetlands was recognized and regulations protecting them were put in place that greatly reduced the loss of wetland habitats. Upland habitats have not, and still do not receive significant protections from development. The scant remaining areas that escaped being farmed or developed were subject to decades of fire suppression and extremely high propagule pressure from an ever increasing amount of nuisance and invasive exotic species. These factors left virtually no areas of coastal Manatee County where one could walk through and get a sense of what the area was like in its natural condition. Besides the intrinsic value of native upland habitats to wildlife and of restoring the balance of habitat types the County also sought to provide a place where those upland habitats could be experienced by future generations in a coastal setting.

The decision was made to take on the challenge of restoring flatwoods and scrub at a portion of upland acreage at Perico Preserve, specifically in areas where application of prescribed fire was feasible and at an acreage where management of undesirable plants, both long-term and through the early establishment period (those first five years that can make or break the project) of the target habitats was feasible to manage with resources currently available and into the foreseeable future. At Ungarelli preserve, where application of prescribed fire was decided to be less practical and worthwhile relative to the benefits provided, the uplands were converted to salt influenced wetland habitats or planted with species that upon maturity would resemble coastal hammock which has a very long fire return interval, closed canopy, and therefore a much less diverse groundcover plant community. Basically, we went for a less complex system at Ungarelli. Less attention was paid to the challenging aspect of ground cover restoration because with the planting palette selected, we were setting the trajectory of the restoration project towards a closed canopy system where, at maturity, the ground cover would be dominated by shade tolerate plants and leaf litter. This may take another 20 to 30 years to achieve. Since we were aware that there was a substantial waiting period before canopy closure, planting of native ground cover species was performed on this site, but in a less complex manner than was done at Perico Preserve. This was done for the temporal benefits to wildlife and to prevent the site from being over-run with invasive exotic plants. We decided cost of planting ground cover was worth the investment for the 20-30 years of benefit.

Other than the, “pure restoration, to be or not to be”, consideration the County made for both of these sites, careful considerations other than future management feasibility and likelihood for success were considered as will always be the case. For instance:

- Saltmarsh creation at Ungarelli, would provide needed material to needed to bury a long established seedbank of undesirable species, (a process call soil inversion which is worth local restoration practitioners being familiar with but will not be discussed in detail in this paper). The saltmarsh was intentionally created in an area that would provide Stormwater treatment of previously untreated runoff coming from Palma Sola Blvd.
- High Marsh creation at Perico in some locations was specifically chosen at those locations because of heavy infestation with the notoriously hard to control exotic species torpedo grass (*Panicum repens*). It was easier to lower the elevations of those infested areas to facilitate exposure to saltwater thereby eliminating the conditions suitable for these species. This also served to increase forage area, for wading birds.
- Freshwater marsh creation at Perico Preserve. This was created for two reasons. The first reason being that freshwater marshes, once common in coastal areas of the county, had largely been ditched and drained, or filled because the western portion of the county had been developed largely before wetland protection measures had been put in place. We wanted to have a representative area for interpretation of a natural condition. The other reason was specifically to benefit wading birds by providing forage areas that concentrated a food source that includes freshwater invertebrates at times of the year that corresponds with nesting season.
- Freshwater pond at Perico Preserve. This was created for its wildlife benefits but also for a very practical management reason. We wanted to have an easily accessible onsite source of freshwater for filling water tanks that are used during application of prescribed fire at the site.
- A nearly 16 acre seagrass basin requiring approximately 300K cubic yards of material to be excavated from upland habitats at Perico Preserve. The initial reason for doing this was funding shortfalls requiring a “don’t bite off more than you can chew” decision to exclude an area from the initial enhancement project. We did not want to water down the approach as we felt that would ultimately lead to the entire system being more subject to the possibility of failure. We chose to apply a more intensive methodology over a smaller area. Considering the long term management challenges of maintaining that large of an upland area an alternative solution was necessary. Opportunities presented themselves for a beneficial use of the material for another county project that would allow for significant cost sharing. An in-depth analysis of feasibility to create seagrass habitat was performed and creation of the basin and subsequent connection to Perico Bayou was completed in late 2015. The intention is for future sale of seagrass mitigation credits for public

projects. Value estimates are in the millions if successful establishment of seagrass is achieved within the created basin. This money would go to recoup taxpayer investments made on the purchase of the property and ideally be utilized for acquisition of environmentally sensitive property or sound management of the county's preservation acquisitions. This is a much simplified synopsis of this aspect of the Perico Preserve project.

- Scrub "mounds" at Perico Preserve. These two mounds at Perico preserve were created for several different reasons, both for habitat value and practicality of construction. In creating wetland habitats at Perico Preserve (excluding the seagrass basin) the material was piled to increase the elevations and create areas of well drained soils that would mimic soil moisture conditions found in coastal scrub that once existed on the site. This increased elevation also serves to prolong the existence of some upland habits as sea level rise increases (eventually this area will be a scrub island). The other reason for mounding was to recreate a sand mound once created by Native Americans that was described on the site but has not been located and is assumed destroyed once the site was used for agricultural purposes.
- An oak hammock planting pallete was used along the border with houses at Perico Preserve to serve as a visual buffer as well and establish a habitat type in those areas that is less likely to carry fire. This was done to increase safety in the case of wild fire and when prescribed fires are performed by staff. At maturity shady oaks with little ground cover plants present is not likely to burn, and that was the specific aim adjacent to homes.

As alluded to in the examples above, there is a myriad of factors to be considered when designing and making decisions about what do with the low quality uplands on a coastal site. There are some greatly helpful resources and documents that apply to any restoration project and are highly recommended to help make the right decision and prevent wasting resources. The most useful and applicable to the Ungarelli and Perico Preserve projects is the Society for Ecological Restoration's document, Guidelines for Developing and Managing Ecological Restoration Projects. This document provides a step by step approach for restoration projects that proved to be very useful during all phases of these projects, but especially valuable for guidance in the planning and conceptual design phases.

IMPLEMENTATION

For the sake of brevity, only restoration considerations implementation methods used to restore pine flatwoods and scrub habitats at Perico Preserve will be discussed here. First a little background to put the task into perspective. Prior to European contact, these habitat types made up the uplands on the Perico site. This was determined by review of historical aerials, soil surveys, old surveyor notes, accounts from longtime residents, and a historical account of Perico Island from 1887. These are the conditions we wanted to regain a semblance of.

Now for some history on what natural habitats occurred on the site and how those habitats degraded from an ecological functions perspective. The earliest available aerial photographs, from 1940, show a signature consistent with native ground cover though by comparison to adjacent areas, (27.504120, -82.683754) it seem likely that a relatively dense spacing of pine trees had already been harvested from the Perico Site. This assumed presence of pine trees would later be confirmed while excavating the seagrass basin where the old root systems of hundreds of pine trees were discovered. The series of aerial photographs take over the ensuing decades shows the site converted to intensive agricultural use in the 1950 including installation of deep wells and the construction of a large perimeter berm along the wetland edge, and installation of clay drainage tiles across upland areas of the site. Later extensive ditching occurred in the mangrove habitats through the 60's and 70's as agriculture continued until about year 2000. From that time the site was largely left fallow. The approximately 50 years of intensive agriculture resulted in few reminders of the original landscape. Small pockets of land (27.499633, -82.678223) appear to have avoided the plows, likely because of the impracticality of their location. These areas host the few remaining mature pines and contain other clues of the pre 1950's upland condition such as the presence of saw palmetto in the understory and pine heartwood snags. What remained over the vast majority of the upland areas of the site was weedy exotic vegetation.

With the challenge defined these are the steps we took in an effort direct the future trajectory of the sites towards what we intend to be representative of native upland conditions. A suitable nearby reference site did not exist so restoration goals were generalized extrapolations based on well managed flatwoods habitats further inland, and other small remnants of degraded coastal habitats. The overarching goal for the restoration of flatwoods and scrub areas was re-introduction of a diversity of native plants typically found in those habitats that was capable of carrying fire and contained very low levels of exotic species. Basically, to restore the primary producers that would in turn provide ecological support to organisms of higher trophic levels. While by most standards, it's too early to claim victory, by qualitative assessment of the author, it appears the restoration is trending towards meeting the goal. The following goals that were achieved are major factors that contributed to the early success.

- Restore physical characteristics of the site to the extent possible. In the cast of the Perico project, the perimeter berm and drainage tiles were altering the hydrology of the site. Breaches were made in the perimeter berm to re-establish surface water exchange between upland and wetland areas. The network of drain tiles were broken up by excavation of wetland features or using heavy equipment specifically to break up the drain lines.
- Remove undesirable plants. Basically any plant in the work area that would not normally be found in flatwoods was targeted for removal. Some weedy species are more difficult to remove than others (some

still exist on the site today). A combination of soil inversion for areas where elevations would increase and repeated herbicide applications were used. Species such as torpedo grass, and Bermuda grass (*Cynodon dactylon*) were targeted more than a year before any earth moving. Most credible sources suggest allowing for at minimum 2 years of herbicide treatments to remove these species and they are correct by our experience at Perico. Both are still present on the site and unfortunately will likely continue to be present for the foreseeable future.

- Site preparation for direct seeding. Before the investment is made to do seeding makes sure the site is in a condition where required equipment can work.
- Direct seeding was applied over the upland areas, a few times. The initial seeding event occurred in December 2012 with material harvested from Thomas Ranch in Venice Florida (27.049083, -82.3360018), this donor site was selected because it was nearest the coast that had been burned the previous growing season (this is a must for viable production of wiregrass (*Aristida stricta*) seed). The line of thinking here was that local ecotype seeds produce plants with specific adaptations for successful regeneration of subsequent generations, so the closer the better. A second seeding occurred a year later with seeds harvested from Duette preserve (again from areas that had burned in the growing season the year leading up to harvest). The goal with this was to add more species diversity and genetic diversity among plants that had established from the prior year's seeding sourced from Thomas Ranch. Beyond that, extra effort has been made to continually harvest and introduce seed from plants that do not produce seed in the fall, many spring blooming wildflowers, for instance.
- Nutrient poor sand piles established with desirable plants very well in this instance. It was a serious concern that areas of the site where re-grading had occurred to build up mounded would be more or less sterile and largely lacking soil symbionts necessary or growth of desirable plants. As it turned out these areas performed the best theoretically because the low nutrient levels and lack of weedy seed bank favored the planted native seeds, which are harvested from natural habitats that are also nutrient poor. Growth of weeds was much slower and allowed for more effective control post planting
- Planting nursery stock can add further diversity in the ground cover and is necessary to restore canopy and shrub strata.

There are valuable resources published within the last several years available to provide guidance for a practitioner attempting groundcover restorations. These references go into much greater detail that is done in this paper. Using these references as well as consulting with practitioners who have completed ground cover projects for guidance is an absolute must. Some valuable resources for groundcover restoration implementation in Florida are:

- Groundcover Restoration Implementation Guidebook prepared by the Florida Fish and Wildlife Conservation Commission
- Groundcover Restoration in Forests of the Southeastern United States prepared by a cooperative known as Conserved Forest Ecosystems: Outreach and Research (CFEOR)

ADAPTIVE MANAGEMENT

Adaptive management is an ongoing, never ending process that continues even after restoration goals have been met. For the restoration practitioner, the direction of change in the system or restoration trajectory is most important not just current conditions. The particulars of a site's history such as when disturbances took place, what equipment was brought in from where, what plant materials were deliberately or accidently brought in and many other factors too numerous to contemplate, conspire to create a unique palette of undesirable and desirable species (but mostly undesirable) that must be carefully documented and monitored. This requires strong plant identification skills and the willingness to become familiar with new species. Beyond simply ascribing a name to the plant the restoration practitioner must be able to recognize these species at many stages in their life history and to be able to teach weed control crews how to recognize and control them effectively. Having a system for documenting these species, their extent and prevalence on the site and for monitoring how their populations respond to management actions is critical.

In the project budgeting process contingency funds should be set aside to be able to make major and unplanned changes in tactics. For example if a La Niña winter yields warm dry conditions just when direct seeding is expected to take place it may lead to widespread germination failure and a surge in weedy species that may have otherwise gone dormant. Extra weed control events, and additional seed may be necessary or project timelines may have to be pushed back by 12 months or more. Budgeting for contingencies may often mean that the overall scale and scope of the project has to be dialed back somewhat to create resource reserves.

Project managers and on-the-ground restoration specialists with experience will have an advantage over those working on novel systems but experience is no substitute for curiosity and interest in learning from mistakes, learning new species etc. Since all projects present unique challenges experience alone and the application of a rigid approach will lead to failures more often than not. One such learning experience presented itself in dealing with Yellow nutsedge (*Cyperus esculentus*) where an intensive control schedule of monthly spray events was prescribed under the assumption that this would quickly reduce the Yellow nutsedge population. However, monitoring indicated that the plant was not being adequately controlled under this regime. Initial response was to look for better more effective herbicides. After trying several herbicides labeled for nutsedge control, and while still not achieving acceptable maintenance level of the population additional research revealed that the lifecycle of nutsedge could be completed between the monthly treatment events allowing remaining individuals to set seed and thereby replenish the population. The resulting stratified seed bank led to episodic germination/recruitment of yet more nutsedge further frustrating control efforts. Research being done in the peanut fields of South Carolina indicated more frequent treatment events on a three week schedule would be more appropriate to prevent seeding in the population, interrupt the lifecycle of the plant, and dramatically reduce effort going into control of this species.

Challenges or threats to achieving success are numerous and come from a variety of sources. Plant material availability is a common limitation. Finding the quantities, sizes, and species is difficult enough. Trying to do the right thing by finding appropriate local ecotype materials adds another degree of difficulty to putting together successful plantings. Often plant materials that arrive can be substandard by harboring disease, having been too recently stepped up in size, or showing other signs of stress. Another challenge, particularly with direct seeding projects, is windy conditions. Often restorations sites are wide open with little to block the wind. This can wrack up or remove entirely your precious and expensive seed mixes. Rain, either too much or too little, leading to flooding and seed washing away or drought like conditions that either lead to failure of seeds to germinate or worse if following a period of decent soil moisture then causing recently germinated seedlings with weak root systems to wither and die.

The take home message regarding adaptive management is that it is a challenging task that should be considered as part of the restoration project. Habitat Establishment Period Adaptive Management (HEPAM) must be performed until a relatively stable state is achieved, at which time maintenance can take place. Think 5 to 10 years of intensive adaptive management on upland projects until normal “maintenance” (not HEPAM) can become the norm. Normal maintenance needs to be work capable of being completed by resources available, to prevent the restored areas from losing gains. Again, if it can’t be sustained, consider a less challenging end product, or putting off the project until resources are available.

SUMMARY

Many more lessons were learned on these projects than could be included in this text. When successful, the rewards for the effort are great and the improved application of habitat restoration techniques will become more and more valuable as man-made pressures on natural systems continue. A common thread throughout this document and can be found in similar accounts by other restoration professionals is that habitat restoration is extremely challenging. The high level of effort expended, funds spent in pursuit of, and nights of sleep lost worrying about germination should serve as a reminder of the most important lesson learned in performing habitat restoration. Our best efforts still do not approach the complexity of natural, un-impacted systems. The greatest value lies in preservation and sound management of what remains of natural habitats.

Anyone interested in touring these sites for the purpose of gaining perspective to be applied on other restoration projects in the region has an open invitation for a guided tour by Damon Moore.

SEEKING SUSTAINABLE STORMWATER MANAGEMENT THROUGH TMDL IMPLEMENTATION IN DELANEY CREEK

Anthony T. Betts

ABSTRACT

The State of Florida has adopted nearly 400 Total Maximum Daily Load (TMDL) documents – more than forty in Hillsborough County alone – and each demands significant costs and effort to manage. The Cycle III National Pollutant Discharge Elimination System permit requires Municipal Separate Storm Sewer Systems prioritize TMDLs, quantify pollutant loading, and make concerted steps toward mandated pollutant reductions. Under this framework, Hillsborough County has developed a plan for improved stormwater management in Delaney Creek. Historically, Delaney Creek was one of the more highly polluted waterbodies in Hillsborough County. Stormwater infrastructure, built before modern stormwater regulations, will be retrofitted with a focus on using green infrastructure and low impact development principles to make measurable improvements in water quality. Pollutant reduction recommendations were developed with high-resolution water quality monitoring, community input, and consultation with engineers, landscape architects, and social marketers. The effort better characterizes stormwater runoff in the watershed, addresses diverse community concerns, and lays out a plan to achieve important reductions in pollutant loading. A comparison between Event Mean Concentration based pollutant loading models and empirically derived pollutant loading through storm event monitoring is also provided. The example developed through this pilot process provides Hillsborough County a practical template to achieve TMDL compliance and can be replicated in future basins.

"If we are to deliver a sustainable built environment, we must create places that people will value and to which they can connect emotionally." —M. Schwartz (2010)

"Sustainability is neither a vision nor an unalterable state but a creative and local process of searching for balance that spreads into all areas of urban management and decision making." – Uzzell, et al (2002)

BACKGROUND

The Florida Department of Environmental Protection (FDEP) divides Hillsborough County into 374 unique planning units – referred to as Water Body Identifiers (WBID) – according to existing watersheds. Each WBID is required to attain state water quality criteria and maintain an appropriate balance of flora and fauna. If monitoring data indicate polluted or degraded conditions, FDEP and/or the Environmental Protection Agency (EPA) may use Total Maximum Daily Loads (TMDL) to require responsible entities to reduce pollutant loading and restore waterbody conditions. TMDLs outline specific restoration goals necessary for polluted waterbodies to attain state water quality criteria. In Hillsborough County, there are forty-five finalized TMDLs (Figure 1). The Cycle III National Pollutant Discharge Elimination System (NPDES) permit requires Municipal Separate Storm Sewer Systems (MS4s) prioritize TMDLs, quantify pollutant loading, and make concerted steps toward mandated pollutant reductions. Under this framework, Hillsborough County has developed a plan for improved stormwater management in Delaney Creek.

Delaney Creek is located entirely within central Hillsborough County and flows to the Hillsborough Bay segment of Tampa Bay. The Delaney Creek WBID (WBID 1605) is 15.53 square miles and largely residential, with approximately fifty percent categorized as residential land uses. The WBID also contains significant amounts of agricultural, commercial, and industrial land uses, with 4.45, 15.99, and 1.47 percent, respectively.

INTRODUCTION

In 2005, EPA established a TMDL for Delaney Creek which set allowable total nitrogen and biochemical oxygen demand (BOD) loadings. The TMDL was designed to restore the waterbody to meet the applicable water quality standard for dissolved oxygen (FDEP, 2005). The TMDL requires a seventy-two percent reduction in both total nitrogen and BOD. According to information provided in the TMDL document, the prescribed reduction equates to a 53,915 lbs/year reduction in total nitrogen loads and a 193,600 lbs/year reduction in BOD.

In 2011, Hillsborough County submitted a TMDL prioritization plan which identified Delaney Creek as the highest priority waterbody and outlined future TMDL compliance efforts (Hillsborough, 2013a). Since then, Hillsborough County Public Works has extensively monitored the Delaney Creek area and identified numerous pollutant sources. The Delaney Creek Water Quality Improvement Feasibility Study was recently completed and will be used to identify further pollutant reduction activities.

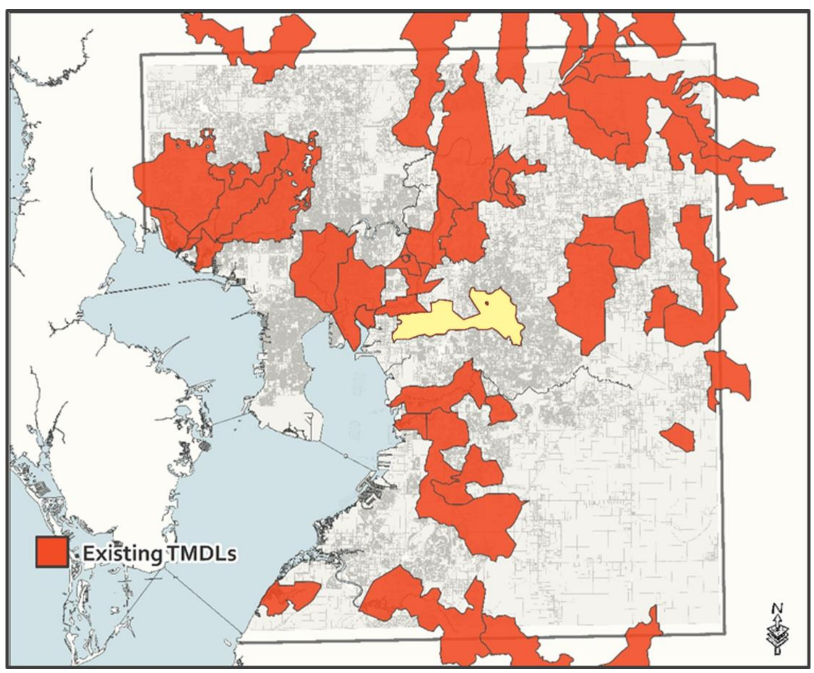

Figure 1. Finalized TMDLs in Hillsborough County. Delaney Creek is highlighted in yellow.

ASSESSMENT & MONITORING

First, a thorough waterbody assessment was used to characterize stormwater runoff and facilitate selection and implementation of Best Management Practices (BMP). This effort included high-resolution ambient monitoring and storm event monitoring at representative stormwater discharge points.

Long-term ambient water quality data have only been collected at one location in the Delaney Creek WBID -- the crossing at South 54th Street. Information from this location was used to establish the TMDL; however, Delaney Creek flows through diverse land uses and includes at least four major tributaries. Therefore, higher resolution monitoring was necessary to better characterize waterbody conditions. Approximately twenty temporary monitoring stations were established throughout creek segments and tributaries to identify areas of increased pollutant concentrations. More than three hundred individual monitoring observations are summarized below (Figure 2). These data suggest nitrogen and fecal coliform concentrations are generally high in the four northern tributaries, while pollutant concentrations are considerably lower upstream and in the main creek segment (Hillsborough, 2013b). Therefore, a subset of the larger WBID was delineated for storm event monitoring and implementation. This area is referenced as the “targeted area”.

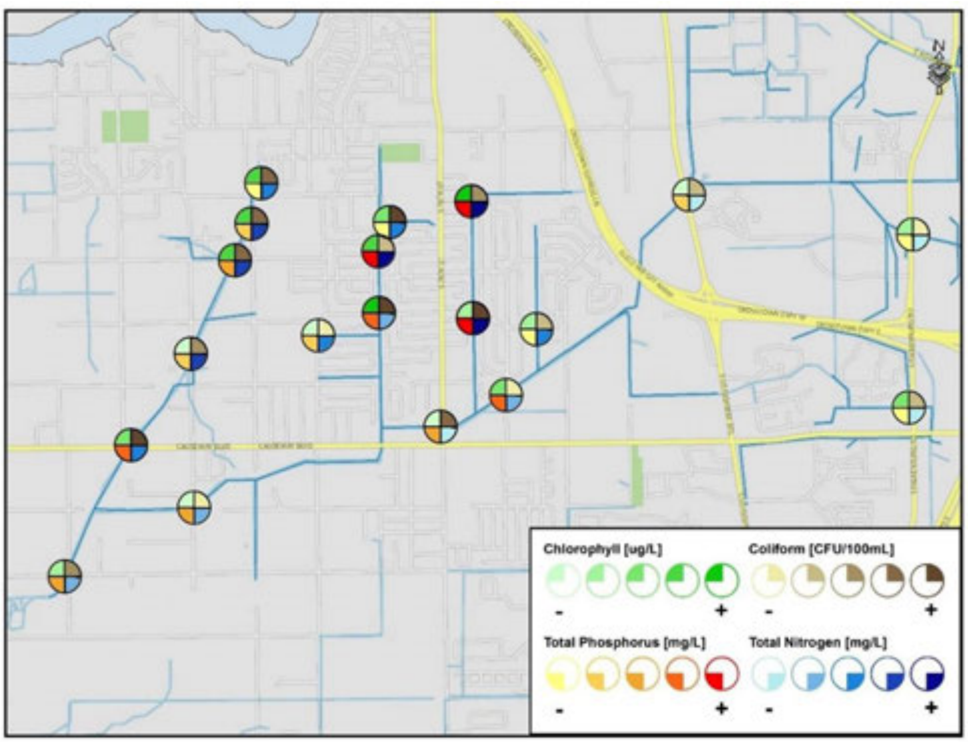

Figure 2. Summary results for high-resolution ambient monitoring.

Hillsborough County maintains sixty-two stormwater discharge points within the targeted area. Event mean concentration (EMC) calculations estimate pollutant loading for these outfalls to be 4,960 lbs/year total nitrogen and 20,543 lbs/year BOD (Hillsborough, 2013c). Further monitoring efforts were designed to more accurately quantify MS4 pollutant loading.

In this further effort, a sample of outfalls within the targeted monitoring area was selected for storm-event monitoring. From August 2013 to May 2014, flow-weighted composite samples were collected to characterize discharge at eight MS4 outfalls. Results provide valuable insight and allow comparison between EMC-based pollutant load estimates and observed conditions (Figure 3). In general, observations show EMC-based pollutant load estimates consistently overestimate MS4 pollutant loads in the targeted area, often by an order of magnitude (Hillsborough, 2014).

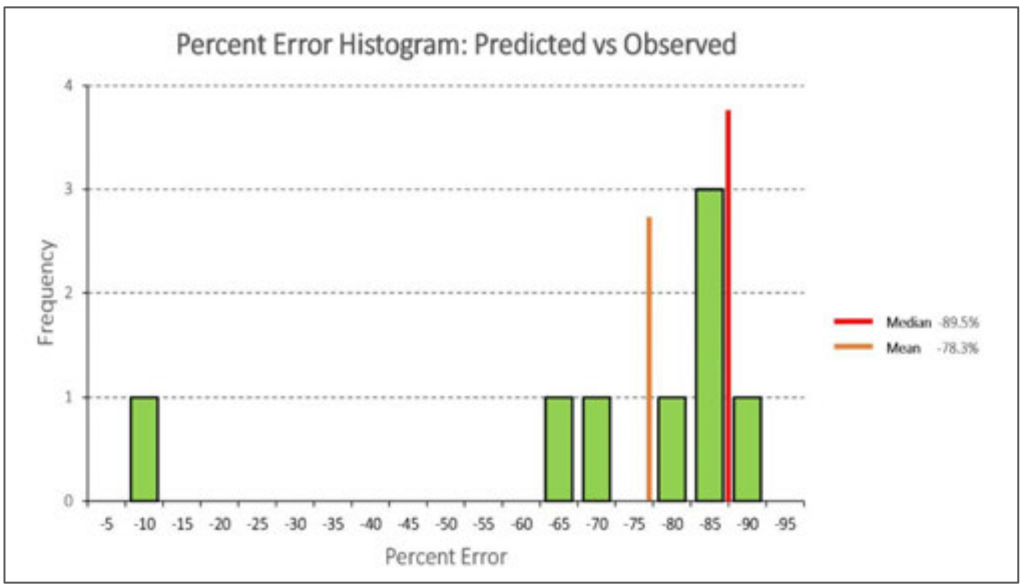

Figure 3. Percent error histogram for total nitrogen loads from stormwater runoff in the target area (EMC-based estimates versus storm event observations).

This effort provides an estimate of pollutant loading for the entire population of Hillsborough County stormwater outfalls discharging within the targeted monitoring area. A statistical summary was used as a benchmark to determine progress toward the percent reductions established in the adopted TMDL.

IMPLEMENTATION

Hillsborough County secured a consulting firm to assist in development of structural and non-structural BMPs for future implementation in the targeted watershed, including analysis of the feasibility and effectiveness of green infrastructure retrofits, enhanced MS4 maintenance, and reduced imperviousness, among others.

The idea that effective solutions for nonpoint source pollution require community engagement was a central tenet of the implementation strategy for this TMDL. Therefore, efforts to reduce pollution should utilize both traditional pollutant removal mechanisms (sedimentation, infiltration, biological transformation, etc.) and affect environmentally significant human behaviors.

Clearly, humans have influence over their environment; however, the converse is also true. Environmental psychology is an applied field of research seeking to explain the relationship between the physical environment and human behavior. Insights into this relationship can be leveraged to promote all types of behavior change, including environmentally sustainable behaviors (Nickerson 2003). For example, principles of environmental psychology have been broadly applied by urban planners and public health experts to design walkable neighborhoods and encourage alternative transportation -- the shape and form of the built environment affecting human behavior.

Further, an environment can engender feelings of both attachment and repulsion. Place attachment is defined by Scannell & Gifford (2010) as the bonding that occurs between individuals and their meaningful environments. These environments –natural and manufactured – derive their meaning from both physical and cultural aspects. Likewise, strong place attachment is associated with enhanced community awareness and strong social cohesion (Uzzell et al, 2002). Conversely, degraded and/or dangerous environments can create feelings of repulsion. In both instances, the physical and cultural environment of a place has compelling influence on emotion and behavior (Guiliani, 2003).

These concepts have application in many areas of urban management. Nonpoint source pollution is one such problem. Solutions for nonpoint source pollution are complex because they require actions by many individuals. For this reason, social factors play important roles in facilitating behavior change. An individual's willingness to change environmentally detrimental behavior is strongly influenced by their perceived level of cooperation. As in Hardin (1968), a rational individual is unlikely to bear the full burden of change without coercion. In this way, the robust social cohesion produced by strong place attachment can predispose environmentally altruistic behavior. Residents that have developed strong connections to their surroundings are more inclined to collaborate in stewarding those valued resources. Likewise, systems that aim to promote environmentally sustainable behavior should encourage place attachment and capitalize on associated social cohesion (Uzzell et al, 2002).

The highly altered and degraded environment found in the Delaney Creek watershed fails to connect with residents in a meaningful way. Projects should aim to engender greater place attachment and bring awareness to the waterbody as a central part of the community. This approach goes beyond silently filtering polluted runoff and attempts to engage the community to action.

CONCLUSIONS

Historically, Delaney Creek was one of the more highly polluted waterbodies in Hillsborough County. Stormwater infrastructure, built before modern stormwater regulations, will be retrofitted with a focus on using green infrastructure, low impact development strategies, and principles of environmental psychology to make measurable improvements in water quality. Pollutant reduction recommendations were developed with high-resolution water quality monitoring, community input, and consultation with engineers, landscape architects, and social marketers. The effort better characterizes stormwater runoff in the watershed, addresses diverse community concerns, and lays out a plan to achieve important reductions in pollutant loading.

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MINING RESTORATION ACTIVITIES

Shelley Thornton and Laura Morris

ABSTRACT

Mosaic's current approach to satisfy compensatory mitigation requirements include both onsite and offsite mitigation. Onsite reclamation is required pursuant to Florida Department of Environmental Protection (FDEP) Reclamation Rule 62c-16, requiring all wetland impacts be reclaimed at least acre for acre, type for type. Offsite mitigation projects focus on benefits at a watershed management level incorporating the Integrated Habitat network (IHN) and the Charlotte Harbor National Estuary Program (CHNEP) Comprehensive Conservation and Management Plan (CCMP) priority actions. This mitigation offsets wetland impacts by preserving, restoring, enhancing, and creating both wetlands and uplands outside the mine boundary, in addition to onsite mitigation, all within the same watershed. Mosaic has reclaimed the Central Florida Phosphate District since the reclamation rule was enacted in 1975. Restoration and reclamation science, as well as the understanding of the watershed's ecology, have evolved over the past 20 years and new advances continue to be developed. Not only are these advances utilized to assure reclamation success, effective maintenance strategies are implemented to proactively manage these landscapes during establishment to ultimately meet specific permit success criteria.

INTRODUCTION

Compensatory mitigation requirements for the mining industry are enforced through federal and state regulations. The federal requirements were memorialized in the Federal Register on April 10, 2008. The 2008 Compensatory Mitigation Rule (Rule) requires avoidance of any potential wetland impacts as a first step. If that is not feasible, the Rule requires minimization of wetland impacts associated with the project. The Rule lays out a three-tiered hierarchy: Mitigation banks, in-lieu fee programs, and permittee-responsible mitigation to offset unavoidable wetland impacts. Mosaic is employing permittee-responsible mitigation to compensate for unavoidable wetland impacts. State reclamation standards for phosphate mining are identified in Part II of Chapter 378, Florida Statutes, and Chapter 62C-16, Florida Administrative Code. The state compensatory mitigation requirements are similar in nature, although utilize different terminology. They first require the permittee to eliminate wetland impacts, then if that is not feasible to reduce the wetland impacts. Compensation for unavoidable wetland impacts can be provided with project(s) of "Regional ecological value with greater long-term ecological value than requested impacts" (Protection, 2013). Mosaic's Offsite Mitigation projects provide the necessary compensatory mitigation to satisfy the State's requirements.

MOSAIC'S COMPENSATORY MITIGATION

Compensatory mitigation is provided by Mosaic through onsite and offsite mitigation projects. Onsite mitigation elements include focusing on mine (site) wide reclamation plans to optimize compensatory mitigation in terms of enhancing wildlife corridors such as the Integrated Habitat Network (IHN). The IHN benefits water quality and quantity of a watershed by mitigation adverse aquatic impacts through a series of connected undisturbed natural communities and reclaimed habitats in a coordinated and protected landscape (Cantrell & Cates, 1992). Additional onsite mitigation elements include the preservation and protection of avoided lands; the in-kind establishment of impacted wetlands to replace the wetlands, streams and their associated functions; and the protection of established wetlands and streams via perpetual conservation easements.

OFFSITE MITIGATION PROJECTS

The offsite mitigation projects are constructed prior to mining activities, which reduces the temporal lag traditionally associated with onsite mitigation. They involve large, ecologically significant parcels and incorporate rigorous scientific and technical analysis. The planning and implementation of the offsite mitigation projects require a significant investment of financial resources and involve many scientific experts. These large scale projects specifically focus on benefits at a watershed/regional scale, as well as site specific benefits. The CHNEP CCMP meets the definition of a watershed plan within the Central Florida Phosphate District and was utilized during the design of the projects. The CCMP identifies four priority problems: water quality degradation, hydrologic alterations, fish and wildlife habitat loss, and stewardship gaps (Program, 2013). All of Mosaic's offsite mitigation projects address at least one or more of the CCMP's priority problems specifically restoring freshwater and estuarine riparian wetland (FW-C), reducing non-point source pollutants by replacing erosive channels with properly sized natural design channel(WQ-D), and protecting water quality through the establishment of wetlands/riparian vegetation and/or conservation easements to offset anthropogenic impacts elsewhere in the watershed (WQ-E) (Program, 2013). All of the offsite projects will also be placed in conservation easements adding to the number of permanently protected conservation lands within the watershed.

BOWLEG'S CREEK ENHANCEMENT PROJECT

One of Mosaic's offsite mitigation projects is the Bowleg's Creek Enhancement project and provides compensatory mitigation for the Ona Mine in Hardee County. The 583 acre property is located at the riparian corridors of Bowleg's Creek and the Peace River. The area was formerly mined and reclaimed by the Watson Mine company on the 1980's. The State Reclamation rules were in place at the time reclamation was completed on the property; however this project allows Mosaic to bring the reclamation up to today's standards. The restoration approach is to retain and build upon some of the good existing conditions. The restoration activities include: enhancing simple wetland communities into diverse native systems, improving stream flow, stabilizing eroding surfaces, adding habitat structure and increasing native species, restoring the fire ecology, and controlling nuisance and exotic species (Amec Foster Wheeler Environment & Infrastructure, 2015).

RECLAMATION PRACTICES

From a regulatory perspective, successful reclamation meets specified criteria listed in an approved permit. From an ecological standpoint, success is also defined as how well the created systems function and, among other things, "fit" into the landscape (*i.e.* how well upland habitat transitions to a wetland or stream).

OLD SCIENCE vs. NEW SCIENCE

Ecological restoration and reclamation activities have evolved substantially over the past thirty plus years with the emergence and development of Restoration Ecology as separate field in the early 1980s (Clewell and Aronson, 2013). This evolution is due primarily to advances in the science of ecological restoration but also enhanced by advances in the basic tools available to scientists and practitioners. Major areas of advancement that are being utilized by Mosaic include the basic tools for design, reclamation methods, design of habitat complexity, and use of adaptive management strategies.

Basic design tools have changed due to technological development and have benefited reclamation activities. Examples of some of these advancements are found in the areas of mapping, hydrologic modeling, and field equipment. Early design of reclamation relied on topographic mapping obtained from U.S. Geological Service (USGS) topographic quads which maintain limited topographic delineations limited to 2 - 5 foot contours. Currently design related to topography utilizes scientific advances such as Light Detecting and Ranging (LIDAR) and Global Positioning System (GPS) survey data which can provide accuracy elevation data within inches or less. Hydrologic modeling has progressed from general understanding of watershed input to surface water modeling and finally to current standards which utilizes an integrated surface and subsurface modeling system which also takes into account post mining soil characteristics. These advancements in design tools are also utilized during the physical reclamation practice. Advanced geospatial technology used in survey and earthmoving equipment has made it possible to achieve very accurate elevations and micro-topography necessary to support the creation of the targeted land use types.

One reclamation method that has changed significantly is the incorporation of highly complex Rosgen level stream design and construction methods that are state of the art. These advanced stream designs mimic naturally occurring systems found in the region, include considerations such as basin size, stream types, functionality, size and sinuosity, and replacement or an increase in linear footage of stream length.

When the State of Florida's Reclamation standards where brought into effect in 1975, generally speaking reclamation's purpose was only to bring lands back into a "useful" purpose. Early reclamation plans created basic land use types within the mined areas that did not always consider the regional landscape. Current design and standards create and consider a very complex habitat mix with diverse transitional zones and a very specific mix of targeted habitat types that consider the regional landscape and replace temporarily impacted habitats.

Current technology and a broader base of scientific knowledge related to ecological restoration have led to project plans and designs which provide for higher quality habitats and landscapes. There are still ongoing projects which were designed and constructed utilizing the tools and designs of “old science”. Some of these older sites require the use of adaptive management techniques and investigation in order to create the target habitat types which were identified in the reclamation plan. Examples of the adaptive management strategies that have been and are being used include the acclimatization of trees and shrubs, adjustment of hydrologic regimes, hummock construction, prioritization and specific targeting of nuisance and exotic species and the utilization of biological controls where approved.

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MULTI-PARTY REUSE AGREEMENTS

Robert Conner

ABSTRACT

Three very different entities, TECO, City of Lakeland & SWFWMD, assembled to undertake a project to supply reclaimed water to the Polk Power Station. This removes a significant flow/load from the Alafia River and Hillsborough Bay for up to 30 years. It also reduces present and planned groundwater pumping in the region. While not yet fully operational, the major components are in place and acceptance testing is underway. Additionally, the project makes a 1600-acre tract of land, similar to Circle B Bar, available for environmental education in 2016.

INTRODUCTION

Central Florida has long relied upon the upper Floridan aquifer as its primary source of potable water. Due to the ease of acquisition and low treatment cost, this source has also been exploited for non-potable uses such as irrigation, mining and industrial water. In recent years, it has become apparent that the total use of the aquifer cannot be sustained. Florida's water management districts are looking for ways to reduce the demand on the upper Floridan aquifer.

Tampa Electric Company (TECO) operates the Polk Power Station in western Polk County, south of Mulberry. Its present source of cooling water is a recirculation pond. To support current and near future needs for cooling water, groundwater was being considered. The Southwest Florida Water Management District (SWFWMD) desired this need to be fulfilled by an alternative water source. The City of Lakeland (COL) Department of Water Utilities operates a Wetlands Treatment system which discharges into ditches leading to the North Prong of the Alafia River just north of Mulberry. Facing increasingly stringent regulations, the COL was examining alternatives to surface water discharge for this water. The three parties TECO, SWFWMD and COL have entered into agreements to supply alternative water and achieve other environmental benefits as well.

THE PARTIES

TECO is a for-profit, publicly-traded corporation. SWFWMD and the COL are government entities. Florida is an open records state, which means government files and meetings are generally open to any entity asking for access. Such practices are not typical in the private sector. The historical relationship of TECO and the COL with SWFWMD was that of regulated parties and regulator. While occasional small projects had been undertaken cooperatively, the bulk of their interactions were involving permits, inspections and rules. The COL had recently completed a particularly contentious permitting cycle that was not resolved short of an Administrative Hearing. TECO and the COL compete in the retail electric and power generation markets. In addition to the Lakeland Water Utility, the City operates Lakeland Electric, one of the larger municipally-owned power providers in the nation. Lakeland Electric's distribution franchise is fully imbedded in the much larger TECO franchise. From the beginning, it was recognized the project would be as much an exercise in understanding and dealing with each other as it was in the technical elements of the design.

THE AGREEMENTS

Notably, upon completion of negotiations, there was no single document signed by all three parties. That alone speaks to the high level of confidence reached between the parties during discussions. TECO and SWFWMD agreed to construction funding for 50% of the eligible components to achieve routing the COL's excess effluent to the Polk Power Station. They further agreed upon a schedule of milestones and dates required to implement the project. TECO and the COL agreed upon a site for a pumping station and transmission mains leaving the Wetlands Treatment system. The City agreed to make a minimum of 4.0 million gallons per day available at the present quality for the next 30 years. TECO agreed to take the total amount available. Noting the COL has 2.0 billion gallons of storage, flow matching on a daily basis would not be required. The water was to be available without charge for the first 20 years. SWFWMD issued the COL a twenty year Consumptive Use Permit based upon the 20-year population projections by the District. The Permit has a 10-year extension clause allowing it to match the timeline of the TECO/COL agreement above. This stabilizes the City's planning for infrastructure to supply utilities for the growth expected for several decades to come.

REQUIREMENTS FOR SUCCESS

Several groups were involved in the initial discussions about meeting the water needs of TECO. Eventually Lakeland was the partner chosen. In retrospect, Lakeland kept a focus on meeting the need of the customer. Others were seen as taking opportunities to gain additional benefit, making the overall deal increasingly one-sided and/or more expensive. Anytime one party becomes the big winner at the expense of the others, the probability of everyone seeing a win-win-win deal drops off.

PROJECT STATUS

The pumping station is operational and delivering flow to the Polk Power Station through 14.75 miles of 30" PVC pipeline. The pretreatment and reverse osmosis plant is functioning. Concentrate is flowing down the two 8000' deep disposal wells. The rate of flow has not yet reached the requisite 'total take', but it is close. The City of Mulberry and the Polk County Southwest Regional Wastewater Plants are in designing connections into the existing system. The last of the 7.5 MGD (Annual Average) flow carrying 11.2 Tons/yr. of N and 26.0 Tons/yr. of P should be coming out of the Tampa Bay basin shortly. The Lakeland Wetlands Treatment System is being repurposed as SE7EN Wetlands Park. This will be the centerpiece of a four park system. Featured will be 22 miles of walking trails with abundant aquatic and terrestrial wildlife viewing opportunities. Look for an opening in 2016 and previews on Lakeland's websites.

A NEED FOR FUTURE INTEGRATED WATERSHED MANAGEMENT IN TAMPA BAY

Ed Sherwood, Holly Greening, Lindsay Cross and Maya Burke

ABSTRACT

The Tampa Bay estuary has undergone a remarkable recovery since the 1980s. Current management practices have been highly effective, but new challenges are anticipated in the future. Particularly for those regions in the Bay where multiple stakeholder pressures and interests may conflict in discrete portions of the watershed. The presentation was intended to introduce a case study example to spur conversation for future Bay management practices. Several regionally significant activities occur within the Hillsborough Bay watershed, including: extractive phosphate mining, domestic consumptive and industrial fresh water use, isolated agriculture operations including fruit and vegetable row crops and cattle ranching, and extensive and expanding suburban development. As intensification of each of these activities is possible in the near future, there is potential risk of user conflict among entities represented in each of these sectors. For example, future gypsum stack closures from phosphate mining activities have the potential to modify future water quality conditions in the Alafia River, potentially impacting consumptive water use practices and the aesthetic qualities of the watershed that are attractive to continuing suburban development. Likewise, the cumulative effects of the combined intensification of these land use activities in the watershed may pose downstream risks in the estuary – reversing the progress made to date to restore seagrass in Tampa Bay. Therefore, an integrated approach to managing the watershed is warranted. The proposed approach will consider future water, nutrient, and land management policy in the watershed.

BACKGROUND

Land development patterns in the Tampa Bay watershed, and the associated impacts to the Bay's flora and fauna, began to be reported in the mid-1960s and 1970s (Sykes 1966; Simon 1974). Since this time, significant efforts to reduce the estuarine impacts of an expanding human population within the watershed have been undertaken (Greening et al. 2014; Sherwood et al. 2015). Despite a >1.5M total population increase from the 1970s to 2014 in the Tampa Bay metropolitan area (US Census Bureau 2015), management efforts to reduce nutrient pollution, dredge and fill activities, and overall estuarine habitat degradation from the expanding metropolis have led to a marked recovery of Tampa Bay (Greening et al. 2014). In 2014, several years of consistent water quality conditions promoted the expansion of seagrass to an areal coverage similar to what was mapped in the 1950s (SWFWMD 2015; Sherwood et al. 2015).

Hillsborough Bay, historically Tampa Bay's most degraded bay segment, has shown great improvements in water quality (Figure 1) and seagrass coverage (Figure 2) over recent periods. When adjusted for annual hydrologic conditions, external nitrogen loadings to this bay segment show decreasing trends across most sectors (Figure 3). Reduced land-based loadings are good news for bay resource managers, as the significant effort and investment in the Bay's recovery continues to elicit positive environmental improvements, particularly for the Hillsborough Bay segment. However, recent trends in population growth, land development, and resource allocation within this portion of the Tampa Bay watershed may pose future challenges to current recovery trajectories.

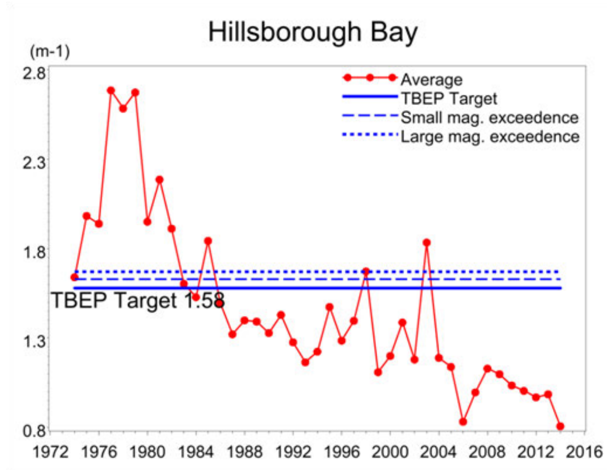

Figure 10. Improvements in effective light attenuation in Hillsborough Bay from 1974-2014. Source: EPCHC.

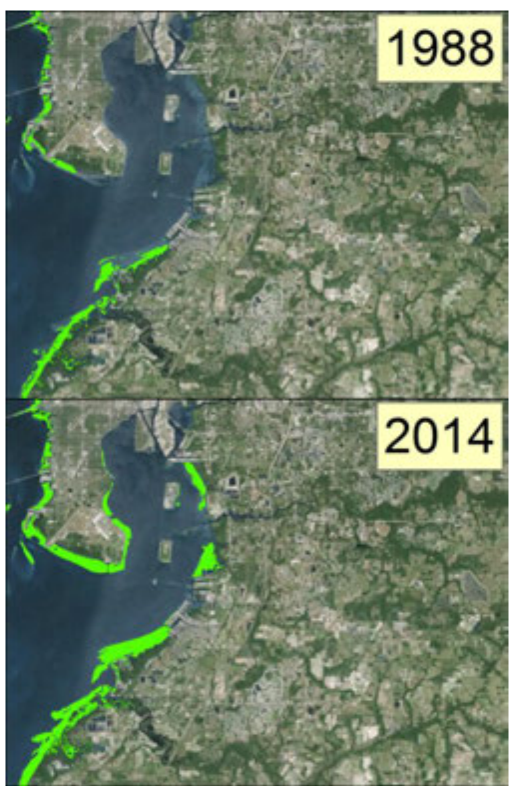

Figure 9. Comparison of seagrass coverage in Hillsborough Bay from 1988 to 2014. Source: SWFWMD.

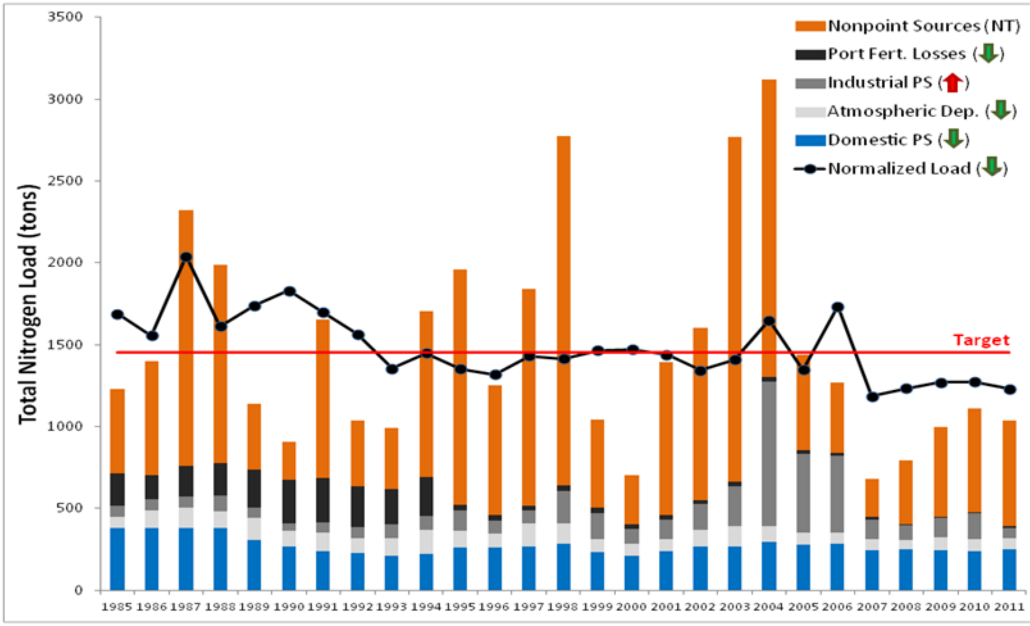

Figure 11. Nitrogen load to Hillsborough Bay. Significant increasing (↑) and decreasing (↓) trends or no detected trends (NT) are denoted in the legend for each major source, as well as, the total bay segment hydrologically-normalized load. Red horizontal line denotes normalized loading target. Source: TBEP.

PATTERNS OF POPULATION GROWTH

Regional recommendations to conscientiously develop the remaining portions of the Tampa Bay watershed in a manner that would reduce environmental and water supply impacts, as well as increase regional economic impact and global competiveness were established in 2010 through the ONEBAY initiative (TBRPC 2010). The shared regional vision expressed in the ONE BAY initiative attempts to focus new development and redevelopment opportunities towards current population centers (Figure 4). More recent building and population growth trends don't appear to be following these recommendations, though. The "Southshore" region of Hillsborough County, as well as, more rural portions of Hillsborough and Manatee Counties have experienced greater population growth over recent decades compared to the preferred "new development" areas under the ONE BAY initiative (Figure 5). These recent development patterns appear to be mimicking the sprawling development model which influenced the Bay's ecosystem decline over the 1950s-1980s period. In addition, new challenges are emerging as more rural development and disconnected

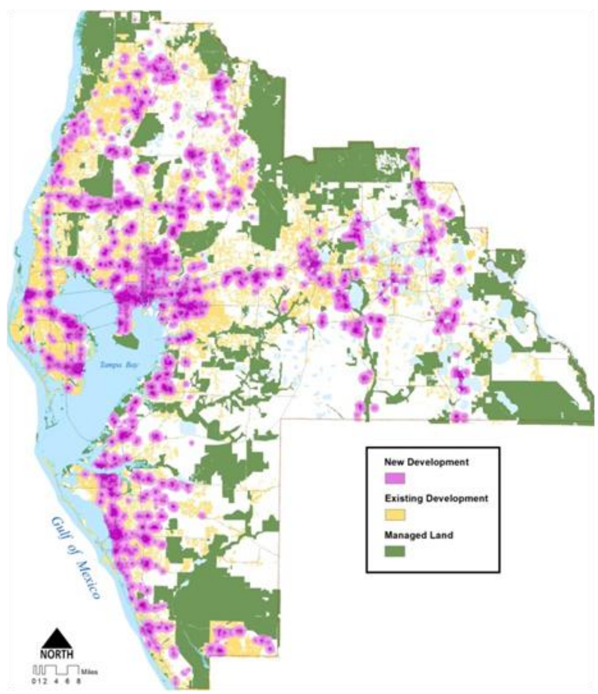

Figure 12: Preferred future development scenarios as developed through the ONE BAY initiative (TBRPC 2010).

communities are created within the watershed. Severe winter temperatures in 2010[1] highlighted the potential environmental resource conflicts that might be exacerbated in the future as competing water use by expanding commercial, agricultural, and domestic user groups occur within this high growth area (Aurit et al. 2011).

BETTER MANAGING HUMAN AND ENVIRONMENTAL RESOURCES DURING CHANGING TIDES

The theme for BASIS 6, "Navigating changing tides: Addressing new challenges with effective science and management," was an attempt by conference organizers to focus regional discussion towards a new set of bay management concerns. Tampa Bay's persistent, expanding population has always been a focal point for bay managers, particularly for efforts related to reducing nutrient loads to Tampa Bay. The manner in which we are now developing the watershed may pose new challenges for this effort and may be complicated by future climate change effects and other watershed management issues. The following broad resource management challenges are highlighted for the Hillsborough Bay watershed in order to justify a renewed effort for better integrated watershed management into the future.

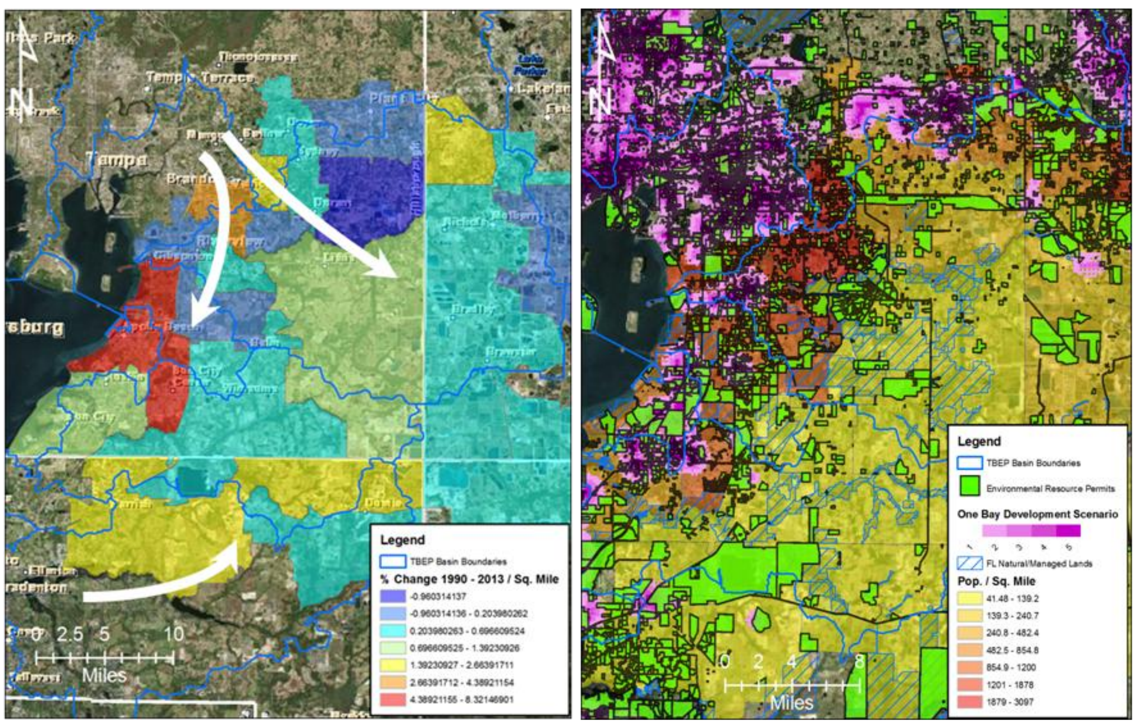

Figure 13. Percent change in population (mi^{-2}) from 1990-2013 (left panel) and total current population (mi^{-2}, right panel) relative to ONE BAY recommendations (purple shade) and recent environmental resource permit sites (green polygons). Data sources: US Census Bureau, TBRPC and SWFWMD.

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[1] Pittman, C. 2010. During record cold, farmers used 1 billion gallons of water daily, causing 85 sinkholes. Tampa Bay Times, 1/26/2010. http://www.tampabay.com/news/environment/water/during-record-cold-farmers-used-1-billion-gallons-of-water-daily-causing/1068208 .

WATER RESOURCES

The importance of freshwater resources to the Tampa Bay estuary and the thriving human population dependent upon it within the watershed has been well established (TBEP 2006; Poe et al. 2006; SWFWMD 2015b). The Southwest Florida Water Management District (SWFWMD) has developed and adopted several minimum flows and levels for important river and freshwater resources within the Hillsborough Bay watershed (SWFWMD 2004, 05, 06; Flannery et al. 2008). For the most part, these regulations have ensured that adequate freshwater inputs from the major freshwater sources within the watershed are maintained to the Tampa Bay estuary, and that the systems' ecological resources are not harmed. The establishment of these regulations has also allowed for more effective diversification of the water supply demand to a growing regional population (Hazen and Sawyer 2013).

Concurrently, the region's water conservation efforts have led to reduced per capita usage (Figure 6), further helping to lessen increases in future demand and impacts from freshwater diversions and withdrawals. The regions' continuing population growth, however, is still predicted to max out current system capacity for total freshwater supply by mid century (Figure 7).

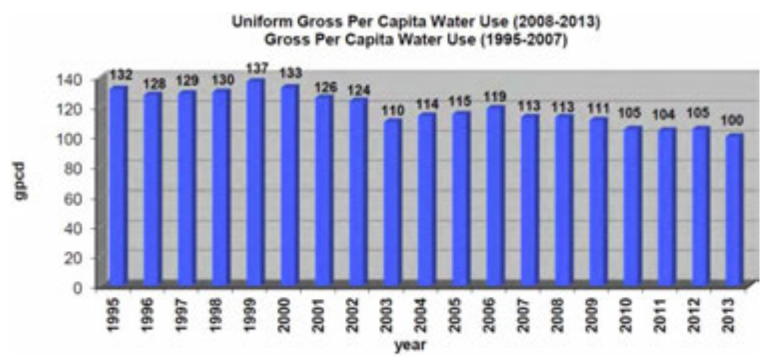

Figure 15. Estimates of gross per capita water use (gallons/person/day) in the SWFWMD region (SWFWMD 2015).

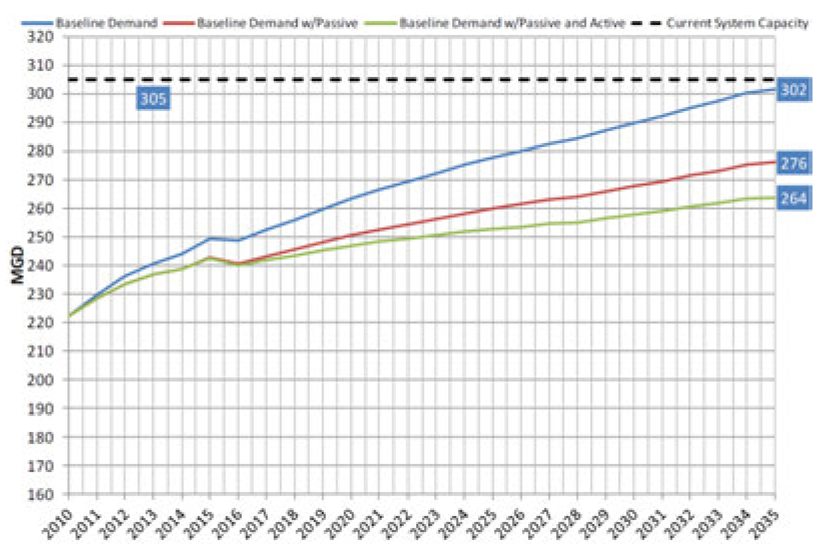

Figure 14. Estimated future water use demand with passive and active savings relative to Tampa Bay Water system capacity (Hazen and Sawyer 2013).

Complicating this issue are recent building practices within the region. Hazen and Sawyer (2013) illustrated that water demand and use for newer constructed dwellings is actually greater than for older residential properties (Figure 8). This analysis highlights regional efforts to improve water conservation practices in the future can be counteracted by building practices of a rapidly urbanizing watershed. As such, efforts to reduce water use and resource conflicts in the future should ensure that our current building practices actually help reduce, rather than exacerbate, future water use and demand.

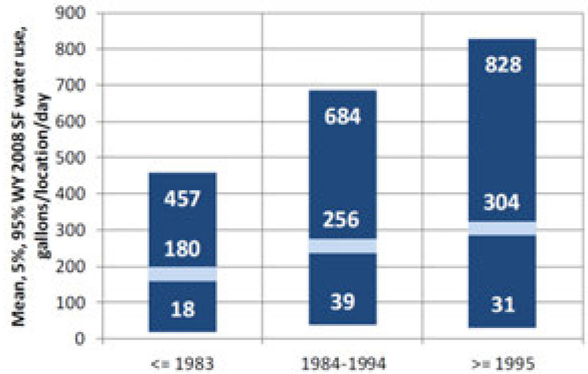

Figure 16. Single family home water use relative to year-built of dwelling (Hazen and Sawyer 2013).

NITROGEN LOADINGS

Often times, competing resource management objectives can negate overarching protection and restoration efforts within a watershed (Conroy and Peterson 2013). These complications were pointed out in the previous section for future water quantity concerns, but the same can be applied to future water quality concerns, as well. Competing watershed management objectives; such as reducing flood risks of an expanding suburban population, closing and reclaiming phosphate mining facilities, and ensuring reduced N loads to Tampa Bay from expanding urban, agricultural and industrial sources; have the potential to affect efforts to improve overall water quality from within the watershed to the bay. To help effectively manage water quality in the future, planning guidance to deal with future total nitrogen loads has been developed for the region (TBRPC 2013). The challenge now will be for local governments to implement these policies into future development and redevelopment strategies within the Hillsborough Bay watershed.

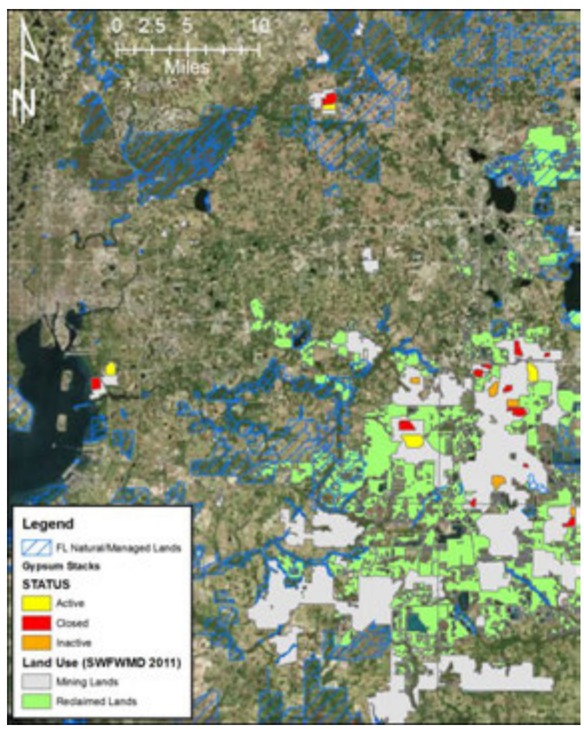

Figure 17. Distribution of phosphate mining/reclaimed lands and status of processing facilities along the eastern portion of the Tampa Bay watershed (Source: FDEP).

One of the greatest challenges facing the Hillsborough Bay watershed, in terms of future N loadings, will be the closure of gypsum stacks related to phosphate mining activities within the watershed (Figure 9). The potential for large N loadings to occur with stack closures may be possible, despite efforts to reduce overall N loads to Hillsborough Bay (Figure 3). In order to minimize potential water quality impacts to the Alafia River, its tributaries or even the Bay, careful consideration for the timing and magnitude of process water releases should be developed ahead of closure schedules. In addition, planned closure activities should not be conducted in isolation of efforts to address other outstanding water quality issues (e.g. TMDL and BMAP development; Figure 10) or continuing land development within the watershed.

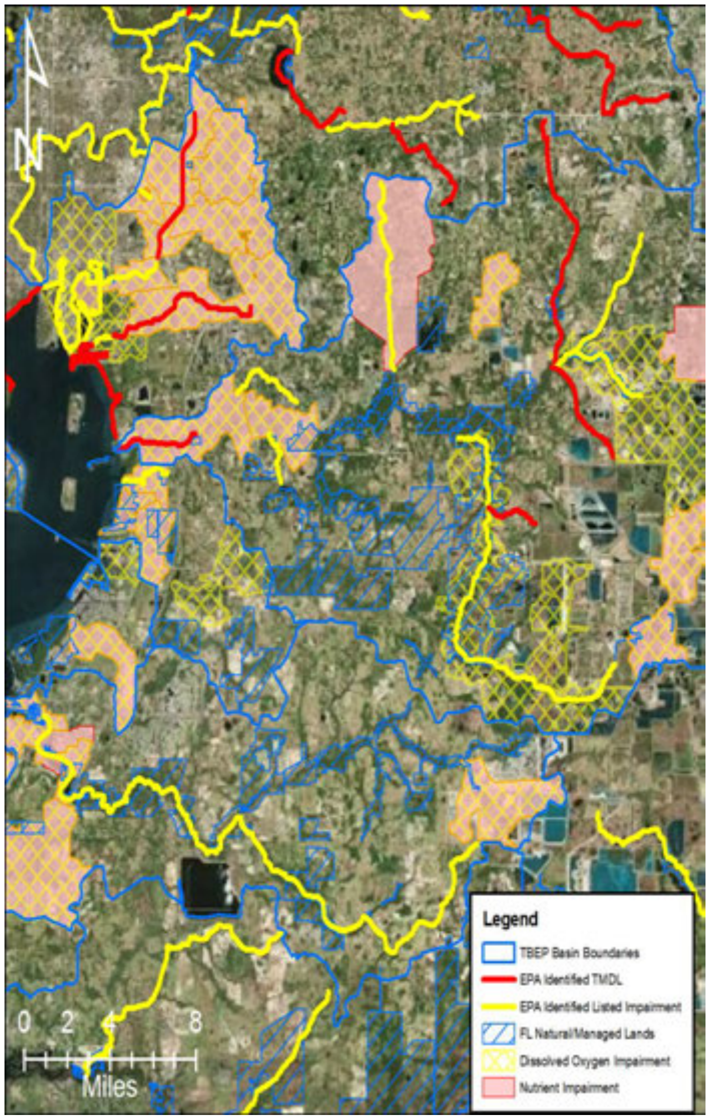

Figure 18. State and federally identified impaired waters along the eastern portion of the Tampa Bay watershed (Source: FDEP & EPA).

CRITICAL COASTAL HABITATS

With continuing land development in the watershed, fewer options to acquire, restore or preserve critical coastal habitats are available to resource managers. Nevertheless, regional recommendations have been established for the maintenance, enhancement or restoration of seagrass, mangrove, salt marsh, salt barren and freshwater wetlands (Robison 2010; Ries and Scheda 2014). Likewise, work continues on establishing protection and restoration goals for other critical habitats (e.g. coastal uplands, oysters, hard bottoms, tidal creeks, etc.). As the region continues to attempt to "Restore the Balance" of these habitats, the realization that a changing climate in combination with an urbanizing watershed may affect our ability to achieve current habitat restoration goals has been acknowledged (Sherwood and Greening 2013). As a result, new habitat restoration strategies (e.g. establishing marine and upland refugia; Figure 11) or paradigms may need to be developed for the region, while reinforcing the ONE BAY initiative recommendations for preferred future development (Figure 4; TBRPC 2010).

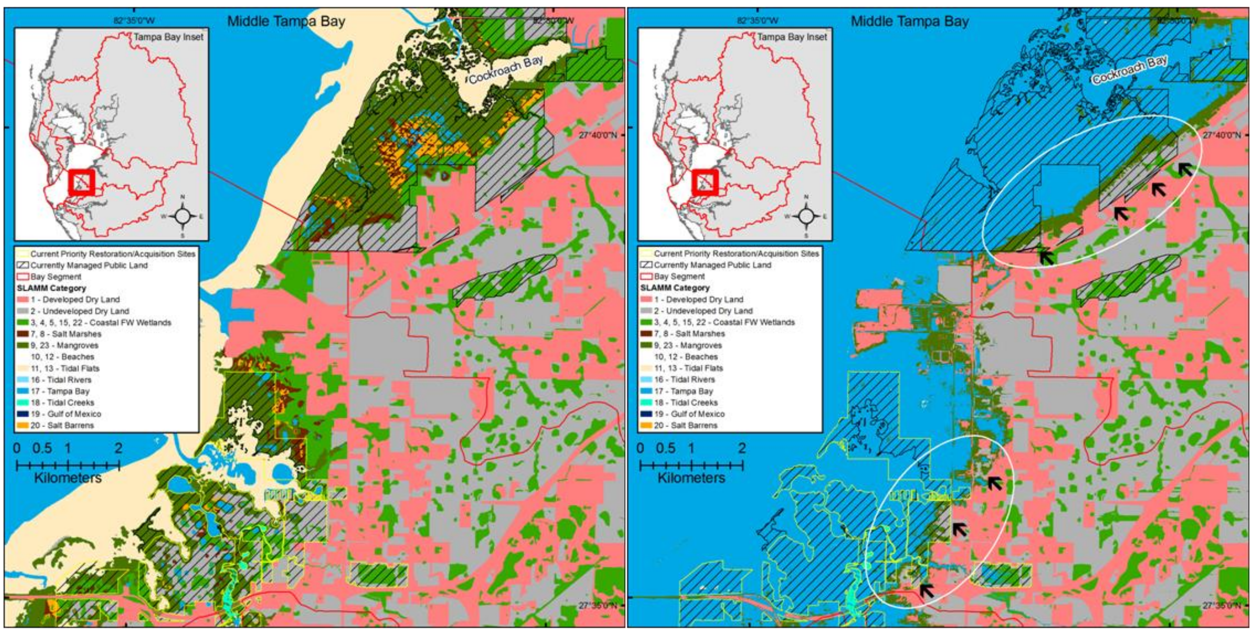

Figure 19. Visual comparison of Sea Level Affecting Marsh Model (SLAMM) categories 1- 23 under current conditions (left) and as estimated under a 2100 worst-case scenario (right; i.e. 2-m sea level rise and implementing an adaptation strategy to protect developed dry land into the future) for the "Southshore" region of Middle Tampa Bay. Categories were developed from Florida Land Use / Land Cover (SWFWMD, 2006 & 2007) and USFWS National Wetland Inventory (SWFWMD, 2002) GIS files. Potential emergent habitat refugia areas to be considered for future land management initiatives are indicated by arrows and white ovals. Potential subtidal refugia areas are revealed within the black hashed polygons (current publicly managed lands) that become inundated in 2100 (Adapted from Sherwood & Greening 2013).

In addition, novel approaches to create new habitats in an urbanizing watershed subject to climate change pressures will need to be pursued. Betts (2016) demonstrated that community perceptions and environmental stewardship can be negatively impacted by poorly-maintained stormwater infrastructure within the watershed, and retrofits that incorporate green infrastructure elements may improve future community environmental stewardship. The community benefits of a green infrastructure approach have been observed in other countries [e.g. Bishan Park, Singapore (PUB 2016); Figure 12], and its application within the Tampa Bay watershed could also directly benefit strategies to restore critical coastal habitats, as well as, water quantity and quality. These multi-use, green infrastructure improvement concepts could also be pursued when mitigation is required or strategically focused towards recommended regions in the watershed (Figure 13; Ries and Scheda 2014).

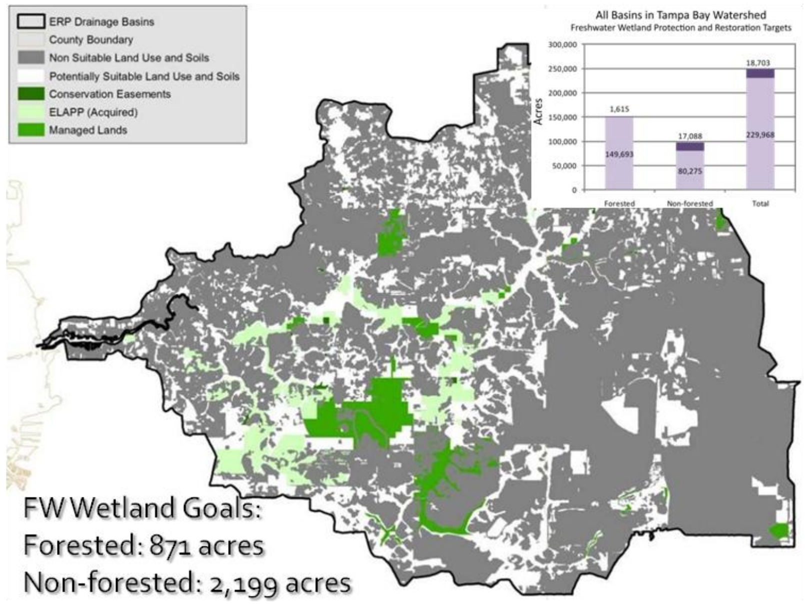

Figure 20. Recommended freshwater wetland restoration goals for Tampa Bay (inset) and focal areas within the Alafia River watershed recommended for future freshwater wetland mitigation activities (Ries and Scheda 2014).

Figure 21. Before (left) and after (right) a stormwater infrastructure retrofit to establish Bishan-Ang Mo Kio Park in Singapore (images from PUB 2016).

DEVELOPING INCENTIVES FOR BETTER WATERSHED MANAGEMENT

Maintaining adequate freshwater quantities while preserving and restoring water quality and critical coastal habitats are fundamental resource management goals currently being implemented with varying degrees of success throughout the entire Tampa Bay watershed. For the Hillsborough Bay watershed, the future challenges highlighted in this paper, as well as the complications that may arise from competing resource management objectives, will require the region to embrace new watershed management solutions. If we do not and the Bay's environmental quality once again declines, then the regional economic benefits derived from maintaining a "healthy" Tampa Bay could be diminished or lost. A "healthy" Tampa Bay translates to about 13% ($22 Billion) of regional economic

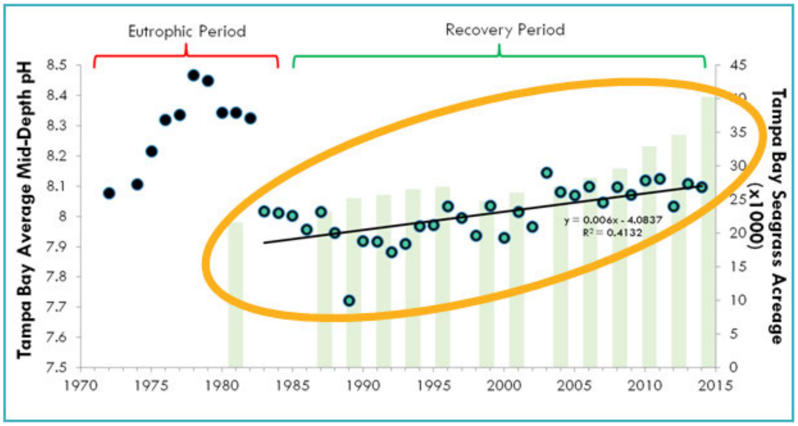

Figure 22. Recent linear trend in average, daytime mid-depth pH (dots) from long-term water quality monitoring stations established in Tampa Bay since 1972 relative to baywide seagrass coverage estimates (bars). Recent pH increases have coincided with increasing seagrass coverage within the estuary which 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. Sources: EPCHC & SWFWMD.

impact, including being directly linked to about 1 in 5 jobs in the region (TBRPC 2014). The prospects of adversely affecting these inherent economic benefits of Tampa Bay by repeating historical development patterns – instead of preserving and bolstering its environmental quality through smart land development practices – is counterintuitive and counterproductive for a growing region, particularly when you consider that the region has already invested greater than $1 Billion in reducing N loads to Tampa Bay since the 1980s, producing positive environmental and economic outcomes.

However, these purely economic incentives do not stand-alone. Maintaining, as well as continuing to restore, the environmental quality of Tampa Bay has inherent global benefits. New research being conducted in Tampa Bay has demonstrated that critical coastal habitats can play a key role in sequestering C from the atmosphere and oceans, reducing greenhouse gas emissions and their resulting climate change and ocean acidification (OA) impacts. An example of this would be the positive increases in pH that has occurred in Tampa Bay coincident to increases in seagrass coverage from the 1980s-present (Figure 14), despite declines in global ocean pH. Therefore, with continued protection and restoration, Tampa Bay seagrasses could become an important OA refuge for estuarine species sensitive to potential declining coastal pHs.

Methodologies to restore "Blue Carbon" estuarine habitats that provide climate change mitigating benefits have recently been adopter for use in global C markets (Verified Carbon Standard, VM0033). "Blue Carbon" habitat restoration investment in C markets may drive future restoration activities in the few, undeveloped coastal and upland areas that remain in the watershed in the future and thereby provide resource managers an additional tool to promote watershed restoration activities in Tampa Bay.

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NAVIGATING THE ROAD TO RECOVERY: A SPATIAL EXAMINATION OF HOW TAMPA BAY ACHIEVED ITS SEAGRASS RESTORATION TARGET

Kristen Kaufman

ABSTRACT

The Southwest Florida Water Management District (District) documented that Tampa Bay supports 40,295 acres of seagrasses in 2014. This marks the successful achievement of the Tampa Bay Estuary Program's 38,000 acre seagrass restoration target. Spatial analyses and creation of seagrass persistence maps provide insight into how seagrass expansion occurred over the last three decades. Persistence maps, documenting the number of years a particular area contained seagrass, show there are portions of Tampa Bay where the presence of seagrass is only documented intermittently during the 27-year mapping program. Examples such as Mobbly Bay, where seagrasses were documented discontinuously over time and experienced gains from 2012 to 2014, will be reviewed. These ephemeral seagrass areas will be further investigated to determine if localized management actions could provide any benefits for sustaining these resources.

LONG-TERM VIABILITY OF CONSTRUCTED FRESHWATER WETLANDS IN HILLSBOROUGH COUNTY, FLORIDA

Aaron Brown and Thomas Crisman

ABSTRACT

In 1987, the first successful constructed wetlands permitted by the Hillsborough County Environmental Protection Commission (EPC) were released from their mitigation obligations. Since then, over 1,200 freshwater wetlands have been constructed in accordance with EPC's environmental policies. Although released wetlands are intended to mature and eventually replace the functions of the impacted, natural wetland, monitoring after release is not required. As such, there is little to no information regarding their long-term viability for ecosystem structure and function. The objective of this study is to determine how design variables such as wetland type, size, location, and vegetation community affect wetland structure and function over time. A total of eighty (N=80) forested and herbaceous freshwater wetlands were selected via stratified random sample for in-depth evaluation to determine if they have continued on their intended design trajectories or have degraded to undesired conditions. Preliminary data analyses are indicating that long-term structure and function of constructed wetlands are affected by factors such as design, location in the landscape, and on-going maintenance. Results from this study may provide invaluable insight into wetland construction and long-term successional trends of freshwater wetlands in the Tampa Bay metropolitan area.

ONE-STOP PERMITTING THROUGH DELEGATION

Jackie Julien, Christina Bryant, Lauren Greenfield and Caitlin Hoch

ABSTRACT

Marine construction projects in Hillsborough County are regulated by multiple federal, state, and local agencies. In an effort to streamline and improve this multi-layered and often confusing permitting process, some Port Tampa Bay minor work permitting authority was delegated to the Environmental Protection Commission (EPC) of Hillsborough County in 2009. This delegation was followed by additional delegations from the Florida Department of Environmental Protection (FDEP) and U.S. Army Corps of Engineers (ACOE) to initiate one-stop regulatory permitting. The goal of this delegation is to create a one-stop permitting program at EPC that satisfies the rules of the Port, EPC, FDEP, and ACOE. This panel will discuss the delegation process, challenges, successes, results, customer feedback, and future goals.

LAKE MANATEE WATERSHED MANAGEMENT PLAN

Greg Blanchard

ABSTRACT

Manatee County and the Southwest Florida Water Management District have developed a Watershed Management Plan for Lake Manatee, the principal potable water supply for Manatee County and the region. An essential component of this effort was the creation of a pollutant loading model encompassing the watershed of Lake Manatee and the upper Manatee River linked to water quality models for the operating reservoir. The final Watershed Management Plan will focus on water quality assessment and support predictive investigations of reservoir water quality. The County will use this tool to consolidate and update the goals and objectives from the District's SWIM Plan, the Tampa Bay Estuary Program (TBEP) CCMP and the County into one strategy that includes comprehensive monitoring of water quality and pollutant loads, detailed mapping, flood and pollutant load modeling and practical projects to improve water quality, restore natural runoff regimes, provide water supply and protect natural resources.

IT TAKES A WHOLE RIVERINE ESTUARY TO RAISE A JUVENILE COMMON SNOOK

Janet Ley and Holly Rolls

ABSTRACT

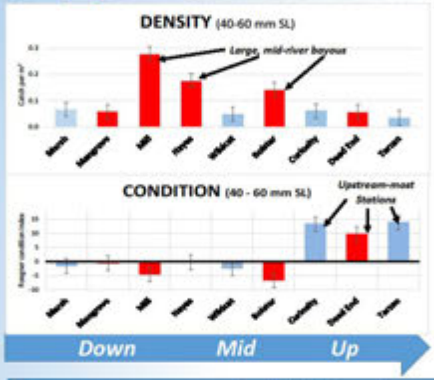
Tracing juvenile fish movements can guide conservation of Common Snook (*Centropomus undecimalis*) (Snook) in coastal ecosystems. Traditional fish sampling and otolith microchemistry were combined to investigate habitat-use by juvenile Snook in the Little Manatee River (LMR). We deployed 9.1-m seines and collected 383 young-of-the-year (YOY) Snook within our focal size/age class (40-60 mm SL, 83-105 days-old) in LMR tributaries during autumn 2013. For this YOY group, high mean densities (20/100m^2) but poor fish condition (CI=-3.8) occurred in mid-river tributaries; however, low mean densities (5/100m^2) and good fish condition (CI=+12.3) occurred in upstream tributaries. For a subset (n=127) of YOY, otolith microchemistry revealed distinct elemental signatures indicative of the LMR river-segment in which each YOY was collected: downstream (0-9 river-km) *vs*. upstream (9-18 river-km). By summer 2014, some YOY from the autumn-2013 cohort would have survived to age-1 (195-335 mm SL, 6-18 months-old). For 40 age-1 individuals collected in summer 2014, signatures of their otolith cores were analyzed and statistically matched to signatures previously derived for the autumn 2013 YOY group, indicating where each age-1 fish had lived as YOY. We found an unexpected prevalence of habitat-use and migration to upstream habitats. One-third (37%) of the 40 age-1 Snook lived upstream as YOY, and most (n=10) remained upstream through age-1. The remaining 63% of the age-1 Snook lived downstream as YOY, but half (n=12) of these individuals had moved upstream by age-1. Thus, although most Snook initially used downstream habitats as YOY nurseries, by age-1 many had moved to upstream habitats taking advantage of more favorable growth conditions. Thus, many juvenile Snook make directed movements along the estuarine gradient early in life, benefiting from unimpeded access to favorable habitats. This complexity of individual behavior and habitat-use may contribute to Snook population resilience under the dynamic conditions in coastal riverine systems.

Juvenile Common Snook Habitat Use and Movement Patterns Derived From Otolith Microchemistry, Fish Condition and Density within the Little Manatee River

Janet Ley & Holly Rolls, Florida Fish and Wildlife Research Institute

Funded by the Tampa Bay Environmental Fund (2012- 2015)

Objectives: **The overall objective of this study was to use otolith microchemistry to determine which nursery locations in a nearly pristine riverine tributary to Tampa Bay produced more Common Snook (*Centropomus undecimalis*) [Snook] recruits that survived their first year of life. We also sought to use catch density and fish condition to identify factors advantageous to successful recruitment.**

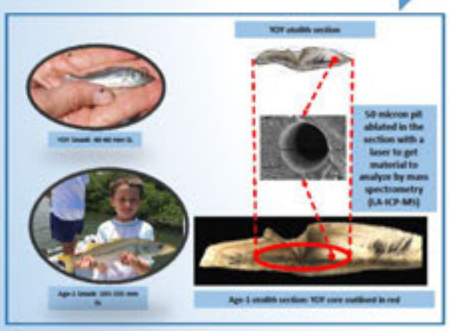


1. Sampling Young-of-the-Year (YOY) Snook

- Pale yellow sites are nine backwater nursery areas where we collected young Snook during Fall 2013
  - These YOY would have first recruited to their nursery habitats in Summer 2013
- The nursery areas included:
  - 5 "bayous:" lake or bay shaped habitats
  - 4 "creeks:" channel shaped habitats
- For the YOY analysis, we focused on the 40-60 mm SL size class (83-105 days old)
- Of 1,232 juvenile Snook netted, 383 were in this size class

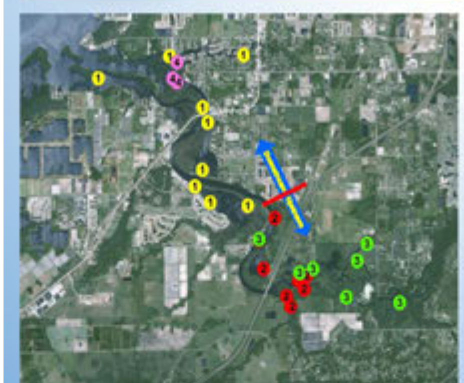
2. Density and Condition of the YOY Snook

- *Density* of YOY Snook netted (40-60 mm SL) = (number caught / area swept by the net)
- *Condition* of YOY Snook = index derived from weight / length (Roegner and Teel 2014)
  - Negative condition: fish are thinner than average
  - Positive condition: fish are heavier than average
  - Positive condition indicates better fish health due to more nutritious and abundant food, less competition, and/or less physiological stress
- *Results:* A trade-off existed between density vs. condition in the nurseries:
  - Densities of YOY Snook at 3 large mid-river bayous (Mill, Hayes, Bolster) were relatively high, BUT mean fish condition was negative (poor)
  - In contrast, densities at the 3 upstream-most locations (Curiosity, Dead End, Tarzan) were lower BUT mean fish condition there was positive (good)



3. Application of Otolith Microchemistry

- Microchemical analysis (LA-ICP-MS) of samples extracted near the edges of 127 otoliths from YOY Snook (40-60 mm) that had been collected in Fall 2013, identified 26 elements
  - *YOY Results:* Based mainly on the elements Na, Mn, Rb & Ba, upstream microchemical signatures differed from downstream
- "The Survivors:" By Summer 2014, some individuals from the cohort that recruited to LMR nurseries in the previous summer (2013) would have survived their first year of life and entered the Age-1 year class (195-335 mm SL); we conducted microchemical analyses of otoliths from 40 Age-1 Snook that we collected in Summer 2014
  - *Age-1 Results:* Microchemical signatures of Age-1 Snook otolith cores (formed while the Snook were living in their YOY nursery habitats) clearly identified YOY nursery habitats for Snook within the LMR



4. YOY Nursery Origin of Age-1 Snook

- 4 "movement" groups of Age-1 Snook were identified based on:
  - Chemical signatures of their otolith cores, and
  - Location where they were collected
- Movement groups were mapped by collection location (n = 40) (some overlap in symbols):
  - Group 1 Yellow symbols (n = 13):
    - *"DD" otolith cores matched the Downstream YOY signature, AND they were also collected Downstream*
  - Group 2 Red symbols (n = 12):
    - *"DU" otolith cores matched the Downstream YOY signature, BUT they were collected Upstream*
  - Group 3 Green symbols (n = 10):
    - *"UU" otolith cores matched the Upstream YOY signature, AND they were also collected Upstream*
  - Group 4 Pink symbols (n = 5):
    - *"UD" otolith cores matched Upstream YOY signature, BUT they were collected Downstream*

Summary:

1. *Of the 40 Age-1 Snook, 57% stayed in their YOY nursery segment (up or downstream), while 43% moved.*
   - *30% of the 40 Snook moved from down- to upstream, while only 13% moved from up- to downstream*
2. *Young-of-the-year Snook were in better condition upstream indicating favorable habitat and resources.*

Resource Management Implications:

Unimpeded connectivity between favorable upstream and downstream habitats may be an important key to strong Snook recruitment from a coastal riverine system.

MIGRATORY BIRD PROTECTION PARTNERSHIP

Christopher Cooley

ABSTRACT

This presentation will highlight the cooperative partnership between Port Tampa Bay (PTB) , U.S. Fish and Wildlife Service, Florida Fish and Wildlife Conservation Commission (FFWCC), Audubon Florida, U.S. Army Corps of Engineers (ACOE), and many other stakeholders to protect a "globally significant" migratory bird population that nests annually in and around Tampa Bay. Due to native habitat loss, Port Tampa Bay's dredge disposal islands have become favored nesting sites for these birds, putting their nests and young in harm's way due to ongoing dredging operations and other related industrial activities. These partners have committed to working together to protect the nesting birds including the formation of a migratory bird protection committee. The committee meets before each nesting season to discuss upcoming projects and after each nesting season to review results of bird protection measures. This panel of stakeholders will present/discuss the bird populations (Audubon), nesting season (FFWCC), regulations(FFWCC), best management practices, site specific protection plans, dredging operations (ACOE/PTB), partnerships, challenges, successes, and results of this ongoing partnership.

MIGRATORY BIRD PROTECTION PARTNERSHIP

Jackie Jullien, Christopher Cooley *Port Tampa Bay*; Ann Paul, Mark Rachal *Audubon Florida*;
Aubree Hershorin, Andy Cummings *USACE*; Nancy Douglass, *FWC*; Cindy Fury, *FWS*; Kristy Apostol, *TECO*

A cooperative partnership between Port Tampa Bay (PTB), the U.S. Army Corps of Engineers (USACE), the U.S. Fish and Wildlife Service (FWS), the Florida Fish and Wildlife Conservation Commission (FWC), Audubon Florida, and many other stakeholders collaborates to protect a "globally significant" nesting bird population in Hillsborough Bay. Harbor management operations that place dredged material onto two diked islands designed and managed to receive this material create habitat that attracts beach-nesting birds. Because natural beach habitat is increasingly unavailable to these beach-nesting birds, Port Tampa Bay's dredge material disposal islands have become favored nesting sites. These partners have committed to work together to protect the nesting birds from adverse effects related to dredging or construction operations that may occur during the bird nesting season, through the formation of the Migratory Bird Protection Implementation Committee (MBPIC). The committee meets before each nesting season to discuss upcoming projects and bird protective measures and after each nesting season to review results. Management of the bird populations during the nesting season, appropriate regulations, best management practices, site-specific protection plans, upcoming dredging operations, and the challenges, successes, and results of each nesting season are discussed by the members of this ongoing partnership.

Audubon FLORIDA → **Migratory Bird Protection Implementation Committee For PTB Dredge Management Areas 2D and 3D Islands** ← **Project Contractors**

US Army Corps of Engineers.

PORT TAMPA BAY. Environmental — PORT TAMPA BAY. Engineering

MIGRATORY BIRD PROTECTION POLICY SUMMARY

The Migratory Bird Protection Implementation Committee (MBPIC) is comprised of staff of PTB, USACE, FWS, and FWC with Audubon participating in an advisory capacity. Other members include the Florida Department of Environmental Protection (FDEP), Environmental Protection Commission of Hillsborough County (EPC), Tampa Bay Estuary Program, and staff from dredging and construction companies. The MBPIC has developed a Site Specific Management Plan (SSP) that outlines basic actions. If strictly followed, the SSP guidelines will effectively minimize or prevent impacts to nesting birds when dredge material placement or construction activities must occur during the official nesting season April 1st to August 31st or between the first and last nesting activity.

Site Specific Management Plan Guidelines:

The MBPIC meets twice annually, once before and once after the nesting season with other meetings scheduled as needed.

PTB and Audubon issue joint press releases to inform the general public of the partnership and efforts undertaken to protect nesting birds.

PTB posts "no trespassing" signage on the two dredged material management islands before March 1 and Audubon conducts early season bird surveys.

The PTB Environmental Director reviews access requests during the bird nesting season and coordinates with MBPIC/Audubon staff to ensure that nesting birds are not impacted.

Demobilization of equipment is scheduled after bird nesting season concludes or under supervision by USACE or PTB Engineering staff, FWS, FWC and Audubon.

SSP For Each Project:

- PTB and USACE with their contractors outline dredge or construction plans and coordinate with MBPIC to develop a project site-specific bird protection plan to avoid impacts to nesting birds during work.
- Bird deterrence measures are reviewed by PTB and USACE in cooperation with Audubon and are approved by FWS and FWC. Deterrence effectiveness evaluations are included in the post-nesting season reports and meeting discussion.
- Audubon or other authorized expert conducts pre-construction in-service training for all dredge or construction contractor staff.
- Daily bird monitoring is conducted in areas of activity during the bird nesting season by qualified personnel.
- Access is limited to approved delineated work areas to reduce impacts to nesting birds.
- PTB, USACE, contractor staff, and Audubon coordinate through weekly communication on activities during the bird nesting season.
- Bird nesting season summary reports are prepared by contractors at the end of the project or the bird nesting season.
- All crew members remove all trash to avoid attracting bird predators to the dredge material islands.

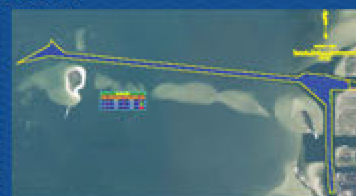
PROJECTS COMPLETED DURING 2015 MIGRATORY BIRD SEASON

USACE Island 3D Levee/Dike Raising & Armoring Outfall Pipe:

Began construction in Nov. 2014; project completed in August 2015.
The contractor, Carter Contracting Services, Inc., raised the levee from +30' to +35' height in elevation (NAVD88) to increase dredge-material holding capacity by an additional 20 million cubic yards.
Approx. 1,800 linear feet of rip-rap was placed along dike slope to control erosion.
Companies followed guidelines prescribed in the Site Specific Management Plan as approved by the MBPIC.
Bird monitoring was undertaken by the sub-contractor, LGL Environmental, which also conducted in-service training for construction staff and attended MBPIC meetings.

NOAA/Mulberry Phosphate Mitigation Oyster Reef Habitat Creation Project at NE corner of 2D Island

Began construction in April 2015; project completed in June 2015.
Project funded to mitigate the Mulberry Phosphate Acid Spill in 1998 and overseen by National Oceanic and Atmospheric Administration (NOAA), FDEP and EPC staff as trustees.
The project was designed to create oyster habitat in Hillsborough Bay to offset losses caused by the acid spill.
Three discontinuous oyster bar rock structures were installed along approx. 1,400 linear feet of shoreline along the east side of Island 2D.
TetraTech was lead contractor; installation carried out by Florida Dredge and Dock.
Contractors followed guidelines prescribed in the SSP as approved by the MBPIC.
Audubon staff conducted in-service training, on-site bird monitoring, and daily bird surveys for the installation contractor, Florida Dredge and Dock.



Tampa Electric Company Big Bend Channel Maintenance Dredge Project with disposal on Island 2D

Began dredge project in April 2015; project completed in June 2015.
The project was implemented to remove sediments in the Big Bend Channel that were impacting shipping. Approximately 132,000 cubic yards of hydraulically dredged material (spoil) was deposited on Island 2D.
Contractors followed guidelines prescribed in the Site Specific Management Plan as approved by the MBPIC.
Audubon staff conducted in-service training, on-site bird monitoring, and daily bird surveys for the contractor, Orion Marine Construction, Inc.

Nesting Surveys - Port Tampa Bay Dredge Material Management Area (DMMA) in Hillsborough Bay (Numbers represent breeding pairs-nests)

Dredge Material Management Area 2D Island

SPECIES	LISTING	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Black-crowned Night-Heron												5							
Common Gallinule												1							
Wilson's Plover				3							8								
American Oystercatcher	SSC	35	36	33	32	37	34	37	32	35	37	33	34	36	29	32	33	27	28
Black-necked Stilt							45		4	12	78	40	33	48	38	20	25		29
Willet			10	36	5	6	6			5	10	15	5	5	5	5	5		
Laughing Gull											100	5,850	1,810	1,250	5,800	1,250	1,500		
Gull-billed Tern										4	7	4	7	18	38	45	12		
Caspian Tern												15	64	95	60	100	36		
Royal Tern													75	130	90	60	150		
Least Tern	T										60	38	33	100		48			
Sandwich Tern																	35		
Black Skimmer	SSC											22	107	190	175	200	190		
Total		35	46	73	38	43	86	37	38	56	260	6,043	3,153	1,914	6,419	1,850	1,886	27	57

Dredge Material Management Area 3D Island

SPECIES	LISTING	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
American Oystercatcher	SSC	18	18	15	17	16	13	15	16	15	15	15	18	18	9	9	12	9	7
Black-necked Stilt		78																15	33
Willet			5	1	8	10	6	5	2	6	1	1	5	3				5	3
Laughing Gull		6,500	6,200	5,600	5,700	4,100	5,255	3,475	4,700	4,700	7,765	450					50	250	450
Gull-billed Tern				1	7	8	16		8										37
Caspian Tern		75	92	77	82	88	80	80	80	88	71	76						65	76
Royal Tern		107	765	860	93	278	156	107	175	420	153	72						18	173
Sandwich Tern		99	180	74	50	286	210	156	260	125	82	3							48
Black Skimmer	SSC	360	320	195	140	250	180		200	210	110							35	37
Total		7,179	6,860	6,260	5,818	5,036	5,810	3,837	5,457	5,584	8,167	617	23	21	9	9	62	376	880

Listing: Florida Fish & Wildlife Conservation Commission, T = Threatened; SSC = Species of Special Concern
Bird nesting numbers and island nest colony locations were influenced by changes in habitat created by dredging or construction activities. Both islands were comprehensively surveyed all years by Audubon except the 2015 DMMA 3D data which is provided by LGL Environmental Solutions, Inc.

Colonial Birds

Black-crowned Night-Heron (*Nycticorax nycticorax*)
Black Skimmer (*Rynchops niger*)
Caspian Tern (*Hydroprogne caspia*)
Gull-billed Tern (*Gelochelidon nilotica*)
Least Tern (*Sternula antillarum*)
Royal Tern (*Thalasseus maximus*)
Sandwich Tern (*Thalasseus sandvicensis*)
Laughing Gull (*Larus atricilla*)

Territorial Birds

American Oystercatcher (*Haematopus palliatus*)
Black-necked Stilt (*Himantopus mexicanus*)
Wilson's Plover (*Charadrius wilsonia*)
Willet (*Tringa semipalmata*)

American Oystercatcher Nests on DMMA Islands

Approximately 20% percent of Florida's oystercatchers nest on these islands in Hillsborough Bay.

100 foot nest buffer

Island 2D and Fantasy Island

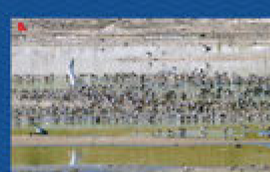
Island 3D Territories

DREDGE MATERIAL DISPOSAL PROCESS

Ships require open channels to safely transport their cargos.
Cranes on barges excavate sediment that has accumulated in a ship channel. Material is transported into the diked dredge island in a slurry of sand, sediments, and bay water.
Islands 2D and 3D dikes contain pumped-in dredge materials. As sands and sediments carried in with the bay water settles out, the clean bay water is returned to Hillsborough Bay through discharge outfall pipes.
Placement of dredge material on islands provides unvegetated open-substrate habitat required by beach-nesting birds remote from human disturbance and ground predators.

Dredge barge excavates bottom sediment material from ship channels and berths

Dredged slurry material is hydraulically pumped into DMMA 2D or 3D island interiors



Settling and separation of dredged material inside DMMAs create bird habitat

Discharge outfall pipes return excess bay water

PINELLAS COUNTY FRESHWATER BIOLOGICAL PROGRAM

Peggy Morgan and Robin Barnes

ABSTRACT

In 2014, Pinellas County established a freshwater biological monitoring program in order to provide macroinvertebrate and floral data to the Florida Department of Environmental Protection's (FDEP) Watershed Assessment program. The stream sampling employs FDEP methods: Stream Condition Index (SCI), Habitat Assessment (HA), Rapid Periphyton Survey (RPS) and Linear Vegetation Survey (LVS). A failing SCI score can put a stream segment on the TMDL planning list for biological impairment; two consecutive failing scores may place it on the TMDL impaired list. Two consecutive RPS failures can put a segment on the impaired list for nutrients, even if the water quality meets the regional criteria for Total Nitrogen and Total Phosphorus.

There are two TMDL basins in Pinellas County: Springs Coast and Tampa Bay. Pinellas County plans to alternate sampling between the basins, collecting SCI, HA, RPS, and LVS in each stream water body ID (WBID) twice each year in each basin. The Impaired Water Rule requires at least two SCI and RPS assessments for each stream WBID per a 5 year TMDL assessment period. Pinellas County's schedule will provide more data than required for these assessments. Data from the first year's sampling season indicates the majority of Pinellas County streams in the Spring Coast basin are either impaired or inconclusive for SCI. The RPS (nutrient criteria compliance) data indicates the streams are either unimpaired or inconclusive. Probable stressors related to stream biological impairment will be discussed.

Pinellas County Freshwater Biological Program

Peggy Morgan and Robin Barnes, Pinellas County Natural Resources, Environmental Monitoring

Pinellas County

Introduction

In 2014, Pinellas County established a freshwater biological monitoring program in order to provide macroinvertebrate and floral data to the Florida Department of Environmental Protection's (FDEP) Watershed Assessment program. The stream sampling employs FDEP methods: Stream Condition Index (SCI), Habitat Assessment (HA), Rapid Periphyton Survey (RPS) and Linear Vegetation Survey (LVS).

Methods

The SCI is a composite macroinvertebrate index for use in flowing streams. Sampling consists of 20 dipnet sweeps of the most productive habitats found in a 100-meter stretch of a stream. Organisms collected in these sweeps are preserved and brought back to the laboratory for processing in accordance with the DEP SOP LT 7200. Data generated on the taxonomy and abundance of these organisms is used to calculate ten biological metrics, each of which has been shown to respond predictably to human disturbance. The metrics are:

•Number of total taxa,
•Number of long lived taxa (require more than one year to complete their life cycle)
•Number of Ephemeroptera (mayfly) taxa,
•Number of Tricoptera (caddisfly) taxa,
•Number of Florida sensitive taxa,
•Number of clinger taxa,
•Percent dominant taxon,
•Percent Tanytarsini,
•Percent very tolerant taxa,
•Percent filterers.

Most of these metrics decrease in response to adverse human influences, while two of the metrics (% dominant taxon and % very tolerant taxa) increase in response to human disturbance. Once the metrics are calculated, points are assigned for each metric based on criteria which have been regionally calibrated and are contained in DEP SOP LT7200. The points from each of these 10 biological metrics are then summed to determine an overall score of biological health. A balanced macroinvertebrate community is attained if the average score of at least two temporally independent SCIs, performed at representative locations and times, is 40 or higher, with neither of the two most recent SCI scores less than 35. A habitat assessment is performed concurrent with each SCI collection. Eight attributes known to have potential effects on the stream biota are rated to produce a score between 8 and 160; the higher the score indicating less human disturbance. This is important when determining potential causes of any biological imbalances because the stressors may be due to the inadequacy of physical habitat and proximity to human activities.

•Substrate Diversity – the number of productive habitats present (snags, logs, tree roots, aquatic vegetation, leaves, rock, or other stable habitat).
•Substrate Availability –the percentage of productive habitats present (as listed above)
•Water Velocity - higher velocities typically receive higher scores
•Habitat Smothering – the percentage of area of the stream bed which is covered or "smothered" by sand or silt accumulation
•Artificial Channelization - anthropogenic channelization of a stream based on its variance from natural stream patterns (sinuosity) and the presence of artificial bank structures
•Bank Stability - the stability of a stream's banks based on evidence of erosion or bank failure
•Riparian Buffer Zone Width –
•Riparian Zone Vegetation Quality

Larvae of the caddisfly, *Cheumatopsyche*

Baetidae mayfly nymph

Robin Barnes collecting SCI in Rattlesnake Creek

Results

In 2014, the Bioassessment Program collected biological data twice at 12 stream sites emptying into the Gulf of Mexico (Springs Coast Basin). The results are shown in Table 1. The majority of the sites had an unresolved assessment; one passing score and one failing score, or only one assessment was done. Only one stream, McKay Creek, had 2 consecutive scores greater than 40. Three streams had scores that were below 40 for both sampling events: Church Creek, Joes Creek, and Spring Branch. The majority of the habitat assessment scores were on the low end of "sub-marginal", indicating that habitat could be a factor in the health of the invertebrate community. Those with the lowest habitat scores, indicating the largest human impact, tended to have the lowest SCIs.

In Winter, 2015, biological sampling in the streams flowing to Tampa Bay commenced. Results will be available in 2016.

Bioassessment Sites and Scores

Station Name	Field ID	Station Description	WBID	Sample Date	Habitat Score	SCI Score
Bee Branch	08-03	Upstream of U.S. 19	1527B	4/17/2014	87	48
Bee Branch	08-03	Upstream of U.S. 19	1527B	12/16/2014	80	37
Church Creek	27-08	Upstream of Wilcox Rd	1643	4/28/2014	85	30
Church Creek	27-08	Upstream of Wilcox Rd	1643	12/3/2014	102	39
Curlew Creek	10-01	Upstream of CR1	1538A	5/8/2014	72	33
Curlew Creek	10-01	Upstream of CR1	1538A	10/24/2014	80	43
Jerry Branch	10-07	Upstream of Brady Rd bridge	1550	11/24/2014	82	43
Joes Creek	35-10	Downstream 62nd St N	1668A	5/14/2014	56	33
Joes Creek	35-10	Downstream 62nd St N	1668A	10/28/2014	61	22
Joes Creek	35-11	Downstream 46th Ave N	1668A	10/30/2014	75	12
Joes Creek	35-16	0.2 miles east of 58th St N	1668A	10/30/2014	66	27
Miles Creek	35-12	Downstream 64th St N	1668A	10/28/2014	67	12
McKay Creek	27-11	End of Bluff Dr	1633B	4/23/2014	98	46
McKay Creek	27-11	End of Bluff Dr	1633B	5/7/2015	93	49
Rattlesnake Creek	17-01	Downstream of bridge	1614	4/24/2014	84	43
Rattlesnake Creek	17-01	Downstream of bridge	1614	11/14/2014	82	34
Spring Branch	15-04	Upstream of Nbetty	1567B	5/15/2014	64	32
Spring Branch	15-04	Upstream of Nbetty	1567B	01/06/15	83	38
Stevenson's Creek	18-06	City of Clearwater golf course	1567C	5/1/2014	75	42
Stevenson's Creek	18-06	City of Clearwater golf course	1567C	10/9/2014	66	32
Hollin Creek	09-01	East Lake Drive golf course	1440	4/7/2015	101	55
Cross Canal	24-07	South of 66th and Bryan Dairy	1625	5/6/2015	68	12

ASSESSING PINELLAS COUNTY SURFACE WATER QUALITY FROM 2003-2013

Robert Burnes, Mark Flock, Andrew Squires, and Michael Wessel

ABSTRACT

Since 2003, the Pinellas County Department of Public Works Natural Resources Section has conducted surface water quality monitoring in Tampa Bay and major lakes using a probabilistic sample program, and in watersheds using a fixed station program. In Tampa Bay and major lakes, County staff collected samples at randomly selected sites on randomly selected days following a probabilistic sample program. This program is based on the Environmental Protection Agency's (EPA's) Environmental Monitoring and Assessment Program (EMAP). The probabilistic sample design ensures a representative distribution of sample sites within Tampa Bay and major lake geographic segments, statistically sound estimates of percentage area of water bodies meeting water quality criteria, and statistically sound inferences of annual and long term water quality status and trends. It also provided data to assess water body impairment relative to State water quality criteria. Watershed fixed stations were situated, where possible, just upstream of tidal influence in order to measure volume discharge from as much of basins as possible. Volume discharge data is collected by continuous flow monitoring stations or by County staff. The fixed station design provides estimates of annual discharge volumes and annual nutrient and suspended sediment loads. It also provided data to assess watershed impairment relative to State water quality criteria. In this presentation the probabilistic monitoring design and fixed station design will be reviewed and results for data collected from 2003 to 2013 will be presented. Future program objectives will be discussed.

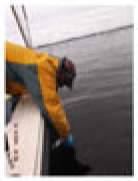
Analysis of Ten Years of Tampa Bay Water Quality Monitoring Data

Rob Burnes M.S.[1], Mark Flock M.S.[1] and Mike Wessel M.S.[2]

[1] Pinellas County Watershed Management; [2] Janicki Environmental

Introduction:

Since October 1990, the Pinellas County Public Works Department Watershed Management Division (WMD) (formerly the Department of Environmental Management and the Department of Environment and Infrastructure) has monitored surface water quality in the County's 52 drainage basins, four lakes, and nine receiving water bodies. The goals of this program are to provide long-term assessments of water quality, measure success of management initiatives, and meet State and Federal regulatory requirements. In January 2003, a revised monitoring program (Janicki 2003) was implemented to provide better geographical coverage of County waters and to provide more statistically defensible results in comparison to the original (1991-2002) program. The new program consists of a probabilistic design consisting of an EPA EMAP based element and a stratified random element. This poster shows some of the results of the analysis of the first ten years of water quality (2003-2013) under this program design.



Methods and Materials:

- The ambient water quality program consisted of two types of sample sites distinguished by selection method.
  - The first type are randomly selected sites in open water bodies (strata). Samples collected at these sites are used to assess status and trends in County receiving water bodies.
  - The second type is a set of fixed land-based sites along rivers, streams, ditches and canals. Samples collected at these sites are used to assess the condition of the waterway and for estimation of nutrient and sediment loads from these waterways to receiving water bodies.
- Field sample collections and measurements were carried out 8 times a year according to Florida Department of Environmental Protection (FDEP) Standard Operating Procedures.
- Physical parameters including temperature, pH, dissolved oxygen, conductivity, and salinity were measured using Hydrolab® multiprobe units. Surface readings were taken at a depth of 0.2m from the surface. If the total water column depth was >0.5m but <1.0m, data were recorded at the surface and 0.2m from the bottom. For depths greater than 1.0m, data were also recorded at mid-depth.
- A wide array of statistical analysis was conducted using SAS and trends were derived from this analysis.
- For spatial interpolations, the variables analyzed included chlorophyll-a, mean percent dissolved oxygen, and transmissivity. The data were checked for location, qualifiers, and normality prior to interpolation. The normality of the data was analyzed using the normality histogram plot, Q-Q normal plot, skewness, and kurtosis. If the data met the assumption of normality OKRG was used. If the data were not normally distributed IDW was applied. The ESRI® ArcMap Geographic Information System (GIS) software was used for the construction and creation of the interpolation surfaces. The ESRI® Geostatistical Analyst Extension was used to calculate the interpolation surfaces.

Results:

Trend Summaries By Major Basin

In Boca Ciega (Figure 1), there was a single decreasing trend in Chlorophyll-a, two increasing trends in DO Lake Seminole (Strata A and B), four decreasing trends in TN, seven decreasing trends in TP, a single increasing trend in salinity, and a single increasing and three decreasing trends in turbidity. In Middle Tampa Bay, (Figure 2) TP was decreasing in all estuarine strata (i.e. E6, E7 and RB). Not fixed site land based stations contained enough data for trend testing. No other trends for any of the principal parameters resulted from the trend tests after accounting for multiple comparisons. In Old Tampa Bay North (Figure 3), there were no trends in Chlorophyll-a or DO, two decreasing trends in TN (ca 16%), one decreasing TP trend, five increasing salinity trends (ca. 23%), and 2 increasing and three decreasing trends in turbidity. In Old Tampa Bay South (Figure 4), there was a single decreasing Chlorophyll-a trend, three Decreasing DO trends (ca. 12%), no trends in TN, seven decreasing trends in TP (ca 54%), no trends in salinity, and a single increasing trend in turbidity.

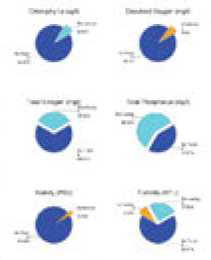


Figure 1. Trends in Boca Ciega Bay

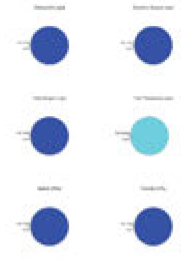


Figure 2. Trends in Middle Tampa Bay

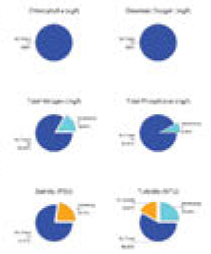


Figure 3. Trends in Tampa Bay North

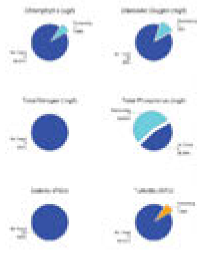


Figure 4. Trends in Tampa Bay South

Spatial Trends Summaries

When comparing spatial interpolation plots over two time periods (2003-2008 and 2009-2013) several trends emerged. On the east coast of the county (Tampa Bay) Chlorophyll-a levels increased from Safety Harbor to Riviera Bay. Chlorophyll-a levels went from a predominantly 6-8 ug/L and 8-11 ug/L concentration in 2003-2008 to a 8-11 ug/L and 11-15 ug/L concentration (Figure 5). Mean dissolved oxygen percent and transmissivity increased slightly in nearly all open water strata between 2003-2008 and 2009-2013 (Figures 6 and 7). All values for mean dissolved oxygen percent were above the state level for impairment. The observed seasonal trends in east and west strata for DO and Chlorophyll-a during were consistent with the expectation that water quality should be better in the dry season. There were inconsistent seasonal trends in transmissivity in east and west strata. This could be due to seasonal differences in the contribution of wind generated sediment re-suspension to TSS, turbidity, and transmissivity levels. Wind associated with weather fronts in the dry season may be higher.

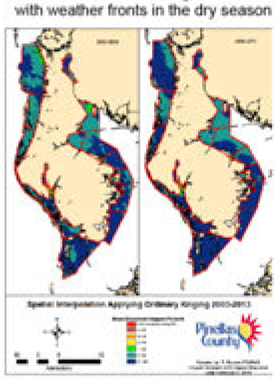


Figure 5. Spatial Trends in Mean Dissolved Oxygen Percent

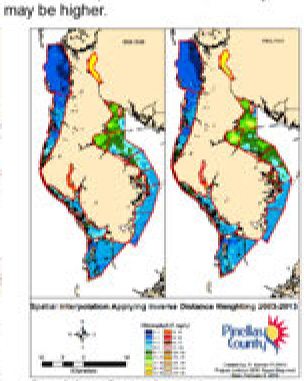


Figure 6. Spatial Trends in Chlorophyll-a

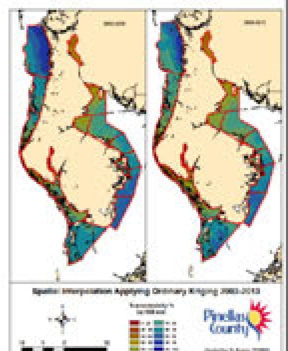


Figure 7. Spatial Trends in Transmissivity

Discussion:

Overall, very few statistically significant trends were found within the ten years of data generated in this program. The trends that were seen generally related to overall increases in water quality, i.e. decreasing chlorophyll and nutrients. Perhaps the most pronounced trend was that of decreasing TP in all of the strata of middle Tampa Bay. Besides this trend several geographic and seasonal trends were observed.

There is an overall geographic trend for water quality in Tampa Bay. That of better water quality in Middle and Lower Tampa Bay compared to Old Tampa Bay This geographic trend is due in part to the much larger drainage area contributing nutrient laden runoff to Old Tampa Bay compared to Middle Tampa Bay. Additionally, Old Tampa Bay does not flush nearly as much as Middle and Lower Tampa Bay which leads to longer residence times and potential for greater productivity.

Seasonal trends were also apparent during the study period. Spatial interpolation plots show that conditions in nearly all strata improved in the dry season for transmissivity, Chlorophyll-a, and DO. This was further supported by GLM test results which confirmed seasonal differences within stratum for DO and transmissivity, with both parameters improving during the dry season. Non-parametric test results confirmed seasonal differences seen within strata for Chlorophyll-a, TSS, and turbidity. The results indicated these water quality parameters were better during the dry season. Transmissivity was better in the dry season from the Feather Sound area, the St Petersburg pier, and Riviera Bay. In Feather Sound mean and median TSS values were lower in the dry season. During the wet season mean and median values for turbidity in Tampa Bay were higher from Oldsmar down to the mouth of Riviera Bay and in Riviera Bay, and in Long Bayou on the west coast, though the overall change in the value ranges were small.

General Trends

- Water quality is better in open water strata compared to enclosed or semi-enclosed strata.
- Water quality is typically better during the dry season compared to the wet season.
- Chlorophyll-a, transmissivity, and TSS appeared to improve in years with lower rainfall.
- Water quality is better during years with lower rainfall though wet season phytoplankton blooms in 2008-2010, moderate rainfall years, tend to compromise this statement.
- Nutrient load discharges from local watersheds contributed to high chlorophyll-a and low dissolve oxygen in Old Tampa Bay.
- Discharges from three eutrophic systems; Lake Seminole, the Seminole Bypass Canal, and the Cross Bayou Canal contributed to high chlorophyll-a and low dissolved oxygen in Long Bayou and Cross Bayou.
- Water quality along the east coast of the county generally improved from north to south with poorer conditions from Oldsmar to Weedon Island and better conditions in the mid and southern bay off St. Petersburg.

Pinellas County

Janicki Environmental, Inc.

CURRENT RISKS IMPACTING THE COASTAL WETLANDS OF TAMPA BAY: RECOMMENDATIONS FOR THE MANAGEMENT OF LOCAL SALT MARSHES AND MANGROVES

Kara R. Radabaugh, Christina E. Powell, Ryan P. Moyer

ABSTRACT

The low coastal topography, frequent tropical storms, and highly developed shorelines make Florida coastal wetlands particularly susceptible to the effects of sea-level rise, habitat loss, and altered hydrology. The Coastal Habitat Integrated Mapping and Monitoring Program (CHIMMP) at the Florida Fish and Wildlife Conservation Commission's (FWC) Fish and Wildlife Research Institute (FWRI) has compiled data from mapping and monitoring efforts for mangroves and salt marshes across Florida. In Tampa Bay and neighboring shorelines, large areas of salt marshes and mangroves have already been lost to coastal development. Remaining coastal wetlands face challenges from remnant mosquito ditches, concentrated and irregular stormwater runoff, invasive vegetation, climate change, and sea-level rise. CHIMMP has identified region-specific threats to coastal wetlands on Springs Coast, Tampa Bay, and Sarasota Bay and compiled management recommendations from federal, state, local, and academic experts. Sea-level rise and hardened or developed shorelines are repeatedly identified by these stakeholders as top threats to coastal wetlands, and recommended management strategies include both mitigation and adaptation. The most frequent recommendations focus on resisting saltwater intrusion through restoration of natural hydrology and on the establishment of elevation-appropriate buffer zones adjacent to extant coastal wetland habitat to facilitate landward movement in response to sea-level rise. Other components of this strategy include replacing hardened seawall structures with living shorelines and altering drainage systems that concentrate and accelerate stormwater runoff. CHIMMP provides a diverse perspective on the growing management challenges and region-specific approaches to the mitigation and protection of Tampa Bay's coastal wetlands.

Current Risks Impacting the Coastal Wetlands of Tampa Bay: Recommendations for the Management of Local Salt Marshes and Mangroves

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Introduction

The Coastal Habitat Integrated Mapping and Monitoring Program (CHIMMP) at the Florida Fish and Wildlife Conservation Commission's (FWC) Fish and Wildlife Research Institute (FWRI) is designed to coordinate efforts, compile data, improve communication, and identify needs for the mapping and monitoring efforts for mangroves and salt marshes in Florida. CHIMMP efforts include:

1. Two workshops at FWRI that brought together statewide coastal wetland experts and stakeholders. Workshop presentations and results are available at ocean.floridamarine.org/CHIMMP/
2. A pilot program for a side-by-side comparison of monitoring methodology
3. Identification of needs and gaps in coastal wetland mapping and monitoring
4. An extensive collaborative report (in progress) detailing ecosystem status, trends, and statewide mapping and monitoring programs in Florida.

Methods

During the two CHIMMP workshops (held in April 2014 and September 2015), attendees presented on mapping and monitoring programs and provided feedback on gaps and needs. Many attendees also volunteered to contribute to the statewide CHIMMP report. The contributions of these local experts were combined with extensive research on the part of CHIMMP to create region-specific chapters (Figure 1). This poster presents some of the results compiled from the Big Bend and Springs Coast, Tampa Bay, and Sarasota Bay chapters of the CHIMMP report. Coauthors for these chapters include Kara Radabaugh, Ellen Raabe, Theresa Thom, Nicole Rankin, Kris Kaufman, Lindsay Cross, Ed Sherwood, Bill Ellis, Chris Miller, Frank Courtney, Jay Leverone, and Jon Perry.

Figure 1. Content of each regional CHIMMP chapter includes an ecological summary, coastal wetland mapping and monitoring programs, threats, and recommendations.

Mapping and Monitoring Efforts on Florida's Central Gulf Coast

Several efforts include data on salt marshes and mangroves. Examples include:

- ***Land Cover Mapping:*** Land cover mapping data is available from multiple sources. The Southwest Florida Water Management District (SWFWMD, Figure 2) has mapping data available for the years 1990, 1994, 1999 and 2004-2011 (SWFWMD 2011). Often these land cover data products vary in their categories and classifications (Figure 3).
- ***Critical Coastal Habitat Assessment:*** Tampa Bay Estuary Program (TBEP) initiative for long-term ecosystem monitoring to track ecosystem changes in response to sea level rise. Sites are revisited every 3-5 years (Sherwood and Greening 2012).
- ***Tidal Tributaries Project***: TBEP initiative to monitor tidal creeks and their importance as fish habitat in the Tampa Bay area (Sherwood 2008).
- ***MangroveWatch***: A citizen science effort led by St. Leo University to periodically map mangroves using video cameras on boats.
- ***Minimum Flows and Levels***: SWFWMD conducted coastal wetland characterizations of the major inlets to Tampa Bay in order to determine needs for minimum freshwater flow (SWFWMD 2015).
- ***Coastal Wetland Elevation Monitoring:*** The U.S. Fish and Wildlife Service Southeast Region Inventory and Monitoring Network is monitoring vegetation, elevation, and salinity near the Suwanee River and St. Marks National Wildlife Refuge (Boyle et al. 2015).
- ***Gulf of Mexico and Southeast Tidal Wetlands Project:*** The USGS partnered with the University of Florida and Florida Geological Survey to use satellite imagery to evaluate changes in water levels, vegetation, and elevation in Big Bend salt marshes (Raabe and Stumpf 1997).

Figure 2. Mangrove and salt marsh coverage in Tampa Bay according to SWFWMD 2011 land use/land cover data.

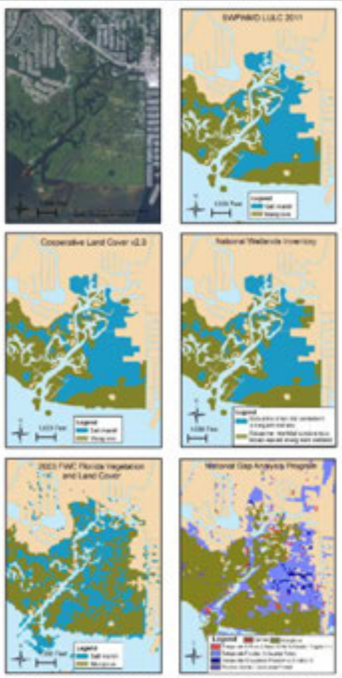

Figure 3. Northeast Tampa Bay example of raster and polygon coastal wetland mapping data from various sources.

Threats to Salt Marshes and Mangroves on Florida's Central Gulf Coast

Region-specific threats compiled by CHIMMP coauthors and contributors include the following:

- ***Climate change and sea level rise***: The survival of coastal wetlands in their current locations will depend upon sediment accretion rates keeping pace with sea level rise (Figure 4a). Due to gentle topography, even small changes in sea level can impact wide areas of coastline (Stumpf and Haines 1998). Landward retreat is possible, but this requires appropriate elevation and a lack of human development in adjacent buffer zones (Figure 4b).
- ***Coastal development***: Urban expansion continues along the coast of greater Tampa Bay, particularly for industrial or port facility developments.
- ***Hydrologic modifications***: Flow of surface water is altered by impervious surfaces, drainage structures, and demand for fresh water.
  - Salinity in coastal wetlands varies widely due to concentrated freshwater flow in drainage structures.
  - Many remnant mosquito ditches are still present around Tampa Bay, altering tidal flow and elevation in wetlands.
  - Less developed areas on the Springs Coast are also impacted. Roads act as levees, fragmenting habitats and altering freshwater flow.
  - Freshwater withdrawals to support a growing population in the Tampa Bay area has reduced flow from groundwater springs and caused saltwater intrusion into groundwater (SWFWMD 2001).
- ***Invasive vegetation:*** Exotic plants, particularly *Schinus terebinthifolius* (Brazilian pepper) and *Casuarinas* sp. (Australian pine) crowd the edges of coastal wetland habitat.
- ***Mangrove trimming:*** Top-down trimming, or hedging, remains popular to maintain water front views and is not always trimmed following regulations (Figure 4c).
- ***Mangrove encroachment:*** The extent of mangrove swamps is increasing both landward and northward, often encroaching onto salt marsh habitat (Clewell et al. 2001, Stevens et al. 2006). Landward migration of coastal vegetation is also encroaching into upland forests and oligohaline wetlands that cannot tolerate salinity.

Figure 4a. Peat accumulation may or may not keep pace with sea level rise

Figure 4b. Shoreline hardening restricts landward migration of vegetation and can pinch out coastal wetland habitat as sea levels rise.

Figure 4c. Illegal mangrove trimming in downtown St. Petersburg

Management Recommendations

Needs and recommendations for the improvement and protection of salt marshes and mangroves in the greater Tampa Bay region include the following:

- ***Consistent monitoring:*** Regular mapping and monitoring efforts and quantitative restoration targets are key components to regional planning. Methodologically-consistent, long-term data sets are needed for wetland extent and quality.
- ***Freshwater management:*** Watershed and groundwater management is key to maintaining natural salinity levels and protecting coastal wetland habitat. Restoration priorities include reducing concentration of freshwater flow and restoring salinity gradients.
- ***Invasive vegetation:*** Active monitoring, early detection, and early removal is needed to prevent the spread of invasive vegetation.
- ***Tracking mangrove encroachment:*** Presence/absence monitoring techniques are necessary to track expansion of mangroves rather than traditional land cover categories which do not map individual trees.
- ***Preserve landward refuges:*** Land adjacent to coastal wetlands should be protected as refuges for landward migration in response to sea level rise. Sea walls and other hardened shorelines prevent landward migration, which will likely lead to the loss of mangrove fringes.
- ***Cooperation and coordination:*** Partnerships with private land owners are key to increasing protected lands due to the limited ability of public entities to acquire new land.

Acknowledgements

The authors wish to thank all CHIMMP coauthors and contributors, Amber Whittle (co-PI), Christi Santi for her GIS and mapping contributions, Kathleen O'Keife and Laura Yarbro for their guidance and recommendations, and Amanda Chappel, Ioana Bociu, Allie Wilcox, Joshua Michael, and Barbara Clark for their assistance with field work. Funding was provided by the US Fish & Wildlife Service's State Wildlife Grants Program (#F13AF00982).

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THE US CLEAN WATER ACT SECTIONS 316(A) AND (B). A BRIEF HISTORY OF THE RULES AND AN EXAMINATION OF AFFECTED FACILITIES AND RESOURCES IN TAMPA BAY AND THE GULF COAST

Brandon Johnson

ABSTRACT

Sections 316(a) and 316(b) of the Clean Water Act (CWA) establish regulations to address ecological impacts from the withdrawal [316(b)] and discharge [316(a)] from cooling water intake structures (CWIS) at industrial facilities. Established over 38 years ago, final implementation of these rules is just now being realized with the publication of the final 316(b) rule on August 15, 2014. These rules are administered through the National Pollutant Discharge Elimination System (NPDES) permitting process and aim to reduce the impacts from the impingement and entrainment of aquatic organisms and thermal impacts from heated water discharges. Provisions of the "new" 316 (b) rule indicate that these two regulations, which have traditionally been handled separately, may now need to be more closely addressed together. The Section 316 rules are meant to provide protections for all effected organisms (and habitats); however, language in the final 316(b) rule indicate a stronger emphasis on imperiled species, while long-established language in the 316(a) rule considers a "balanced indigenous population" as the primary metric.

Four facilities within Pinellas, Hillsborough, and Manatee Counties are subject to both of the Section 316 rules. These facilities are permitted to withdrawal and discharge a combined 6,160 million gallons per day (MGD) of Tampa Bay and Gulf waters. This talk will provide a brief history of the Section 316 rules, a primer on power plant CWIS and the nature of impacts they can have, and an assessment of how the final 316 rules may be implemented in Tampa Bay.

The US Clean Water Act Sections 316(a) and 316(b)

A brief history of the rules and an examination of affected facilities and resources in Tampa Bay

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Stantec

Abstract: Sections 316(a) and 316(b) of the Clean Water Act (CWA) establish regulations to address ecological impacts from the withdrawal [316(b)] and discharge [316(a)] of cooling water at industrial facilities. Established over 39 years ago, final implementation of these rules is just now being realized with the publication on August 15, 2014 of the final 316(b) Phase II rule for existing facilities. These rules are administered through the National Pollutant Discharge Elimination System (NPDES) permitting process and aim to reduce the impacts from the impingement and entrainment of aquatic organisms in cooling water intake structures (CWIS) and the thermal impacts from heated water discharges. Provisions of the final 316(b) rules indicate that these two regulations, which have traditionally been handled separately, may now need to be more closely addressed together. The Section 316 rules aim to provide protections for all affected organisms (and habitats); however, language in the final 316(b) rule indicate an emphasis on commercially and recreationally important and imperiled species, while long established language in the 316(a) rule considers a "balanced indigenous population" as the primary metric.

Three facilities in Tampa Bay are subject to both of the Section 316 rules. These facilities are permitted to withdraw and discharge a combined 3.2 billion gallons per day of Tampa Bay waters. Compliance options available to the Tampa Bay facilities as well as a brief history of the Section 316 rules and a primer on power plant CWIS operations and impacts are presented.

History of the 316 Rules

1972 - Clean Water Act
- Section 316 – design, location, construction and capacity for cooling water intake structures (CWIS)
- Section 402 – permitting process

316(b)

1976-EPA published first 316(b) guidance
- Rule was remanded in 1979

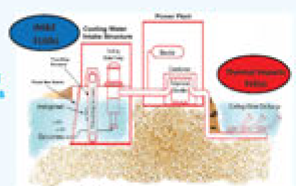
316(a)

- 1977 USEPA Interagency Guidance Document (Thermal Effects Sections of Nuclear Facilities EIA)
- 2008 USEPA Memo to Division of Water Directors, Regions 1-10

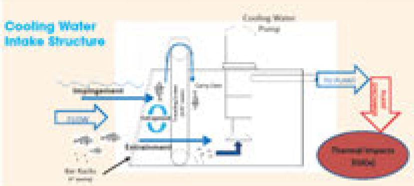
316(b)

- 2001 - New Facility Rule **(Phase I Rule)**
- 2004 - Larger Flow Existing Power Plants **(Phase II Rule)**
- 2006 - Low Flow Existing Power Plants, Existing Manufacturing Facilities, and New Offshore Oil and Gas Facilities (Phase III Rule)
- 2007 - EPA suspended provisions of the Phase II Rule
- 2010 - Remanded Phase III rule for existing facilities (power and industrial)
- 2011- Proposed new rules for all existing power facilities and industrial facilities
- 2014 - May 2014, Joint FWS-NMFS Biological Opinion, ESA Section 7 Consultation – October 14.
- **October 14, 2014 Final combined rule for All Existing Facilities—Final Phase II Rule**

Power Plant and CWIS Operations



Cooling Water Intake Structure



316(a) Thermal Variance

Definition
Intent of the rule
40 C.F.R. § 125, subpart H, authorizes the NPDES permitting authority [FDEP] to impose alternative effluent limitations for the control of the thermal component of a discharge in lieu of the effluent limits that would otherwise be required under sections 301 or 306 of the CWA.

1977 USEPA Draft Guidance Document
"Interagency 316(a) Technical Guidance Manual and Guide for Thermal Effects Sections of Nuclear Facilities Environmental Impact Statements"

Balanced Indigenous Community/ Balanced Indigenous Population
40 C.F.R. § 125.71(c): "A biotic community typically characterized by diversity, the capacity to sustain itself through cyclic seasonal changes, presence of necessary food chain species and by lack of domination by pollution tolerant species. May include historically non-native species and species whose presence or abundance results from substantial irreversible environmental modifications. Such a community will not include species whose presence or abundance is attributable to the introduction of pollutants that will be eliminated by compliance with Section 301(b)(2) of the Act; and may not include species whose presence or abundance is attributable to alternative effluent limitations imposed pursuant to Section 316(a).

Thermal Limits
Peninsular Florida, Coastal Limits:

Summer	Remainder
92° F Max	90° F Max
∆T> AM + 2°	∆T> AM + 4

Thermal Variance
Permittee must demonstrate that a thermal effluent limit necessary to meet the requirements of sections 301 or 306 is more stringent than necessary to assure the protection and propagation of a BIP

Demonstrations
In support of any proposed alternative thermal limit, the discharger must demonstrate that the alternative limit will **assure protection of the BIP**, considering the "cumulative impact of its thermal discharge together with all other significant impacts on the species affected."

Beneficial Thermal Considerations
Manatee Protection Plans
Winter thermal refuge

316(b) (Phase II-Existing Facilities)

Definition
Intent of the rule
That the location, design, construction, and capacity of the cooling water intake structures (CWIS) reflect the best technology available (BTA) to minimize adverse environmental impacts (i.e. to reduce impingement mortality and entrainment of aquatic organisms and ensure controls required by the rule are not likely to jeopardize the continued existence of T&E species or adversely modify critical habitat).

Direct impacts:
Impingement and Entrainment of fish, shellfish and other invertebrates, marine mammals, aquatic T&E species.

Indirect impacts:
Reduction of prey base, flow alterations, spawning/habitat loss (thermal impacts, seagrasses, corals, thermal barriers in rivers).

Who is subject to the rule?
- Point source discharge (NPDES Permit)
- Withdraw water from "Waters of the US"
- 25% withdrawn exclusively for cooling water
- Design Intake Flow (DIF) >2 million gallons/day (mgd); additional requirements if DIF>125 mgd

EPA has identified that 1,260 existing facilities are in scope with the final rule:
- 670 Electric generators
- 590 Manufacturers

316 (a) and (b) in Tampa Bay

Tampa Bay Facilities > 125mgd
Duke Energy Florida Bartow Plant
TECO Big Bend Station
TECO Bayside Station

Resource concerns
- Impingement and Entrainment Recreational/Commercial Important
- Seagrass
- T&E (recovery range, manatees)

Stressors
- Population growth (electricity demand)
- Climate change/warming (electricity demand)
- Sea Level Rise (CWIS resilience/efficiency)

316(b) Reporting Requirements

2mgd < DIF < 125mgd

Source Water Physical Data - §122.21(r)(2)
hydrological, chemical, geomorphological, etc.
-CWIS area of influence

Cooling Water Intake Structure Data - §122.21(r)(3)
-water balance and operations

Source Water Baseline Biological Characterization - §122.21(r)(4)
-Description of biological community (including protected species)
-Seasonal and temporal patterns

Cooling Water System Data - §122.21(r)(5)
-Proportionate water use

Chosen Method of Impingement Compliance - §122.21(r)(6)
7 options

Entrainment Performance Studies - §122.21(r)(7)
-Historical entrainment monitoring

Operational Status - §122.21(r)(8)

DIF > 125mgd

Entrainment Characterization Study - §122.21(r)(9)
2 years

Comprehensive Technical Feasibility and Cost Evaluation - §122.21(r)(10)
Cooling towers, fine mesh screens, and water reuse alternatives

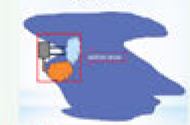
Benefits Valuation Study - §122.21(r)(11)
-Describe water quality and resource benefits (Monetized and non-monetized)

Non-Water Quality Environmental and Other Impacts Assessment - §122.21(r)(12)
Social and economic (air, energy consumption, public health, noise, safety)

Peer Review - §122.21(r)(13)
-Peer review of items 10, 11, and 12
-Input from USFWS/NMFS and state agencies

ESA Aspects of the Rule

Action Area



Endangered Species Act Considerations (T&E Species)

To protect federally-listed T&E species and designated critical habitat, the Director [FDEP] may require:
- additional control measures,
- monitoring requirements, and
- reporting requirements.

FWS and NMFS have two opportunities to review and comment in the permitting process
- Permit Application

60 days before a draft permit can be issued
- Draft Permit

60 days after the permit is issued (to verify comments were incorporated)

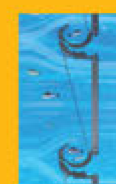
Impacts to ALL federally-listed T&E species are considered (not just fish and shellfish)
Director may consider state-listed species
Candidate and Proposed species (5-year permitting cycle)

EPA estimates that 94% of potentially regulated facilities overlap with listed species.

Impingement Mortality Compliance Alternatives (§125.94(c))

All Existing Facilities must meet one of the following compliance options:

1. Operate a closed-cycle recirculating system as defined at § 125.92
2. Operate a cooling water intake structure that has a maximum through-screen design intake velocity of 0.5 fps
3. Operate a cooling water intake structure that has a maximum through-screen intake velocity of 0.5 fps
4. Operate an offshore velocity cap as defined at § 125.92 that is installed before October 14, 2014
5. Operate a modified traveling screen that the Director determines meets the definition of §125.92(s) and that the Director determines is the best technology available for impingement reduction
6. Operate any other combination of technologies, management practices and operational measures that the Director determines is the best technology available for impingement reduction
7. Achieve the specified impingement mortality performance standard



Tampa Bay Power Generation Facilities

Facility Name	Generating Capacity (megawatts)	Annual Estimated Utilization	DIF (mgd)	CWIS	IM&E Reduction Technologies	Thermal Reduction Technologies	Thermal Variance	Impingement*: Estimated Flow-Adjusted Impingement Rates	Impingement*: Intake Density vs. Nearfield	Impingement*: # of Taxa / Dominant Species	Entrainment*: Estimated Flow-Adjusted Entrainment Rates	Entrainment*: Intake Density vs. Nearfield	Entrainment*: Dominant Species	T&E Considerations
Duke Energy Bartow Plant	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	Designated Manatee Refuge Manatee Protection Plan
TECO Big Bend Power Station	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TECO Bayside Power Station	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Manatee Protection Plan

[illegible]

References

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FIX ‘IN A HOLE: POST-RESTORATION RECOVERY OF THE BENTHIC MACROFAUNAL COMMUNITY AT THE FILLED MCKAY BAY DREDGE HOLE

David J. Karlen, Kris A. Kaufman, Thomas L. Dix, Kevin W. Campbell and Joette M. Jernigan

ABSTRACT

Dredge holes are submerged borrow pits left when sediments are dredged to provide fill for construction projects. The Tampa Bay Estuary Program conducted a study evaluating the habitat quality and restoration potential of dredge holes in Tampa Bay in 2003 and ranked the McKay Bay dredge hole as the worst in terms of poor water and sediment quality and a degraded benthic community. The study made the recommendation that this dredge hole should be filled to the surrounding depth in order to eliminate hypoxic conditions and allow for the establishment of a healthy benthic community. The Southwest Florida Water Management District provided funding for filling the dredge hole using material provided by Port Tampa Bay from the dredging of a new berth and a mitigation project on the McKay Bay peninsula. The Environmental Protection Commission of Hillsborough County conducted pre- and post- restoration benthic monitoring to evaluate the success of the project. A total of 30 sites were sampled in August 2011 prior to restoration and resampled in May 2014 approximately 1 year after the dredge hole was filled. Fifteen sites were within the dredge hole and 15 sites were located outside of the dredge hole as controls. Post-restoration results found improvements in bottom dissolved oxygen within the restored areas and increases in benthic species richness, abundance and a higher Benthic Index Score. Benthic species composition was also more similar between the dredge hole and control sites indicating the dredge hole filling was successful in restoring the benthic community.

Fix'n a Hole: Post-Restoration Recovery of the Benthic Macrofaunal Community at the Filled McKay Bay Dredge Hole

David J. Karlen[1], Kris A. Kaufman[2], Thomas L. Dix[1], Kevin W. Campbell[1], Joette M. Jernigan[1]

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Introduction

Dredge holes are submerged depressions caused by the removal of sediments to provide fill for construction projects or to create navigation channels. These deep borrow pits typically have poor water and sediment quality and are characterized by a stratified water column, bottom hypoxia, and accumulation of silty sediments. These conditions can lead to impoverished benthic communities (Vose et al. 2005; Palmer et al. 2008; Reine et al 2013b; Kotwicki et al. 2015) however, some dredge holes may provide bottom relief which can attract fish (Vose et al. 2005; Reine et. al. 2013b). Dredge holes are restored by filling or partially filling with sediments w20hich has been shown to reduce water column stratification, improve bottom dissolved oxygen and increase species richness and abundance of the benthic community (Reine et al. 2013a & 2014). Restored dredge holes can also provide suitable substrate for the growth and recovery of seagrass beds (Dial and Deis 1986).

A previous study by the Tampa Bay Estuary Program ranked the McKay Bay dredge hole as the worst in terms of poor water and sediment quality, a degraded benthic community, and low utilization by fish. This study made the recommendation that this dredge hole should be filled to the surrounding depth in order to eliminate hypoxic conditions, cap potentially contaminated sediments, and allow for the establishment of a healthy benthic community. (Tampa Bay Dredged Hole Habitat Assessment Advisory Team, 2005; Grabe et al. 2005). Fill material from the dredging of a new berth in Port Tampa Bay and from a mitigation project on the McKay Bay peninsula was made available for the filling of a portion of the McKay Bay dredge hole (Swingle and Brice, 2011).

The Environmental Protection Commission of Hillsborough County was contracted by the Southwest Florida Water Management District to conduct pre- and post- restoration benthic monitoring for this project.

Materials and methods

The study employed a Before-After-Control-Impact (BACI) study design to assess the post-restoration recovery of the benthic infaunal community. A total of 30 locations were sampled in August 2011 (pre-restoration period) and resampled in May 2014 (post-restoration period) (Fig.1). Fifteen sites were within the dredge hole restoration area (dredge hole treatment) and 15 sites were located outside of the dredge hole restoration area (control treatment). Twenty-one of the 30 sites were selected from locations previously sampled by the EPCHC between 1999 – 2010 and provided baseline monitoring data in McKay Bay (Karlen et al., 2012). These sites were selected based on their similarity to the expected post-restoration depth of the dredge hole and the sediment composition of the fill material (Swingle and Brice 2011). The 21 sites included all 15 control sites and six of the dredge hole sites. An additional nine sites were added within the restoration area to give a total of 15 dredge hole sites to balance the sampling design.

Figure 1 . The McKay Bay dredge hole pre-restoration (left) and post-restoration (right) and sediment sampling sites.

Sediment samples for benthic macrofaunal community analysis and sediment composition were taken at each site using a Young-Modified Van Veen grab sampler (Young grab). A hydrographic profile was taken at each site using a Hydrolab® Quanta multi-probe sonde. Measurements were taken from the surface (0.1 meters) and bottom for temperature, salinity, pH, and dissolved oxygen (D.O.).

Results

Depths were significantly shallower at the control sites than at the dredge hole sites during the pre-restoration period but there was no significant difference between the control and dredge hole sites during the post-restoration period (Fig. 2A). Bottom water temperatures were significantly lower at both sites during the post-restoration period (Fig. 2B). The post-restoration bottom D.O. was significantly higher relative to the pre-restoration period for both treatments and there was no significant difference between the control and dredge hole sites during the post-restoration period (Fig. 2C). The %silt+clay was higher at the dredge hole site with no significant change between the pre and post-restoration periods (Fig 2D).

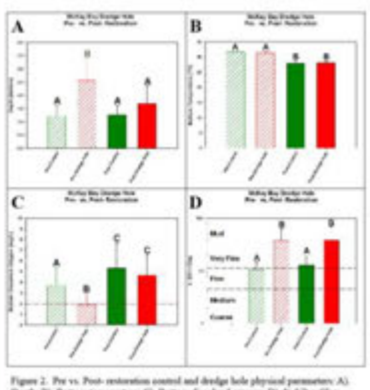

Figure 2. Pre vs. Post- restoration control and dredge hole physical parameters: A). Depth; B). Bottom temperature; C). Bottom dissolved oxygen; D). % Silt + Clay. Different letter designations reflect pair-wise statistical differences (p<0.05).

The number of benthic species increased during the post-restoration period at both the control and dredge hole sites but was still significantly higher at the control sites during both the pre- and post-restoration periods (Fig. 3A). Benthic abundance, Shannon diversity and the Tampa Bay Benthic Index also increased at the dredge hole sites during the post-restoration period and were not significantly different from the control sites during the post-restoration period (Figs. 3B-D).

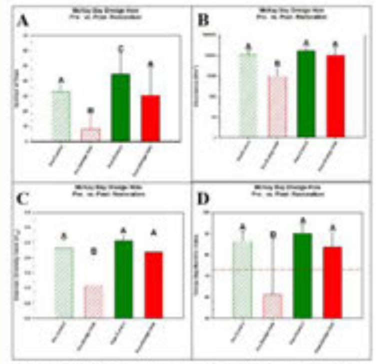

Figure 3. Pre vs. Post- restoration control and dredge hole biological parameters: A). Species richness; B). Abundance; C). Shannon Diversity Index; D). Tampa Bay Benthic Index. Different letter designations reflect pair-wise statistical differences (p<0.05).

The non-metric multidimensional scaling analysis (MDS) illustrates the shift in the benthic community structure from the pre-restoration to the post-restoration periods. Most of the pre-restoration dredge hole sites separate out from the other sites due largely to low numbers of taxa and abundances (Fig. 4). The control sites for both the pre- and post-restoration periods group together along with most of the post-restoration dredge hole sites. Within this grouping there is some separation between the pre- and post-restoration control samples, while there is more overlap among the post-restoration control and dredge hole sites indicating a greater similarity in their benthic community composition relative to the pre-restoration period.

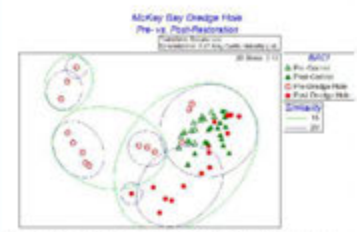

Figure 4. Non-metric Multidimensional Scaling (MDS) plot depicting benthic community similarity among pre-restoration (open symbols) and post-restoration (closed symbols), control (green triangles) and dredge hole (red circles) samples. Ellipses indicate Bray Curtis similarity index values of 15 (green) and 20 (blue).

Discussion and conclusions

The BACI monitoring design used in this study is useful in discriminating between seasonal effects and changes attributable to the restoration efforts. Seasonal effects were evident in the lower water temperatures and higher bottom salinity observed during the post-restoration period. The physical parameters which showed the greatest response to the restoration were depth and bottom dissolved oxygen while the % silt+clay showed no change between periods or treatments.

The benthic community measures were higher during the post-restoration period at both the control and dredge hole sites which implies that these increases were in part due to seasonal effects. The increases at the dredge hole sites however was much greater than at the control sites indicating that the restoration project did have a positive impact on the benthic community. The benthic community composition was more similar between the control and dredge hole sites during the post-restoration period than during the pre-restoration period which indicated the benthic community within the restoration area has improved after the dredge hole was filled.

The filling of the McKay Bay dredge hole was successful in reducing the depth and improving the bottom dissolved oxygen although the composition of the sediments has not changed. The benthic community within the restoration area indicated recovery as reflected by the increases in the biological metrics and the increase in the species similarity to the control sites. The restoration area, however, has not reached the same level of species richness as the surrounding control sites. It remains to be seen if the benthic community will continue to recruit more species for long term recovery. One recommendation would be to revisit the monitoring sites periodically in future years to assess the long-term recovery of a stable benthic community at the former dredge hole site.

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EVALUATION OF 40 YEAR WATER QUALITY TRENDS IN TAMPA BAY

David J. Karlen, Kevin W. Campbell, Thomas M. Ash

ABSTRACT

The Environmental Protection Commission of Hillsborough County (EPCHC) has been collecting monthly water samples and taking *in situ* field measurements at over 120 monitoring stations throughout Tampa Bay and the surrounding tributaries within Hillsborough County since the 1970s. During this time period, the water quality has shown dramatic improvements, particularly with decreases in chlorophyll a and fecal coliform, since the initiation of advanced wastewater treatment in the early 1980s. The data collected by the EPCHC surface water monitoring program has been instrumental to bay area managers in developing restoration strategies for Tampa Bay and documenting the success of the bay's recovery. A water quality index (WQI) specific to Tampa Bay's recovery targets has been developed as a simple method to evaluate the overall water quality condition and to provide an easy to interpret summary for the general public. The Tampa Bay WQI incorporates seven parameters including turbidity, Secchi depth, fecal coliform, chlorophyll a, total phosphorus, total nitrogen, and bottom dissolved oxygen and assigns a letter grade (A-F) and color code based on the percentage of parameters meeting their targets.. The letter grade and color scheme provide an easy to interpret visual presentation of spatial and temporal water quality trends in Tampa Bay.

Evaluation of 40 Year Water Quality Trends in Tampa Bay

David J. Karlen, Kevin W. Campbell, Thomas M. Ash
Environmental Protection Commission of Hillsborough County, 3629 Queen Palm Drive, Tampa, FL 33619.

Introduction

The Environmental Protection Commission of Hillsborough County (EPCHC) has been collecting monthly water samples and taking *in situ* field measurements at 52 stations within Tampa Bay (Fig. 1) and over 120 monthly monitoring stations throughout the surrounding tributaries within Hillsborough County since the 1970s. Tampa Bay water quality has shown dramatic improvements, particularly with decreases in chlorophyll a and fecal coliform, since the initiation of advanced wastewater treatment in the early 1980s. The data collected by the EPCHC has been instrumental to bay area managers in developing restoration strategies for Tampa Bay and documenting the success of the bay's recovery. A water quality index (WQI) specific to Tampa Bay's recovery targets has been developed as a simple method to evaluate the overall water quality condition. The Tampa Bay WQI incorporates seven parameters assigning a letter grade (A-F) and color code based on the percentage of parameters meeting their targets.. The letter grade and color scheme provide an easy to interpret visual presentation of spatial and temporal water quality trends in Tampa Bay.

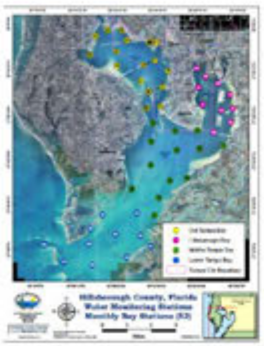

Figure 1 . EPCHC Tampa Bay surface water quality monitoring stations.

Materials and methods

Tampa Bay Water Quality Index (WQI)
Based on 7 parameters: Chl a; TN; TP; Bottom D.O.; Fecal Coliform; Secchi depth; Turbidity
Parameter targets
  State criteria (Water Class specific)
  TBEP targets (Bay segment specific)
  Calculated targets (historical mean; regression analysis)
Pass/Fail:
  Meets target = 1
  Does not meet target = 0

Water Quality Index calculation:
WQI = (mean of the 7 parameters) x 100
  Sample WQIs averaged by location and/or time period
Final Scale 0 – 100
WQI Report Card:
  A: WQI = 90 – 100
  B: WQI = 80 – 90
  C: WQI = 60 – 80
  D: WQI = 30 – 60
  F: WQI <30

Results

Chlorophyll a:
Tampa Bay
  TBEP Segment Targets
  (Janicki et al. 2000)
    HB = 13.2 µg/L
    OTB = 8.5 µg/L
    MTB = 7.4 µg/L
    LTB = 4.6 µg/L
Tributaries
  Estuarine = Bay Targets
  Freshwater = TSI
  (Paulic et al. 1996)
    20 µg/L
> =Fail (0); < = Pass (1)

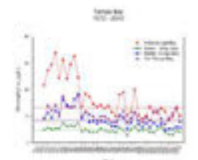

Figure 2. Tampa Bay mean annual chlorophyll a .

There was a decline in Chl a levels in the early 1980's which can be attributed to the conversion to advanced wastewater treatment. The individual bay segments have generally been at or below the target levels set by the TBEP since the late 1980s except for peaks during high rainfall years or algal bloom events (Fig. 2). Old Tampa Bay however has consistently failed to meet its targets and remains an area of concern.

Total Nitrogen:
TBEP Proposed targets
(Janicki Environmental 2010)
    HB = 1.02 mg/L
    OTB = 0.94 mg/L
    MTB = 0.88 mg/L
    LTB = 0.72 mg/L
  Freshwater = State NNC for West Central Florida
  (FDEP 2013)
    1.65 mg/L
> =Fail (0); < = Pass (1)

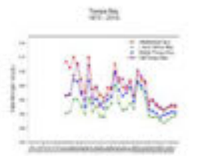

Figure 3. Tampa Bay mean annual total nitrogen.

Total nitrogen (TN) has generally been highest in Hillsborough Bay and between 1980-2000 bay-wide values show several peaks during high rainfall years (Fig. 3). Since 2000 TN values have been decreasing in all bay segments (Fig. 3)

Total Phosphorus:
  TBEP Proposed targets
  (Janicki Environmental 2010)
    HB = 0.45 mg/L
    OTB = 0.32 mg/L
    MTB = 0.29 mg/L
    LTB = 0.10 mg/L
  Freshwater = State NNC for West Central Florida
  (FDEP 2013)
    0.49 mg/L
  > =Fail (0); < = Pass (1)

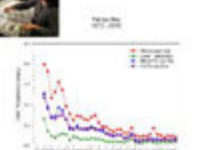

Figure 4. Tampa Bay mean annual total phosphorus.

Historic trends for total phosphorus (TP) show a decrease in all bay segments since the 1970's (Fig. 4) due to AWT and better regulation of the phosphate industry.

Bottom Dissolved Oxygen:
State Criteria
  Tampa Bay
    4 mg/L
  Tributaries
    Estuarine = 4 mg/L
    Freshwater = 5 mg/L
> =Pass (1); < = Fail (0)

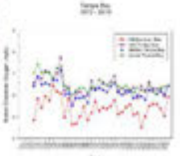

Figure 5. Tampa Bay mean annual bottom DO.

The average annual bottom DO trend in Tampa Bay also showed a drop in the early to mid-1980s (Fig. 5). Average annual bottom DO was above 4 mg/L in all bay segments, but Hillsborough Bay consistently had the lowest bottom DO across all years.

Fecal Coliform:
State Criteria
  400 cfu/100 ml
> =Fail (0); < = Pass (1)

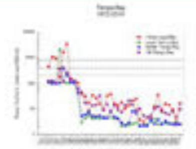

Figure 6. Tampa Bay mean annual fecal coliform.

Annual mean fecal coliform levels in Hillsborough Bay exceeded 800 cfu/100 ml. during the late 1970's, but dropped dramatically since then (Fig. 6). A similar drop was noted bay-wide and can be attributed to the implementation of AWT systems at regional sewage treatment plants during this time period.

Effective Light Penetration (Secchi depth):
TBEP Bay Targets
(Janicki et al. 2000)
  HB = 1.0 meter
  OTB = 1.8 meters
  MTB = 1.8 meters
  LTB = 2.9 meters
Freshwater
  Historical avg. 1974-2012
  0.77 meters
> =Pass (1); < = Fail (0)
Secchi > bottom = 1

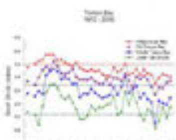

Figure 7. Tampa Bay mean annual Secchi depth. (note: reverse y axis scale)

Effective light penetration (Secchi depth) showed an overall increase since the late 1970's across all four bay segments (Fig. 7). The greatest improvements were seen in HB and MTB which have met or exceeded their TBEP targets for most years since the mid-1980's. OTB, however, consistently did not meet its target which may be due to higher chl a levels and nutrient loading in that part of Tampa Bay.

Turbidity:
  Calculated from Secchi depth targets
  Power function:
  NTU = 5.0941(secchi)$^{-0.756}$
  Turbidity Targets:
    HB = 5.0 NTU
    OTB & MTB = 3.3 NTU
    LTB = 2.3 NTU
    Freshwater = 6.2 NTU
  > =Fail (0); < = Pass (1)

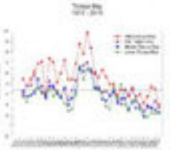

Figure 8. Tampa Bay mean annual turbidity.

There was a bay-wide trend of increasing turbidity through the late 1980's peaking in 1991, most notably in Hillsborough Bay (Fig. 8). Since then turbidity has decreased across all bay segments.

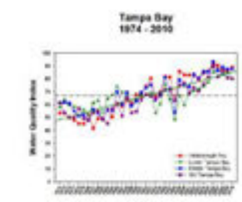

Figure 9. Tampa Bay mean annual WQI score by bay segment. Note green trend line indicating bay-wide WQI increase over time.

Historical trends in the WQI indicate improving water quality bay-wide and among the four bay segments over the past four decades (Fig. 9).

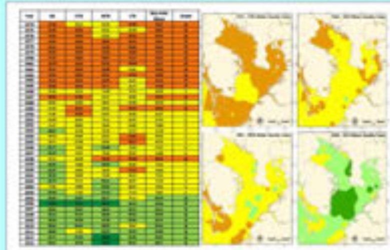

Figure 10. Tampa Bay annual WQI report card and 10 -year average spatial distribution maps.

The annual bay-wide WQI grades (Fig. 10) were consistently in the "D" range during the earlier years of the monitoring program (1974-1985). Water quality started to show improvements in the late 1980's and bay-wide WQI grades of "C" were seen annually from 1980 – 2004 with one exception (1998) due to high rainfall that year (Figs. 9 & 10). From 2005 – 2013 the bay-wide WQI grade has consistently been a "B", across most bay segments. The maps in Fig. 10 show the spatial improvements in the WQI over time.

Discussion and Conclusions

Water quality conditions in Tampa Bay have shown tremendous gains since the early 1970's. Challenges remain however despite the improvements seen over the last 40 years. Population growth and development continue to add stress to the Tampa Bay through increased stormwater runoff and nutrient loading. These effects have been seen especially in Old Tampa Bay which has experienced repeated blooms of the toxic dinoflagellate *Pyrodinium bahamense* since 2000. Climatic events, such as Hurricane Francis in 2004, can also have noticeable impacts on the bay water quality as can isolated industrial accidents and infrastructure failures.

The historical improvements to Tampa Bay's water quality can be attributed to several factors. The single event which has had the greatest impact has been the Grizzle-Figg Advanced Wastewater Treatment Act passed in 1978 and the subsequent upgrades to wastewater treatment facilities discharging into Tampa Bay. The positive effects of this legislation are reflected in the dramatic decreases in fecal coliform, nutrients and chlorophyll a concentrations observed through the 1980's in our monitoring data. Throughout this time the EPCHC monitoring program has been central for providing the data needed for making scientifically sound management decisions and tracking long term water quality improvements in Tampa Bay.

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EMERGING ISSUES, TECHNOLOGIES AND METHODS

THE POTENTIAL BIOTIC EFFECTS OF SEDIMENT CONTAMINANTS IN MCKAY BAY

Gerold Morrison and Ed Sherwood

ABSTRACT

McKay Bay has been subject to various anthropogenic discharges that have contributed to its existing sediment contamination. In 2009-2010 the area was sampled extensively to identify localized sediment contaminant "hot spots." Several contaminants of potential concern (COPCs) were identified, and approximately 300 acres of tidal flat sediments with active fish and wildlife use were identified as degraded based on observed contaminant levels. Nine sediment quality management areas (SQMA) were identified based on the types and concentrations of contaminants present. Some of the COPCs present in the bay (such as low molecular weight PAHs) have the potential to be acutely toxic to some resident organisms, while others (such as high molecular weight PAHs and organochlorine pesticides) have the potential to bioaccumulate and have impacts at higher levels of the food web. The current project was undertaken in 2013 to quantify the acute toxicity and bioaccumulation of sediment contaminants and provide information on their potential impacts on fish and invertebrates in the area. Ten-day laboratory bioassays were used to assess acute toxicity, and 28-day bioassays were used to assess potential bioaccumulation. In the 10-day tests significant acute toxicity was detected in sediment samples from three SQMAs. In the 28-day bioaccumulation test, two individual PAHs – the LMW acenaphthene and the HMW fluoranthene – were detected in test bivalve tissue at concentrations exceeding EPA Region 4 thresholds for potential ecological effects. Updated risk assessment information, and identification and control of active contaminant sources in the watershed, are potential next steps in the bay management process.

BACKGROUND

At the national level, among the major urban estuaries in the United States, Tampa Bay is one of the least contaminated (Long and Greening 1999, Long 2000). On the other hand, however, the U.S. Environmental Protection Agency (EPA) has identified Hillsborough Bay and Tampa Bay, along with 11 other bays and rivers, as water bodies "that appear to have the most significant sediment contamination in Region 4," the EPA region that covers the southeastern U.S. (EPA 2004).

McKay Bay is a highly urbanized embayment located in the northeastern portion of Tampa Bay, above the 22nd Street Causeway (see Figure 1 below). Unlike some nearby areas such as the Port of Tampa, East Bay and the Palm River that have been extensively dredged for commercial shipping and flood control purposes, much of McKay Bay consists of shallow, un-dredged mudflats surrounded by mangroves and salt marshes. During winter low tides the shallow flats in the upper portion of the bay provide feeding areas for thousands of migratory shorebirds, waterfowl and wading birds. Species found in the area in different seasons include American avocet, black-necked stilt, black skimmer, white pelican, northern shoveler, canvasback, green wing teal, ruddy duck and glossy ibis. A man-made cooling pond associated with a City of Tampa municipal waste incinerator provides freshwater habitats that compliment the estuarine mud flats of the bay. As a result the area serves as regionally important habitat for overwintering birds and for migratory species during the spring and fall migration periods (Parsons Engineering Sciences, Inc. [PES] 1998).

Although McKay Bay has experienced fewer anthropogenic modifications than nearby water bodies such as the Palm River and East Bay, historical patterns of urbanization, shoreline development, and channel dredging for flood control and commercial shipping purposes have significantly impacted its hydrologic, hydraulic, and water and sediment quality characteristics.

In 2007 the Tampa Bay Sediment Quality Assessment Group (SQAG), a subcommittee of the Tampa Bay Estuary Program (TBEP) Technical Advisory Committee, included McKay Bay as a priority sediment management area due to elevated levels of potentially toxic chemical contaminants. The Tampa Bay Comprehensive Conservation and Management Plan (TBEP 2006) seeks to identify and remediate priority areas containing elevated levels of potentially toxic sediment contaminants by developing and implementing site-specific action plans for contaminated areas on the priority list. Depending on conditions at a given site, the action plans are anticipated to include recommendations on pollution abatement and other source-control strategies and (if necessary and appropriate) sediment remediation actions.

Using grant funds provided by the Environmental Protection Commission of Hillsborough County (EPC), the Tampa Bay Environmental Fund and the National Fish and Wildlife Foundation, and building on earlier sediment chemistry and benthic community assessments provided by PES (1998) and others, a multi-agency working group carried out two sediment quality assessment projects in McKay Bay during 2009–2011 and 2012–2013. The first project quantified and mapped sediment contaminant levels and developed an initial sediment quality management action plan for the area (summarized by Morrison and Sherwood 2011). The second included laboratory-based acute toxicity and bioaccumulation tests, measurements of contaminant levels in the tissues of resident fish and invertebrates, and health assessments of resident fish species (summarized by Morrison and Sherwood 2014). The purpose of this paper is to give a brief overview of those projects. More detailed descriptions of project design, field and laboratory methods, and results and resource management recommendations are provided in the summary reports noted above and other references cited below.

IDENTIFYING CONTAMINANTS OF POTENTIAL CONCERN (COPCS) IN MCKAY BAY SEDIMENTS

Measurements of sediment contaminant concentrations in McKay Bay and other portions of Tampa Bay are available from a number of surveys and monitoring programs conducted during the past several decades, including:

- Metals data collected by Brooks and Doyle (1992) as part of a characterization of Tampa Bay sediments;

- Metals and organic chemicals data compiled for FDEP and TBEP by MacDonald (1994), MacDonald et al. (1996, 2002) and Zarbock et al. (1996) from multiple sediment quality studies;
- Metals and organics data collected by Long et al. (1994); and
- Metals and organics data collected by EPC to support the national Environmental Monitoring and Assessment Program and local monitoring efforts (e.g., Grabe et al. 1997, 1999; Karlen et al. 2008).

Through a series of projects funded by TBEP and the Southwest Florida Water Management District, sediment chemistry data from those surveys and other sources were analyzed and ecological and human health risk assessments were performed by McConnell et al. (1996), McConnell and Brink (1997) and PES (1998) to identify COPCs for McKay Bay and other segments of Tampa Bay. For risk assessment purposes, the McKay Bay area was divided into two zones:

- Upper McKay Bay, which as noted above contains large amounts of shallow-water mudflat, marsh and mangrove habitats and is a regionally-important feeding and resting area for resident, migratory and overwintering shorebirds; and
- The remainder of McKay Bay and adjacent East Bay (the waterbody located immediately down-estuary from the 22nd Street Causeway), which consist largely of deeper, open-water habitats.

The ecological risk assessment (PES 1998) focused on species at various trophic levels within the food web. Species potentially exposed directly to sediment contaminants included polychaetes and oysters (*Crassostrea virginica*), representing benthic deposit feeders and filter feeders, respectively. Fish species potentially exposed to sediment contaminants through ingestion of prey organisms included the spot (*Leiostomus xanthurus*) and the spotted seatrout (*Cynoscion nebulosus*), representing benthic and aquatic piscivores, respectively. Piscivorous bird species potentially exposed to sediment contaminants through ingestion of prey included the little blue heron (*Egretta caerulea*) and the osprey (*Pandion haliaelus*). One benthic omnivore, the blue crab (*Callinectes sapidus*), was selected to represent macroinvenebrates potentially exposed to sediment contaminants directly and through ingestion of food organisms.

Human health risks were evaluated to estimate the likelihood of adverse effects occurring as a result of exposure to noncarcinogenic and carcinogenic sediment contaminants through ingestion of contaminated fish or dermal contact. Ecological COPCs were identified based on a significant potential for ecological effects (hazard quotients greater than 10, 2 or more species affected at different levels, or potential effects by direct and/or food web exposure). Human health COPCs were identified based on a significant potential for human health effect (reasonable mean exposure excess cancer risk greater than 10^{-4}, central tendency excess cancer risk greater than 10^{-6}, or noncarcinogenic central tendency hazard quotient greater than 1)(PES 1998).

The COPCs identified in the sediment-chemistry-based risk assessments for the two areas fell into four general categories (metals, PAHs, PCBs and pesticides). Specific COPCs within each category are listed in Tables 1 and 2.

Table 1. Sediment COPCs in McKay Bay and East Bay based on human health risk assessment. (Source: PES 1998).

Area	COPC Category	COPC
Upper McKay Bay	High Molecular Weight PAHs	Benzo(α)anthracene Benzo(α)pyrene Benzo(α)fluoranthene Chrysene
Remainder of McKay Bay Plus East Bay	Pesticides	Aldrin Chlordane, total DDD DDE DDT Heptachlor Heptachlor epoxide Hexachlorobenzene Lindane
	PCBs	PCBs, total
	High Molecular Weight PAHs	Benzo(α)anthracene Benzo(α)pyrene Benzo(α)fluoranthene Chrysene

Table 2. Sediment COPCs in McKay Bay and East Bay based on ecological risk assessment. (Source: PES 1998).

Area	COPC Category	COPC
Upper McKay Bay	Low Molecular Weight PAHs	Phenanthrene LPAHs, total
	High Molecular Weight PAHs	Benzo(α)anthracene Benzo(α)pyrene Benzo(α)fluoranthene Chrysene Fluoranthene Pyrene HPAHs, total
	Metals	Cadmium Chromium Copper Lead Mercury Zinc Metals, total
Remainder of McKay Bay Plus East Bay	Pesticides	Chlordane, total DDD, total DDE, total DDT, total DDTs, total Endrin Heptachlor Heptachlor epoxide Hexachlorobenzene Lindane Pesticides, total
	PCBs	PCBs, total
	Low Molecular Weight PAHs	LPAHs, total
	High Molecular Weight PAHs	Benzo(α)anthracene Benzo(α)pyrene Benzo(α)fluoranthene Chrysene Fluoranthene Pyrene HPAHs, total
	Metals	Cadmium Chromium Lead Mercury Silver Metals, total

IDENTIFYING MCKAY BAY SEDIMENT QUALITY MANAGEMENT AREAS (SQMAS)

During the years 1993 through 2009, EPC conducted extensive sediment sampling in McKay Bay, using the methods summarized by Courtney et al. (1995), to provide information on the locations and concentrations of chemical contaminants. Sediment chemistry data from those surveys are summarized in Figure 1. The contaminant levels shown in Figure 1 are based on the number of exceedances of “threshold effects levels” (TELs) and “probable effects levels” (PELs) observed in the sediment chemistry data set. For a given chemical contaminant the TEL and PEL values, which were derived from an extensive database of laboratory toxicity studies (MacDonald 1994, MacDonald et al. 1996), can be used to identify three ranges of concentrations: a low range (below the TEL) within which the contaminant is unlikely to cause adverse biological effects; a middle range (between the TEL and PEL) within which adverse biological effects are possible; and an upper range (above the PEL) within which adverse biological effects are expected to occur.

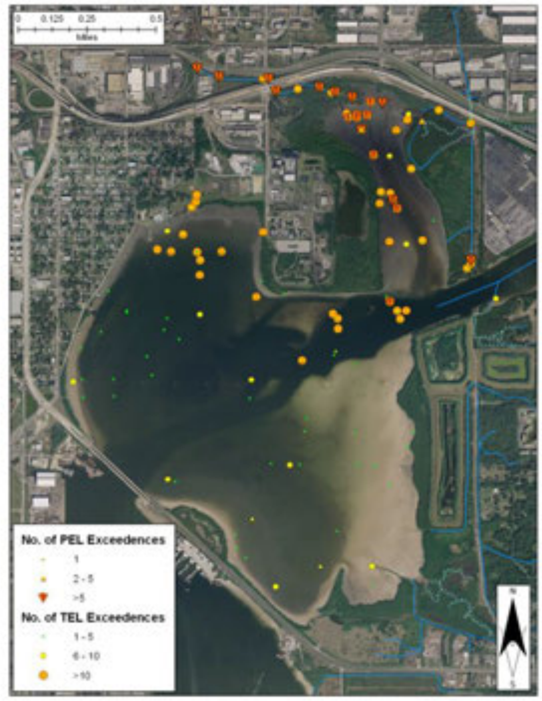
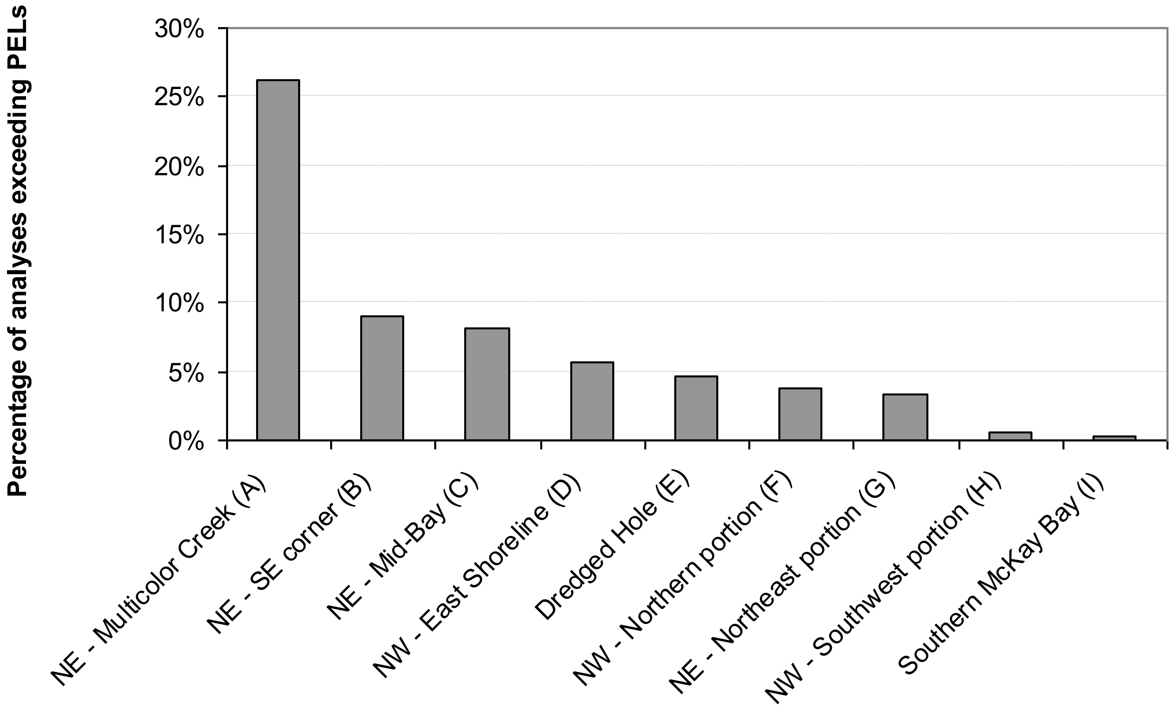


Figure 1. Locations of EPC sediment monitoring sites exhibiting TEL and PEL exceedances.
(Source: Morrison and Sherwood 2011)

Estimated volumes and depths of contaminated sediments in McKay Bay are shown in Figure 2. Given the PEL exceedances observed in the sediment chemistry data, approximately 46.2% of the surveyed sediments (about 1.2 million cubic yards) appeared to have a moderate-to-high probability of producing adverse impacts on the resident benthic biota (Morrison and Sherwood 2011).

Based on the locations of potential contaminant source areas, the spatial pattern of TEL and PEL exceedances (Figure 1), differences in the percentages of analyses in which TELs and/or PELs were exceeded (Figure 3), and differences in the types of contaminants causing the TEL and PEL exceedances (Table 3), nine relatively distinct sediment quality management areas (SQMAs) appear to be present in McKay Bay. The locations of those areas are shown in Figure 4 and the sediment contaminants that produced PEL and TEL exceedances in each area during the 1993 – 2009 sampling period are listed in Table 3.

Figure 2. Extent and calculated volumes of sediment contamination within McKay Bay.(Source: Morrison and Sherwood 2011)



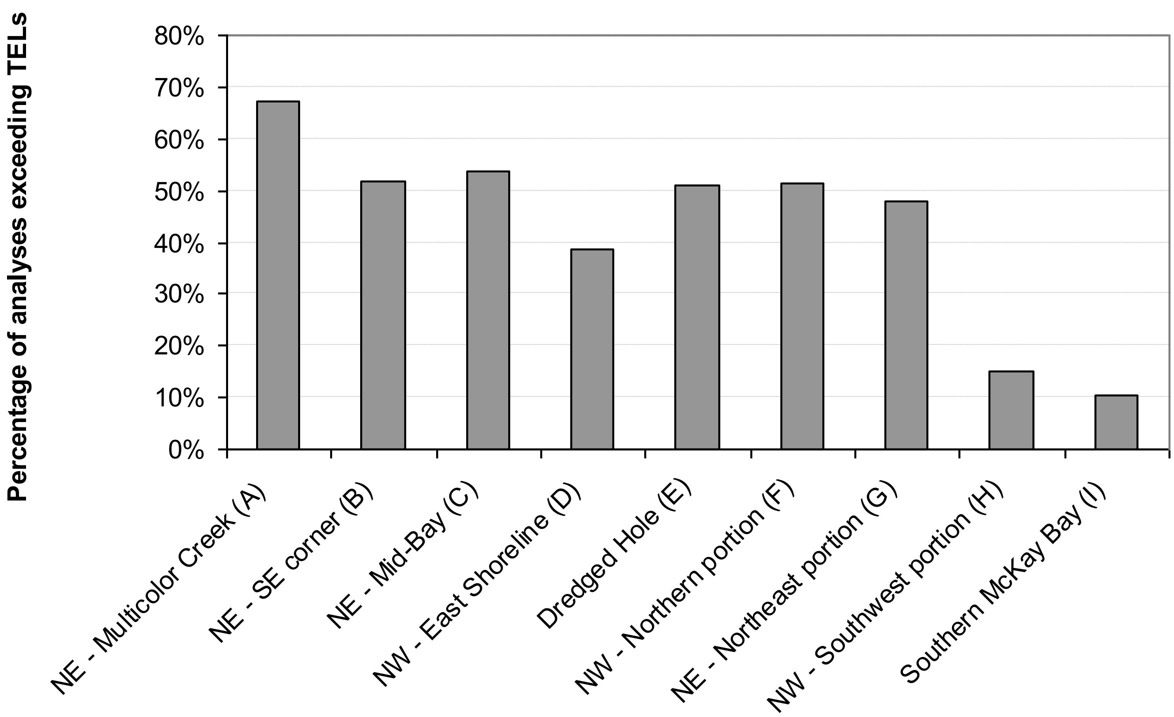


Figure 3. Percentages of samples exceeding TELs and PELs in the nine proposed sediment quality management areas during the 1993 – 2009 sampling period. (Source: Morrison and Sherwood 2011)

Table 3. Summary of TEL and PEL exceedances by sediment quality management area (SQMA) and parameter group. (Source: Morrison and Sherwood 2011)

Sediment Quality Management Area	Parameter Group	No. of TEL exceedances	No. of PEL exceedances
A	Metals	67	12
Multicolor Creek portion of	PAHS	274	131
NE McKay Bay	PCBS	6	0
	Pesticides	72	20
B	Metals	18	3
SE corner of	PAHS	47	11
NE McKay Bay	PCBS	2	0
	Pesticides	13	0
C	Metals	25	3
Mid portion of	PAHS	98	12
NE McKay Bay	PCBS	2	1
	Pesticides	33	8
D	Metals	8	0
East shoreline of	PAHS	29	1
NW McKay Bay	PCBS	0	0
	Pesticides	10	6
E	Metals	54	3
McKay Bay dredged hole	PAHS	111	8
	PCBS	3	1
	Pesticides	30	6
F	Metals	16	0
North-central portion of	PAHS	114	8
NW McKay Bay	PCBS	3	0
	Pesticides	18	3
G	Metals	19	1
NE portion of	PAHS	82	5
NE McKay Bay	PCBS	0	0
	Pesticides	15	2
H	Metals	26	0
SW portion of	PAHS	61	2
NW McKay Bay	PCBS	0	0
	Pesticides	8	2
I	Metals	59	0
Southern portion of	PAHS	54	0
McKay Bay	PCBS	1	0
	Pesticides	11	3

The SQMAs can be prioritized for management actions based on their magnitude (e.g., number of contaminants causing TEL and PEL exceedances, overall number of exceedances) and consistency (e.g., percentage of contaminant analyses exceeding TELs and PELs) of contamination (Morrison and Sherwood 2011). Using those criteria, the sites would be prioritized as follows:

- **Area A** – the "Multicolor Creek" portion of NE McKay Bay. Receives baseflow and stormwater discharges from a number of major stormwater outfalls (e.g., 29th, 34th, 37th, 39th and 43rd streets) draining a highly industrialized portion of East Tampa (PES 1998). Exhibits the largest number of contaminants producing PEL exceedances and the highest percentages of contaminant analyses producing TEL and PEL exceedances. Contaminants causing PEL exceedances include PAHs, metals and pesticides.
- **Area B** – a localized site located on a small tidal creek in the southeastern corner of NE McKay Bay that exhibits the second highest percentages of analyses with PEL exceedances and second highest number of contaminants causing PEL exceedances. Contaminants causing PEL exceedances include PAHs and metals. The hydrology of this site appears to require additional investigation to determine potential contaminant source areas.

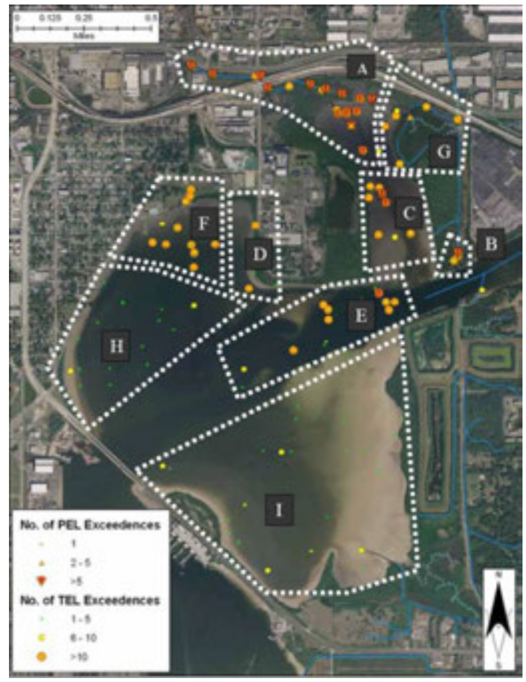


Figure 4. Locations of sediment quality management areas, prioritized (A = highest priority) on the basis of the number of PEL exceedances per sample. (Source: Morrison and Sherwood 2011)

- **Area C** – the mid-bay portion of NE McKay Bay, located immediately east of the manmade peninsula that houses the City of Tampa waste-to-energy facility. Similar to Area B in the percentages of analyses and number of contaminants exceeding PELs. Differs from Areas A and B in that it includes Dieldrin and total PCBs among the contaminants causing PEL exceedances.
- **Area D** – the eastern shoreline of NW McKay Bay, which appears to receive runoff from the western portion of the City of Tampa waste-to-energy facility. Pesticides (DDT, DDD, Dieldrin, Lindane and Chlordane) cause most (6 out of 7) of the PEL exceedances detected in this area.
- **Area E** – the McKay Bay dredged hole (TBEP 2005), which appears to receive stormwater discharges from the mid-bay peninsula and may also receive contaminants as a result of down-bay transport from Upper McKay Bay and the Palm River. Contaminants exceeding PELs in this area include (in descending numerical order) PAHs, pesticides, metals and total PCBs.

- **Area F** – the north-central portion of NW McKay Bay, which receives runoff from an area that includes DeSoto Park, Bermuda Boulevard and 34th Street South. PAHs (8 exceedances) and pesticides (3 exceedances) produced the 11 PEL exceedances detected in this area.
- **Area G** – the northeastern portion of NE McKay Bay, which receives runoff from a large urban stormwater outfall (43rd Street) monitored by PES (1998). This area is similar to Multicolor Creek (Area A) in terms of the mix of PAHs, metals and pesticides that cause PEL exceedances, but it exhibits a much smaller number of exceedances (Table 4) and a much lower percentage of analyses producing exceedances than the Multicolor Creek area.
- **Area H** – the southwestern portion of NW McKay Bay, which receives stormwater discharges from the Bermuda Boulevard area as well as possible down-bay transport of contaminants from areas D and F. PAHs and pesticides (but no metals) caused PEL exceedances in this area.
- **Area I** – the southern portion of McKay Bay, which receives stormwater discharges from an area between the southern portion of the 22nd Street Causeway and South 50th Street. This area has the least heavily urbanized watershed of the nine SQMAs and exhibits the lowest number of PEL exceedances (one exceedance, for Lindane), and is therefore the lowest priority for management action.

EVALUATING ACUTE TOXICITY, BIOACCUMULATION AND FISH HEALTH

While sediment chemistry evaluations such as these provide helpful information for assessing the potential risks that contaminated sediments may pose for the resident biota and human consumers, other types of data are needed to confirm the results and provide multiple lines of evidence for assessing risks. Given the potential complexity and costs of sediment remediation efforts, it is important to provide a "weight of evidence that is proportional to the weight of the decisions" that may need to be made to manage contaminated sites (e.g., MacDonald et al. 2002, 2004).

MacDonald et al. (2002, 2004) developed an ecologically-based framework for assessing and managing contaminated sediments in Tampa Bay. For sites that are found to contain potentially toxic and/or bioaccumulative contaminants the framework recommends conducting additional investigations, including acute toxicity and bioaccumulation tests, assessing fish health, and quantifying tissue contaminant residue levels in sessile invertebrates and fish in the potentially impacted areas. Using that framework, a multi-agency project was undertaken in 2012 – 2013 to quantify the acute toxicity and bioaccumulation of sediment contaminants in McKay Bay and provide information on their potential impacts to the health of fish and invertebrates in the area. Acute toxicity was evaluated using laboratory bioassays, while bioaccumulation and organism health were assessed using a combination of bioassays and tissue analysis of fish and invertebrates collected in the bay (summarized by Morrison and Sherwood 2014). The conceptual site model used in designing the project is shown in Figure 5.

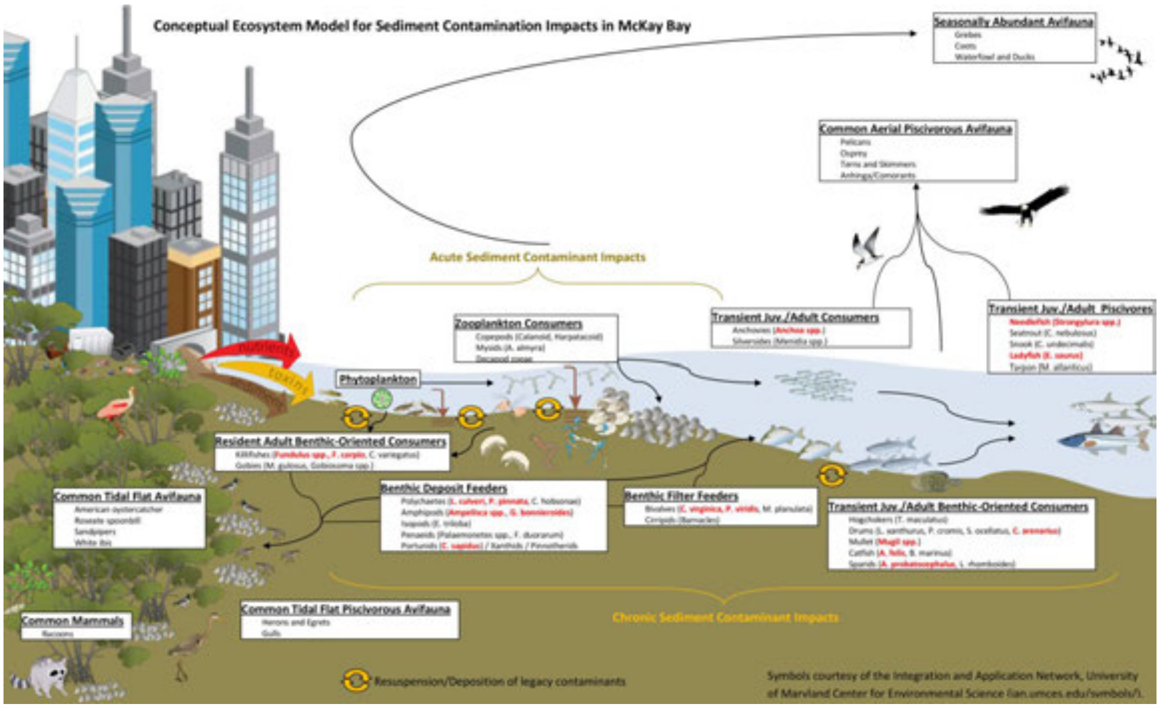


Figure 5. Conceptual ecosystem model of sediment contaminant impacts in McKay Bay. Highlighted species represent proposed trophic guilds targeted for sediment contaminant tissue sampling. (Source: Morrison and Sherwood 2014)

For the laboratory tests, sediment samples were collected from McKay Bay in April 2013 by EPC benthic monitoring staff following the agency's adopted SOPs (Courtney et al. 1995). Eight sampling locations were selected SQMAs A, B, C, D and F based on the presence and frequency of TEL exceedances in previous sediment chemistry studies. Samples from each site were composited to comprise approximately 10 gallons of test material per site. Acute toxicity (10-day) and bioaccumulation (28-day) tests were performed using SOPs developed by the U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (ACOE), as described in the agencies' joint guidance manual (EPA/ACOE 1991). For the 10-day acute toxicity bioassays, the sediment dwelling estuarine amphipod, *Ampelisca abdita,* and the epibenthic mysid shrimp, *Americamysis bahia*, were used as the test organisms. The bioaccumulation tests were conducted for 28 days, using a polychaete worm (*Nereis virens*) and a bivalve mollusk (*Macoma nasuta*).

As a cost-saving measure, laboratory analyses of tissue samples from the 28-day bioaccumuluation study were restricted to a subset of contaminants (e.g., organchlorine insecticides, PCBs and PAHs) that were identified as potential bioaccumulation risks in the sediment chemistry study discussed earlier. Detailed summaries of test methods and results are given in Morrison and Sherwood (2014).

In the 10-day acute toxicity bioassay, significant toxicity to *Americamysis bahia* (the epipenthic mysid shrimp) was detected in sediment samples from SQMAs A and B. Significant toxicity to *Ampelisca abdita* (the benthic estuarine amphipod) was detected in SQMAs A and C.

In the 28-day bioaccumulation test, a number of low molecular weight (LMW) and high molecular weight (HMW) PAHs were detected in test organism tissues at concentrations above laboratory reporting limits at most stations. Two individual PAHs – the LMW acenaphthene and the HMW fluoranthene – were detected in *Macoma nasuta* (bivalve) tissue at concentrations exceeding EPA Region 4 thresholds for ecological effects. The ecological non-specific effects (ENSE) threshold for acenapthene (7.3 µg/kg) was exceeded in a sample from SQMA F. The ENSE threshold for fluoranthene (8.6 µg/kg) was exceeded in each of the sampled areas except the one located in SQMA B. The ENSE thresholds are conservative values, defined by EPA/ACOE as "tissue concentrations of given compounds that are not expected to have unacceptable effects in marine organisms. They have been calculated based on (1) water quality criteria (WQC) for chronic effects in saltwater organisms and (2) the potential of the given compounds to accumulate in tissues of marine organisms once equilibrium is established between the concentration of the compound in water and the concentration of the compound in given species' tissues."

Total PAHs in both *Macoma* (bivalve) and *Nereis* (polychaete) tissue from the 28-day bioaccumulation test exceeded EPA carcinogen-based screening values (SVs) for human health effects among recreational and subsistence fishers at every McKay Bay station sampled. The screening values are defined by EPA as "concentrations of target analytes in fish or shellfish tissue that are of potential public health concern and that are used as threshold values against which levels of contamination in similar tissue collected from the ambient environment can be compared. Exceedance of these SVs should be taken as an indication that more intensive site-specific monitoring and/or evaluation of human health risk should be conducted".

To evaluate COPC levels in the resident biota, whole fish and selected invertebrates were collected by Florida Fish and Wildlife Conservation Commission (FWC) staff during fall (October 2012) and spring (April 2013) sampling events in McKay Bay. Whole fish representing the various trophic (feeding) guilds (e.g., *Fundulus* spp., *Anchoa mitchilli, Ariopsis felis, Strongylura* spp., *Mugil* spp.) were collected using various sampling gears (21.3-m and 160-m center bag seine, 7.1-m otter trawl, and trammel net), and transported to the FWC St. Petersburg laboratory for processing and analysis. Invertebrate collections consisted of *Callinectes sapidus, Palaemonetes* spp., and/or *Farfantepenaeus duorarum* or other benthic deposit feeders. Additional invertebrate collections were conducted by EPC benthic monitoring staff during a spring 2013 sampling event. Laboratory analyses of tissue samples from these collections included a broader range of contaminants than were covered in the analyses of the 28-day bioaccumulation study. To assess potential ecological and human health risks from bioaccumulative contaminants, measured tissue contaminant concentrations were compared to published "acceptable tissue level" (ATL), "critical tissue level" (CTL) and EPA "screening" values (EPA SV) provided by the Oregon Department of Environmental Quality (ODEQ 2007) and EPA (2000, 2008).

Whole-body contaminant concentrations in the sampled biota suggest that several COPCs may pose bioaccumulation risks. Total PCBs were present in several trophic guilds at levels with potential population-level effects on avifauna. Total DDTs were present at concentrations that raise concerns regarding potential individual and population-level effects on avifauna. Several metals (e.g., lead, mercury, and selenium) and pesticides (total chlordane and total DDT) were found at levels of potential concern for other marine-oriented species and populations. Two PAHs (acenaphthene and fluoranthene) exceeded EPA non-specific ecological effects thresholds in tissues from several trophic guilds.

With respect to potential human health effects of bioaccumulative contaminants, it should be noted that whole-body samples were utilized in this study. Edible tissues were included in the samples, but caution should be exercised in interpreting the results for potential human-health related impacts because other, nonedible tissues (e.g. fish livers, stomachs, vertebrae, etc.) were also included in the analyses. In addition, several sampled species and trophic guilds are not traditionally used for human consumption. Nonetheless, total PCBs, total PAHs, and several pesticides (e.g., dieldrin, total DDT and chlordane) were present in whole-body samples from several recreationally or commercially-targeted species (e.g. blue crabs, mullet, drums, and snook species) at concentrations that suggest potential health risks for recreational or subsistence fishers within McKay Bay. Several metals (e.g. arsenic, lead, mercury) were also found at sufficient whole-body tissue concentrations to potentially cause human-health related effects, primarily in subsistence fishers.

Fish for health assessments were captured by FWC staff in McKay Bay during the fall (October 2012) and spring (April 2013) seasons and grossly examined for the presence of any apparent external skin lesions (including e.g. nodules, ulcerative lesions). Fish were then graded (weight and total/standard length taken), necropsies conducted, and the liver tissue excised, grossly examined, and weighed. Health examinations were conducted on 200 common fish species representing the various trophic feeding guilds within McKay Bay between 2–4 October 2012 (n = 100) and 9–10 April 2013 (n = 100) (fall and spring sampling periods respectively). Although a small number of gross abnormalities were seen during both seasons, they were characterized by FWC staff as typical of those usually seen in the Hillsborough Bay region of Tampa Bay.

POTENTIAL NEXT STEPS

For SQMAs A, B and C, whose sediments produced significant acute toxicity in the 10-day bioassays, a key management action appears to be the identification and control of contaminant sources. Information that is available in agency databases and reports (e.g., from US EPA, FDEP, FDOT, and EPC) could serve as a starting point for identifying potential key sources. FDEP, for example, maintains records on various types of cleanup sites that are present in the watershed. An evaluation of the land use and regulatory compliance histories of these sites could potentially provide information that could be used to identify additional sites where cleanup activities may be needed. Targeted water quality monitoring of stormwater discharges and baseflows from watershed areas where land use history indicates a potential for significant soil/groundwater contamination could also be used as a source identification tool. Information provided by FDOT following extensive site evaluation and cleanup activities that were required on numerous parcels the agency acquired for a recent highway construction project in the McKay Bay watershed could be used to help design a targeted monitoring effort. Source control also appears to be an important management action for SQMAs D, E, F and G, which can be classified as moderately impacted based on the benthic community effects predicted by the available sediment chemistry data. And given the numerous screening level exceedances by bioaccumulative contaminants that were observed in each of the SQMAs evaluated in this study, in both the 28-day bioaccumulation bioassays and the fish and invertebrate tissue samples, it appears that source control of both acutely toxic and bioaccumulative compounds may be needed in much of the McKay Bay watershed.

Updated ecological and human health risk assessment information also appears needed for the entire McKay Bay area. The TBEP sediment management framework calls for screening level environmental and human health risk assessments when sediment chemistry data and/or acute toxicity tests indicate potentially significant risks of acute amphipod toxicity or benthic community impacts. SQMA A appears to reach these thresholds. The numerous exceedances of environmental and human health screening values by bioaccumulative contaminants in the 28-day bioassays and resident biota tissue samples further highlight the need for updated risk assessment information. Once the results of screening level assessments become available, additional decisions can be made regarding more detailed (e.g., baseline) risk assessments and other potential management actions that may be needed in certain SQMAs.

For SQMAs H and I, protection from future contamination appears to represent the most appropriate sediment management objective. Some of the management options that could be considered for these areas include:

- Conducting periodic chemical and biological monitoring to confirm that sediment quality conditions are not deteriorating over time, and evaluating the available data to identify any substances that pose potential concerns;
- Limiting physical disturbances (such as dredging) to maintain benthic productivity in the McKay Bay area; and
- Acquiring adjacent lands or securing conservation easements to limit the potential for future development of adjacent shoreline areas, particularly when such sediment management areas coincide with critical fish and wildlife habitats (e.g., sea grass beds, mangroves).

ACKNOWLEDGMENTS

This work was supported by grants from the Environmental Protection Commission of Hillsborough County, the National Fish and Wildlife Foundation and the Tampa Bay Environmental Fund. Project oversight and technical support (including collection and analysis of sediment, fish and invertebrate tissue and benthic community samples; assistance with the review, analysis and interpretation of project data; and the development of resource management recommendations) was provided by multi-organization project-specific working groups assembled by the Tampa Bay Estuary Program. Complete lists of working group members are too lengthy to include here, but are provided in the relevant TBEP technical reports. Sincere thanks to you all.

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HOW LOSING EGMONT KEY WILL IMPACT TIDES AND STORM SURGE IN TAMPA BAY

Steven D. Meyers, Mark E. Luther, Marius Ulm, Arne Arns, Thomas Wahl and Jurgen Jensen

ABSTRACT

The Egmont Key barrier island at the mouth of Tampa Bay is documented to be shrinking and, at current rate of loss, is projected to disappear within a few decades. A calibrated numerical circulation model (based on the Delft3D code) for Tampa Bay is run with realistic boundary and forcing conditions using present day bathymetry and coastline morphology. A second model run is performed assuming Egmont Key has completely eroded. The amplitude and phase of the dominant astronomical tides are calculated from the model water levels along with changes in these quantities due to the loss of Egmont Key. Similar calculations are being performed for tidal velocities as well as a large storm surge event during Hurricane Frances in 2004.

INTRODUCTION

The formation and evolution of barrier islands is generally a centennial to multi-centennial scale process that depends on local conditions such as sediment supply, tides and waves (Hayes, 1979; Hoyt, 1967; Oertel, 1985), though large atmospheric storms can generate significant changes in island morphology in hours (Houser et al., 2008; Morton and Asbury, 2003). These islands help protect mainland areas from damaging effects of surface waves from the open ocean through dissipation and reflection (Elgar et al., 1997; Elgar et al., 1994). Sea level rise brings the possibility of increased erosion of barrier islands (Dai et al., 2015; Gerald et al., 2006; Irish et al., 2010), and a resultant alteration of the hydrodynamics around the islands and in the inter-coastal region between the island and the mainland.

Here the focus is on the hydrodynamic effects of barrier island loss at the mouth of a large estuary off the coast of western Florida. See Davis and Barnard (2003) for a discussion of barrier island morphodynamics in this region. Specifically, the loss of Egmont Key (EK), situated at the mouth of Tampa Bay (TB) with its long axis orientated about parallel to the mouth (Fig. 1), is simulated using the Delft model (Elias et al., 2001) in the vertically-integrated mode. EK, about 3 km long, blocks a large fraction of the ~9 km mouth of TB, so the consequence of losing this barrier island is likely to be significant for the interior of the estuary. EK is known to be eroding, having lost about 40% of its above-water area in the last century (Stott and Davis, 2003) and is likely to continue eroding.

The numerical model is run with two different bathymetries, one with EK in its present day configuration and a second with EK completely removed. While the total erosion of EK is unlikely to occur in the next few decades this experiment helps reveal the protective value provided by EK to TB. This study is also illustrative for other estuaries with eroding barrier islands. The next section describes the numerical model used in the simulations, followed by the results and discussion sections.

METHODS

The TB circulation model is based on the Delft3D code calibrated to observed tidal forcings as described by Ulm et al. (2016). The model is run in the vertically integrated, two-dimensional mode. The horizontal cell sizes range from 40 m to 150 m. The grid begins approximately 15 km offshore of the western coast of FL and extends into the northern lobes of TB (Fig. 1). Surface wind stress is generated from the ERA-20C reanalysis data obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF). The large western boundary located in the Gulf of Mexico is forced by water levels obtained from another, Gulf-wide model. For a detailed description of the model setup see Ulm et al. (2016).

Bathymetry for the TB model is obtained from the hybrid topobathy dataset which provides elevation data across the TB region with 30 m grid spacing. These data are averaged within the (larger) model grid cells to obtain the depth associated with each grid cell. This provides the present day bathymetry used in the first model. For the second model the bathymetry is altered by setting the region of EK to 7 m depth, the nominal depth around the base of EK (Fig. 1).

Changes to the hydrodynamics within Tampa Bay induced by the loss of EK are examined by calculating the relative change in amplitude and phase of the dominant semi-diurnal (M2, amplitude ~16 cm) and diurnal (K1, amplitude ~15 cm) tides (Weisberg and Zheng, 2006), using the "t-tide" package (Pawlowicz et al., 2002). Model water level (elevation) and velocity are extracted for the month of March 2001, a time period of relatively light winds. The velocity is rotated to obtain the components along the local main bay axis (U) and transverse to that axis (V) which are analyzed separately.

RESULTS

The loss of EK results in a ~10% increase in the amplitude of the M2 elevation (Fig. 2). This increase begins on the western shore of EK in a line that extends from the north to the south of the island and extends into most of the model domain. The upper western lobe of the model (Old Tampa Bay, OTB) has amplitude changes < 5% north of the Gandy Bridge. The influence of the bridges on tidal propagation, particularly in OTB should be investigated further. These bridges are known to influence the subtidal circulation (Meyers et al., 2013) and residence time of the estuary (Meyers et al., 2016). The northeastern lobe, Hillsborough Bay (HB) does not have significant blockage by bridges and the change in M2 elevation is found throughout this region. Changes to the K1 elevation amplitude are < 5% throughout the model domain.

For both M2 and K1 the tidal velocity has a spatially complex adjustment to the loss of EK (Fig. 2). The axial component in the vicinity of EK, essentially east-west at this location, increases significantly on either side of the island, but decreases to the north and south. The maximum increase is more than 100% in the immediate vicinity of EK. This large increase is because in the present-day configuration the axial component in the vicinity of the island is very weak so any increase is relatively large. The decrease to the north and south is nominally 75% but varies over a wide range of values, with greater decrease closer to the island. These changes near EK are related to the interaction of the tidal currents, which are roughly axial at this location (Weisberg and Zheng, 2006), with the island, which forces their diversion around its perimeter. Removing EK eliminates this diversion yielding the large changes in tidal currents. However, away from the island the relative changes are very different. Specifically, amplitude changes associated with M2 are 5-10% and found throughout most of the TB domain including most of HB and portions of OTB. In contrast changes to the K1 velocity amplitude are <5 % thought most of the bay away from EK.

Changes to the transverse tidal velocity component are qualitatively similar to those for the axial component. In particular, the largest changes are found around EK, and changes associated with M2 penetrate through much of the estuary but changes associated with K1 are confined to the regions around EK. However, the structure of the changes around the island are different than those for the axial component. For both M2 and K1 the transverse component decreases to the east of the island. To the west of the island there are alternating regions of increasing and decreasing tidal amplitude.

Changes in the tidal phase are generally on the order of minutes throughout the estuary for both M2 and K1. The exception to this result is near EK where both positive and negative phase shifts of ~1 hr are found (not shown). Again, this is related to the diversion of tidal currents around the island.

The simulation period includes the year 2004. During September of that year three hurricanes passed near the Tampa Bay region. The largest of these was Hurricane Frances with peak winds ~23 m/s and total water levels of about 50-130 cm (Fig. 3). Removal of EK has relatively small effect on the water level across most of the bay with the exception of the northern region and in the vicinity of EK (Fig. 3). There is an increase of total water level of up to 5 cm near the city of Tampa.

DISCUSSION

The loss of Egmont Key has been shown to create changes to dominant tidal components around the island and, in the case of M2, throughout most of Tampa Bay. Changes to the amplitude of the elevation (water level) field associated with the M2 are fairly uniform. Changes to the tidal currents are much more complicated in their spatial structure, particularly in the vicinity of EK. This complicated response is likely due to the interaction of the EK and the tidal currents, which are roughly perpendicular to the main axis of the island. As they interact with the island topography the tidal currents are diverted around the perimeter of the island generating significant transverse velocity components similar to classic solutions of fluid flow around an obstacle (Prandtl, 1928). When the island is removed these diversion no longer exist and the flow is more nearly uniform and axial as it flows through the now open mouth of TB. Further work is needed to examine the details of the results presented here. Of special note is the asymmetrical response of the M2 and K1 tides to the loss of EK.

There is a protective effect of the barrier island against storm surge, which is highly variable around the shoreline due to variations in bottom bathymetry and coastline morphology. In some locations the protective effect is negligible, in others it is significant. Whether this result is specific to Hurricane Frances or is more general requires further study.

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Figures

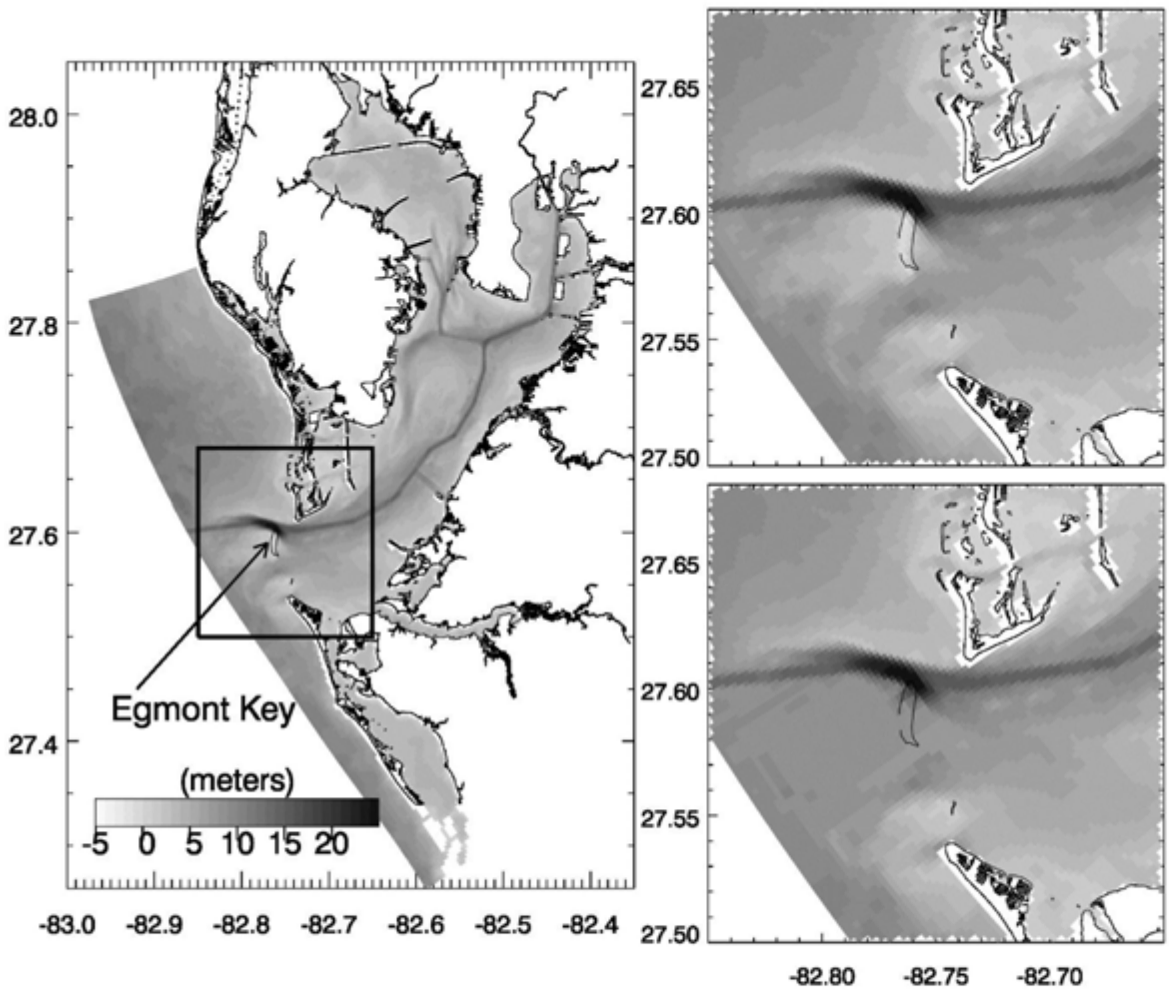

Figure 1. Model bathymetry. (left) The model domain, excluding the westernmost region. Egmont Key is indicated. Shading represents depth relative to mean sea level. The square indicates zoomed region to right. (right upper) zoomed region, bathymetry includes EK. (left upper) bathymetry without EK.

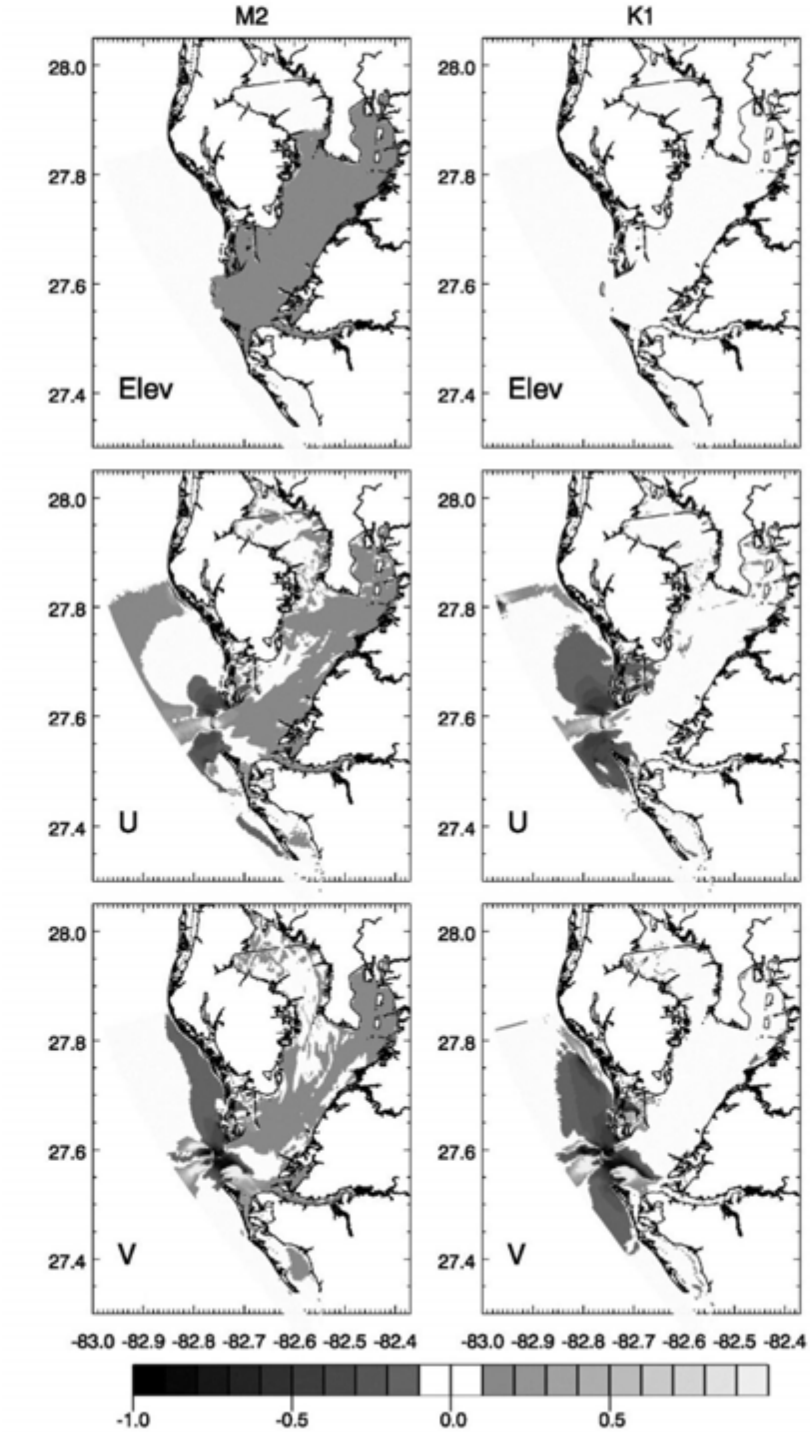

Figure 2. Relative change in amplitude of tide over model domain. Columns are tidal constituents M2 and K1 as indicated. Variables are elevation (Elev), axial velocity (U) and transverse velocity (V) as indicated. Relative changes of < 5% are not indicated.

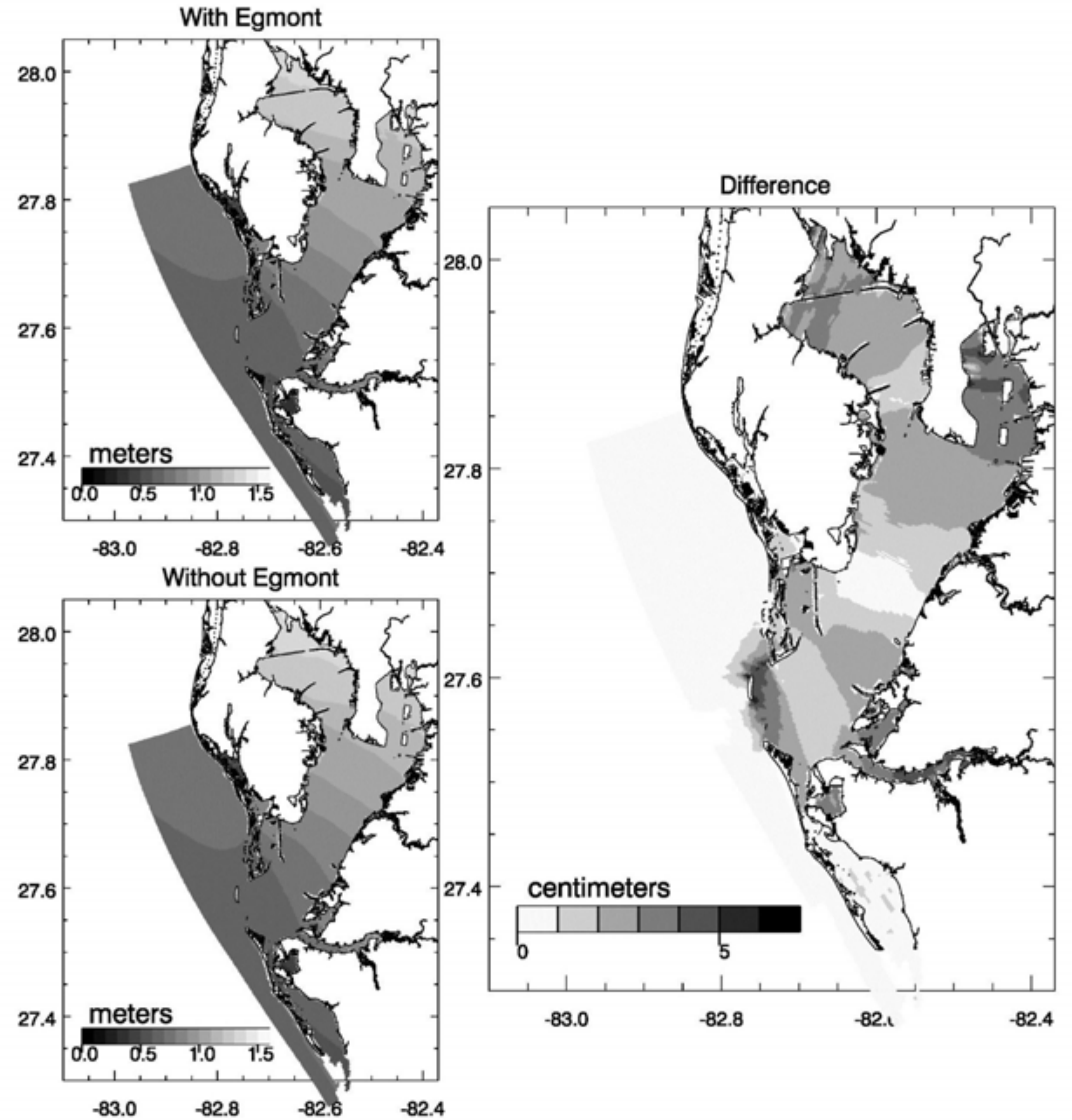

Figure 23. Maximum water level during Hurricane Frances and the difference between model runs.

MICROPLASTICS IN TAMPA BAY: ABUNDANCE, SPATIAL AND TEMPORAL VARIABILITY

David Hastings, Scott Adams, Breege Boyer, Holly Buresh, Bradford Cederburg, Alice Frye, Connor Gallagher, Kristina Petraites, Cameron Raguse and Emily Smith

ABSTRACT

The discovery of ubiquitous microplastics in our oceans and waterways has highlighted plastic waste as a significant threat to estuarine health. Microplastics result from the breakdown of larger plastics and fishing line, from laundry lint or plastic microbeads added to cosmetics. Some marine species consume these microplastics, which can cause digestive blockages and accumulation of toxic chemicals absorbed by the plastic. A unique microbial assemblage is associated with the plastic surfaces. We have sampled microplastics for the past three years in Tampa Bay using two different methods. Our primary approach was to collect discrete water samples, filter through 0.45µm filters and count microplastics under a dissecting microscope. For comparison, we identified particles collected in a 220µm plankton net towed at 1-2m depth, a method frequently used in other studies. The primary type of particle we identified were plastic fibers, 1-5mm long. Spherical beads from 100-500µm were also identified, but were much less common. Both types are distinctive and recognized by their coloration and shape, unlike any natural marine particle. The abundance of microplastics varied considerably in Tampa Bay from 10-72 particles/L using the first method. Sampling with the plankton net resulted in lower abundances, ranging from 0.02 to 1.6 particles/L. In general, the lowest values were at the mouth of Tampa Bay, near Egmont Channel with higher values in Middle Tampa Bay. We compare values for Tampa Bay with those of the Jiulong Estuary, Fujan Province, China. We will continue to monitor microplastics in Tampa Bay to constrain temporal changes.

PHYSICAL MONITORING OF VARIOUS BEACH NOURISHMENTMETHODS ON EGMONT KEY, FLORIDA BEACH

Zachary Tyler and Ping Wang

ABSTRACT

Nourishment of the highly eroded northern and western portions of Egmont Key, Florida occurred from November 2014 to March 2015. The nourishment material was obtained from the dredging of Tampa Harbor's navigation channel entrance. These beneficial use nourishments were permitted to place material with in situ fines content (material passing the 230 sieve) of 20.7%. Two placement methods were utilized: a traditional methodology on the northern portion of the island, and an experimental "cross shore swash zone placement" method on the south-western portion. Pre and post construction monitoring of both nourishments has been conducted by the Coastal Research Laboratory at the University of South Florida. In addition, beach changes have been monitored since August 2012, two years prior to this most recent nourishment. Twenty- seven beach profile transects have been measured monthly since construction of the nourishments. Profiles extend from the dune field to approximately 3 meters water depth. Sediment cores were procured from the navigation channel margins and characterized. Beach and nearshore surficial and core sediment samples have been collected and analyzed pre and post construction. High resolution UAV aerial imagery has been collected during all phases of the nourishment. Aerial LiDAR imagery from 2013 and 2015 has been collected and analyzed. Morphological and sedimentological analyses of both nourishments allowed for the comparison of the performance of each nourishment. An examination of the fate of the fine grained material placed on the beach indicates that initially the fine grained materials are deposited in relatively large volumes in the nearshore. Subsequently energetic wave and tidal action transported and deposited the fine grained material out of the nearshore zone.

BREAKWATERS TO PROTECT ERODING ISLANDS AND CONSERVE LIVING SHORELINES

Mark Rachal and Ann Paul

ABSTRACT

Waves and wakes generated by sea level rise and increases in the amount of commercial ship and recreational boat traffic and the size of ship vessels threaten nesting bird islands in the Tampa Bay area. Breakwaters of various size and configurations installed to dissipate on-shore wave and wake energy provide a near-shore quiet water "lagoon" and protect shoreline habitats important to wildlife, including nesting birds. Design of breakwaters should consider site-specific shoreline configurations, on-shore wave energy components, and cost of the breakwater installation. We will discuss breakwater design, installation and effectiveness. Additional habitat benefits of breakwater installation include oyster attachment substrate, in-water reef habitat for small fish and bird foraging sites.

HYPERSPECTRAL IMAGING AS AN INDICATOR TOOL FOR RESTORATION SUCCESS

Alissa Powers, Kathleen Barrett, Mitch Stack and Brian Ormiston

ABSTRACT

In an effort to better understand, quantify and document the real benefits of hydrologic restoration projects in east Manatee County, the County began a data intensive, three-year monitoring program. The protocol for this program aims to efficiently document changes in water storage, wetland acerage, as well as vegetative composition over a large area (i.e., greater than 23,000 acres). The primary tool for assessing the hydrologic restoration activities is an advanced remote sensing technique called Hyperspectral Imaging (HIS), which utilizes specialized spectral aerial imaging and mapping techniques, supported by on-the-ground field studies to obtain the soil moisture, wetland hydration and functional condition data. HIS is being used to extrapolate and map soil moisture and wetland hydration across the entire project area. Efforts to effectively evaluate restoration projects provide valuable information in support of current restoration methods and provide opportunities for adaptive management strategies in support of further success. As a result of the County's extensive restoration efforts on Duette Preserve, preliminary findings indicate that the designed restoration strategies are working. Wetlands are experiencing longer hydrologic regimes as a result of ditch blocking and filling. The data gathered is confirmation that the resources expended have fulfilled the desired outcome and that future funding of restoration in the watershed will continue to be beneficial to the drinking water supply.

ENVIRONMENTAL ASSESSMENT USING EMERGING TECHNOLOGIES: 21ST CENTURY ADVANCEMENTS FOR RESOURCE MANAGERS AND THE PUBLIC

Brad Weigle

ABSTRACT

New century advances in the acquisition and processing of aerial and terrestrial imagery, LiDAR, and satellite imagery along with ever increasing computer processing power and storage capabilities have stimulated development of mature automated analytical algorithms for classification, mapping, and quantitative inventory of our global environment, both on a local scale in high resolution and on a landscape scale. Since BASIS 5 in 2009, we have achieved what I once considered the holy grail of automated vegetation mapping: species identification, height and density measurements, and canopy coverage for a variety of natural and human-impacted landscapes using remote sensing. Visual (3D, 4D, & VR) immersion into the enhanced digital data is nearly mature as geospatial software and hardware providers move their focus to the consumer market. This presentation will demonstrate currently available geospatial analytical and visualization technologies and discuss monitoring and analyzing the earth's environment utilizing remote sensing and GIS technologies over the next decade.

EVALUATING NEW SOLUTIONS TO PERSISTENT PROBLEMS IN HABITAT RESTORATION

Stephanie Powers

ABSTRACT

The Southwest Florida Water Management District (District) has completed over 60 habitat restoration projects in Tampa Bay, many with several phases of work. New techniques to conquer old and ongoing problems are constantly being evaluated. In 2004, the District employed the use of hydroblasting, or hydroleveling, to eliminate spoil mounds and their associated exotic vegetation in mangrove ecosystems, limiting collateral damage normally experienced with this activity. Ten years post-construction, the District has completed a monitoring exercise to evaluate the efficacy of this technique. Additionally, the use of remote sensing has been explored to provide an inexpensive, efficient method of monitoring habitats, such as mangrove systems, on sites that are too large or inaccessible for on-the-ground methodologies. Results from these approaches will be presented.

IMPROVED COASTAL WETLAND MAPPING USING VERY-HIGH SPATIAL RESOLUTION IMAGERY

Matthew J. McCarthy

ABSTRACT

Accurate wetland maps are a fundamental requirement for land use management and for wetland restoration planning. Several wetland map products are available today; most of them based on remote sensing images, but their different data sources and mapping methods lead to substantially different estimations of wetland location and extent. We used two very high-resolution (2 m) WorldView-2 satellite images and one (30 m) Landsat 8 Operational Land Imager (OLI) image to assess wetland coverage in two coastal areas of Tampa Bay (Florida): Fort De Soto State Park and Weedon Island Preserve. An initial unsupervised classification derived from WorldView-2 was more accurate at identifying wetlands based on ground truth data collected in the field than the classification derived from Landsat 8 OLI (82% vs. 46% accuracy). The WorldView-2 data was then used to define the parameters of a simple and efficient decision tree with four nodes for a more exacting classification. The criteria for the decision tree were derived by extracting radiance spectra at 1,500 separate pixels from the WorldView-2 data within field-validated regions. Results for both study areas showed high accuracy in both wetland (82% at Fort De Soto State Park, and 94% at Weedon Island Preserve) and non-wetland vegetation classes (90% and 83%, respectively). Historical, published land-use maps overestimate wetland surface cover by factors of 2-10 in the study areas. The proposed methods improve speed and efficiency of wetland map production, allow semi-annual monitoring through repeat satellite passes, and improve the accuracy and precision with which wetlands are identified.

Improved Coastal Wetland Mapping Using Very-High Spatial Resolution Imagery

Matthew J. McCarthy[a], Elizabeth J. Merton[b], Frank E. Muller-Karger[a]

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Background

- Wetlands provide billions of dollars worth of ecosystem services including
  - Fishery nurseries
  - Flood protection
  - Coastal erosion mitigation
  - Water pollution control
  - Tourism (Dahl & Stedman 2013; Ozesmi & Bauer 2002; Turner & Gannon 2014)
- Nevertheless, development and pollution caused the areal extent of wetlands to decline rapidly in the 20th century (Dahl & Stedman 2013; Raabe et al. 2012).
- This has led to important restoration efforts in the U.S. and elsewhere, which may conserve habitat biodiversity, and ecosystem services and goods (Ozesmi & Bauer 2002; Rains et al. 2012).
- Accurate, updated wetland maps are vital to efficient monitoring and restoration efforts.
- Many organizations map wetlands, but their approaches differ in terms of:
  - Imagery type (e.g. aerial photograph vs satellite image)
  - Spatial Resolution
  - Wetland definition (e.g. saltmarsh vs mangrove vs aquatic vegetation
  - Mapping method (e.g. manual digitization vs automated classification)
- The result is a variety of "wetland" maps with substantial differences such as these:

Figure 1. Wetlands (red) in Fort De Soto Park in Tampa Bay as mapped by (left) NOAA Coastal Change Analysis Program (C-CAP) 2010, (center) Southwest Florida Water Management District (SWFWMD) 2011, (right) National Wetland Inventory (NWI) 2009

- The primary objective of this study was to develop a simple and robust methodology for improving wetland mapping accuracy and precision.

Data

- Study Areas
  - Fort De Soto State Park (Fig 2)
  - Weedon Island Preserve (Fig 2)

Figure 2. Study areas: Fort De Soto (red), Weedon Island (green).

- Satellite Imagery
  - Two recent satellite sensors were compared for wetland mapping capabilities:
    - WorldView-2
      - Spatial Resolution: 2 meters
      - Spectral Bands: 8
    - Landsat 8 OLI
      - Spatial Resolution: 30 meters
      - Spectral Bands: 9

Methods

- Field Survey
  - Ground control points were collected in each study area with a high-resolution Trimble GeoExplorer GPS unit
    - 55 points in Fort De Soto
    - 52 points in Weedon Island
- Image Pre-processing
  - Satellite images were radiometrically calibrated to radiance values in ENVI (v 5.0)
  - Research shows that this approach maintains higher signal-to-noise ratios as compared with more intensive atmospheric correction methods (Harris 2012)
- Unsupervised Classification
  - ISODATA classifications were run on one WV2 image and one L58 image over Fort De Soto to determine which could better identify wetlands
  - Field survey data was used to assess each for accuracy
- Decision Tree
  - A Decision Tree is a hierarchical, multi-stage classifier that is fast and efficient.
  - The Decision Tree was developed based on 1,500 spectral profiles of wetland (720 profiles) and upland (780 profiles) vegetation in order to distinguish accurately between the two
- Accuracy Assessment
  - After the Decision Tree was applied to each image, they were assessed for accuracy with a Confusion Matrix in ENVI based on the field survey validation data

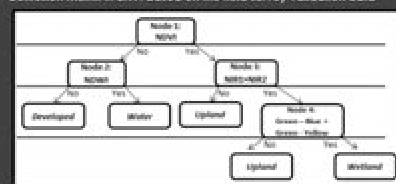

Figure 3. Decision tree developed for this project.

Results

- Unsupervised Classifications
  - WorldView-2 wetland class accuracy was substantially greater than Landsat
  - WorldView-2 was chosen for applying the Decision Tree

	Fort De Soto	
Class	WorldView-2	Landsat 8 OLI
Wetland	**82%**	**46%**
Upland	67%	58%
Grass	22%	67%

Table 1. Unsupervised classification accuracy assessments.

- Decision Tree Classification Maps:

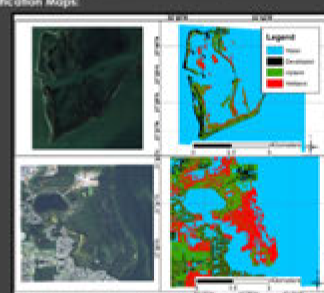

Figure 4. WorldView-2 images (left) and Decision Tree classification maps (right).

Results (continued)

- Decision Tree Classifications

Class	Producer's Accuracy (%)	User's Accuracy (%)	Commission Error (%)	Omission Error (%)
Wetland	94.44	77.27	22.73	5.56
Upland	82.76	88.89	11.11	17.24
Bare/Developed	60.00	100.00	0.00	40.00

Table 2. Accuracy assessment results for Fort De Soto map (90.9% overall accuracy, Kappa 0.8169)

Class	Producer's Accuracy (%)	User's Accuracy (%)	Commission Error (%)	Omission Error (%)
Wetland	81.82	90.00	10.00	18.18
Upland	90.48	90.48	9.52	9.52
Bare/Developed	95.65	91.67	8.33	4.35

Table 3. Accuracy assessment results for Weedon Island map (84.6% overall accuracy, Kappa 0.7346)

Conclusions

- High-resolution satellite imagery combined with this Decision Tree allow the accurate identification of wetland vegetation as distinguished from upland and other non-wetland vegetation.
- WorldView-2 affords greater wetland-mapping accuracy than Landsat 8 OLI, likely due to the substantially higher resolution of the former.
- The automated Decision Tree classification method allows the analyst the fully exploit the high spatial resolution of the imagery, which results in the more precise identification of wetland vegetation (Figs 5 & 6).

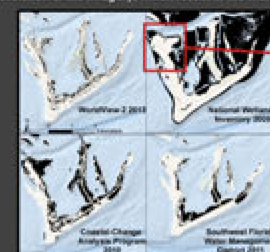

Figure 5. Wetlands (black) of Fort De Soto from this study (top left) and comparable mapped products with map source and year of imagery data.

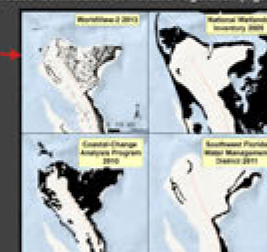

Figure 6. Wetlands (black) of North Beach subsection of Fort De Soto.

	Fort De Soto		Weedon Island	
Map Source	Wetland area (km²)	Factor difference from this study	Wetland area (km²)	Factor difference from this study
WorldView-2	0.94	N/A	6.17	N/A
SWFWMD	2.49	2.64	8.19	1.33
C-CAP	4.99	5.31	12.74	2.06
NWI	9.92	10.55	12.43	2.01

Table 4. Wetland area computed from maps of Fort De Soto (22 km²) and Weedon Island (27 km²).

Acknowledgements

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- WorldView-2 images were facilitated by Digital Globe under licensed agreement with the National Science Foundation and were provided by Dr. Paul Morin of the Polar Geospatial Center, University of Minnesota.
- The authors thank Tampa Bay Estuary Program employees Lindsay Cross and Ed Sherwood for their comments in preparation of this work.
- Field work was permitted by Pinellas County for both study areas.

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<u>THE DISTRIBUTION OF RESTING CYSTS OF THE TOXIC DINOFLAGELLATE *PYRODINIUM BAHAMENSE* IN OLD TAMPA BAY SEDIMENTS</u>

David J. Karlen, Cary Lopez, Kevin W. Campbell, Alina A. Corcoran

ABSTRACT

Summer blooms of the toxic dinoflagellate *Pyrodinium bahamense* have been a reoccurring phenomenon in Old Tampa Bay (OTB) since the early 2000s. *P. bahamense* forms dormant cysts which remain in the sediment until water conditions are favorable for bloom formation. The Environmental Protection Commission of Hillsborough County conducted three surveys of the distribution of *P. bahamense* cysts in OTB sediments following bloom events during the summers of 2009, 2011 and 2014. The first survey in spring 2010 recorded the highest cyst densities in the northwest section of OTB, with a maximum density of 30 cysts/gram sediment. A second survey in late fall 2011 found much higher cyst densities with a mean of 288 and a maximum of > 2,200 cysts/gram sediment. The third survey in spring 2015 found cyst densities nearly 3x higher than in 2011 with a mean density of 698 and maximum of >6300 cysts/gram sediment. Highest cyst densities in 2011 and 2015 occurred in the north central portion of OTB which corresponded to the area of highest *P. bahamense* bloom concentrations. High cyst densities also corresponded with sediment composition which suggests that currents and sediment transport processes redistribute and concentrate the cysts resulting in seed banks for future blooms. The increasing density over time further suggests that the cysts accumulate with each reoccurring bloom event and may contribute to increasing bloom intensities in the future.

The distribution of resting cysts of the toxic dinoflagellate *Pyrodinium bahamense* in Old Tampa Bay sediments

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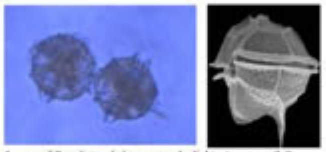
Introduction

Pyrodinium bahamense is a dinoflagellate that blooms regularly in Florida coastal waters, including Tampa Bay, Florida Bay and the Indian River Lagoon. Blooms of *P. bahamense* have recurred annually in Old Tampa Bay (OTB) since the early 2000s. These blooms result in water discoloration, and in some cases, fish kills due to oxygen depletion. This species also produces saxitoxin, which is the cause of Paralytic Shellfish Poisoning (PSP) and Saxitoxin Pufferfish Poisoning in humans following consumption of contaminated shellfish and puffer fish.



Images of *Pyrodinium bahamense* under light microscopy (left, two daughter cells) and scanning electron microscopy (right).

P. bahamense bloom resulting in water discoloration near the Bayside Bridge in Old Tampa Bay during the summer of 2009.

Life cycle dynamics play a key role in *P. bahamense* blooms (Figure 1). Resting cysts, which form during bloom maintenance and termination, can remain dormant in the sediment for many years until conditions are favorable for germination. In this study, we surveyed cyst abundance to evaluate the potential for bloom formation in Old Tampa Bay.

Figure 1. *Pyrodinium bahamense* life cycle (left) and image showing encystment of *P. bahamense* cysts (right). The illustration was produced by Melissa Miller and copied from Karlen and Miller (2011) and the image was provided by C. Lopez.

Methods

Sediment samples were collected in Old Tampa Bay at 21 sites during May 2010 and 25 sites during November - December 2011, and March 2015. The sampling sites included EPCHC's 19 monthly water quality monitoring stations (square symbols in Figure 2). Two additional sites were added in Safety Harbor (site 01) and near the Bayside Bridge (site 02) during the 2010 survey and four more were added during the 2011 and 2015 surveys in central OTB and near the Howard Frankland Bridge (sites 03-06; Figure 2).

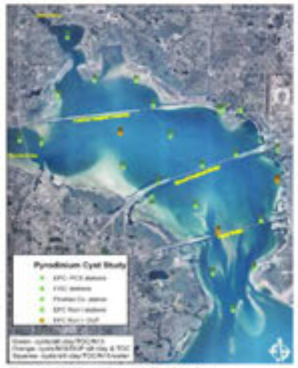
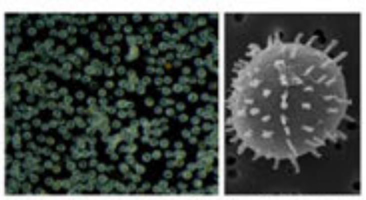


Figure 2. Old Tampa Bay sampling locations.

Sediment was collected at each site using a Young grab sampler. The top 1 cm was removed from the grab, homogenized in a stainless steel beaker, and split into two subsamples, which were placed in pre-cleaned HDPE bottles and refrigerated until processing. One subsample was used for dinoflagellate cyst extraction and one for sediment composition analysis (percent silt/clay [%SC] and total organic carbon content [TOC]).

The %SC was measured following Tampa Bay Benthic Monitoring program protocols (Versar 1993). Sediment categories were estimated from %SC measurements following Karlen et al. (2008) and based on the Wentworth size class system. Sediment categories were defined as: Coarse (%SC <1.70); Medium (%SC = 1.70–4.51); Fine (%SC = 4.51–11.35); Very Fine (%SC = 11.35–25.95); and Mud (%SC >25.95). TOC content was measured using a Shimadzu TOC-VCPH equipped with a solid sample module and non-dispersive infrared detector.

Dinoflagellate cysts were extracted from a 50 to 100 gram wet weight subsample of sediment from each site using the sodium polytungstate centrifugation method modified from Bolch (1997) following protocols developed by the Florida Fish and Wildlife Conservation Commission. Cyst extractions were performed by the EPCHC for the 2010 and 2011 surveys and by FWC for the 2015 survey. Cysts were counted using an inverted compound microscope and cyst abundance was standardized to #/gram sediment.



Pyrodinium bahamense cysts extracted from sediment. Images show cysts at 100x magnification (left) and XXX magnification (right, photo from S. Keller-Abbe).

Results

Mean cyst density across all sites increased through time (Fig. 3A, note logarithmic scale). The greatest cyst densities during the spring 2010 survey were recorded in northwest OTB (Fig 3B), with a maximum of 30 cysts/gram (Karlen and Miller, 2011). Greater densities were found during the fall of 2011, with a mean of 288 and a maximum of >2,200 cysts/gram (Karlen and Campbell, 2012). Spring 2015 cyst densities were ~3X greater than in 2011 -- with a mean of 698 and maximum of >6300 cysts/gram, however there was no significant difference between 2011 and 2015 (Fig. 3A; ANOVA, $p = 0.65$). The greatest cyst densities in 2011 and 2015 occurred in north central OTB (Fig. 3C-D), which corresponded to the area of greatest *P. bahamense* abundance during the previous blooms.

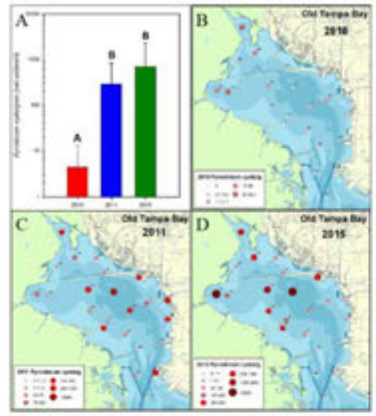


Figure 3. Mean (± SD) *P. bahamense* cyst density through time in OTB (A) and *P. bahamense* cyst density and distribution during surveys conducted in 2010 (B), 2011 (C) and 2015 (D).

As predicted, cyst abundance covaried with sediment composition; the greatest densities occurred in very fine grained sediments with grain sizes approximating cyst size (Figure 4).

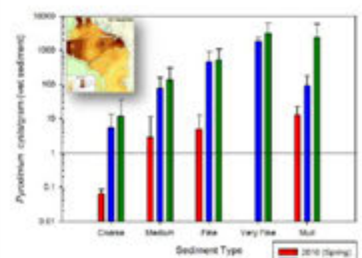


Figure 4. *Pyrodinium bahamense* cysts abundance in different sediment types. Inset: Sediment distribution in OTB (2015 silt+clay results).

Discussion & Conclusions

Circulation models for Tampa Bay indicate that the portion of OTB between the Howard Frankland Bridge and Courtney Campbell Causeway is characterized by surface current gyres and long residence times (Weisberg and Zheng 2006; Meyers et al. 2007; Meyers and Luther 2008). These conditions concentrate the *P. bahamense* blooms, subsequently resulting in greater deposition of cysts at these sites.

High cyst densities were also recorded along the east side of the bay and south of the Gandy Bridge during the 2011 survey, even though the *P. bahamense* cell counts in these areas were relatively low during the previous summer. This result suggests that cysts are being moved and redeposited from other areas by tides, bottom currents, and other transport processes. The greatest cyst densities were also associated with fine grained sediments. Given the diameter of *P. bahamense* cysts (50 – 65 µm) is within the upper range of silt and very fine grained sand, we would expect cysts to behave (i.e., transport and settle) as similar sized sediment particles.

The effects of sediment transport within Old Tampa Bay on the redistribution of cysts and the potential for these processes to contribute towards the spread of bloom events to new areas of Tampa Bay warrants further investigation. This finding suggests that currents and sediment transport redistribute and concentrate the cysts resulting in possible new seed banks for future blooms. (Karlen & Campbell 2012).

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For Further Information

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NEW FORENSIC METHODS FOR DESCRIBING THE HISTORIES OF FISH

AA Wallace, EB Peebles, DJ Hollander, SA Murawski, JE Granneman, JL Ostroff, and GS Ellis

ABSTRACT

We are developing novel methods that use carbon and nitrogen stable-isotope records within fish eye lenses to describe lifetime trends in the geographic histories and trophic positions of individual fish. Eye lenses are composed of metabolically inert optical proteins deposited in successive, concentric layers (laminae), much like tree rings or the layers of an onion. Analysis of laminae from Red Snapper, Red Grouper, Gag, and White Grunt revealed useful isotopic trends among and within species. We took our analyses one step further, using compound-specific isotope analysis of amino acids to isolate trophic growth effects. These trophic effects can be subtracted from the overall isotopic trends in the lens, exposing the geographic histories of individual fish. We are currently determining the relationship between lens diameter and otolith-based age, which will allow us to assign calendar dates to events in the lives of fish. These events include exposure to oil spills, which we can now detect by examining trends in oil-associated trace metals within otoliths. In the wake of disasters like the Deepwater Horizon oil spill, we can now gather data that lets us know if, when, and where individual fish were exposed to oil, as well as how their movement, growth rate, or trophic position may have changed in response to exposure. These new forensic methods provide a relatively low-cost approach that has general application to studies of fish life history, habitat use, trophic relationships, and other information needed by fisheries managers.

New Forensic Methods for Describing the Histories of Fish

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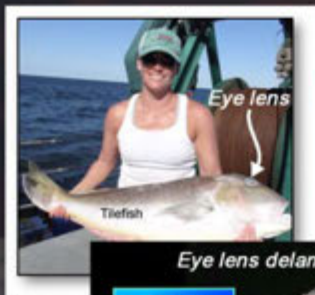
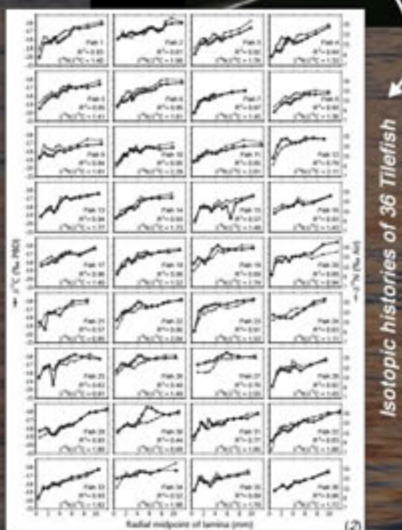
C-IMAGE - II Center for the Integrated Modeling and Analysis of Gulf Ecosystems

Abstract: In the wake of disasters such as the *Deepwater Horizon* oil spill, we can now gather data that lets us know if, when, and where individual fish were exposed to oil, as well as how their movement, growth rate, or trophic position may have changed in response to exposure. We previously developed novel methods using carbon and nitrogen stable-isotope records within fish eye lenses to describe lifetime trends in the geographic histories and trophic positions of individual fish. More recently, we have separated trophic growth and migration patterns in individual fish using compound-specific isotope analysis of amino acids within eye lenses. These trophic effects can be subtracted from the overall isotopic trends in the lens, exposing the geographic histories of individual fish. We are currently determining the relationship between lens diameter and otolith-based age, which will allow us to assign calendar dates to events in the lives of fish determined from stable isotope and/or otolith microchemistry anomalies. These events include exposure to oil spills, which we can now detect by examining trends in oil-associated trace metals within otoliths. New forensic methods provide a relatively low-cost approach that has general application to studies of fish life history, habitat use, trophic relationships, and other information needed for fisheries management.

Eye Lens Isotopes

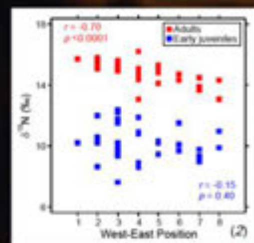


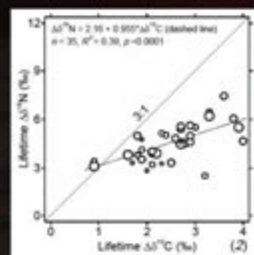


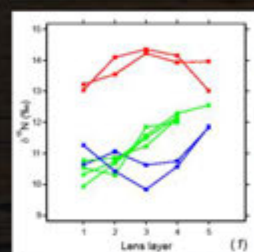
Fish Lifetime

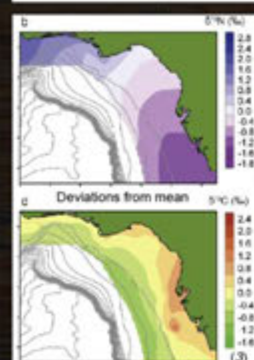
Why this works . . .

Eye lenses form concentric layers of cells that are primarily composed of crystallin, a durable, optical protein. After the formation of each new layer, all organelles are removed from the cells to improve optical clarity. Organelle removal also makes new protein synthesis impossible. The principal protein that remains behind is the crystallin that was produced at the time of layer formation. Unlike otoliths, eye lenses are rich in both $\delta^{13}C$ and $\delta^{15}N$ (*1*).









Site Fidelity

Burrow-inhabiting adult Tilefish match the geographic trend in their isotopic background (see map below), indicating they have high site fidelity.

Early juveniles, in contrast, have no geographic trends, indicating they are more mobile (*2*).

Ecosystem Subsidy

Tilefish live on the outer continental shelf. Most of the 35 Tilefish in the figure at left deviated widely from the 3:1 isotopic ratio that is expected from trophic fractionation. This figure indicates the deviation was due to $\delta^{13}C$, not $\delta^{15}N$. (Bubble size is relative fish length.)

The most likely source of elevated $\delta^{13}C$ is inshore fish (Tilefish prey) that migrate far offshore each fall and winter. This finding suggests inshore fish production provides a substantial subsidy to offshore Tilefish production (*2*).

Geographic Subgroups

Each colored line at left represents a single Red Snapper collected offshore of John's Pass, FL. Although the fish were collected in proximity to each other, they had three distinctive patterns in their isotopic histories (*1*), which contrasts with the uniformity of the 36 Tilefish curves at far left.

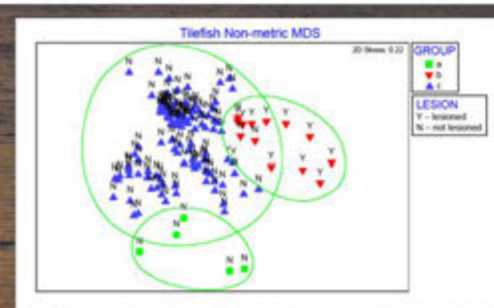
Knowing whether fish form two or more geographic subgroups, as indicated by this type of analysis, is useful to fisheries managers.

Individual Movement

If isotope maps ("isoscapes") are available (*3*), then geographic histories can be interpreted more explicitly. Among the three Red Snapper subgroups (above left), the red subgroup originated from farther north. The dark blue subgroup first moved south and then north towards John's Pass. The trend in the green subgroup resembles that of the burrow-inhabiting Tilefish at far left.

The increase in $\delta^{15}N$ values during life (Tilefish and green Red Snapper subgroup) is due to the increase in trophic level that occurs as the fish grow larger. *Trophic growth can be calculated by measuring $\delta^{15}N$ in different amino acids extracted from different parts of the eye lens.* Once trophic growth has been subtracted in this manner, only the geographic movement effects of predator and prey remain, which simplifies interpretation.

Otolith Microchemistry



Potential Oil Exposure *(J. Granneman, unpublished data)*

Metals associated with oil from the Macondo Prospect (*4*) are compared within Tilefish otoliths, where each column in the top panel represents standardized (% of total) mean metal concentrations for a year in the life of an individual fish. Note that iron (^{57}Fe) is physiologically regulated to the point of near uniformity across all samples. Vertical black lines in the top panel separate significant groups of measurements, as determined by SIMPROF analysis. One of the three SIMPROF groups (group *b*) was dominated by individuals with external lesions—the presence of lesions did not enter into the analysis; these are passive labels. The lesioned group had relatively high concentrations of ^{60}Ni and ^{66}Zn. The lower panel depicts the same data in the form of a non-metric multidemensional scaling (MDS) plot. Group *a* had relatively high concentrations of ^{63}Cu.

Combined Methods

Combining eye-lens isotopes with otolith microchemistry allows determination of geographic locations where particular events, such as oil exposure, occurred. Otolith microchemistry can also augment the geographic information obtained from eye lenses—otolith barium, for example, is an indicator of exposure to river discharge, and is abundant within the otoliths of Red Snapper from the north-central Gulf of Mexico. Likewise, multivariate analyses of multiple otolith elements can be used to identify geographic fingerprints within otoliths.

Otolith ageing methods allow dates to be assigned to specific events during life (oil exposure, migration, diet shifts, etc.), and can also be used to reconstruct individual growth-rate histories (Fraser-Lee method). Growth rates, in turn, can be used to evaluate the relative success of the different patterns that are exposed by forensic methods (i.e., the examples provided herein). Because fast growth is considered beneficial to survival and lifetime reproductive potential, interpretations of "good" vs. "bad" individual histories based on growth rate are conceptually robust.

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CLIMATE CHANGE

MANAGEMENT OF TAMPA BAY BLUE CARBON HABITATS IN RESPONSE TO SEA LEVEL RISE

Doug Robison, M.S., PWS, Lindsey Sheehan, P.E., Brendon Quinton, GISP, David Tomasko, Ph.D. and Steve Crooks, Ph.D.

ABSTRACT

Mangroves, salt marshes and seagrass beds not only provide critical food and shelter for economically important fish and shellfish, but they also uptake large quantities of the greenhouse gas carbon dioxide from the atmosphere, potentially reducing global climate change. In recent years these coastal wetlands have been referred to as coastal "blue carbon habitats" because of their capacity to sequester and store large quantities of carbon. When these habitats are damaged or destroyed their carbon sequestration capacity is lost, and carbon stored in sediments and biomass are recycled, potentially contributing to increased greenhouse gas emissions. With strong wetland regulatory protections in place, sea level rise now represents perhaps the most significant threat to Tampa Bay coastal wetlands. Without proper planning, coastal wetlands may not be able to keep pace with rising sea levels, thus leading to major habitat conversions and losses in Tampa Bay. Such changes would likely reduce both estuarine productivity as well as the regional carbon storage capacity of Tampa Bay blue carbon habitats. This paper summarizes the threat of sea level rise on Tampa Bay coastal wetlands, the potential ramifications of inaction, and planning and policy recommendations to mitigate this threat.

INTRODUCTION

In the 1950s and 1960s, scientists, ecologists, and conservationists began to articulate the importance of wetlands and the functions they provide. Wetland functions have been broadly grouped into three general categories: habitat; hydrology; and water quality (Mitsch & Gosselink, 1993). Habitat functions include the provision of food, water, and shelter for fish and wildlife populations. Hydrologic functions include such factors as the reduction of flow velocities, ground-water recharge or discharge, and the influence of wetlands on atmospheric processes such as evapotranspiration. Water-quality functions include the settling and trapping of sediment, and the uptake and assimilation of nutrients and other pollutants. With the recognition of the importance of wetlands and the functions they provide, major federal and state environmental regulations were promulgated in the 1970s and 1980s to protect wetlands from destruction from dredge and fill and other activities.

It is now widely understood that coastal wetlands in Tampa Bay – including mangroves, salt marshes, and seagrasses – provide critical food and nursery habitat for estuarine-dependent guilds of invertebrates, fish and birds (Lewis & Robison, 1996), as well as stabilize and protect shorelines from storm surge and coastal erosion. In addition to these ecosystem services, coastal wetlands have also been recognized in recent years for their ability to uptake large quantities of carbon dioxide from the atmosphere, potentially reducing greenhouse gases. Accordingly, mangroves, salt marshes, and seagrasses are now sometimes referred to as "coastal blue carbon habitats."

In terms of primary productivity, coastal wetlands are among the most productive habitats in the world (Mitsch and Gosselink, 1986). As a function of this high productivity, these habitats also perform two key functions with regard to atmospheric carbon and global climate change:

- **Carbon sequestration -** the process of capturing carbon dioxide from the atmosphere, measured as a rate of carbon uptake per year; and

- **Carbon storage -** the long-term confinement of carbon in plant biomass or sediment, measured as a total weight of carbon stored.

Mature coastal wetlands contain large stores of carbon accumulated over hundreds or even thousands of years, and are considered to be long-term carbon sinks if they are not disturbed (Crooks et al., 2011; Pendleton et al., 2012). Recent studies suggest that mangroves annually sequester carbon at a rate two to four times greater than mature tropical forests, and store three to five times more carbon per equivalent area than tropical forests (Murray et al., 2011). Most coastal blue carbon is stored in soil and sediments, not in above-ground plant biomass, as is the case with tropical forests. Figure 1 shows the comparative carbon storage capacity of blue carbon habitats versus tropical forest.

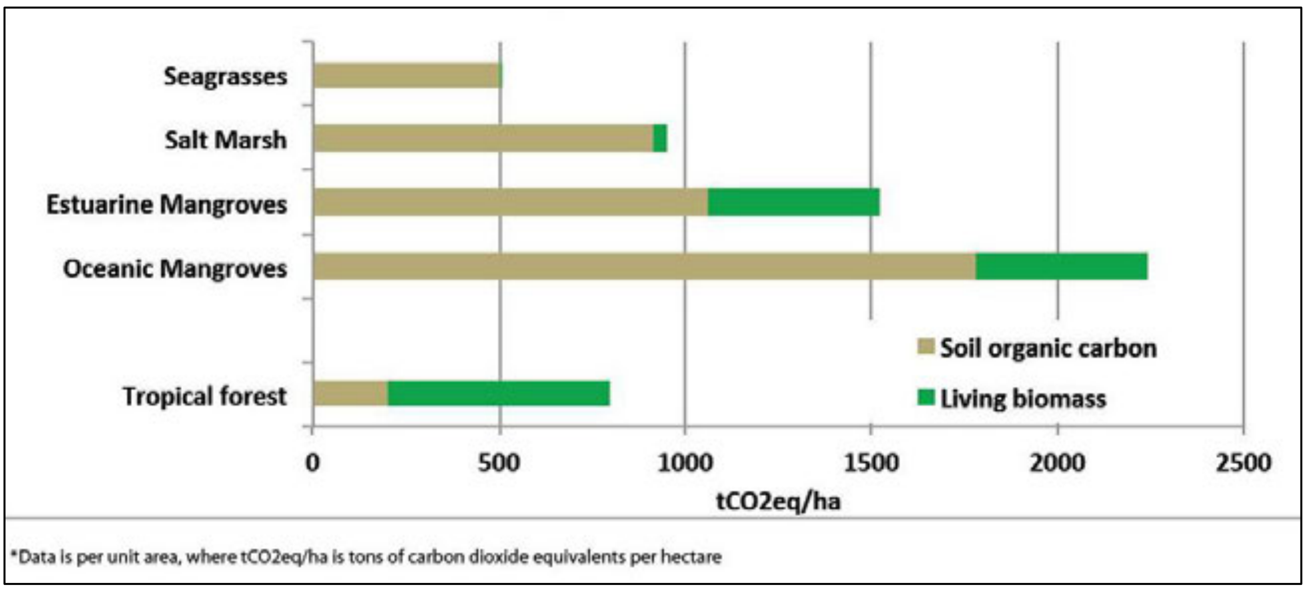

Figure 1 - Comparative carbon storage capacity of blue carbon habitats versus tropical forest (Murray et al., 2011).

When coastal wetlands are damaged or destroyed the ecosystem services they provide are diminished or lost. However, with regard to global climate change, not only is their carbon sequestration capacity lost, but stored carbon can actually be released resulting in localized increases in greenhouse gas emissions. As a result, damaged or destroyed coastal wetlands change from being net carbon sinks to net carbon emitters (Crooks et al., 2011; Pendleton et al., 2012). For these reasons, carbon sequestration and storage should now be added to the list of critically important ecosystem services provided by coastal wetlands, further justifying our commitment to the protection and restoration of these habitats in Tampa Bay; and the proper accounting and consideration of these services should be factored into future management decisions (Needleman et al., 2012).

Major federal and state regulations addressing dredge and fill activities and wastewater discharges have been remarkably effective in Tampa Bay, resulting in an effective no net loss of mangroves and salt marsh habitats since the 1990's, and a substantial increase in seagrassess, over the past decade. Unfortunately, however, global climate change and associated sea level rise now constitute a serious threat to the long-term integrity of Tampa Bay coastal wetlands, and further regulatory protections and restoration efforts alone will not be adequate to address this new challenge.

SEA LEVEL RISE - THE NEW CHALLENGE

Global sea levels have been rising since the last ice age; however, recent data show that current rates of sea level rise have roughly doubled since the pre-1992 rates of sea level rise during the 20th century (Watson et al. 2015). Projections of future sea level rise include a high degree of uncertainty due to the largely unpredictable effects and interactions of the many variables and feedbacks related to greenhouse gas emissions, the melting of polar ice caps, etc. Nonetheless, there is general consensus that sea levels will continue to rise, and that the rate of sea level rise will likely increase through this century. Figure 2 shows a plot of observed and projected global mean sea levels through 2100 (NOAA, 2012).

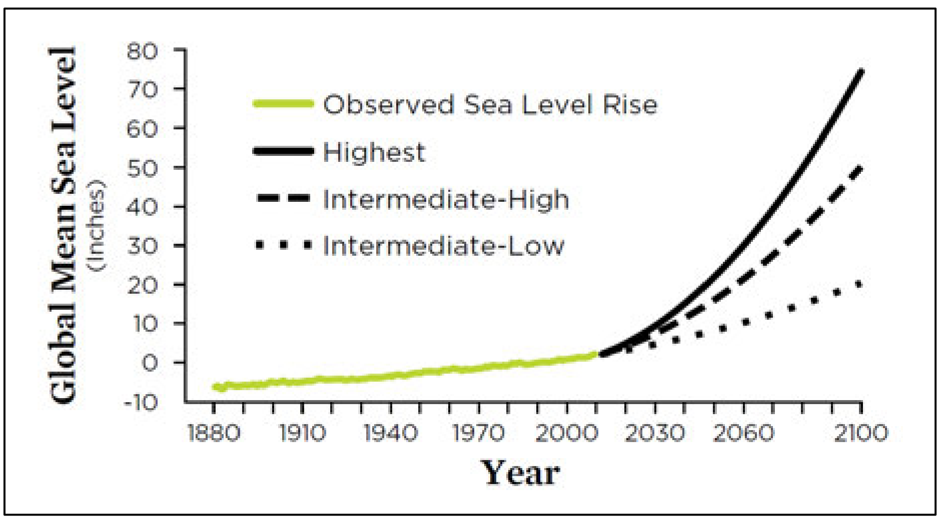

Figure 2 – Observed and projected global mean sea level through 2100 (NOAA, 2012).

The U.S. Fish & Wildlife Service has been monitoring wetland status and trends in coastal watersheds of the coterminous U.S. since 1998 (Dahl & Stedman, 2013). While coastal wetlands are now generally well protected by federal and state regulations that restrict development-related dredge and fill activities, the rate of coastal wetland loss in the Gulf of Mexico more than doubled from 44,800 acres during the period 1998-2004 to 95,300 acres during the period 2004-2009 (Dahl & Stedman, 2013). The vast majority of these coastal wetland losses were attributed to the conversion of estuarine vegetated wetlands to open saltwater in coastal Louisiana caused by severe coastal storm erosion, subsidence, sediment deprivation, and sea level rise. By comparison, a small percentage of these coastal wetland losses were attributed to discrete anthropogenic actions (Dahl & Stedman, 2013).

While the combined effects of coastal storm erosion, subsidence, and sediment deprivation are somewhat unique to coastal Louisiana, sea level rise must now be recognized as a significant long-term and insidious threat to the stability of coastal wetlands throughout the Gulf of Mexico, including Tampa Bay. Field data collected in support of a project entitled *Critical Coastal Habitat Assessment* (Atkins/ESA, 2016 – in preparation) being conducted for the Tampa Bay Estuary Program has indicated that topographic differences as small as 3 cm in the intertidal zone can have a significant effect on the zonation and species composition of coastal wetlands in Tampa Bay. Based on these observations, it is clear that coastal wetland communities in Tampa Bay will undergo substantial changes by 2100 under even the most conservative sea level rise projections.

The potentially deleterious effects of global sea level rise on coastal wetlands have been recognized in the scientific literature since at least the mid-1980s. As described by Titus (1986), coastal wetlands throughout the world have kept pace with the slow rate of sea level rise that has characterized the last several thousand years. Thus, the area of coastal wetlands has increased as new lands have become inundated. However, if in the future sea level rises faster than the ability of coastal wetlands to keep pace through sediment accretion, then the area of coastal wetlands will decline. Construction of bulkheads or dikes to protect developed areas will greatly exacerbate this decline, preventing new wetlands from forming inland, resulting in a total loss of coastal wetlands in some areas (Titus, 1986). Figure 3 illustrates the effects of accelerating sea level rise and development of coastal wetland losses.

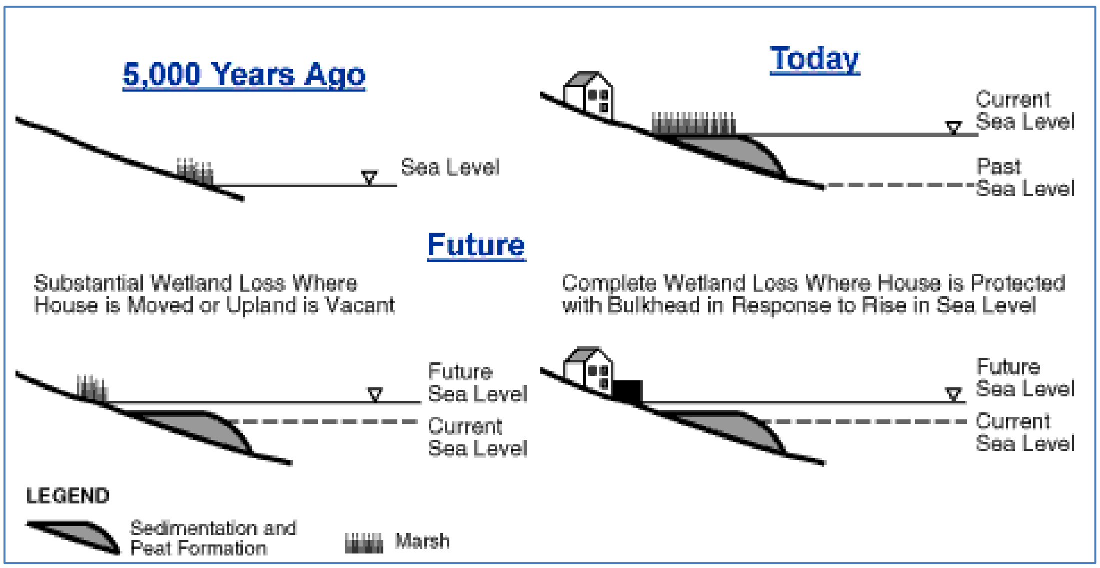

Figure 3 – The effects of accelerating sea level rise and development on coastal wetland losses (adapted from Titus, 1986).

The processes depicted in Figure 3 are not unique to marshes, but rather are applicable to all types of intertidal wetlands in Tampa Bay. The most pronounced outcome is intuitive. When rising sea levels encroach upon developed areas protected by bulkheads and dikes, the intertidal zone becomes compressed. As sea level continues to rise, intertidal wetlands will eventually be “pinched” up against the hardened shoreline, resulting in their complete loss. However, when rising sea levels move up the slope onto undeveloped uplands the outcomes are more difficult to predict. If the upland slope is gradual, and sedimentation and peat formation through carbon sequestration can keep pace with the rate of sea level rise, then the natural slope-dependent continuum of intertidal coastal wetlands can be maintained. On the other hand, if the slope is variable, and sedimentation and peat formation cannot keep pace with the rate of sea level rise, then some types of intertidal wetlands may be favored over others.

PREDICTING COASTAL HABITAT RESPONSES TO SEA LEVEL RISE

Over the past two decades geospatial modeling tools have been developed to predict changes in coastal wetland habitats in response to sea level rise. The *Sea Level Affecting Marshes Model* (SLAMM) developed by Warren Pinnacle Consulting, Inc. simulates the dominant processes involved in coastal wetland conversions and shoreline modifications during long-term sea level rise. A complex decision tree incorporating geometric and qualitative relationships is used to represent transfers among coastal habitat classes. The study area is divided into cells of equal area with each cell having an elevation, slope, and aspect. Within the contiguous United States, most required data for the model (NOAA tidal data, Fish & Wildlife Service National Wetland Inventory data, and USGS digital elevation model data) are readily available for download from the Web. If LiDAR elevation data are available they can also be utilized by the model to reduce model uncertainty. Relative sea level change is computed for each site for each time step. It is the sum of the historic eustatic trend, the site-specific rate of change of elevation due to subsidence and isostatic adjustment, and the accelerated rise depending on the scenario chosen. Within SLAMM, there are five primary processes that affect wetland fate under different scenarios of sea-level rise: inundation; erosion; over-wash; saturation; and accretion (Warren Pinnacle Consulting, Inc.).

Sherwood and Greening (2013) utilized SLAMM to model changes to the suite of intertidal coastal habitats within the Tampa Bay estuary under various sea level rise (SLR) scenarios. They also evaluated two future scenarios related to the disposition of existing developed lands. Under the “habitat migration” scenario all uplands, whether developed or open lands, are allowed to accommodate habitat migration with sea level rise. Under the “upland protection” scenario developed uplands are protected and cannot accommodate habitat migration with sea level rise. Figure 4 below shows the estimated composition of critical coastal habitats in Tampa Bay over time as reported by Robison (2010), and the anticipated changes in their composition due to climate change and sea level rise as estimated from the SLAMM (2013) under a worst-case scenario of 2 m of sea level rise by 2100.

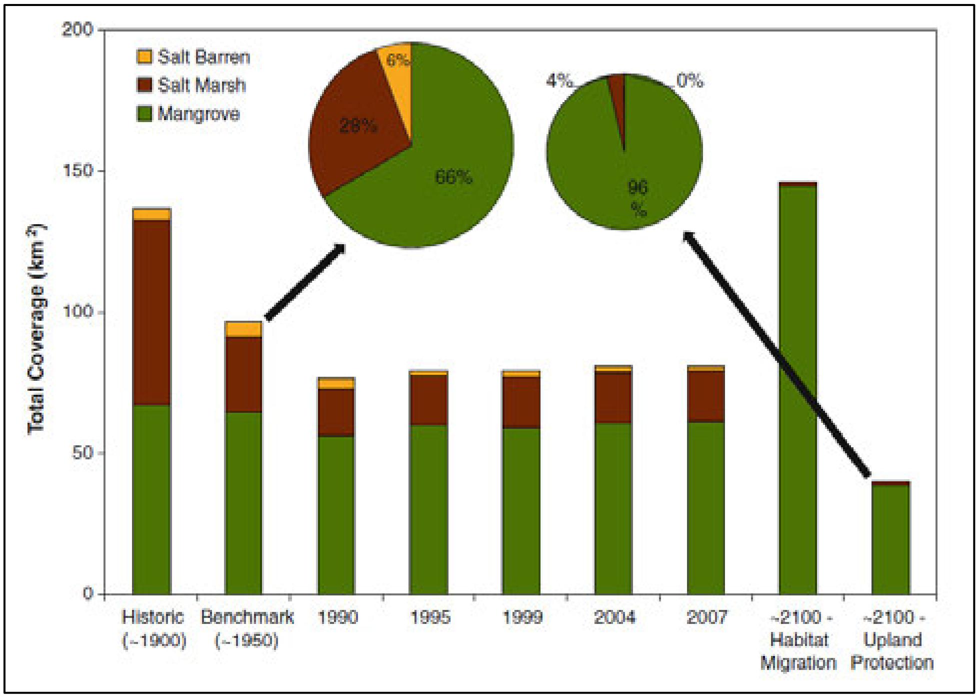

Figure 4 - Estimated composition of critical coastal habitats in Tampa Bay over time and modeled changes in their composition in response to 2m sea level rise by 2100 (from Sherwood and Greening, 2013).

Sherwood and Greening (2013) concluded that Tampa Bay will likely become a mangrove dominated system by the year 2100, with salt marsh and salt barren habitats converting to mangroves. Furthermore, their results showed that if all existing developed areas were protected against sea level rise then the total area of intertidal wetlands would be reduced by almost 50 percent.

It is intuitive that new shallow subtidal areas will be created by sea level rise. However, as acknowledged by Sherwood and Greening (2013) the SLAMM employed in their study was not able to simulate changes in seagrasses in response to sea level rise. Seagrasses are extremely important to the overall ecology of Tampa Bay, and understanding their response to sea level rise is critical to developing future habitat management strategies. Furthermore, SLAMM does not accurately simulate the more subtle and localized habitat conversion processes that are important in Tampa Bay. For example, in tropical and subtropical locales, SLAMM predicts that virtually all habitat categories will convert to mangroves as sea level rises, leading to an overestimate of mangrove dominance. This is because SLAMM does not adequately simulate the evolution of fringing high marsh and salt barrens created by irregular tidal inundation, or the migration of brackish *Juncus* marshes maintained by localized freshwater inputs.

To improve predictions of habitat responses to sea level rise, Environmental Science Associates (ESA) developed a GIS-based habitat evolution model specific to Tampa Bay as part of a study being conducted for both the Tampa Bay Estuary Program and Restore America's Estuaries entitled *A "Coastal Blue Carbon" Assessment of the Tampa Bay Estuary: Accounting for the Climate Change Mitigation Benefits of Integrated Climate Change Adaptation and Ecosystem Restoration in Tampa Bay* (ESA, 2016 - in preparation). The Tampa Bay Habitat Evolution Model (HEM) improves upon SLAMM by:

- Creating the flexibility to edit the habitat categories to facilitate cross-walks from site-specific vegetation mapping;

- Customizing the habitat evolution decision tree to incorporate more complex and locally-specific topographic, hydrologic and biological relationships; and
- Building a structure that allows for different "modules" to be added to or updated in the model.

The HEM includes a habitat evolution decision tree specific to Tampa Bay habitats, elevations, tidal data, and climate conditions. In addition, the HEM incorporates a seagrass module that predicts the establishment of seagrasses in newly inundated subtidal areas based on current water quality and light penetration conditions. The Tampa Bay specific habitat evolution decision tree is shown in Figure 5 below.

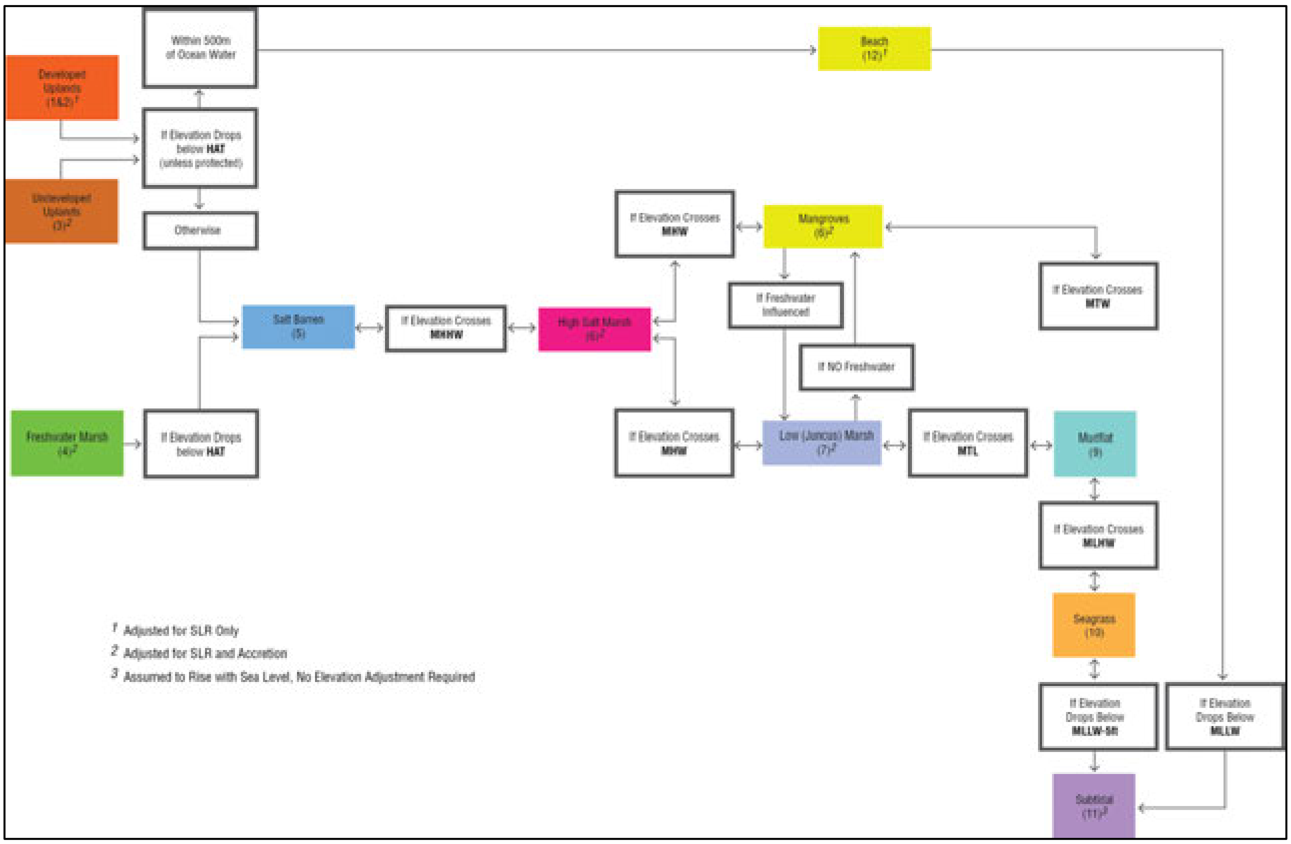

Figure 5 – Tampa Bay Habitat Evolution Model (HEM) decision tree.

Preliminary HEM results indicate that habitat changes are most sensitive to differences in sea level rise projections and accretion rates as opposed to differences in development protection scenarios. Table 1 below summarizes modeled habitat changes between 2007 and 2100 for the intermediate low (23.6 inches) and intermediate high (51.1 inches) sea level rise scenarios, with low accretion rates applied to both.

Table 1 – HEM predictions of habitat changes for the period 2007-2100 for two SLR scenarios.

Run	Modeled Acreage in 2007	Acreage in 2100		Acreage difference 2100-2007	
		(Run 1) Int. Low	(Run 3) Int. High	(Run 1) Int. Low	(Run 3) Int. High
Developed Upland- Hard	461,640	461,640	461,640	0	0
Developed Upland- Soft	210,310	210,310	210,310	0	0
Undeveloped Upland	230,600	227,370	222,870	-3,230	-7,730
Freshwater Marsh	81,390	79,260	77,590	-2,130	-3,800
Salt Barrens	1,520	2,870	2,280	1,350	760
High Salt Marsh	2,290	2,500	1,090	210	-1,200
Juncus Marsh	4,250	4,530	2,430	280	-1,820
Mangroves	13,990	16,040	4,870	2,050	-9,120
Mudflat	0	0	840	0	840
Beach	70	30	10	-40	-60
Seagrass	33,310	33,550	48,280	240	14,970
Open Water	338,710	339,960	345,880	1,250	7,170

In the lower sea level rise scenario acreage increases are predicted for salt barren, high salt marsh, *Juncus* marsh, and mangrove habitats, which are converted from uplands and freshwater marshes. However, in the higher sea level rise scenario, acreage decreases are predicted for high salt marsh, *Juncus* marsh, and mangrove habitats, which are replaced by open water as well as an approximate 15,000 acre increase in seagrass. These results underscore the sensitivity of coastal wetlands to variable sea level rise and accretion rate scenarios, and indicate that under higher sea level rise scenarios Tampa Bay could actually transition from a mangrove dominated system to a seagrass dominated system if accretion rates remain in the lower ranges typical of Tampa Bay coastal wetlands.

HEM output can be exported to GIS and graphically displayed to show areas of gain, loss, or no change, for particular habitat types between two time periods for various sea level rise scenarios. Figures 6 and 7 below show examples of graphical output for mangrove and seagrass habitat changes in the Middle Tampa Bay segment, respectively, for the intermediate high sea level rise (51.1 in.) /low accretion rate (1.6 mm/year) model scenario (Run 3). These results indicate that many existing large contiguous stands of mangroves could be sufficiently inundated by sea level rise in 2100 to convert to shallow subtidal zones suitable for landward seagrass expansion. Conversely, existing seagrass beds could be extinguished by reduced light penetration caused by a deeper water column associated with sea level rise.

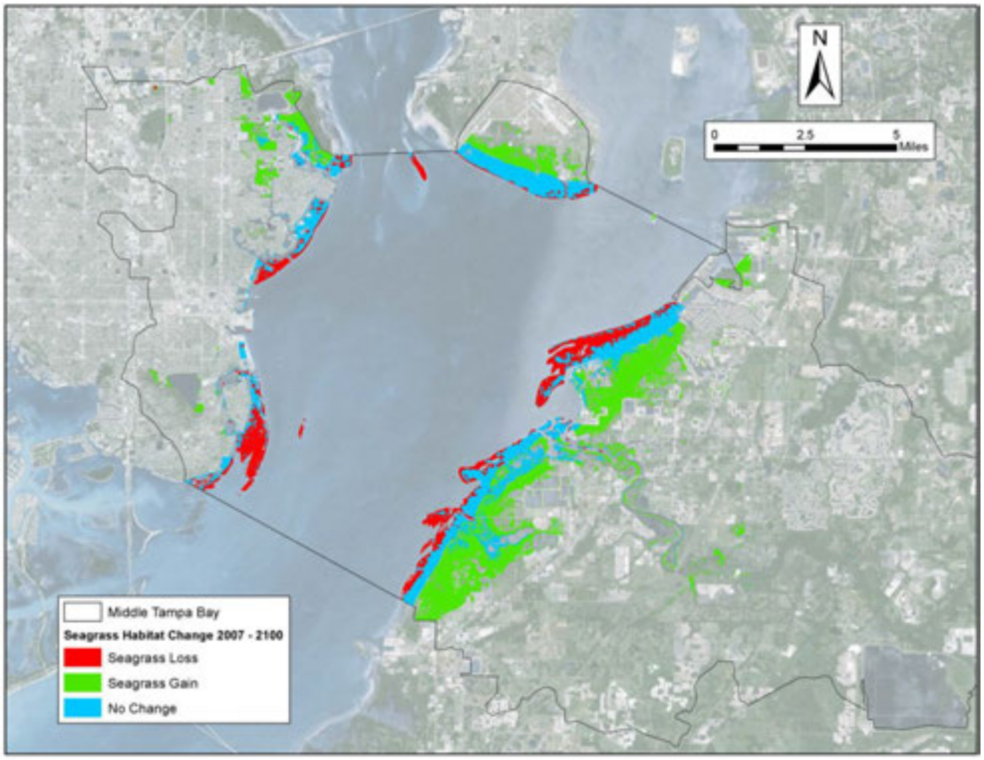

Figure 6 – HEM simulation of seagrass changes between 2007 and 2100 in Middle Tampa Bay.

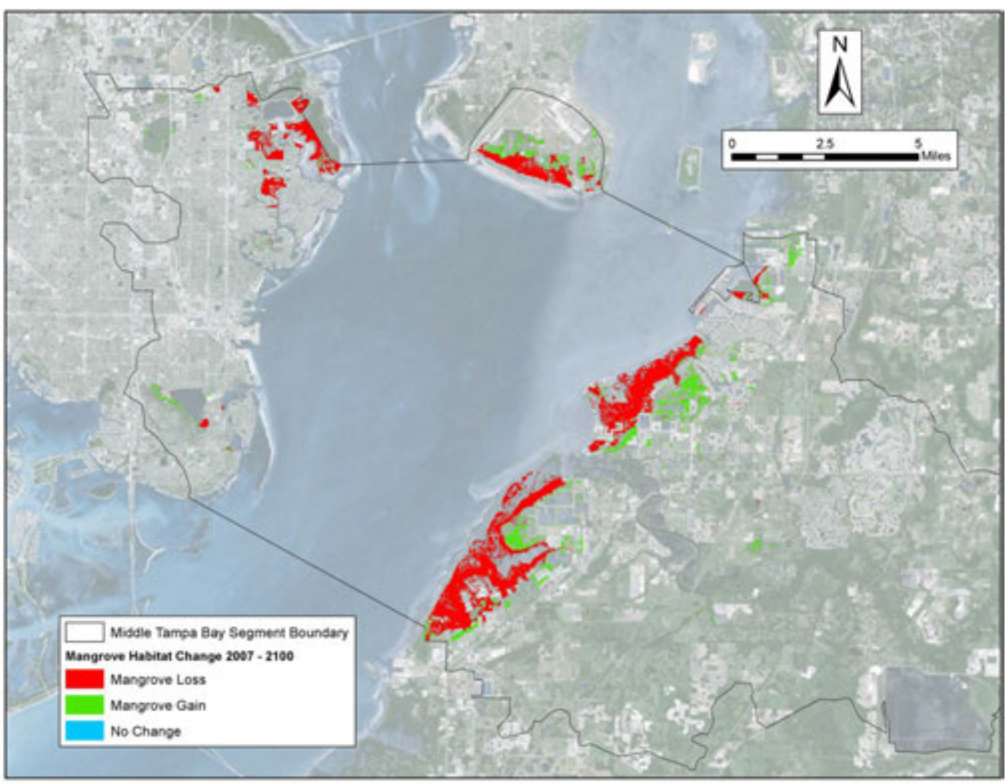

Figure 7 – HEM simulation of mangrove changes between 2007 and 2100 in Middle Tampa Bay.

Modeling changes in Tampa Bay salt marshes in response to sea level rise is particularly challenging due to their restricted distributions. Due to its subtropical climate, mangroves dominate the lower intertidal zone in Tampa Bay, while salt marshes are relegated to higher intertidal zones. Furthermore, black rush (*Juncus roemerianus*) marshes in Tampa Bay are also spatially restricted primarily to lower salinity zones found in tidal rivers and creeks, even though this species can tolerate a wide salinity range (Stout, 1984). For these reasons, *Juncus* marshes in Tampa Bay may be particularly vulnerable to sea level rise. The largest remaining stands of *Juncus* marsh in the Tampa Bay estuarine system are located in the Manatee River bay segment, where both the Manatee River and the Braden River are impounded for public water supplies. Rising sea levels in these truncated tidal rivers could result in substantial losses of the remaining stands of *Juncus* marsh there. Figure 8 shows HEM simulation of *Juncus* marsh in the Manatee River bay segment for the same intermediate high sea level rise (51.1 in.)/low accretion rate (1.6 mm/year) model scenario (Run 3). The losses depicted in this graphic would likely be even greater if freshwater inflows to these systems were further reduced.

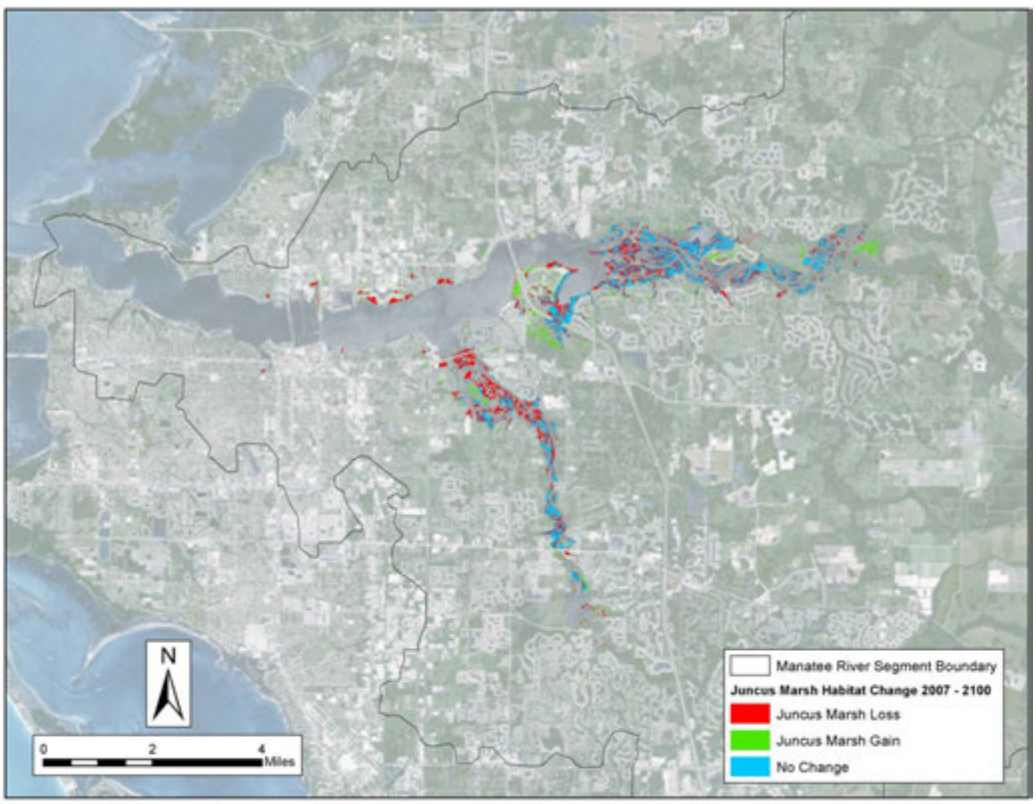

Figure 8 – HEM simulation of *Juncus* marsh changes between 2007 and 2100 in the Manatee River.

Despite advancements in modeling tools and techniques for simulating changes in coastal wetland habitats in response to sea level rise, there are still great uncertainties in the modeled predictions. Small differences in the rates of sea level rise and sediment/organic matter accretion can result in very large differences in predicted habitat changes. And the actual evolution of coastal wetland habitats in Tampa Bay will almost certainly be further affected by localized changes in rainfall patterns, freshwater inflows, flushing and circulation patterns, dredge and fill, and urban development activities. The one certainty is that sea levels are indeed on the rise, and recent evidence suggests that the rate of sea level rise is actually increasing (Watson et al., 2015). Tampa Bay coastal wetland habitats will continue to dynamically respond to sea level rise for centuries to come.

STRATEGIES FOR MANAGING COASTAL BLUE CARBON HABITATS

In 1996 the Tampa Bay National Estuary Program published the document entitled Setting Priorities for Tampa Bay Habitat Protection and Restoration: Restoring *the Balance* (Lewis and Robison, 1996) which was subsequently adopted as the "Tampa Bay Master Plan for Habitat Restoration and Protection" and incorporated into the original Comprehensive Conservation and Management Plan for Tampa Bay, entitled *Charting the Course*. In 2010, the Tampa Bay Estuarine Program adopted the *Tampa Bay Habitat Master Plan Update* (Robison, 2010), which provided an updated status and trends analysis, and established quantitative restoration and protection targets for critical coastal habitats in Tampa Bay. Both documents utilized a restoration paradigm referred to "restoring the balance."

The essence of the "restoring the balance" paradigm is that the relative proportions or balance of the various habitat types that existed in circa 1950 – the reference "pre-development" benchmark period – should be replicated since the restoration of the total acreage of the various habitat types that existed in 1950 is not economically feasible due to urban and port development. The underlying principle of the paradigm is that by restoring critical habitats to their historical ratios the habitat requirements of key estuarine dependent species will be provided throughout the life histories. It should also be noted that this paradigm assumes more or less static sea levels and climatic conditions, and that the primary drivers of habitat loss and/or change are direct anthropogenic perturbations such as dredge and fill and water quality degradation.

While the *Tampa Bay Habitat Master Plan Update* recognized the clear threat posed by sea level rise, and described the processes depicted in Figure 2 above, the updated restoration and protection targets recommended in the document were developed using the "restoring the balance" methodology. However, there now appears to be a consensus within the Tampa Bay scientific and resource management community that sea level rise is exerting a demonstrable and significant effect on Tampa Bay coastal wetlands, altering their species composition, abundance, and distribution. Accordingly, under rising sea level conditions the "restoring the balance" paradigm is probably no longer appropriate for determining habitat restoration and protection targets. A more comprehensive, long-range planning approach will be needed to ensure the future integrity of Tampa Bay coastal wetland habitats under rising sea level conditions.

The first response to the threat of sea level rise should be the identification, prioritization, and conservation of low-lying, undeveloped coastal uplands as buffer zones to allow for the landward migration of coastal wetlands over time. This strategy is consistent with that recommended by Sherwood and Greening (2013) describing the establishment of "refugia" to allow for sensitive coastal wetland habitats to persist under anticipated climate changes and sea level rise impacts. The term "refugia" is typically used in biology to describe areas that are protected for an isolated or relict population of a once more widespread species. It is suggested here that a more appropriate term for this strategy is the establishment of "migratory pathways" for dynamic coastal wetlands, with "migration" in this case occurring over multi-decadal time scales.

As part of the study entitled *A "Coastal Blue Carbon" Assessment of the Tampa Bay Estuary: Accounting for the Climate Change Mitigation Benefits of Integrated Climate Change Adaptation and Ecosystem Restoration in Tampa Bay* (ESA, in preparation) the HEM was utilized to identify low-lying coastal uplands that are currently undeveloped, and that are predicted to become intertidal by 2100. Polygons of these areas were then intersected with county parcel data to develop a spatial database of the property owners – both public and private sector. HEM output was exported to GIS to create a series maps showing high priority coastal uplands. Figure 9 is a map from this series for the Middle Tampa Bay segment. This figure shows undeveloped (e.g., non-impervious areas) upland parcels in 2007 that are predicted to be intertidal or subtidal in 2100 under the intermediate high sea level rise scenario (51.1 in.), contiguous undeveloped uplands, and associated publicly- and privately owned parcels. This information was developed as a tool to identify and prioritize parcels for the potential conservation of habitat migratory pathways.

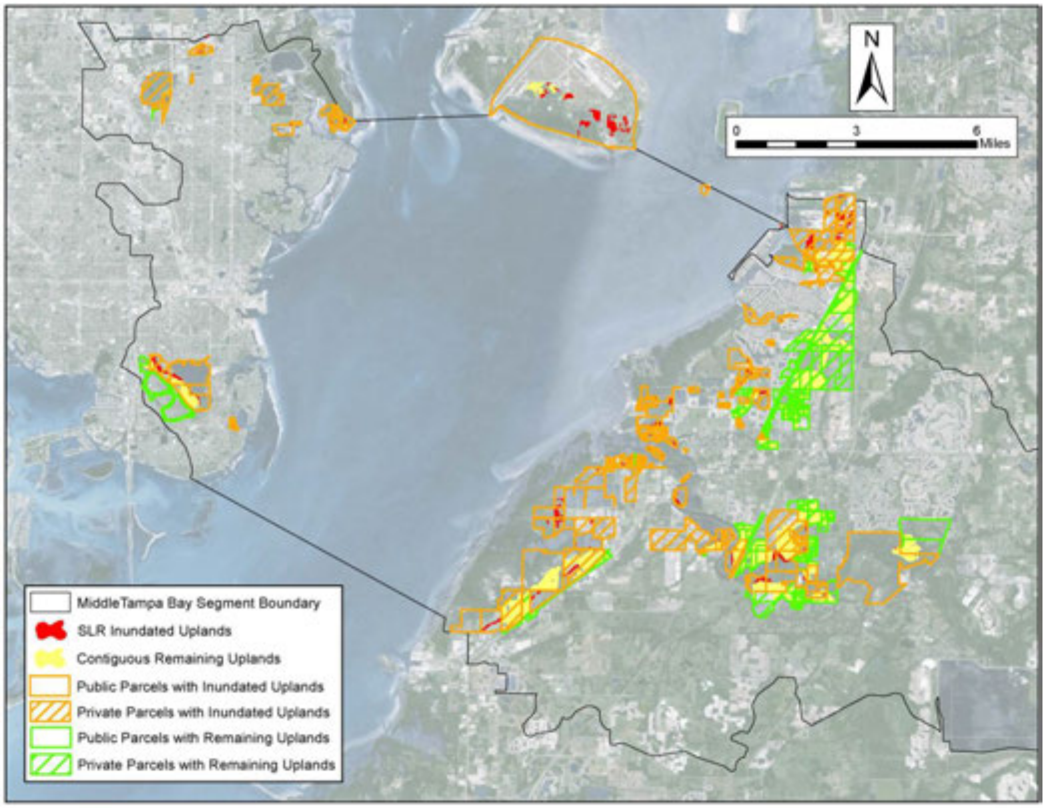

Figure 9 – Undeveloped 2007 coastal uplands predicted to be inundated by 2100 with associated parcel data.

It should be noted that conserving existing undeveloped coastal uplands alone will likely not be adequate to ensure the integrity of coastal wetlands in the future. In addition to just conserving parcels, it may be necessary to physically prepare many parcels to properly "accommodate" tidal inundation in a manner that allows for the succession of natural zonation patterns and the establishment of a mosaic of coastal wetland habitats. Such preparation may include grading and contouring, as well as the creation of drainage pathways and erosion control features, perhaps decades in advance of tidal inundation.

In addition to undeveloped coastal uplands, consideration should be given to identifying low-lying developed areas that will no longer be economically viable to maintain due to persistent tidal flooding and inadequate drainage. Developed lands that are abandoned due to rising sea levels will require even more preparation, as structures, impervious surfaces, and other infrastructure will need to be removed in advance of tidal inundation. Figure 10 below shows a rendition of a hypothetical developed parcel that has been abandoned and physically prepared to accommodate sea level rise in a manner that leads to the succession of diverse coastal wetland habitats.

Figure 10 - Rendition of an abandoned developed parcel prepared to accommodate sea level rise.

Given the certainty and relative predictability of the problem, sea level rise should now also be factored into all potentially affected water and environmental resource management and regulatory programs, including:

- Minimum flows and levels;
- TMDLs and BMAPs;
- 404 and ERP permitting and related mitigation; and
- Coastal restoration planning (e.g., RESTORE Act and related funding).

In the face of sea level rise, the future paradigm for coastal restoration planning and design may largely be focused on modifying existing upland landscapes to accommodate future tidal inundation, habitat migration, and natural succession.

STRATEGIES FOR IMPROVING URBAN COASTAL RESILIENCE

Like all other low-lying coastal cities, the Tampa Bay metropolitan area is now facing much more challenging decisions than ever imagined, even with the more conservative estimates of sea level rise. A significant portion of the Tampa Bay metropolitan area was built on low-lying coastal lands at elevations that will be inundated by the end of this century. Figure 11 shows the extent of the projected Mean Higher High Water (MHHW = 5.61 feet NAVD) in the year 2100. Most of the area inundated in this projection is currently in urban development, which will necessitate both adaptation strategies and planned retreat.

Figure 11 – Extent of the projected 2100 Mean Higher High Water line (MHHW = 5.61 feet NAVD) in the Tampa Bay area (ESA, 2106 – in preparation).

While coastal habitat loss is certainly a major issue of concern, nearly every aspect of coastal zone management, zoning, infrastructure, and planning will need to be reconsidered in light of sea level rise projections. This will require a detailed analysis and documentation of: elevations of roadways and other infrastructure; susceptibility of coastal, wetland and artificial fill areas to erosion; potential sources and releases of pollutants and contaminants; changing drainage and storm surge risks; structural viability of buildings and levees with changing groundwater levels; risk of saline water intrusion to existing fresh potable water sources; and structural modifications necessary to maintain connectivity of roadways and other infrastructure. Unfortunately, public awareness of these challenges and the political will to begin addressing them has not yet reached a critical mass in the Tampa Bay area.

The Southeast Florida Regional Climate Change Compact is an example of another coastal region in Florida where both public awareness and political will have taken hold. The Compact is an agreement adopted by the Broward, Miami-Dade, Monroe and Palm Beach County Commissions in January 2010. The counties recognized the vulnerability of the Southeast Florida region to the impacts of climate change and resolved to work collaboratively on mitigation and adaptation strategies such as joint policies to influence climate/energy legislation and funding at state and federal levels, developing a *Regional Climate Change Action Plan*, and hosting annual summits to review progress and discuss strategies. Common sense measures being planned and implemented to improve coastal resilience in densely populated southeast Florida include the following.

- **Identification and protection of essential existing infrastructure and development.** Protective measures include shoreline armoring, levees and pumps, and elevated structures, roadways and other critical infrastructure.

- **Restriction of new infrastructure and development in coastal flood prone areas.** Restrictive measures include a range of regulatory and planning tools to curtail new development in coastal areas subject to tidal flooding.

- **Public acquisition of developed parcels depreciated by coastal flooding.** Strategies include the dedication of funding sources to acquire developed coastal parcels depreciated by nuisance tidal flooding and/or damaged by hurricane storm surge.

- **Conservation of undeveloped coastal parcels threatened by sea level rise.** Strategies include the development of incentives and disincentives for private owners of undeveloped coastal parcels to maintain their properties as open lands suitable for accommodating future tidal inundation and habitat migration. The concept of “rolling easements” to “reserve” coastal uplands for future habitat migration (Titus, 2011) is a promising legal mechanism that should be further explored.

The Southeast Florida Regional Climate Change Compact provides a model for Tampa Bay area local governments to follow. This type of local government collaboration will be needed to effectively manage sea level rise, for both the built and natural environments.

Although a near-term increase in sea level rise and nuisance tidal flooding may be locked in, there are still many uncertainties with regard to the long-term trajectory of sea level rise. To slow the rate of sea level rise, and enable coastal communities to adapt in affordable and manageable ways, emissions of greenhouse gases must be reduced now. Given their ability to sequester and store large quantities of atmospheric carbon, ensuring the sustainability of coastal blue carbon habitats should be a component of the overall climate change adaptation strategy for the greater Tampa Bay area.

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REFINING CARBON SEQUESTRATION ESTIMATES OF SEAGRASS MEADOWS IN TAMPA BAY

David Tomasko, Stephen Crooks and Doug Robison

ABSTRACT

As of 2012, there were an estimated 14,243 ha of seagrass meadows in Tampa Bay. Seagrass meadows are the dominant blue carbon habitat in Tampa Bay, compared to the estimated 6,127 ha of mangroves and 1,779 ha of saltmarsh. However, and unlike mangroves and saltmarshes, the entirety of carbon fixation, growth and decay in seagrass meadows occurs in a submerged environment. While rates of primary production in seagrass meadows rank among the highest for any ecosystem on the planet, the organic content of sediments below seagrass meadows is typically much lower than the organic content of soils associated with mangroves and saltmarshes. This paper compares bay-wide estimates of primary production of seagrass meadows in Tampa Bay to estimates of carbon sequestration via sediment burial alone. The much greater rates of primary production found, compared to rates of carbon sequestration via burial, leads to two main conclusions – either sequestration can occur via pathways other than burial alone, or a much smaller percentage of assimilated carbon is sequestered by seagrass meadows, compared to other blue carbon habitats. Based on a combined estimate of both physical and chemical sequestration processes and pathways, the seagrass meadows of Tampa Bay appear to be able to sequester approximately 41,731 Mg C / yr, which approximates the annual carbon output of ca. 32,000 typical cars.

INTRODUCTION

Recently, the term "blue carbon" has gained significant levels of attention by marine researchers and resource managers. Blue carbon refers to that amount of carbon storage and sequestration that is associated with marine ecosystems. Tampa Bay is one of four members of the EPA's National Estuary Program to contain three major blue carbon habitats: salt marshes, mangroves, and seagrass beds (Russell and Greening 2015).

More than 30 years ago, seagrass meadows were suggested to be an important carbon sink that could mitigate some of the impacts of anthropogenic CO_2 loads to the atmosphere (Smith 1981). The idea that seagrass meadows could be an important component of carbon sequestration is in part due to the documentation of very high levels of primary production, as early researchers noted that primary production rates of seagrass meadows "…can rival the most productive agricultural areas" (Westlake 1963 as cited by Zieman and Wetzel 1980). While carbon storage values and sequestration rates are fairly well documented for some blue carbon habitats, sequestration rates for seagrass meadows need to take into account that seagrass meadows are fully submerged habitats, and the fate of assimilated carbon is likely more strongly influenced by water chemistry than is the case with salt marshes and mangroves.

This paper summarizes the uncertainties that exist related to carbon sequestration rates for seagrass meadows by comparing bay-wide estimates of carbon sequestration against each other using different assumptions available in peer-reviewed literature. In addition, these separately derived carbon sequestration estimates were then compared against a bay-wide estimate of the potential amount of annual carbon assimilation via seagrass throughout Tampa Bay. The literature related to carbon assimilation rates was also compared to a short-duration experiment conducted with the species *Thalassia testudinum,* to determine if literature-based estimates might over or under estimate bay-wide and annualized primary production estimates, based on expectations of variability due to water depth and season. Finally, discrepancies between an estimate of bay-wide carbon assimilation and various literature-derived carbon sequestration rates are discussed as to how such differences can be resolved in the future.

MATERIALS AND METHODS

Developing literature-based carbon assimilation rate estimates for seagrass

Estimates of primary production rates of seagrass meadows date back more than 100 years, when Peterson (1918, as cited in Zieman and Wetzel 1980) estimated production rates of *Zostera marina* in Danish waters. Rates of primary production have typically been measured either through changes in above-ground biomass over time or rates of carbon uptake for all the major species of seagrass found in Tampa Bay. A summary of area-normalized rates of carbon assimilation, by species, was developed based on literature for those genera, if not species, that are found in Tampa Bay. For those studies where production was originally expressed in units of grams dry weight, rather than grams of carbon, we assumed a carbon content of 35 percent of dry weight to convert units of dry weight to units of carbon, as per Fourqurean et al. (2012). When values were not available on a yearly basis, an annual estimate was derived based on the average of all available values (sometimes estimated from graphs if no data were shown in tabular form) for each report. For most of the literature, it appears that the primary method of data collection was such that production rates are derived based on changes in above-ground biomass overtime, which likely underestimates total production.

For the species *S. filiforme*, prior work has shown that perhaps 60 percent of above-ground productivity is exported to other locations (Zieman 1980). For the purposes of this study, that amount of exported productivity is not counted, as the purpose here is to estimate the potential for carbon sequestration within Tampa Bay itself. Export rates of 1 percent were applied to areal production rate estimates for both *Halodule wrightii* and *Thalassia testudinum*, consistent with estimates from Zieman and Wetzel (1980).

The area-normalized net primary production rate estimates in the literature vary substantially between species. To develop bay-wide estimates of net primary production, seagrass acreage estimates for different bay segments were combined with transect data to come up with estimated coverage, by species, for each major segment of Tampa Bay. Species composition in each of the major bay segments was estimated using data within Avery and Johansson (2001) who recorded information on the species distribution along each of 61 seagrass monitoring transects throughout Tampa Bay. Transects were located in Hillsborough Bay (11), Old Tampa Bay (12), Middle Tampa Bay (13), Lower Tampa Bay (14) and Boca Ciega Bay (11). For those transects where seagrass was encountered, the percent frequency of occurrence for each species was calculated and that frequency of occurrence was then multiplied by the acreage of seagrass per bay segment for the year 2012. For example, if the combined transects in Old Tampa Bay had *H. wrightii* occurring 75 percent of the time when seagrass was found, and *T. testudinum* occurring 25 percent of the time when seagrass was found, and the total acreage of seagrass was 500 acres, then it would be estimated that *H. wrightii* meadows would account for 375 acres of seagrass (0.75 x 500 acres) and *T. testudinum* would account for 125 acres of seagrass (0.25 x 500 acres). These acreage estimates for each bay segment were then multiplied by the species-specific primary production estimate, and the values for each species, for each bay segment, were then summed to develop a bay-wide primary production estimate for all species combined.

Field study to measure seagrass carbon assimilation rates

To verify the appropriateness of the literature-based carbon assimilation rates, a field study was conducted during the period of May11 to May 22, 2015. The field study was conducted at two locations, a *T. testudinum* meadow on the east side of Old Tampa Bay south of the Courtney Campbell Causeway (site OTB; 27° 58' north latitude, 82° 33' west longitude) and a second *T. testudinum* meadow offshore of Ft. De Soto Park (site LTB; 27° 38' north latitude, 82° 42' west longitude). The two sites were chosen to represent locations with both low (OTB) and high (LTB) sediment carbonate contents (data from USGS 2007).

Study sites were at the deep edge (where shoots occupied approximately 10 percent of 10 cm by 10 cm cells in a 1 square meter quadrate), the shallow edge (where *T. testudinum* was at 100 percent coverage but where shallower depths were not occupied by *T. testudinum*) and at a mid-depth, approximately half way (distance) between the shallow and deep edges.

At each depth, above-ground primary production was estimated using the needle-marking technique, as in Dawes and Tomasko (1988) Tomasko et al. (1996) and Tomasko and Hall (1999). This technique involves marking seagrass blades (n =5) with a hypodermic needle, and recording the amount of blade material produced over time based on the upward displacement of blades compared to a reference point on the seagrass shoot. Shoot densities were enumerated in 10 replicate 25 cm by 25 cm quadrats. Areal primary production rate estimates were derived by taking the shoot-specific production rate estimates and multiplying them by shoot densities normalized to a square meter. Due to either vandalism or other factors, the marked shoots at the shallow edge in Old Tampa Bay could not be found. Different shoots were used to estimate biomass per shoot, and per shoot biomass was multiplied by the mean turnover rate at the other two locations in Old Tampa Bay to derive a productivity estimate for the shallow edge at that location.

A previously developed regression between blade area and dry weight (Prado and Heck 2011) was combined with leaf carbon content estimates from Fourqurean et al. (2012) to derive carbon assimilation rate estimates in units of g C m^{-2} d^{-1}.

Developing literature-based carbon sequestration rates for seagrass

Bay-wide estimates of carbon sequestration were developed based on an approach outlined in Russell and Greening (2015). In that paper, the authors used bay-wide estimates of seagrass coverage and combined that information with literature-derived estimates of carbon sequestration rates for seagrass. Using those two parameters, estimates of carbon sequestration across the entire bay were then developed (Russell and Greening 2015). For purposes of the assessment outlined in this memorandum, the bay-wide seagrass coverage estimate for the year 2012 of 14,243 ha (35,194 acres) was used, to allow comparison with other blue carbon sequestration amounts listed in Russell and Greening (2015).

RESULTS

Literature-based carbon assimilation rate estimates

A summary of area-normalized rates of carbon assimilation for various species found in Tampa Bay is shown in Table 1. The values in Table 1 are the arithmetic averages of all the annual estimates for each species from each report cited. The rate estimate from Chiu et al. (2013) is for the species *T. hemprichii*, rather than *T. testudinum*, the species found in Tampa Bay.

Table 1 – Literature-derived area-normalized rates of carbon assimilation by species.

Species	Annual net primary production estimate ($g\ C\ m^{-2}\ yr^{-1}$)	Studies used to develop estimate
Halodule wrightii	584	Dillon (1971 [as cited in Zieman and Wetzel 1980]), Tomasko and Dunton (1995), Neely (2000)
Syringodium filiforme	292	Zieman and Wetzel (1980)
Thalassia testudinum	979	Zieman and Wetzel (1980), Tomasko et al. (1996), Tomasko and Hall (199), Lee and Dunton (1996), Chiu et al. (2013)

Using the approach outlined above, the species composition estimates by bay segment were then compiled for the bay as a whole for the year 2012. The amount of seagrass coverage, bay-wide and by species, is estimated as: H. wrightii – 7,297 ha, T. testudinum – 4,598 ha, Syringodium filiforme – 2,126 ha, Halophila engelmannii – 202 ha, and Ruppia maritime – 19 ha.

These bay-wide estimates of seagrass coverage, by species, were than multiplied by the primary productivity estimates in Table 1 to develop a carbon assimilation rate estimate. This bay-wide estimate came to 89,255 Mg C per year, or 89 million kg C per year.

Field study of seagrass carbon assimilation rates

Table 2 summarizes results of the seagrass primary production field study, in terms of shoot density, biomass per shoot, and leaf turnover rate. Shoot densities are shown as estimates per square meter, based on multiplying the mean value of n=10 recordings of shoot density per 25 cm by 25 cm quadrat.

Table 2 – Results from shallow, mid and deep depths of *Thalassia testudinum* in Old Tampa Bay and Lower Tampa Bay. Shoot density is represented as mean per square meter, based on 25 cm by 25 cm quadrats (n = 10). Other estimates are based on n = 5. Turnover rates could not be directly measured at Old Tampa Bay shallow depths (see text for explanation).

Site	Depth	Shoot density (no. / m^2)	Biomass per shoot (mg dw / shoot)		Turnover rate (percent / d)	
		Mean	Mean	Std. dev.	Mean	Std. dev.
Old Tampa Bay	**Shallow**	**488**	**190.0**	**66.4**	**nd**	**nd**
Old Tampa Bay	**Mid**	**77**	**67.1**	**42.6**	**5.7**	**2.2**
Old Tampa Bay	**Deep**	**43**	**64.7**	**26.2**	**4.6**	**1.1**
Lower Tampa Bay	**Shallow**	**454**	**516.6**	**125.6**	**2.5**	**0.4**
Lower Tampa Bay	**Mid**	**384**	**237.0**	**53.7**	**2.7**	**0.6**
Lower Tampa Bay	**Deep**	**19**	**202.5**	**52.4**	**2.9**	**0.6**

Shoot densities and biomass per shoot declined from shallow to deep edges, as had been previously found for *T. testudinum* meadows in Tampa Bay (Dawes and Tomasko 1988, Tomasko and Dawes 1990). However, there was no evidence of a difference in leaf turnover rates between depths. Turnover rates measured here were either similar, or slightly higher than rates previously measured in the spring to summer in both Sarasota Bay (Tomasko et al. 1996) and Charlotte Harbor (Tomasko and Hall 1999).

With leaf turnover rates being similar with depth, any differences in area-normalized primary production rates would thus reflect differences in shoot density and biomass per shoot. Converted to units of grams of carbon per square meter per day, results show that productivity often differs more with depth at a single location than it does between different locations at the same depths (Figure 1).

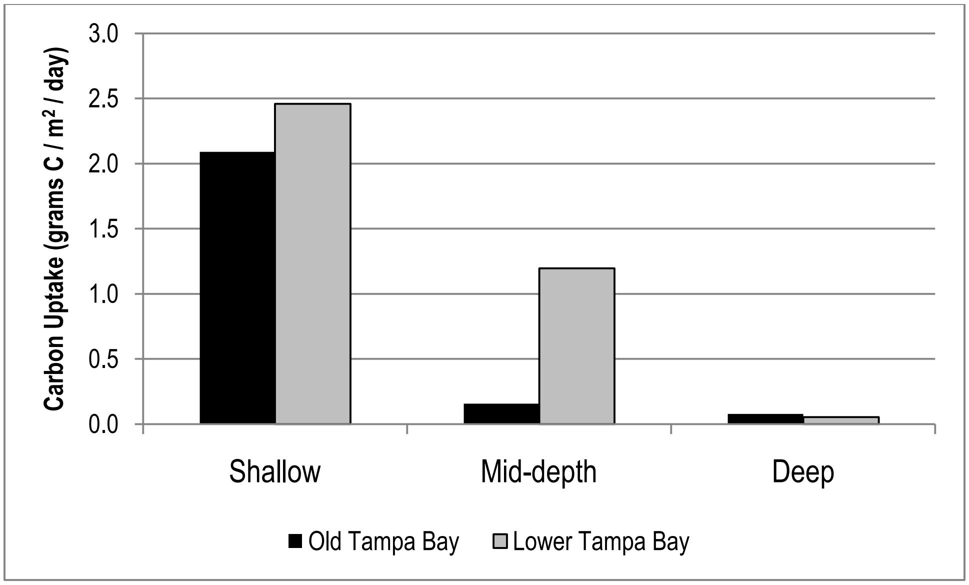

Figure 1 – Above-ground primary productivity (grams C / m² / d) at shallow, mid and deep edges of *T. testudinum* meadows in Old Tampa Bay and Lower Tampa Bay.

The mean value of above-ground primary production from both shallow locations was 2.28 g C m-2 d^{-1}. Multiplying that rate by 365 days, the resulting annual estimate of primary production is 830 g C m^{-2} yr^{-1}, similar to the literature-derived estimate for *T. testudinum* of 979 g C m^{-2} yr^{-1} shown in Table 1. These results suggest that literature-based values of annual production might be over-estimates, as they are similar to values recorded here from shallow depths in the spring growing season. As production rates of *T. testudinum* are known to be lower in deeper depths (Dawes and Tomasko 1988, Tomasko and Dawes 1990) and in fall to winter months (Tomasko et al. 1996, Tomasko and Hall 1999) it is thus likely that literature-based values of primary production overestimate production across the combination of depths and seasons that would be needed to develop a bay-wide and annual average value of primary production.

Literature-based carbon sequestration rates

Literature-derived estimates of carbon sequestration rates for seagrass vary widely. In their paper, Russell and Greening (2015) used a carbon sequestration rate for seagrass meadows of 138 g C m^{-2} yr^{-1}, as listed in McLeod et al. (2011). In turn, McLeod et al. (2011) developed their estimate from six published and one unpublished study on carbon burial rates in seagrass meadows.

Other researchers have published carbon sequestration rates via burial in sediments below seagrass meadows. Duarte et al. (2005) derived a global carbon sequestration rate estimate for seagrass meadows of 83 g C m^{-2} yr^{-1}. In the coastal waters of Virginia, newly reestablishing seagrass meadows were estimated to sequester carbon at a rate of 38 g C m^{-2} yr^{-1} (Greiner et al. 2013) while researchers in Korea developed carbon sequestration rates for seagrass meadows of 20 g C m^{-2} yr^{-1} (Chiu et al. 2013). Thus, if bay-wide estimates of carbon sequestration rates (amounts of carbon sequestered per year) are based on the spatial extent of meadows multiplied by area-normalized sequestration rates (g m^{-2} yr^{-1}) then bay-wide estimates could vary by a factor of nearly 7-fold, depending upon which sequestration rate estimate was used.

Figure 2 compares literature-based estimates of bay-wide carbon assimilation in Tampa Bay with literature-based bay-wide estimates of carbon sequestration via burial.

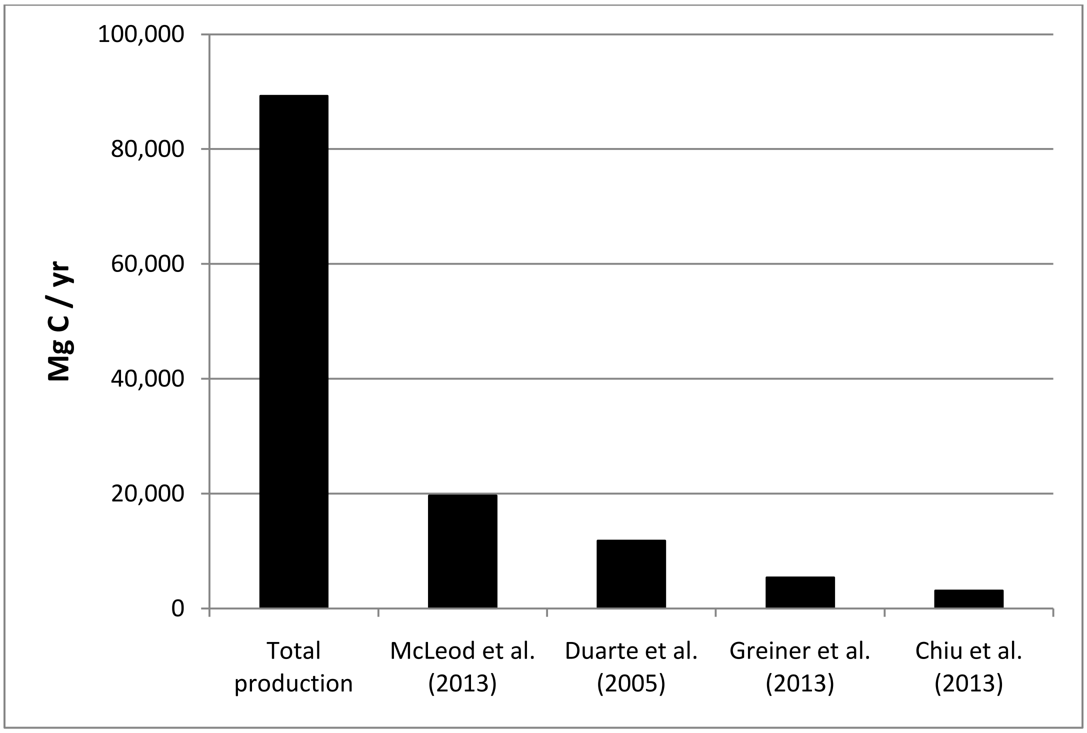

Figure 2 – Comparison of bay-wide estimates of carbon assimilation vs. various literature-based and bay-wide estimates of carbon sequestration via burial. Data are in units of mega grans of carbon per year (1 mega gram = 1,000 kg).

Even if the highest literature-based carbon sequestration estimate (138 g C m^{-2} yr^{-1}; McLeod et al. 2011) is used, there appears to be a much larger amount of assimilation of carbon by seagrass meadows in Tampa Bay than the amount of carbon sequestered through burial alone.

DISCUSSION

Most of the literature related to quantification of carbon sequestration benefits of seagrass meadows is based on the process of burial of fixed carbon in the sediments below these meadows (e.g., Duarte et al. 2010, Fourqurean et al. 2012, Greiner et al. 2013, McLeod et al. 2013). Using this technique, carbon sequestration is quantified as a function of the rate of accumulation of sediments over time, and the organic carbon content of those same sediments.

When annual estimates of primary production of seagrass meadows in Tampa Bay are compared to literature-based estimates of sequestration via burial alone (Figure 2) there appear to be much higher rates of carbon assimilation than even the highest estimated rate of carbon sequestration via burial. These results would suggest that there is a much larger amount of carbon assimilated by seagrass meadows than the amount of carbon sequestered by burial alone. This discrepancy is likely due to some combination of factors, such as the likelihood that literature-based estimates of annual primary production are biased on the high end, and that other mechanisms of carbon sequestration other than burial could be involved. Conversely, it could be that the vast majority of carbon assimilation via seagrass meadows is not sequestered in any way, but is recycled back into the water column or exported elsewhere, as noted for *S. filiforme* by Zieman and Wetzel (1980).

In seagrass meadows, carbon sequestration has been documented to occur via an alternative process to burial alone, the so-called bicarbonate pathway, described more than 30 years ago by Smith (1981). In tropical and carbonate-rich sediments, researchers have noted that the very high production rates of *T. testudinum* in the Bahamas did not correlate with similarly high rates of carbon accumulation in sediments. Despite very high densities of seagrass meadows, and high rates of primary production, the organic content of sediments in seagrass meadows in the Bahamas averaged less than 1 percent (Burdige and Zimmerman 2002). For seagrass meadows, the global average values of organic content of sediments listed in Duarte et al. (2010) and Fourqurean et al. (2012) are 0.7 and 1.4 percent of dry weight, respectively. In contrast, the organic content of sediments associated with mangroves and saltmarshes are typically much higher, ranging from ca. 20 to 80 percent of dry weight (when converted to similar units; Chmura et al. 2003).

For seagrass meadows, the question of “where does the fixed carbon go?” was answered in part by Burdige and Zimmerman (2002) based on the following equation:

$$CH_2O + O_2 + CaCO_3 \longleftrightarrow Ca^{2+} + 2HCO_3^-$$

This equation summarizes the process through which fixed carbon (CH_2O) is decomposed in carbonate sediments ($CaCO_3$) under conditions where sediments are oxygenated via the seagrass root/rhizome complex (O_2). The end result of this process is both free calcium ions (Ca^{2+}) and previously fixed carbon now present in the form of bicarbonate ions ($2HCO_3^-$). The bicarbonate portion of the world’s oceans has been referred to as a global and benign (in terms of greenhouse gas dynamics) carbon sink by various researchers (Rau and Caldeira 1999, Rau et al. 2001, Isobe et al. 2002, Harvey 2008).

In addition, Unsworth et al. (2012) have noted that the bicarbonate sequestration pathway is a mechanism though which seagrass meadows could provide a positive benefit to any nearby coral reefs, via their ability to offset impacts of ocean acidification associated with CO_2 enrichment of coastal waters. The bicarbonate sink pathway was the primary mechanism through which it is believed carbon sequestration occurs for the seagrass meadows in the Bahamas Banks (Burdige and Zieman 2002, Burdige et al 2010) and Tokyo Harbor (Isobe et al. 2012).

In Tampa Bay, recent work by Yates et al. (2015) which was conducted concurrent with the field investigation described here, determined that seagrass meadows were capable of increasing daytime pH values by 0.5 units, consistent with expectations as inorganic carbon is taken up by photosynthesis. As well, seagrass meadows were found to increase, at least locally, carbonate saturation rates in the water column, suggesting that the mechanisms involved in the bicarbonate pathway outlined by Burdige and Zimmerman (2002) could be occurring in Tampa Bay seagrass meadows.

As an initial assessment, we combined estimates of seagrass-associated rates of carbon sequestration via the physical process of burial (138 g C m^{-2} yr^{-1}; MacLeod et al. 2013) with estimates of seagrass-associated rates of carbon sequestration via the chemical processes of the bicarbonate pathway (155 g C m^{-2} yr^{-1}; Unsworth et al. 2012) to produce a combined carbon sequestration estimate of 293 g C m^{-2} yr^{-1}. This combined sequestration estimate is nearly identical to the literature-based annualized primary production rate estimate for *S. filiforme*, but lower than the primary production rate estimate of *H. wrightii*, and substantially lower than that of *T. testudinum* (Table 1). Most importantly, this estimate of combined (physical and chemical) carbon sequestration pathways is not higher than the annualized primary production estimates of any of the main species of seagrass in Tampa Bay, as listed in Table 1, which would signify that sequestration was occurring in excess of assimilation (which would be difficult to interpret).

If this combined carbon sequestration rate estimate of 293 g C m^{-2} yr^{-1} is extrapolated out to the 16,307 ha of seagrass in Tampa Bay (as of 2012) then the annualized bay-wide estimate of carbon sequestration comes to 41,731 Mg C yr^{-1}. This amounts to approximately 47 percent of the estimated bay-wide annualized carbon assimilation rate for seagrass meadows of 89,255 Mg C yr^{-1}. Based on the on-line Greenhouse Gases Equivalency calculator developed by the US Environmental Protection Agency (http://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator) the seagrass meadows of Tampa Bay appear capable of sequestering an amount of carbon equivalent to the carbon footprint of ca. 32,000 cars.

To increase the confidence in carbon sequestration estimates for seagrass meadows in any location, it would be useful to have multiple and site-specific data collected on sediment organic and carbonate contents within seagrass meadows, as well as the collection of data that could be used to test for the presence of the carbonate dissolution and bicarbonate sequestration pathways outlined by Burdige and Zimmerman (2002), Burdige et al. (2012) and Unsworth et al. (2012). With these additional data, sequestration rate estimates for seagrass could be derived other than through the use of literature alone, and resource managers would have enhanced confidence in their model output for what could be a dominant blue carbon habitat, as in Tampa Bay. Without this additional data collection, the carbon sequestration values derived for seagrass meadows could vary considerably, dependent upon which study was used in calculations.

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OCEAN ACIDIFICATION BUFFERING EFFECTS OF SEAGRASS IN TAMPA BAY

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ABSTRACT

The Intergovernmental Panel on Climate Change has identified ocean acidification as a critical threat to marine and estuarine species in ocean and coastal ecosystems around the world. However, seagrasses are projected to benefit from elevated atmospheric pCO2, are capable of increasing seawater pH and carbonate mineral saturation states through photosynthesis, and may help buffer against the chemical impacts of ocean acidification. Additionally, dissolution of carbonate sediments may also provide a mechanism for buffering seawater pH. Long-term water quality monitoring data from the Environmental Protection Commission of Hillsborough County indicates that seawater pH has risen since the 1980's as seagrass beds have continued to recover since that time. We examined the role of seagrass beds in maintaining and elevating pH and carbonate mineral saturation state in northern and southern Tampa Bay where the percent of carbonate sediments is low (<3%) and high (>40%), respectively. Basic water quality and carbonate system parameters (including pH, total alkalinity, dissolved inorganic carbon, partial pressure of CO2, and carbonate mineral saturation state) were measured over diurnal time periods along transects (50-100 m) including dense and sparse Thalassia testudinum. seagrass beds, deep edge seagrass, and adjacent bare sand bottom. Seagrass density and productivity, sediment composition and hydrodynamic parameters were also measured, concurrently. Results indicate that seagrass beds locally elevate pH by up to 0.5 pH unit and double carbonate mineral saturation states relative to bare sand habitats. Thus, seagrass beds in Tampa Bay may provide refuge for marine organisms from the impacts of ocean acidification.

INTRODUCTION

The IPCC has confirmed that ocean acidification (OA) has a profound effect on ocean and coastal ecosystems and communities around the globe (IPCC, 2014). Many marine and estuarine species will be negatively impacted (Barton et al., 2012; Gazeau et al., 2007; Fabry et al., 2008; Kurihara, 2008; Kroecker et al., 2010; Narita et al., 2012; Waldbusser et al., 2011); and it is projected that some species (especially calcifying species) may become locally and/or globally extinct. Management strategies have focused on reducing local stressors to reduce the impact of multiple stressors on ecosystems, and on identifying and establishing protected areas with environmental conditions that promote resiliency to marine organisms (Salm et al., 2006).

Long-term water quality monitoring data from the Environmental Protection Commission of Hillsborough County (EPC-HC: http://www.epchc.org/index.aspx?nid=219) indicates that daytime values of seawater pH in Tampa Bay decreased from approximately 1970 to the early 1980's when the rate of seagrass habitat loss was at its peak. However, these same daytime pH values have steadily risen in Tampa Bay since the early 1980's when local management strategies improved water quality and seagrass beds have continued to recover since that time (Sherwood et al., 2016). Seagrasses are projected to benefit from elevated atmospheric pCO_2 (Kleypas and Yates, 2009), are capable of increasing seawater pH and carbonate mineral saturation states through photosynthesis, and may help provide protection to organisms living in close association with seagrass beds (e.g. Semesi et al., 2009; Anthony et al., 2011; Manzello et al., 2012; Hendriks et al., 2014).

We hypothesized that the recovery of seagrass in Tampa Bay has helped buffer against the chemical impacts of ocean acidification, may confer some resiliency to organisms (such as shellfish and other economically important fish species) that are particularly sensitive to OA, and may serve as an important regional OA refuge. Additionally, dissolution of carbonate sediments may also provide a buffering mechanism for seawater pH (Kleypas and Yates, 2009). Tampa Bay is characterized by a natural gradient in sediment composition with upper portions of the bay dominated by siliciclastic sediments and lower portions of the bay dominated by carbonate sediments (Edgar et al., 2007). This mineralogical gradient in Tampa Bay provides a unique opportunity to examine the role of carbonate sediments in the ocean acidification process. To further examine these hypotheses, we performed a pilot study to examine the potential role of seagrass beds in elevating pH and carbonate mineral saturation state by measuring carbonate system parameters and related water quality parameters in representative habitats of Tampa Bay including seagrass beds and sand bottom communities and in siliciclastic and carbonate sediment dominated regions.

METHODS

Upper and lower Tampa Bay study sites were selected based on minimum and maximum carbonate sediment content, similarity of seagrass species and light availability. Lower bay study sites were located near Ft. Desoto Park where carbonate content of seafloor sediments is approximately 57% (Edgar et al., 2007). A 98 m shore-perpendicular transect was established beginning at the seaward extent on bare sand, near the deep edge of seagrass, and ending at the shoreward edge in a dense (80-90% estimated) seagrass bed (Table 1). Seagrass consisted primarily of *Thalassia testudinum* with scattered *Syringodium filiforme*. Characteristics of the seagrass meadows at the different locations are shown in Table 2. Upper bay study sites were located near the east end of Courtney Campbell Causeway where carbonate content of seafloor sediments is approximately 1-2% (Edgar et al., 2007). A 72 m shore-perpendicular transect was established beginning at the seaward extent on bare sand near the deep edge of seagrass, and ending at the shoreward edge in a dense seagrass bed. Seagrass consisted primarily of *T. testudinum* with scattered *S. filiforme* and *Halodule wrightii*.

Table 1. Location of Tampa Bay Study Sites.

Description	Latitude	Longitude	Depth (m)
Upper Tampa Bay Transect			
Bare sand	N 27.96120	W 82.55422	2.4
Deep edge	N 27.96120	W 82.55421	2.1
Transitional	N 27.96125	W 82.55417	1.5
Dense seagrass	N 27.96150	W 82.55393	0.9
Lower Tampa Bay Transect			
Bare sand	N 27.63576	W 82.69315	2.4
Deep edge	N 27.63584	W 82.69322	2.4
Transitional	N 27.63611	W 82.69355	1.8
Dense seagrass	N 27.63622	W 82.69365	1.2

Table 2. Characteristics of T. testudinum at study sites (data from May 2015, Tomasko et al., this issue).

Description	Mean shoot density (no. m^{-2})	Mean biomass per shoot (mg dw $shoot^{-1}$ ± stdev)	Depth (m)
Upper Tampa Bay Transect			
Deep edge	43	64.7 ± 26.2	2.1
Transitional	77	67.1 ± 42.6	1.5
Dense seagrass	488	190.0 ± 66.4	0.9
Lower Tampa Bay Transect			
Deep edge	19	202.5 ± 52.4	2.4
Transitional	384	237.0 ± 53.7	1.8
Dense seagrass	454	516.6 ± 125.6	1.2

We measured small-scale, spatial variability (sub-100 m) in basic and carbonate system parameters [including temperature (T), salinity (S), dissolved oxygen (DO), pH on the total pH scale (pHT), total alkalinity (TA), dissolved inorganic carbon (DIC), and aragonite saturation state (ΩA)] along transects from shallow, dense seagrass, to transitional and deep-edge seagrass, to bare sand during May 14-15, 2015 in Upper Tampa Bay and during May 20-21, 2015 in Lower Tampa Bay. We installed duplicate water sampling tubes at each study site by attaching the tube ends to cement blocks positioned in each substrate type approximately 16 cm above the seafloor and affixing the sampling end to a moored research vessel at the surface. Discrete seawater samples were collected for TA, DIC, and pHT analyses from each site every 4 h (n = 7) throughout 24 h periods. A peristaltic pump was used to pump seawater through a 0.45 µm filter into 500 ml borosilicate glass bottles. Samples for TA and DIC were preserved by adding 100 µL saturated $HgCl_2$ solution. Bottles were positive-pressure sealed with ground glass stoppers coated with Apiezon grease. Seawater samples for pHT were collected from the same peristaltic pump and filtered into 30mL glass optical cells, and were analyzed within 1 h of collection. Samples were analyzed for TA (± 1 µmol kg^{-1}) using spectrophotometric methods of Yao and Byrne (1998) with an Ocean Optics USB2000 spectrometer and bromocresol purple indicator dye, for DIC (± 3 µmol kg^{-1}) using a UIC carbon coulometer model CM5014 and CM5130 acidification module using methods of Dickson et al. (2007), and for pHT (± 0.005) via spectrophotometric methods of Zhang and Byrne (1996) with an Ocean Optics USB2000 spectrometer and thymol blue indicator dye. Dissolved oxygen (± 0.1 mg l^{-1}), temperature (± 0.01 ^{o}C), and salinity (± 0.01) were measured using a YSI ProDSS multi-meter calibrated daily. Certified reference materials (CRM) for TA and DIC analyses were from the Marine Physical Laboratory of Scripps Institution of Oceanography (A. Dickson). Duplicate or triplicate analyses were performed on at least 10% of samples. Carbonate system parameters for all study sites including aragonite mineral saturation state (ΩA) and pCO_2 were calculated from TA and pHT (or TA and DIC), temperature, and salinity measurements using the carbonate speciation program CO2sys (Pierrot et al., 2006) with dissociation constants K1 and K2 from Merbach et al. (1973) refit by Dickson and Millero (1987), KSO_4 from Dickson (1990), and using the total pH scale. A 1200 kHz RDI Workhorse Monitor Acoustic Doppler Current Profiler was installed at the seaward end of each transect in bare sand to collect water current profiles at each study site.

PRELIMINARY RESULTS AND DISCUSSION

Preliminary results indicate considerable heterogeneity in all water chemistry parameters over small spatial scales (meters) and diurnal time periods (Table 3, Figure 1). Greatest spatial and temporal variability occurred along the Upper Tampa Bay transect where average current magnitude was slowest (0.02 ms^{-1}). Average pHT, DO, and ΩA were higher and DIC, pCO_2 and TA were lower at all seagrass sites than in bare sand at the Upper Tampa Bay study site. Spatial and temporal gradients were generally lower along the Lower Tampa Bay transect where average current magnitude (of 0.1 ms^{-1}) was 5 times greater than at the Upper Tampa Bay study site, and average pH and ΩA were slightly lower in dense seagrass than in bare sand.

Table 3. Average values for discrete sample parameters at each study site in Upper and Lower Tampa Bay.

Description	pHT	stdev	DO	stdev	TA	stdev	DIC	stdev	pCO_2	stdev	ΩA	stdev
Upper Tampa Bay Transect												
Dense seagrass	8.188	0.288	127.8	53.4	2420.7	32.2	2070.0	165.5	367.8	185.5	4.7	1.7
Transitional	8.134	0.244	118.9	42.3	2423.4	26.2	2112.8	135.5	419.1	166.0	4.2	1.4
Deep edge	8.123	0.218	105.0	46.6	2424.9	21.3	2144.9	103.7	459.0	133.8	3.8	1.1
Sand	7.985	0.104	86.2	10.9	2448.7	15.5	2243.8	19.0	658.0	91.3	2.9	0.2
Lower Tampa Bay Transect												
Dense seagrass	7.951	0.137	96.7	35.3	2445.2	66.0	2141.1	128.2	545.9	239.9	3.7	0.8
Transitional	8.006	0.094	103.2	25.1	2433.4	34.3	2107.7	86.7	460.4	131.5	3.9	0.7
Deep edge	8.023	0.092	107.1	20.7	2426.0	25.9	2093.0	69.2	441.9	104.6	4.0	0.6
Sand	8.020	0.093	108.2	18.4	2419.4	24.0	2089.5	65.8	446.4	105.1	3.9	0.6

stdev = standard deviation

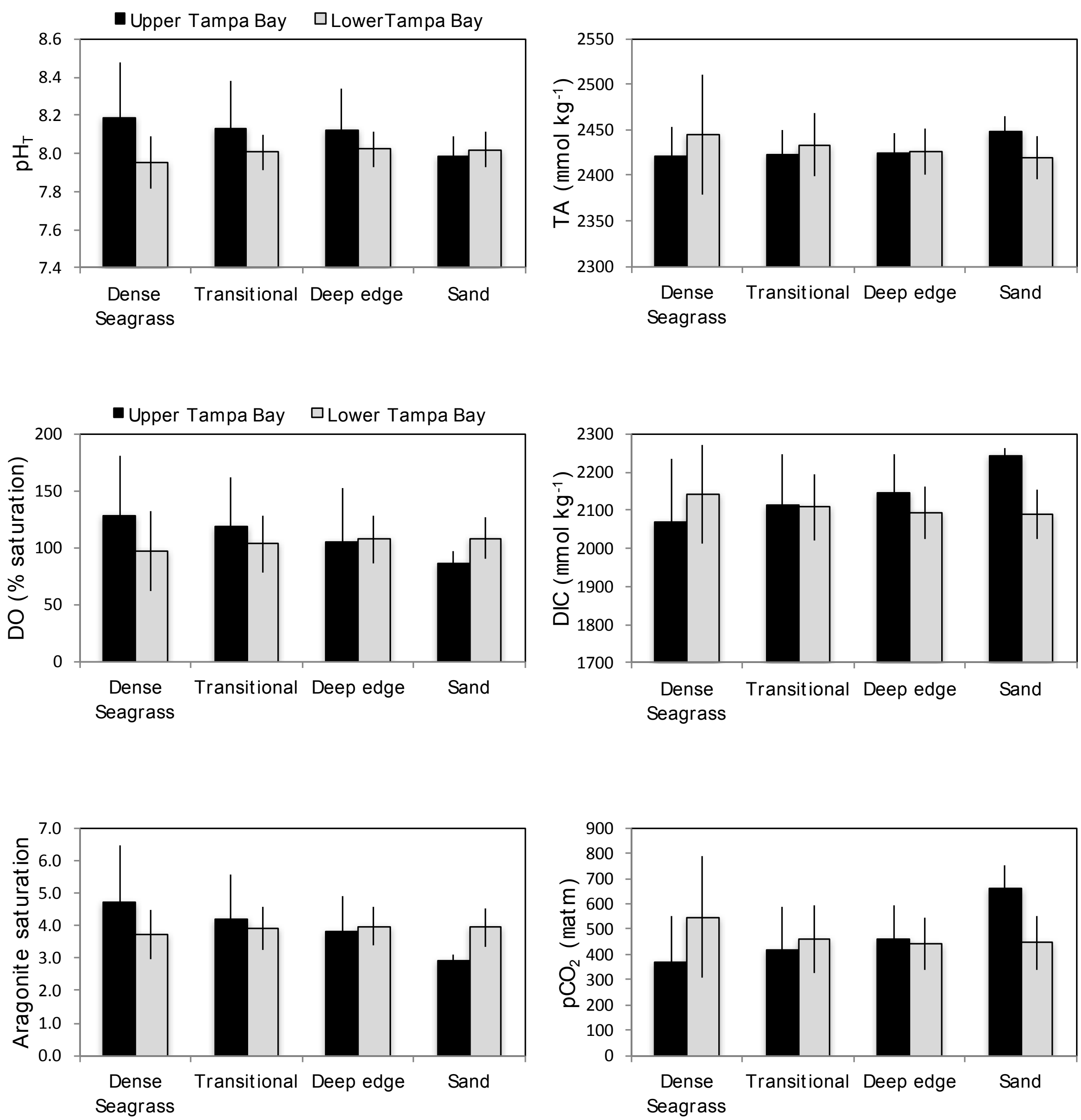

Figure 1. Average pHT, DO, aragonite saturation state (ΩA), TA, DIC, and pCO$_2$ for each substrate type along sampling transects in Upper (black) and Lower (gray) Tampa Bay. Vertical lines indicate plus and minus one standard deviation.

Greatest spatial variability occurred during afternoon (15:30) and evening hours (19:30) in Upper Tampa Bay (Figure 2). During these time periods, pH, DO, and ΩA were as much as 0.5 pH unit, 107% saturation, and 4.2 higher (and pCO_2 and total alkalinity were as much as

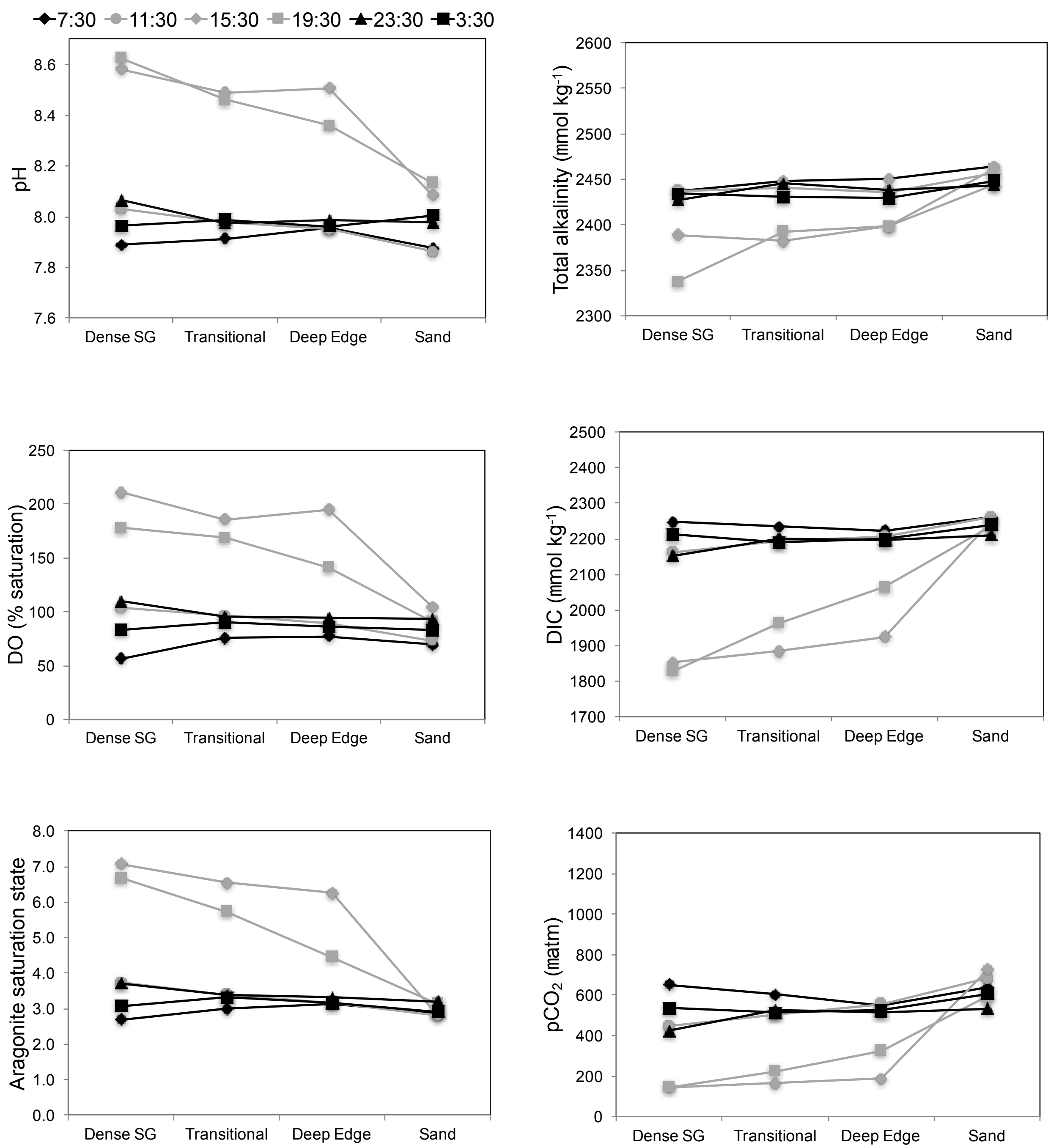

Figure 2. Time series for pHT, DO, aragonite saturation state (ΩA), TA, DIC, and pCO_2 for each substrate type along sampling transects in Upper Tampa Bay. Black lines indicate dark and early morning hours. Gray lines indicate day light and evening hours.

580 µatm and 123 µmol kg^{-1} lower) in dense seagrass than in sand, respectively. Greatest temporal variability occurred in dense seagrass beds with highest pH and DO, and lowest pCO_2 occurring during late afternoon and evening hours likely due to seagrass photosynthesis. Lowest TA also occurred during late afternoon and evening hours, possibly due to calcification by seagrass epiphytes. However, little variation occurred in TA at the sand site possibly due to a lack of calcifying organisms and carbonate sediments and, therefore, little calcification or dissolution at this location. High and low chemical parameter values generally occurred during early morning (07:30) or late afternoon to evening (15:30 to 17:30) at all seagrass sites.

Greatest spatial variation at the Lower Tampa Bay site occurred at 07:30, concurrently with a slack tide during which pH, DO and ΩA was 0.2 pH unit, 52% saturation and 1.1 lower, respectively, (and pCO_2 and TA was 594 µatm and 108 µmol kg^{-1} higher, respectively) in the dense seagrass bed than in sand likely due to respiration throughout the night (Figure 3).

TA at the dense seagrass site in Lower Tampa Bay showed greater temporal variability than in Upper Tampa Bay possibly due to the higher percentage of carbonate sediments in the Lower Bay and the potential for carbonate sediment dissolution (that may buffer decreases in pH).

Our preliminary results indicate that seagrass beds in Tampa Bay can elevate pH and ΩA over short (diurnal) time periods, and may provide a local buffer against ocean acidification. However, respiration in seagrass beds during dark hours may cause a decrease in pH and ΩA relative to surrounding substrate. Longer term and larger scale (e.g. baywide) benefit from seagrass buffering of pH depends upon diurnal, seasonal and annual variability in carbonate system parameters, and the magnitude and balance of high and low pH exposure periods over seagrass growth cycles. The considerable gradients in chemical parameters over small spatial scales, and an increase in magnitude of variation with decreasing current velocity, indicates that direct benefit from seagrass buffering of pH also depends upon proximity to seagrass and hydrodynamic effects including water mass residence time and water flow direction. The relatively consistent occurrence of diurnal high and low carbonate parameter values during early morning and late afternoon can be used in combination with basic hydrodynamic information such as tidal stage to formulate a longer-term and larger scale ocean acidification monitoring program to more fully characterize ocean acidification buffering effects of seagrass in Tampa Bay.

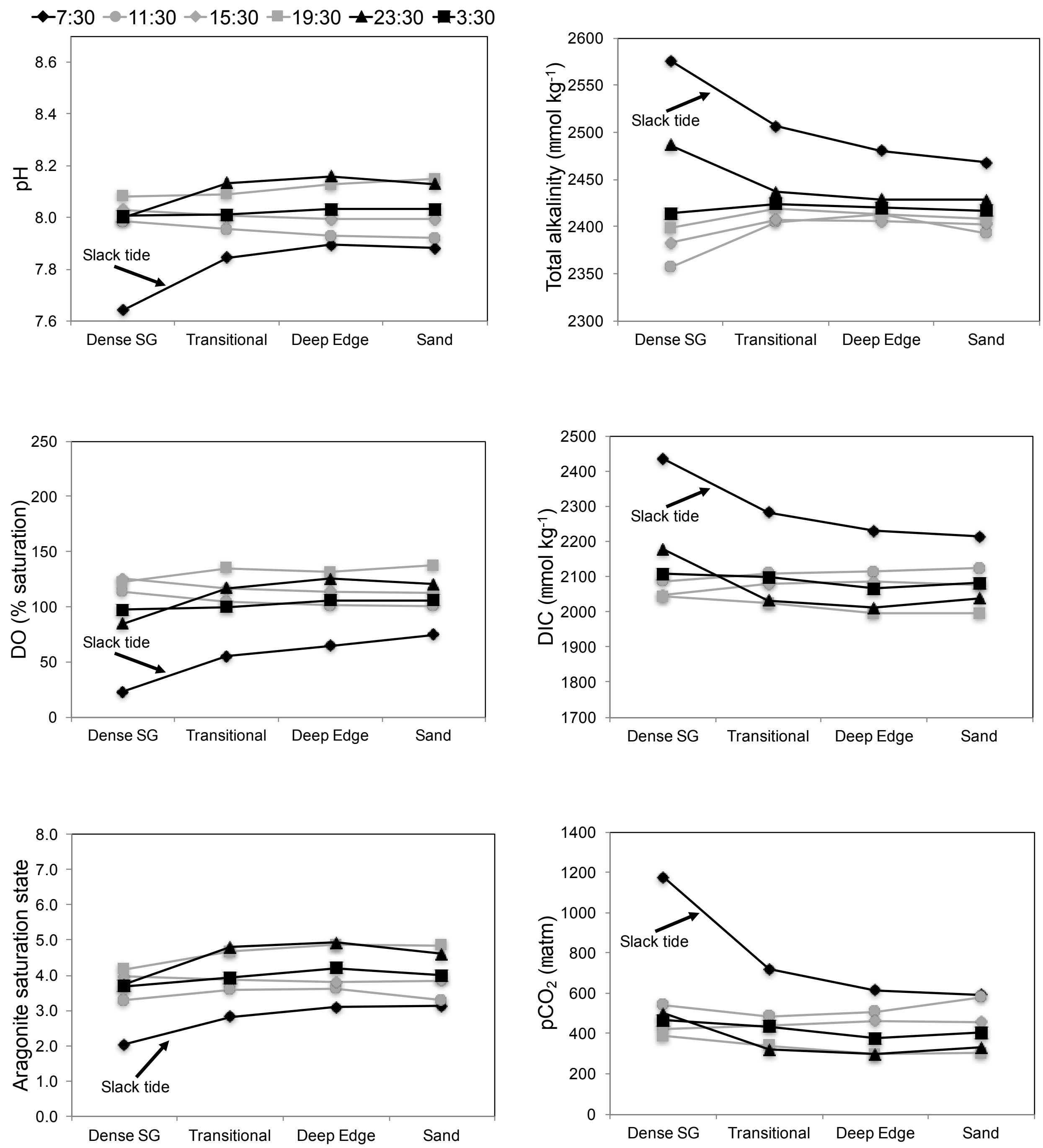

Figure 3. Time series for pHT, DO, aragonite saturation state (ΩA), TA, DIC, and pCO_2 for each substrate type along sampling transects in Lower Tampa Bay. Black lines indicate dark and early morning hours. Gray lines indicate day light and evening hours.

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HELPING HABITATS GET A HAND UP FOR CLIMATE CHANGE

Lindsay Cross

ABSTRACT

Climate change is anticipated to have significant impacts on habitats in the Tampa Bay region and scientists are exploring ways to improve their resiliency and to share pertinent messages with community members. The Tampa Bay Estuary Program has implemented several initiatives to research potential impacts, explore what habitats may be most vulnerable, and collaboratively develop appropriate management strategies for making them more resilient. Examples include the Critical Coastal Habitat Assessment - a long-term monitoring program to detect climate change impacts to coastal habitats; a blue carbon study that will examine how protecting or restoring estuarine habitats can assimilate carbon; and the "Chasing the Waves" photo exhibit that shows community members what sea level rise may look like in the future, using real-world examples of high, "King" tide events.

INTRODUCTION

Climate change may be one of the most significant stressors facing habitats and natural resources in Tampa Bay in the coming decades and centuries. Following extraordinary efforts by federal, state, regional and local partners to reduce nitrogen pollution and improve water quality and clarity, 40, 029 acres of seagrass were mapped in 2014 (Kaufman 2015). This not only meets, but exceeds, the Tampa Bay seagrass restoration and protection target of 38,000 acres adopted by Tampa Bay Estuary Program (TBEP) and its partners in 1995 (TBEP 2006, Figure 1). Following large losses of critical coastal habitats associated with urban development during the mid 20th century, land acquisition and habitat restoration have resulted in increases in the acreages of other critical habitats – including mangroves, salt marshes, salt barrens, and freshwater wetlands (Robison 2010). Much of this is due to the collective setting and implementation

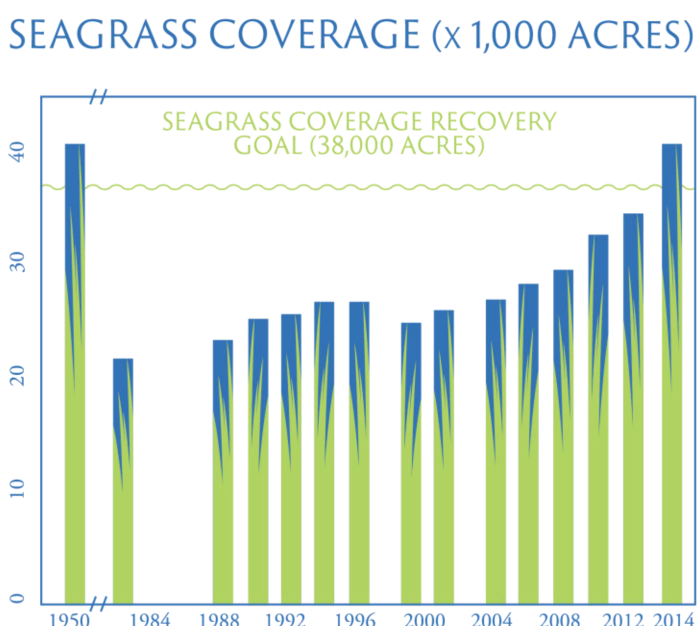

Figure 1. Seagrass acreage in Tampa Bay (SWFWMD 2015).

of habitat restoration goals through the Comprehensive Conservation and Management Plan (CCMP) and the Habitat Master Plan (HMP) (Lewis and Robison 1996, Robison 2010). Ecosystem practitioners have also implemented regionally-supported paradigms for more effective restoration of habitats, such as incorporating a “habitat mosaic” approach, (Lewis and Robison 1996, Robison 2010), leading to larger and more functional restoration projects that more closely mimic natural systems. Quantitative restoration and protection targets have allowed partners to direct limited public dollars towards the acquisition and restoration of habitats that have been disproportionately impacted, as outlined in the “restore the balance” approach (Robison, 2010; Figure 2). Targets for other habitat types, including freshwater wetlands, oyster reefs, hard bottoms, and coastal uplands, have been or will be developed during the next update to the HMP. It is evident that thoughtful planning for natural resource protection and enhancement, such as the CCMP and HMP, can lead to not only an increase in habitat acreage, but an improvement in functionality.

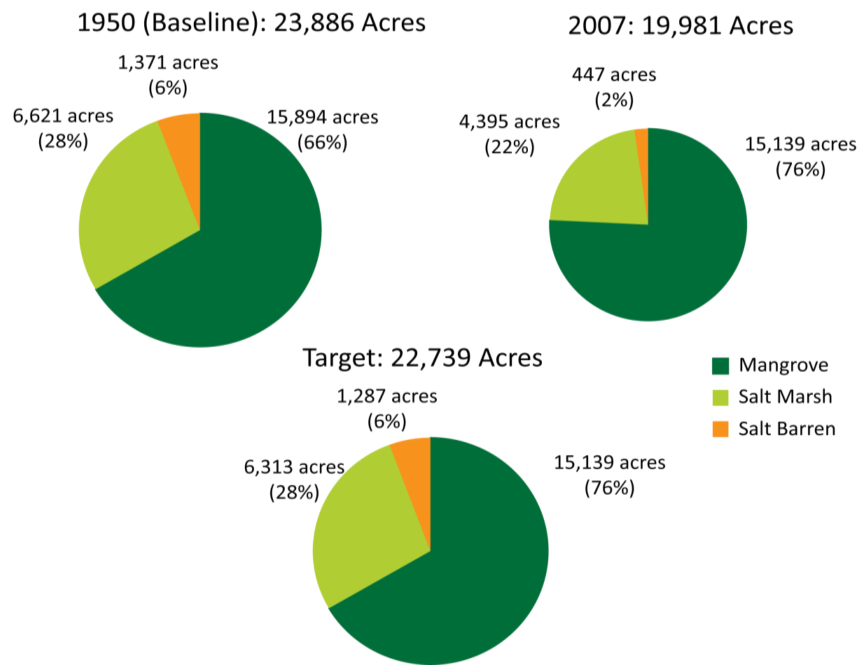

Figure 2. Restore the Balance targets for critical coastal wetland habitats (Robison 2010).

Maintaining current acreage of vital coastal and upland habitats, let alone increasing acreage, will be challenged in the future due to changing climatic conditions, particularly rising sea levels. Within the approximately 2,600 mi^2 watershed, approximately 43% is urban and suburban, 20% agricultural and 5% mining land uses, leaving only 32% as natural areas (SWFWMD 2012). The current population of nearly 2.5 million is expected to double to more than 5 million over the next 40-50 years (TBRPC 2015).

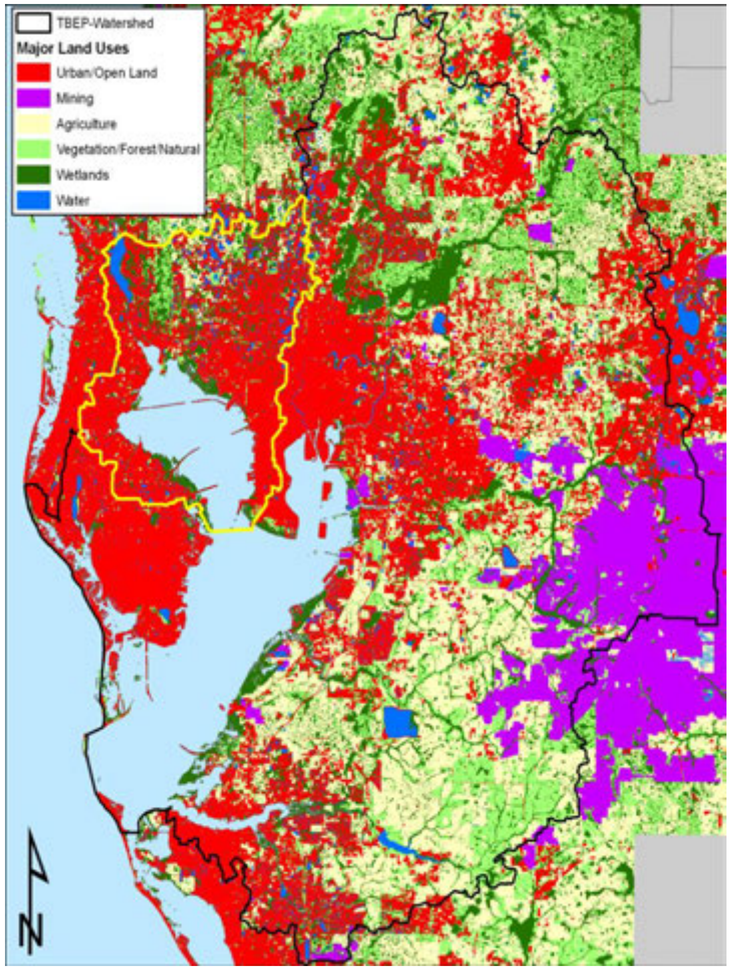

Figure 3. Major land uses in the Tampa Bay watershed, outlined in black and yellow (SWFWMD 2012).

Sea levels have been measured by the National Oceanic and Atmospheric Administration (NOAA) in Tampa Bay since the 1940s. Records from a tidal gauge station in St. Petersburg indicate a rise of approximately an inch per decade (NOAA 2015) and this rate is anticipated to rise due to global phenomena (TBCSAP 2015). TBEP and other agencies are examining the possible implications for coastal and upland habitats and the myriad species they support.

A study by National Wildlife Federation (2006) suggested that 15 inches of sea level rise in Tampa Bay may result in a loss of 96% tidal flats, 86% salt marsh and 10% dry land. This may affect recreationally and commercially valuable fish species such as flounder, permit, redfish, sheepshead, snook, spotted seatrout and tarpon (NWF 2006). Conversely, mangrove area is expected to double.

Over the last several decades, mangrove acreage has expanded in Tampa Bay for a variety of reasons. While Tampa Bay was historically dominated by salt marsh in the nineteenth century with a ratio of roughly 86:14 marsh:mangrove, the proportion has reversed to 25:75 in the twentieth century (Raabe et al. 2012). Mangroves generally cannot withstand freezing temperatures and hard freeze events (20-26° F) can knock back mangroves, maintaining their coverage at more consistent levels. Between the years of 2005-2015, there were only six days in Tampa with a low temperature below 32° F and only one day below 26° F (US Climate Data 2015), allowing mangrove populations to expand. Mangroves are also a climax wetland species, often migrating into areas inhabited by other species such as salt marsh. Curiously, mangrove restoration is often accomplished by planting of salt marsh with the understanding that it will be replaced, naturally, by mangroves. While these occurrences are not inherently bad, the expansion of mangroves often occurs at the expense of other wetland species such as salt marsh and salt barren. Mangroves around Tampa Bay have also demonstrated, thus far, the ability to keep up with current levels of SLR due to sediment accretion; while salt marsh has not (Moyer et al. 2015). Rising seas may further give them a competitive advantage over other estuarine wetland plants.

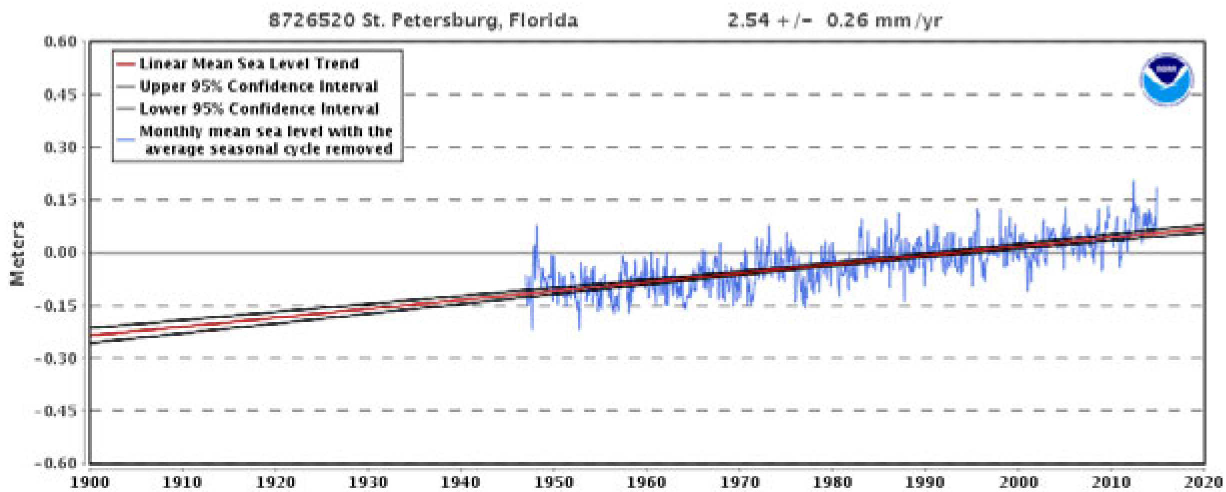

Figure 4. Monthly sea level as measured by NOAA tidal gauge station (NOAA 2015).

METHODS

TBEP has initiated several programs to address potential impacts to habitats from climate change and how that information can be used to improve their future management and protection. The projects highlighted here include a long-term coastal wetland monitoring program, sea level rise modeling, and a public education campaign to visualize what future sea level rise will look like along our coasts.

Critical Coastal Habitat Assessment

TBEP spearheaded a project in 2014 to assess the current status, trends and ecological function of the mosaic of critical coastal habitats and to detect future changes due to natural and indirect anthropogenic impacts, including sea level rise and climate change. Other indirect anthropogenic impacts may include things such as warmer temperatures, changes in rainfall patterns or changes in freshwater due to climate variability. The Critical Coastal Habitat Assessment (CCHA) will serve as a long-term monitoring program within coastal wetland (mangrove, marsh, and salt barren) and coastal upland habitats. The program builds upon the successful, long-term seagrass transect monitoring program that provides valuable annual, site-specific seagrass data at more than 60 sites around the bay and has been used to detect small-scale changes in seagrass species and coverage (Avery and Johansson 2010). The coastal habitat baseline assessment was performed in late 2014-2015 at five (5) locations around coastal Tampa Bay. The sites selected (Figure 5) exhibit the following characteristics:

- Natural emergent tidal wetland zonation pattern (i.e., mangroves, salt marsh, salt barrens and coastal uplands) that is typical of the Tampa Bay coastal watershed;
- Mesohaline to oligohaline salinity regime;
- Topographic contours perpendicular to tidal vectors to capture zonation patterns and a naturally steep topographic gradient to ensure feasibility of monitoring;
- Permanently protected either through public land acquisition or a conservation easement,
- Have had little to no historical disturbance, e.g., mosquito ditching, or restoration; and
- Easily accessible by the study team.

Establishment of an accurate elevation baseline, marked with permanent benchmarks, is the critical first step to detect changes over time. Permanent transects are aligned perpendicular to the primary elevation gradient at each site; beginning at the mangrove/water interface and continuing into the coastal upland fringe. Using the elevations and aerial photographs, habitat zones are demarcated to establish the sampling universe (Figure 6). The sampling design incorporates both fixed and random locations within the individual habitat zones. A 20-meter-wide belt transect is established and vegetation monitoring (basal coverage by species) is collected along the entire transect. Within each vegetative zone, three locations are randomly selected for additional biological and chemical sampling. Water sampling, using a piezometer, occurs at a randomly selected location along the transect within each zone. A Feldspar horizon is also established within each vegetation zone at a randomly selected location to measure future erosion or accretion. Transect sampling includes physical gradient parameters (soils, elevation and interstitial salinity), as well as within- and between- vegetation community metrics suitable for statistical analyses. The general methodology is as follows:

Biological sampling (Vegetation):

- Continuous herbaceous basal vegetative cover by species is collected along the entire 20-meter-wide transect within 0.25 x 0.25 meter quadrats.
- Percent cover, species richness/diversity and shoot density is collected at random plots.
- Within forested zones, additional data is collected at three random plots within each vegetative zone using the Point-Center-Quarter methodology:
    - Tree height

- Diameter at breast height (DBH)
- Species composition
- Canopy coverage

Physical sampling (collected at stratified random sites within each habitat zone):

- Interstitial salinity
- Total percent organics
- Sediment grain type/size
- Depth to water table
- Sediment accumulation/erosion using Feldspar horizons

Baseline assessment of five transects were completed in late 2014 through 2015. The program is being expanded to include five locations with some physical and/or hydrological disturbances, such as mosquito ditching or restoration, as a way to examine whether altered systems react differently to climate perturbations than relatively unaltered areas. This effort will commence in 2016 and will include a multi-media training manual to support implementation in other areas. Initial results of the CCHA are included in the results section. TBEP and partners hope to monitor all sites on a rotating basis, visiting each site approximately every three years.

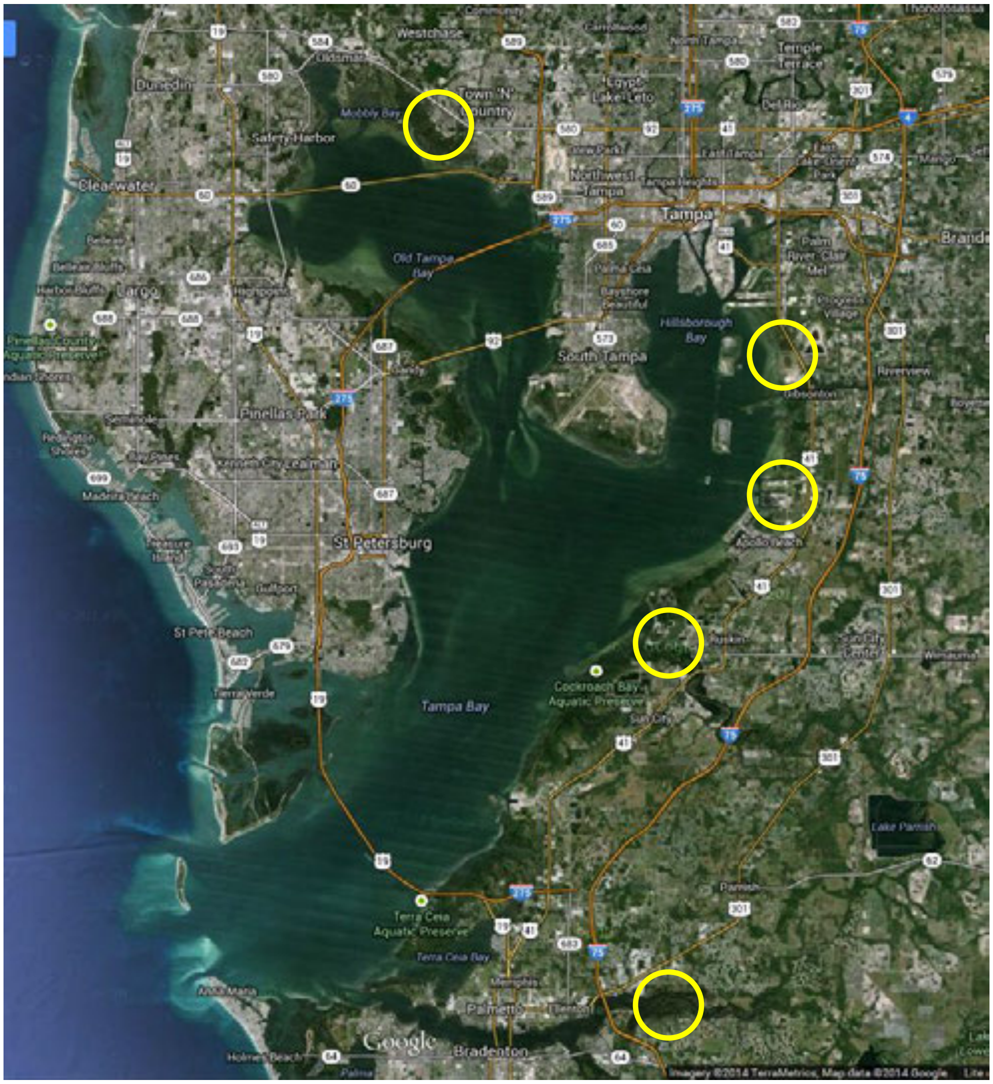

Figure 5. Location of CCHA monitoring sites.

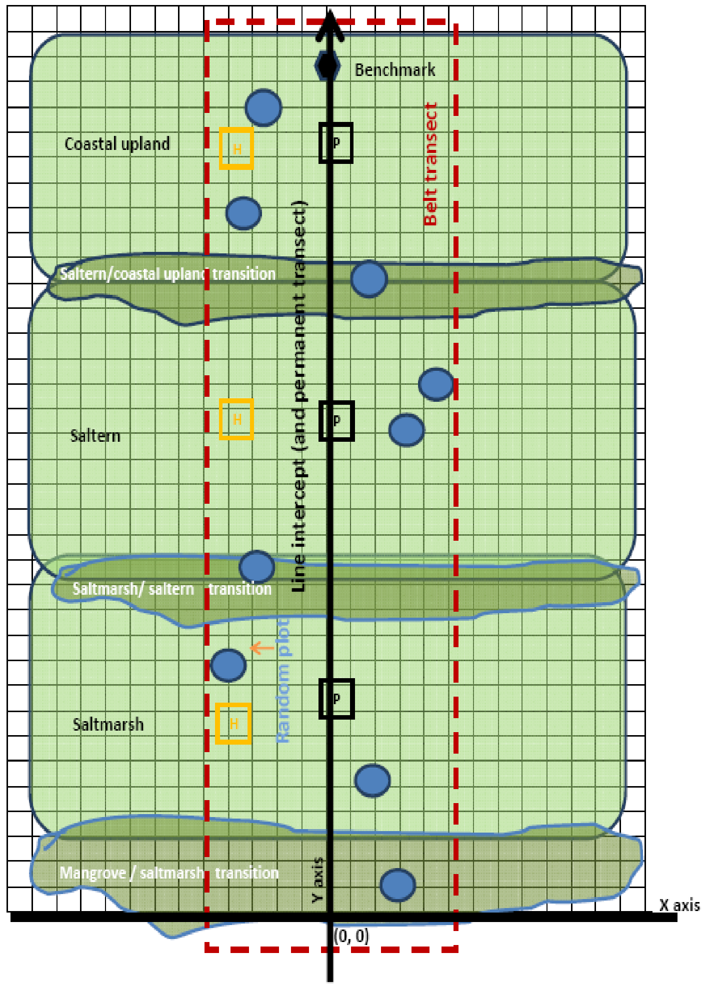

Figure 6. CCHA sampling design. Black line with dashed red line = permanent belt transect. Blue circles = locations for additional biological and physical data collection. Black P in square = Piezometer location. Yellow H in square = Feldspar horizon location.

Sea Level Rise Modeling

TBEP modeled a range of sea level rise scenarios using the Sea Levels Affecting Marshes Model (SLAMM) to determine potential impacts to estuarine and coastal habitats. The modeling looked at sea level rise of 0.5 m, 1.0 m, 1.5 m and 2.0 m by 2100. It also examined two contrasting management scenarios. The first assumed that any currently-developed land areas (e.g., roads, infrastructure or urban development) would be protected through various means, such as higher seawalls. The second scenario assumed that habitats would be able to migrate into currently-developed areas. This would require relocation or abandonment of coastal properties and/or infrastructure and, possibly, the removal of barriers to habitats and water movement. An example of the modeling near the Weedon Island area along western Old Tampa Bay is demonstrated in Figure 7.

The modeling shows that the area currently contains a mix of habitat types, but is predominately mangrove. Under two meters of sea level rise and allowing habitat migration, the area would support primarily mangroves, much in areas that are currently suburban sites; the overall coverage of coastal habitats in Tampa Bay would exceed the current extent (Figure 8). If dry land were protected, two meters of SLR would lead to a significant overall loss in habitat coverage with only a few areas at higher elevation populated by either mangroves or inland freshwater marshes. Both scenarios show that Tampa Bay will transition to a mangrove-dominated system.

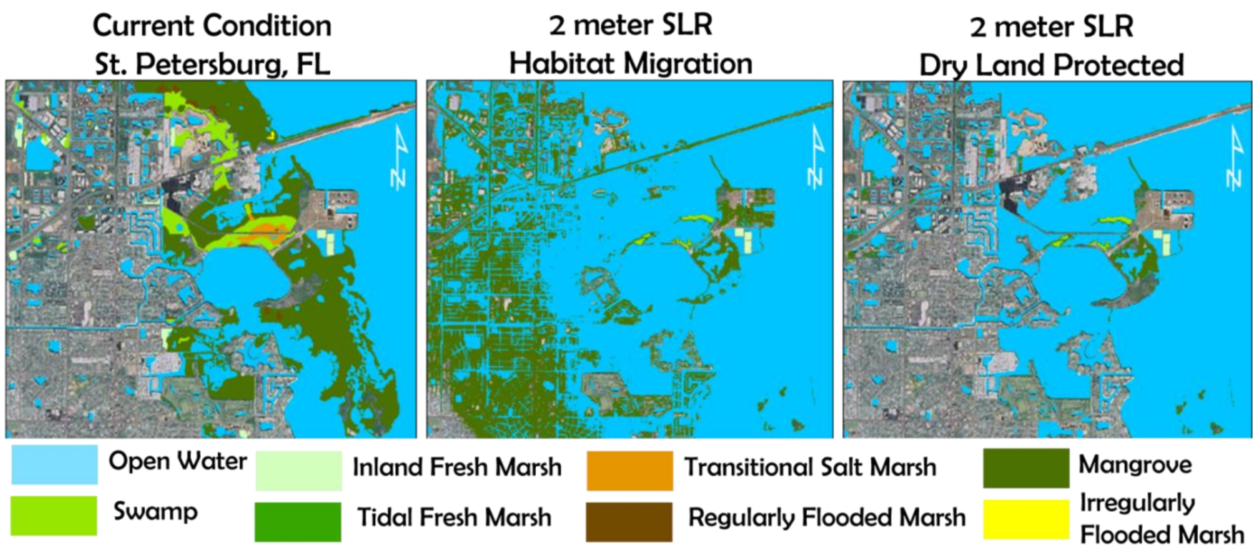

Figure 7. Modeling of 2 meters sea level rise at Weedon Island, western Old Tampa Bay. Graphics depict current conditions (left), potential conditions with habitat migration (center) and potential conditions if habitats are restricted from upward migration (right). Source: http://www.tampabay.wateratlas.usf.edu/TB_SLRViewer/

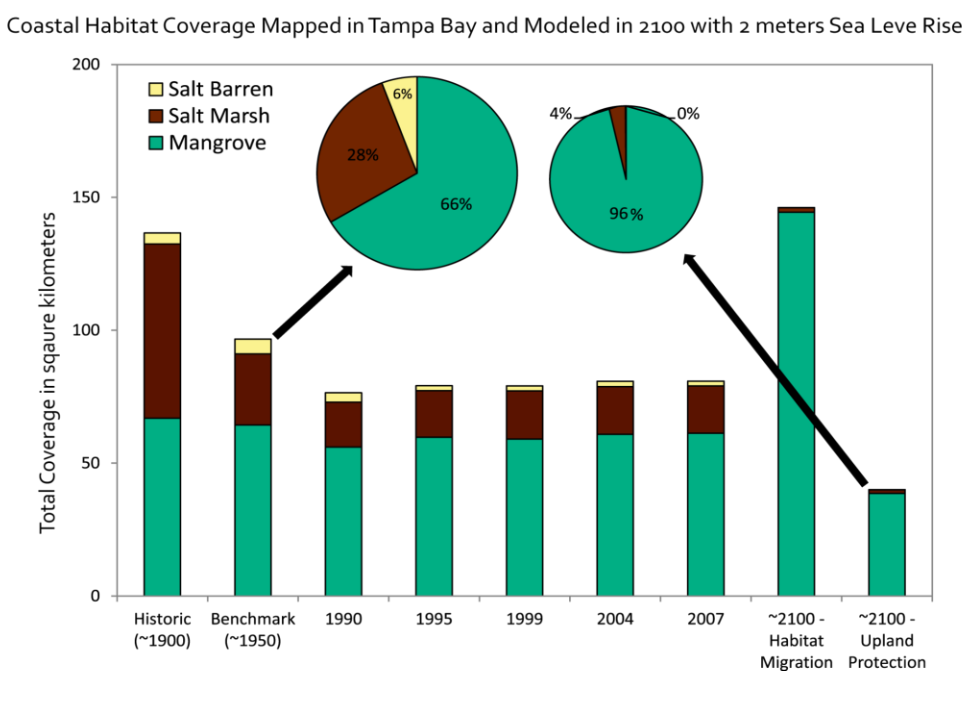

Figure 8. Impact of 2 meters sea level rise on coverage and proportion of coastal habitats in Tampa Bay (Sherwood and Greening 2010).

These modeling tools are intended for use by planners, policy makers, land managers and the public as a way to initiate dialogue regarding appropriate future planning and land uses, including natural areas.

Modeling efforts by the Tampa Bay Regional Planning Council using similar SLR projections suggest that many coastal areas will likely be "protected" through various mechanisms, which may further reduce land available for coastal habitats (Figure 9, TBRPC 2006).

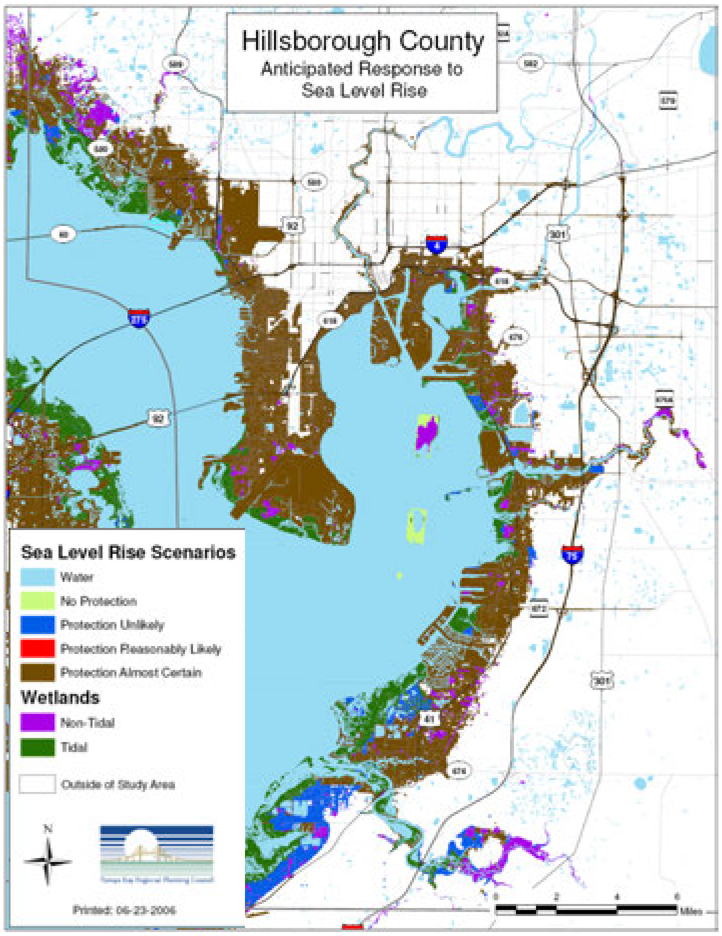

Figure 9. Anticipated land use responses to sea level rise along Hillsborough County coastline (TBRPC 2006).

King Tide Photo Exhibit

The King Tide project is a public outreach and engagement effort that recruits residents to take pictures of coastal areas during a low tide and, again, at a very high "King Tide" – the highest tides of the year. The King Tides can portray what a daily high tide may look like in the future, given rising sea levels. These visual representations can increase public awareness of coastal flooding risks and potential impacts on the bay. An exhibit of citizen-submitted photos traveled around the Tampa and Sarasota Bay areas at public sites, such as municipal buildings and libraries, and can be viewed at: http://www.flickr.com/photos/62725999@N04/

Figure 10. Differences in water levels during a low tide (left) and King Tide (right) period. Photos by Larry Schultz.

RESULTS

Initial results from the CCHA suggest that habitat migration is already occurring in Tampa Bay. Elevation profiles at all sites were consistent around the bay, demonstrating that these sites accurately represent natural coastal areas and may serve as an appropriate barometer for future change. The average elevation gain from the water's edge into the upland fringe was approximately 3.5 feet. Changes in habitat type were driven by small elevational changes, sometimes on the order of 1-2 inches, suggesting that sea level rise of even a few feet may significantly impact the current habitats and where they can successfully be sustained in the future. A site at Upper Tampa Bay Park was re-visited one year after initial monitoring. The project team noted that mangroves were encroaching into salt marsh and salt barren zones in some locations. These sites are actively migrating and evolving, possibly due to climate change impacts. Oligohaline marshes are a relatively rare marsh type, found along the edges of rivers and tidal tributaries. These lower salinity salt marshes, i.e., *Juncus roemerianus,* may be especially susceptible due to sea level rise, urban development and increasing surface water withdrawals that alter the natural hydrologic regime (Figure 11).

Modeling of sea level rise impacts on habitats suggests that coastal wetlands, such as salt marshes and salt barrens, that are already disproportionately impacted, may continue to be replaced by mangrove species, altering the historic balance of coastal habitats (Figure 8).

DISCUSSION

Much of the coastal areas of Tampa Bay have already been developed as residential, commercial or port facilities. While public agencies have purchased some remaining coastal areas, such as the nearly 3,190- acre Weedon Island Preserve (Pinellas County 2015) in Pinellas County and the expansive restored sites at Cockroach Bay, Rock Ponds and Schultz Preserve in Hillsborough County, for example (see SWFWMD 2014, and SWFWMD 2015), partnerships with private landholders such as Mosaic and Tampa Electric may provide additional opportunities for habitat protection and restoration. An emphasis on purchasing areas upslope of existing coastal lands, as “refuge” area will also be paramount in allowing habitats to migrate.

The efforts highlighted are intended to project what the Tampa Bay region may look like in the future, in response to climate change impacts. The tools are meant to empower scientists, planners, citizens and policy makers to make thoughtful decisions and prioritize future restoration and protection of habitats. Hard decisions will be required – where and how to allow urban develop, how to incorporate habitat refuges into restoration planning, and how to protect places and habitats that provide ecosystem services and enhance community vitality. Existing habitat paradigms such as the Restore the Balance approach may not be feasible in the coming decades and ecosystem managers will be tasked with determining how best to manage, enhance and increase natural areas for the support of other species, ecosystem services and their intrinsic value. While Tampa Bay may not look like it did in the past, or today, thoughtful planning, hybrid solutions that incorporate both green and gray infrastructure, such as living shorelines, and appropriate management driven by quantitative monitoring and modeling data, can ensure that coastal and upland habitats are afforded the best opportunities to adapt to and thrive under future environmental conditions. The TBEP will continue to engage the regional community in priority research, education and outreach through development of its CCMP, HMP and other strategic process to help to protect and restore Tampa Bay now and in the future.

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[BLUE CARBON: A NEW TOOL FOR COASTAL CONSERVATION]

Steve Emmett-Mattox, Steve Crooks, Stefanie Simpson

ABSTRACT

Coastal wetlands – salt marsh, seagrass and mangroves – have the ability to sequester and store significant amounts of carbon dioxide, while their destruction can result in the emission of CO_2 and other greenhouse gases. We refer to this flux of GHGs into and out of coastal wetlands as "coastal blue carbon". This newly recognized ecosystem service has the potential to elevate prioritization of coastal restoration and conservation and influence management of these ecosystems to mitigate the impacts of climate change. An ongoing project in Tampa Bay has brought together scientists and managers working together in coastal blue carbon ecosystems to quantify the carbon storage and sequestration of these habitats and explore application of this knowledge to restoration and conservation efforts. Tampa Bay provides a unique setting for this study as it includes all three coastal habitats and has shown signs of increasing carbon sequestration abilities over the last decade.

This presentation will include an overview of blue carbon science and opportunities by national leaders in the field, as well as local perspectives on the role blue carbon has for management of Tampa Bay coastal habitats. Panelists will also present on the carbon sequestration and storage abilities of mangrove, salt marsh and seagrass habitats in Tampa Bay. This innovative project is a unique partnership of national and local agencies and the private sector, including the Tampa Bay Estuary Program, Tampa Bay Watch, Restore America's Estuaries, The Tampa Bay Environmental Restoration Fund, NOAA, U.S. EPA, U.S. FWS, ESA and Scotts Miracle Gro.

ORGANIC CARBON BURIAL AND ACCRETION RATES IN TAMPA BAY'S COASTAL WETLANDS

Amanda R. Chappel, Ryan P. Moyer, Joseph M. Smoak, Megan P. Burford, Simon E. Engelhart, Joshua L. Breithaupt, Andrew C. Kemp, Thomas J Smith III

ABSTRACT

Mangroves and salt marsh are the predominate terrestrial-to-marine transitional ecosystems along the Florida coast. These systems have historically been underestimated in terms of their role in the global carbon cycle. Climate change and sea-level rise (SLR) disrupt the wetland hydrologic cycle, compromising sediment accumulation and the rate of organic carbon (OC) burial, a direct measure of ecological integrity and viability of these systems. This study evaluates and compares the organic carbon content, sediment accumulation, and carbon burial rates in salt marsh and mangrove ecosystems of Southwest Florida. Tampa Bay has been a focus, as its natural shorelines are co-dominated by both marsh and mangrove habitats. Peat cores have been collected from marsh and mangrove sites in the Little Manatee River (LMR) basin of Tampa Bay and are compared to those from Charlotte Harbor estuary. Loss-on-ignition (LOI) analysis was used to estimate the OC content at these sites. Burial rates of organic carbon were assessed using constant rate of supply age models using measurements of excess 210Pb for short (centennial) time scales and 14C for longer (millennial) time scales. Preliminary results indicate that mangroves may have the ability to sequester carbon more efficiently than salt marsh, with deposition rates in marshes not keeping pace with SLR, thus furthering marsh-to-mangrove conversion. Additionally, wetlands in Tampa Bay tend to have a lower rate of carbon burial, demonstrating the need for proper mitigation and adaptation strategies to be established in the greater Tampa Bay area relative to future projections of SLR.

THE RISING SEAS: MANAGING EXPECTATIONS FOR HABITAT RESTORATION ALONG FLORIDA'S SPRINGS COAST

Chris J Anastasiou, Ph.D

ABSTRACT

Sea-level rise along Florida's Springs Coast is a reality. How to protect and restore the spring-fed tidal habitats that make this region so unique must be placed within the context of a rising sea. So too must the public's expectations of restoration success also be placed within the same context. Fifty years ago, many of the spring-fed rivers and bays along Florida's Springs Coast, just north of Tampa Bay, were fresher than they are today. In only a few decades, these systems have become more marine and the ecological impacts have been profound. For example, today there is evidence of a greater abundance of saltwater fish, the presence of barnacles in traditionally freshwater areas, and loss of freshwater submerged aquatic vegetation. Ultimately systems like Kings Bay and the Homosassa River will look very different in the future than they did 50 years ago, or even as they look today. Stakeholders and citizens must work together to re-define what these systems can, and should, look like in a world with higher sea-level. Terms like "habitat creation" or even "ecological engineering" more accurately describe the necessary actions that must be undertaken to ensure these systems are the best they can be. Introducing salt-tolerant species of SAV through novel re-vegetation techniques is one example of how improving these systems may be accomplished in the face of what will undoubtedly be a much saltier world.

HABITAT VULNERABILITY AND SUSTAINABILITY OF URBAN SEAGRASS RESOURCES TO SEA LEVEL RISE

Cynthia Meyer, Ph.D and Ruiliang Pu, Ph.D

ABSTRACT

The seagrass resource, an essential habitat in the marine ecosystem, may be quite vulnerable to impacts of sea level rise (SLR). We developed a spatial habitat suitability model (HSM) to evaluate the suitable habitat loss and gain from SLR impacts on the urban seagrass resource. High resolution bathymetry and field survey water quality data were used to develop the HSM from general additive models (GAM) for the seagrass resource in St. Joseph Sound (Adjusted R2= 0.72, n=134) and Clearwater Harbor North (Adjusted R2= 0.75, n=138) including salinity, chlorophyll-a concentration, total suspended solids, turbidity, and a light metric. The only significant variable was the light metric (logarithmic light attenuation) calculated from the water quality field survey transmittance (660nm) data and the high resolution bathymetry. Based on the predicted SLR scenarios (1ft-6ft: 2010 – 2100), the potential suitable seagrass habitat loss from the current 60 km2 of seagrass habitat ranged from 14 km2 (SLR 1ft) to 26 km2 (SLR 2ft) to the entire 60 km2 (SLR 6ft). The potential seagrass habitat gain ranged from 4 km2 (SLR 1ft) to 19 km2 (SLR 6ft). In this urbanized area, the current seawalls (47% of the shoreline) or further shoreline armoring could impede the inundation of the seawater and the seagrass colonization of these areas by creating a vertical boundary for seagrass growth. While management of water quality would continue to benefit the seagrass resource, additional management strategies may be necessary to mitigate for potential decrease in suitable seagrass habitat related to the effects of SLR.

ACTIONABLE SCIENCE IN PRACTICE: CO-PRODUCING CLIMATE CHANGE AND SEA LEVEL RISE INFORMATION FOR DECISION MAKING

Tirusew Asefa, Ph.D., P.E., D.WRE and Alison Adams, Ph.D., P.E.

ABSTRACT

The impact of climate variability, climate change and sea level rise on regional water supply availability and environmental sustainability has come to be a major concern for communities around the nation. Changes in precipitation patterns, increased temperature, and sea level rise pose significant risk in water supply reliability may alter demand patterns of a given region. One of the most challenging aspects of assessing and understanding these impacts, hence being able to be prepared for a climate hazard, is the lack of ready-to-use climate information that is consistent to a given locality's hydrological and climatological foot print at a spatial and time scale resolution that is meaningful. Often time production of such information does lack enough involvement of stakeholders who are better informed about their local challenges. This presentation highlights local, state, and national level ongoing collaborative efforts in co-producing actionable climate science data that is relevant to Tampa Bay area and demonstrates its application in understanding climate change impacts to the region. Efforts on making available "locally vetted" statistically and dynamically downscaled products that may be used for wide range of applications are underway.

CHANGING THE CONVERSATION: COMMUNICATING ABOUT LOCAL CLIMATE CHANGE IMPACTS AND SCENARIOS FOR THE TAMPA BAY REGION

Rebecca Zarger, Libby Carnahan, Ramona Madhosingh-Hector and Lara Milligan

ABSTRACT

In this discussion the four panelists discuss key findings and insights from a two-year collaborative effort to understand how key stakeholders and local residents view climate change risk and vulnerability in the Tampa Bay region, and how to effectively translate this information for multiple public audiences. Jointly designed "Climate: Change the Conversation" community engagement programs were attended by 130 participants at four workshops between 2013 and 2015. Pre- and Post-program surveys were administered to participants. The public events are informed by findings from an NSF-funded study at USF, an interdisciplinary project that integrated global and regional climate science, local population demographics, and input from policy makers, planners, and scientists to develop visual climate change scenarios about potential impacts on linked social and ecological systems in Tampa Bay, with a particular emphasis on water resources. Interviews and development of spatial maps informed the public programs and facilitated dialogue on visualizing transformations linked to climate change on a relatable, localized scale. A 12 minute video describing three possible scenarios and additional visual materials will be available online to the public, other researchers, educators, and policymakers. The discussion will focus on lessons learned from the workshops about translating climate science from global or regional scales to local scales, communicating with decision makers, and gathering data about perceptions of climate change. We will discuss the opportunities and challenges of university/extension partnerships to conduct climate change education outreach that may be applicable to similar efforts taking place in the state of Florida and beyond.

CLIMATE ENGAGEMENT: AN ASSESSMENT OF LOCAL CLIMATE CHANGE PERCEPTIONS

Ramona Madhosingh-Hector and Libby Carnahan

ABSTRACT

Beginning in 2014, UF/IFAS Extension Pinellas County organized community engagement events to assess local perceptions regarding climate change and sea level rise. Program goals include (1) educate at least 250 residents, (2) conduct face-to-face interviews with attendees, and (3) utilize public venues to reach diverse audiences. Faculty managed half-day information sessions at community venues including farmers' markets, sustainability fairs, and science festivals. Faculty utilized simple visualization maps to illustrate potential impacts of sea-level rise to landmarks and personal property, educated attendees about additional local impacts, and discussed possible adaptation strategies. Survey participants were rewarded with an insulated tote bag after completing a 5-question survey about climate change. A total of five climate outreach stations reached 669 residents and 89% of survey respondents (n=573) reported that climate was changing. On a scale of 1 to 5 where 1 is least concerned and 5 is most concerned, 89% reported values of 3 or more indicating a high level of concern about climate change. Participants reported that the most likely impacts of climate change were sea level rise (27%), temperature variability (21%), and pollution/emissions (21%). Additional concerns included flooding, impacts to natural resources like habitat and wildlife, and increased hurricane frequency/intensity. Local communities benefit from a targeted educational approach to enhance learning about complex issues. Community-based learning events allow Extension faculty to collect information that can be used to develop responsive educational programs and provide vital information to assist local communities in decision-making processes.

Climate Engagement: An Assessment of Local Climate Change Perceptions

UF | IFAS Extension
UNIVERSITY of FLORIDA

Ramona Madhosingh-Hector and Libby Carnahan
Extension Faculty, University of Florida/IFAS Extension, Pinellas County

Sea Grant
Florida

Introduction

Communicating the challenges of urban issues such as climate change is an important component of Extension's mission to educate residents and improve their quality of life. Climate change is a "complex, uncertain and variable" (Monroe et. al, 2015) issue and requires the use of multiple strategies to inform and educate audiences. Monroe et al (2015) also recommend the use of "visible differences, research-based evidence of changes over time, and suggestions for how people are likely to be affected by climate change" locally as an opportunity to educate audiences about this challenging issue.

Designing effective education programs about climate change should be tempered with the knowledge that audiences vary in their familiarity with the issue and that there will be different and opposing perspectives about climate change. Information presented by the Six Americas (Monroe et al, 2015) identify six descriptions that apply to audiences responding to climate change – *alarmed, concerned, cautious, disengaged, doubtful, and dismissive*.

Extension agents in Pinellas County conducted a local research project to collect information about climate change perceptions in Tampa Bay. The data will be used to design educational programs to extend science-based information and research to local and regional audiences.

Program Goals:

Complex issues require a multi-pronged approach to educate audiences and encourage large scale behavioral changes. Extension agents are equipped with the skill set to effectively liaise with local clientele and bridge the gap between science and education. The overall goals of these community engagement events include:

- Educating at least 250 residents about climate change and sea level rise in Tampa Bay
- Conducting face-to-face interviews to collect information about perceptions relating to climate change and sea level rise
- Engaging with diverse audiences through the use of atypical public venues for information collection.

The Survey Instrument:

A combination of quantitative and qualitative questions were included in the survey as shown below.

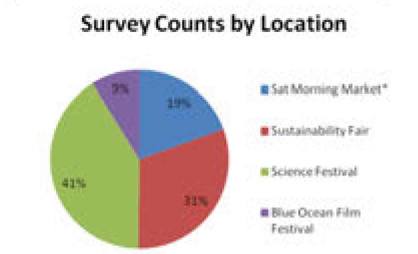
- Do you think climate is changing in your area?
- On a scale of 1 to 5 where 1 is least concerned and 5 is most concerned, how concerned are you about climate change?
- What do you think are the most likely impacts of climate change affecting the Tampa Bay area?
- How will climate change in Tampa Bay affect you personally?
- Where do you get your information about climate change?

Survey adapted from Oregon Sea Grant, 2013.

Methods

Between March 2014 and December 2014, Extension agents hosted five (5) climate outreach stations at public locations throughout the county (see **Figure 1**). Each climate station ranged in duration from two to four hours and included visualization maps of sea level rises (0.5 meter, 1 meter, 1.5 meter) created by the University of South Florida Department of Anthropology. Attendees who visited the climate booth and participated in the activity were invited to complete a 5-question survey. Participants who completed surveys received an insulated tote bag.

Participants were also educated about potential impacts to landmarks and personal property as well as possible adaptation strategies that could be implemented personally or through policy intervention. Additionally, residents unfamiliar with Extension and its diverse programs were informed about the educational opportunities available for personal and professional development.



*Saturday Morning Market was collapsed into one entry although surveys were conducted on two separate dates.

Figure 1

Results

A total of 669 residents participated in the short survey and 86% of survey respondents reported that climate was changing (n=573) as shown in **Figure 2** below.

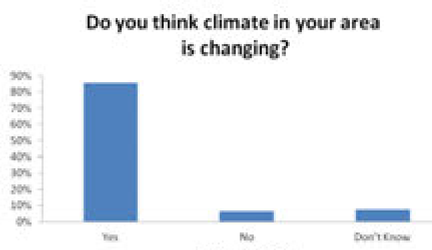


Figure 2

Results

Figure 3 below shows that participants reported a high level of concern about climate change with 88% of respondents choosing values of 3 or more on a scale of 1 to 5.

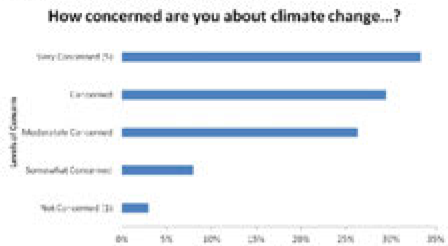


Figure 3

When asked about the most likely impacts in Tampa Bay, respondents provided a range of qualitative responses which were then grouped into larger categories; the top five local impacts are shown in **Figure 4** below.

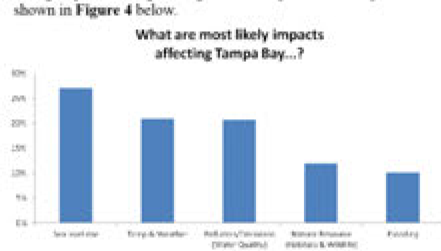


Figure 4

With respect to personal impacts, respondents were particularly concerned with changes in weather patterns (intense heat or increased storm frequency), quality of life, and impaired natural resources (**Figure 5** below).

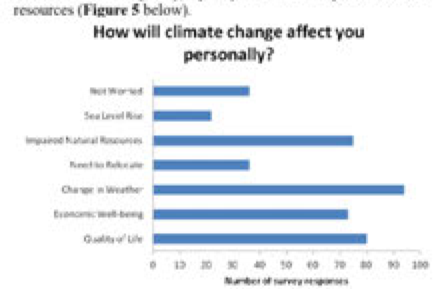


Figure 5

Results

Survey respondents provided a range of responses related to sources of information as shown in **Figure 6** below.

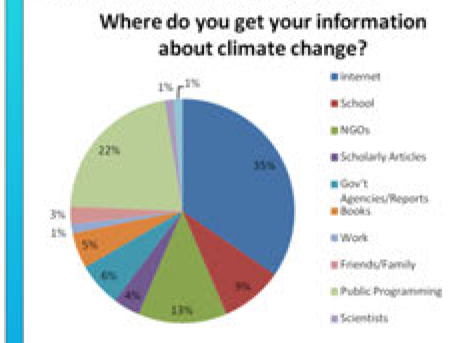


Figure 6

Conclusions

Survey participants were fairly knowledgeable about the term climate change but had varying perceptions of local and personal impacts that could be connected to climate change. Participants were disturbed by the projections of 0.5 meter, 1 meter and 1.5 meter sea level rise as it fueled concerns about property impacts due to increased sea levels and flooding.

Community engagement at diverse public venues provides a unique opportunity for Extension to educate local audiences about topical issues in a non-traditional educational setting. It also provides vital information that can be used to design additional educational programs and assist local communities in decision-making processes.

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SIMULATED WIND DRIVEN ANOMALIES IN TAMPA BAY, FL 1975-2006

Monica Wilson, Ph.D.

ABSTRACT

This research provides insight into changes in volumetric flushing of the Tampa Bay estuary caused by extratropical/winter storms and hurricanes. Volumetric changes are investigated using a numerical circulation model simulation over the years 1975-2006. Strong wind speeds, duration of high winds, and wind direction during these events affect the amount of water flushed in/out of the estuary. All storms examined in this study had peak wind speed greater than 15 m/s. Volume anomalies (total minus tidal) are largest when wind components blow up/down the estuary. For the 10 largest extratropical/winter storms during the simulation the total volumetric changes range from 12% to 40% and from 14% to 40% for all the hurricanes. Wind direction and timing of each storm had an impact on the flushing rates during these extreme events. Storm #9 (February 1998) and Hurricane Gabrielle (September 2001) experienced the smallest total volume changes (14% and 13%). Both storms produced locally weak peak winds (16 and 19 m/s) causing small volume changes. The Storm of the Century (March 1993) and Hurricane Frances (September 2004) saw the largest total volume changes of 40% and 36%, both had strong peak winds (~25 and ~23 m/s) blowing in the NE direction. Hurricane Frances had two wind peaks and lingered in the area for approximately 48 hours, both strength and duration of winds played a large role in the total volume change. Total inflow and outflow rates per year show that there is year to year variability of flushing in Tampa Bay.

Simulated wind driven anomalies in Tampa Bay, FL 1975-2006

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Purpose:

Examine synoptic scale, weather systems typically lasting 2-20 days, wind induced volumetric changes in Tampa Bay (Figure 1a).

Why is this important?

- Flushing rates are a key variable for maintaining estuarine viability
- Water quality is directly related to the removal of pollutants
- Past studies discuss short term impacts, long term studies are rare

Objectives:

1. Gather observational data to provide boundary conditions for model simulation and evaluation.
2. Use the Environmental Fluid Dynamics Code (EFDC) to calculate wind induced volumetric changes caused by extratropical/winter storms and hurricanes.

Introduction:

The health of estuaries is, in part, dependent on the flushing of pollutants out of the estuary to the open ocean through hydrodynamic circulation circulation (Geyer and Signell 1992; Ketchum 1954; Oliveira and Baptista 1997). Flushing rate can be defined most simple as the time required to replace the volume of a basin by the volume influx (Dyer 1973). Flushing times in estuaries can range from hours to minutes for small streams entering directly into the sea, to weeks or months in bigger systems having a large volume (Statham 2012). To help aid in maintaining and improving the water quality of an estuary, the effects of winds, tides, and freshwater inflow on flushing must be well understood.

Large-scale weather patterns such as winter storms and hurricanes can alter wind-induced circulation causing an increase/decrease of water flow into/out of an estuary. Winter storms, extratropical storms, or extratropical cyclones are all large-scale weather systems that are related to strong cold fronts (Feng 2009). Extratropical cyclones tend to form along these fronts due to the atmospheric instability produced by the strong horizontal temperature gradients. Associated with these extratropical cyclones are strong wind fields that can then generate waves and storm surges that cause sea level fluctuations along the coasts (Davis and Dolan 1993). Hurricanes can produce sudden massive disturbances in estuaries and other coastal ecosystems around the world (Greening et al. 2006). Each hurricane has its own individual characteristics causing their effects on ecosystems to be unpredictable.

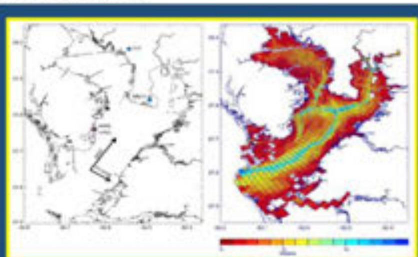


Figure 1. Map and model bathymetry of Tampa Bay. Blue circles indicate location of wind observations and red circle indicates location of water level data.

Model:

Environmental Fluid Dynamics Code (EFDC)

- Physics and computational scheme are equivalent to the Princeton Ocean Model
- Model allows for wetting and drying in shallow areas
- Curvilinear grid that is 70 x 100 x 10 cells, minimum depth of 1.3 MLLW (figure 1b)
- Inputs: freshwater input, salinity, zonal and meridional wind components, and water elevation
- Vertical sigma-coordinate (terrain following)

Simulation:

- Model was initialized with uniform salinity and elevation through out the model grid
- Simulation from 1975 to 2006
- Model time step: 60 seconds
- Elevation and salinity at the mouth, spatially uniformed winds and precipitation, and freshwater point sources
- Model variables were archived hourly

Evaluation:

- Model salinity, elevation, and velocity are compared with observed data (figures 2 and 3).

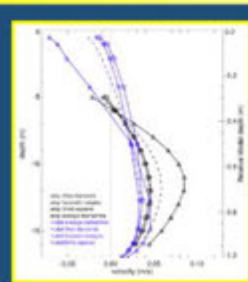


Figure 2. Axial (v-component) velocity depth comparison between the ADCP (black) under the Sunshine Skyway Bridge and the corresponding model grid cell (blue) for 2004. The labels first, second, and third correspond to the three groups of gap free data available for 2004.

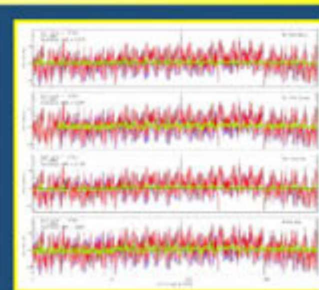


Figure 3. Model (red) and observational (blue) elevation data comparison for 4 sites around the bay for 2005. Difference is shown in green.

Methods:

Two main drivers of water volume in the bay are winds and tides. Instantaneous total model bay volume is

$$V(t) = \sum_{i,j} \left[(e(t)_{i,j} + h_{i,j}) \times dx_{i,j} \times dy_{i,j} \right]$$

where elevation (e) at location (i,j) is added to the mean model depth (h), multiplied by the area of each grid cell (dx,dy), and then summed for all active grid cells. Similarly, the tidally predicted bay tidal volume is:

$$V(t)_{tidal} = \sum_{i,j} \left[(e_{tidal}(t)_{i,j} + h_{i,j}) \times dx_{i,j} \times dy_{i,j} \right]$$

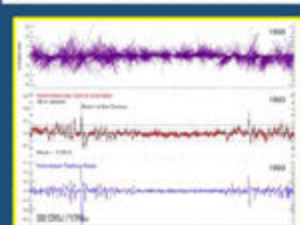
where e_{tides} is the sum of elevations for the eight primary tidal constituents for Tampa Bay plus the annual and semi-annual constituents.

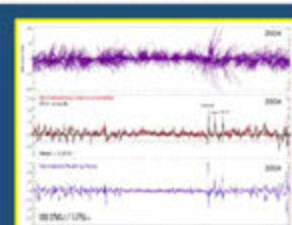
The difference yields bay volume anomalies

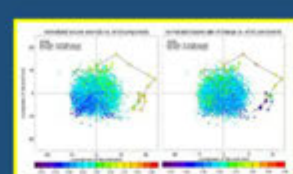
$$V_a(t)^* = V(t) - V(t)_{tidal}$$

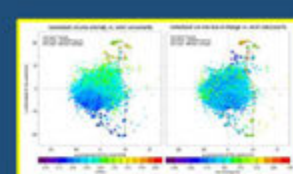
By removing the dominant tides it can be reasonably assumed that $V_a(t)$ is mostly comprised of the wind-generated signal. Volume anomalies are normalized by the mean bay volume, $V_a(t) = V_a(t)^* \bar{V}^{-1}$, where $\bar{V} = 3.8 \times 10^9\ m^3$. The time derivative of the normalized volume anomalies yields the wind-driven component of the volumetric flushing $\partial V_a(t)/\partial t$. Positive flushing rates indicate net inflow conditions and negative flushing rates indicate net outflow conditions.

Scatter plots of hourly winds from the Storm of the Century and Hurricane Frances are coded by V_a and $\partial V_a(t)/\partial t$, helping elucidate the relation of the wind components with these variables (figures....).









Results:

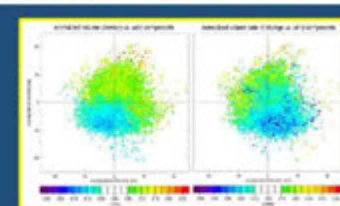
The two largest anomalies in the 1993 flushing rate are associated with the "Storm of the Century" in March, and with the strong winds in October of an unnamed storm. Both show a strong inflow followed by a transition to equally strong outflow all occurring within about one day. The Storm of the Century had peak wind speeds ~25 m/s, storm surges up to 0.6 m, and created 14 tornadoes. The Storm of the Century produced a maximum unfiltered $V_a(t) \cong 0.25$ which then dropped to minimum of $V_a(t) \cong -0.15$, for a total change in volume of 40% (Figure 5). It produced a peak inflow rate of 0.27 bay volumes per day and a peak outflow rate of -0.38 bay volumes per day. The unnamed October storm has peaks roughly half those values.

In 2004 (Figure 6) the summer RMS $V_a(t)$ and $\partial V_a(t)/\partial t$ are 0.028 and 0.029 respectively, and 0.03 and 0.029 for the rest of the year. There are several relatively large flushing events during this year. Three of these are associated with Hurricanes Frances, Ivan and Jeanne, in September 2004, with Frances generating the largest response. As Frances moved through the Bay the unfiltered $V_a(t)$ decreased to -0.11 NBV followed by a surge to $V_a(t) \cong 0.25$ NBV for a total swing of 36% of bay volume. Frances produced a peak inflow rate of 0.31 bay volumes per day and a peak outflow rate of -0.20 bay volumes per day (Figure 6). The large event occurring at the end of the year is associated with an extratropical/winter storm that occurred on December 26, 2004 (denoted as storm 10 in this study). This latter event generates $\partial V_a(t)/\partial t$ comparable to that during Frances, surpassing that found during Ivan and Jeanne.

At the beginning of the Storm of the Century winds are relatively weak and are in the SE direction (Figure 7). As the winds begin to strengthen they rotate towards the NW direction and V_a increases. The anomalies reach their maximum value of about 0.25 when the winds are blowing towards the ENE at 25 m/s. Corresponding behavior is seen in the volume rate of change (Figure 7). There is a large positive rate of change when the winds are blowing towards the NE direction, but as the winds begin to slow slightly and blow towards the E/SE the rates of change switch from a positive value to large negative rate of change. As the winds begin to relax all the water that was being pushed into the Bay starts to make its way out causing outflow values to increase.

Hurricane Frances lasted approximately 2.5 days and had two phases of strong winds (>20 m/s) with a short time of relaxed winds (~9 m/s) between the two peaks. In the beginning of the storm winds were blowing towards the SE, causing about a 10% drop in bay volume (Fig. 8). When the winds relaxed and began rotating towards the NE, the volume anomalies change from negative to positive. As the second wind peak occurs winds begin to blow towards the NE direction causing the 25% increase in volume anomalies mentioned previously. As for the volume rates of change, we see the largest positive changes happening when the winds begin to transition from the SE to the NE. The largest volume outflow occurs at the end of the storm when the winds begin to die down and the water flows out of the bay as indicated by a negative volume flux (Figure 8).

The temporal response of the bay is seen in the scatter plots of $\partial V_a(t)/\partial t$. Peak inflows are found in the NW and NE quadrants with a few instances occurring with winds to the SE and to the W. The bulk of the peak outflows occur when the winds are towards the SE (i.e., $\tau(t,\theta) \sim 0$), meaning the windstress in (1) and the elevation response would be minimal.



Conclusions:

- Synoptic wind events cumulatively affect the overall flushing of the estuary.
- Extreme events only occur a few times a year and are short lived, but they can cause large volumes of water to flush in and out of the bay.
- Direction of winds can cause large differences in the total volume anomaly changes and flushing rates
- Any type of change in storminess can alter the flushing rates of the bay.

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TEMPERATURE OF TAMPA BAY AND THE EASTERN GULF OF MEXICO

Lianyuan Zheng and Robert H. Weisberg

ABSTRACT

Regularly sampled in situ temperature observations exist for Tampa Bay for several decades and for the west Florida coastal ocean since 1998. Satellite remotely sampled surface temperatures are also available. What do these data suggest regarding secular rises in west Florida ocean and estuary temperatures? The answer depends on the analysis because trends depend on start times. For instance, the Tampa Bay, Hillsborough County EPC data, optimally interpolated to a regular grid and then averaged over the entire bay, show a secular rise from 1982, but not from 1998. Similarly, no secular rise is seen on the west Florida continental shelf since 1998, nor in the contemporaneous satellite SST. Being that the inter-annual variability is itself fairly large, it is not sensible to argue for any trend based on record lengths of only a decade or so. These results are consistent with the longest global temperature records, where we see a slow trend with much larger multi-decadal and inter-annual variations.

Has There Been a Trend in Eastern Gulf of Mexico Temperature in Recent Decades?

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Introduction

Given that globally averaged SST shows a small increase trend from 1880 to the present, what can be said about ocean temperature in Tampa Bay and the eastern Gulf of Mexico? Data from various sources were obtained, including: 1) NOAA global ocean monthly-mean SST anomaly (based on 1971–2000 climatology) (www1.ncdc.noaa.gov/pub/data/noaaglobaltemp/operational/timeseries); 2) Monthly Tampa Bay SST sampled by the Hillsborough County Environ. Protection Commission (fin.epchc.org/); 3) NOAA daily-mean OI SST (www.esrl.noaa.gov/); 4) Hourly near surface temperature from six west Florida shelf buoys (ocgweb.marine.usf.edu); 5) Hourly near surface and bottom temperatures from our West Florida Coastal Ocean Model (WFCOM) simulations for period 2004 to 2014 (ocgweb.marine.usf.edu). To be consistent with the global SST anomaly dataset, anomalies were calculated for each of the other datasets. Net SST changes and trends, along with 95% confidence intervals (based on degrees of freedom varying start time determined record length) are calculated. For both Tampa Bay and the eastern Gulf of Mexico, there is slight SST increase prior to 1990, after which there is not significant trend. In other words there has been neither warming nor cooling in Tampa Bay or the eastern Gulf of Mexico water over the past 25 years.

Data Resources

We collected the observed and modeled sea surface temperatures from various resources including:

- NOAA monthly-mean global ocean SST anomaly available from 1880 through 2015 (www1.ncdc.noaa.gov/pub/data/noaaglobaltemp/operational/timeseries/);
- Monthly sampled SST in Tampa Bay collected by the Hillsborough County Environmental Protection Commission (HCEPC) available from 1972 through 2015 (fin.epchc.org/);
- NOAA daily-mean optimum interpolation (OI) SST available from 1982 through 2015 (www.esrl.noaa.gov/);
- Hourly near surface temperature from the six buoys deployed over the west Florida shelf (WFS) available from 1997 through 2014 (ocgweb.marine.usf.edu);
- WFCOM simulated near surface and bottom temperatures at buoy stations for periods of 2004 to 2015 (ocgweb.marine.usf.edu).

Monthly-mean global ocean SST anomaly

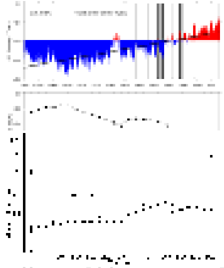

Figure 1: Monthly-mean global ocean SST anomaly (based on 1971 – 2000 climatology) and the trend (upper) calculated over the entire record length; net SST changes (middle) and trends, plus 95% confidence intervals (C.I., lower) for varying start times and hence record lengths.

HCEPC measured SST

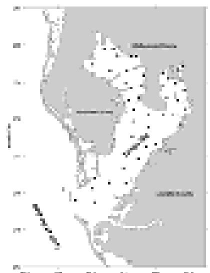

Figure 2: Hillsborough County Environmental Protection Commission (HCEPC) monthly water sample stations used herein. An objective analysis was used to map onto a standard grid before weight-averaging.

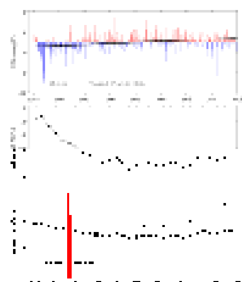

Figure 3: Times series of Tampa Bay SST anomaly, trend plus 95% C.I., and net SST change from 1972 through 2015 (upper), net SST change (middle) and SST anomaly trend plus 95% C.I. (lower) varying with start time. Note: there is no significant trend for Tampa Bay beginning 1990.

NOAA OI SST anomaly over GoM

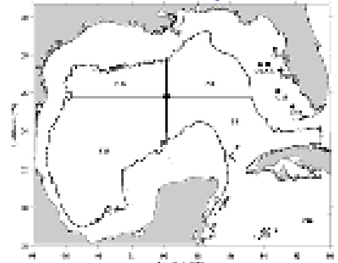

Figure 4: Motivated by the recent work of Muller-Karger et al (2015), we analyze the NOAA OI SST in the GoM over the four deep ocean quadrants [SE, NE, SW & NW centered at (89.85°W, 25.70°N)]. The WFS buoys C10, C12, C13, C14, C16 and C17 are used for the coastal ocean.

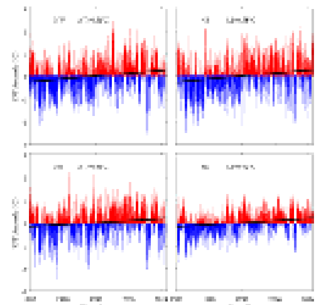

Figure 5: Paralleling Muller-Karger et al (2015), similar positive trends of area-averaged SST are observed in the four deep water quadrants for the period 1982-present.

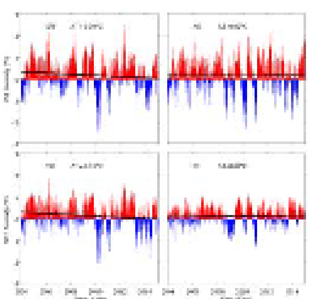

Figure 6: However the deep water quadrant trends change when looking at a shorter interval (2004-present). Note: the net SST anomaly changes are negative (cooling) in NW & SW quadrants, zero in NE quadrant and positive (warming) in SE quadrant.

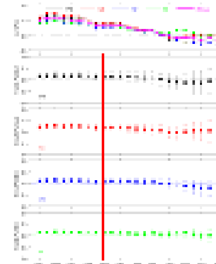

Figure 7: Given the trend dependence on record length, let's consider trends when start each successive year after 1982. The net SST change varies with start time in all four quadrants (upper). From the 2nd to 5th panels are trends and 95% C.I. varying with start time in each quadrant. Note: there is no significant trend from 1990 through present time in GoM.

WFS buoy measured SST

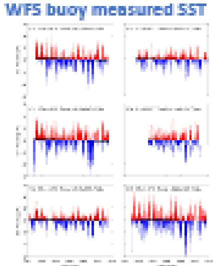

Figure 8: Time series of SST anomaly, net SST change, and trend plus 95% C.I. at six buoys (shown in Figure 4) between 1997 and 2014. Note: there is no significant trend from 1997 through 2014 at any station, consistent with the NOAA OI SST result in eastern GoM. The variations are largely interannual.

WFCOM simulated near surface temperature

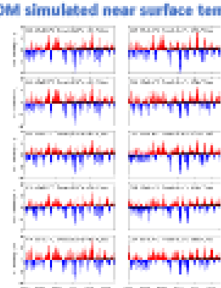

Figure 9: WFCOM simulated time series of near surface temperature anomaly, trend plus 95% C.I., and net SST change from 2004 through 2015 at 10 buoy stations. Note: although the net SST anomalies are positive, there are no significant trends in any of the buoy stations.

WFCOM simulated near bottom temperature

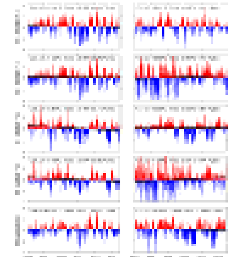

Figure 10: WFCOM simulated time series of bottom temperature anomaly, trend plus 95% C.I., net SST change from 2004 through 2015 at 10 buoy stations. Note: although the net SST changes are either positive or negative, there are no significant trends; instead there is substantial interannual variability due to ocean circulation dynamics.

Conclusions

Based on various SST data sources, we calculated the trends and their corresponding 95% C.I. varying with start time. The following results are concluded:

- While the global ocean SST anomaly shows the small increase trend from 1880 through present, HCEPC 43 years measurement in Tampa Bay, NOAA 32 years OI SST product, 18 years WFS buoy data, and 11 years WFCOM simulation show that while there is small SST increase trend prior to 1990, after which there is no significant SST trend in both Tampa Bay estuary and the eastern GoM.
- From statistics, providing trend alone without inclusive of its related 95% confidence intervals is not sufficient evidence to draw the conclusion of whether the SST warming or cooling.
- Since the SST anomaly time series data are not independent, it is necessary to provide the correct degree of freedom of the SST anomaly data before estimating its 95% confidence intervals.

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RECOMMENDED PROJECTION OF SEA LEVEL RISE IN THE TAMPA BAY REGION

Maya Burke and Libby Carnahan

ABSTRACT

Coastal communities surrounding Tampa Bay are low-lying, densely-populated and therefore vulnerable to sea-level rise. In response to requests from local governments in the Tampa Bay region, Florida Sea Grant (FSG) and the Tampa Bay Regional Planning Council (TBRPC) are facilitating coordinated efforts to guide sea-level rise adaptation planning in the region. The FSG Agent is facilitating the Climate Science Advisory Panel (CSAP), an ad hoc group of experts whose goal is to provide scientific counsel to local governments planning for a changing climate. The TBRPC is convening a network of planners, developers, emergency managers and policy makers through the ONE BAY: Resilient Communities Working Group (OBRCWG) improve the regional capacity of the area to withstand uncertainty and adverse impacts associated with sea level rise and other coastal hazards. Together, these groups are working to promote the pragmatic application of scientific data in public policy. The CSAP has completed a sea-level rise projection recommendation which will be shared with the OBRCWG to be used in future decision support systems and adaptation planning efforts.

INTRODUCTION

The Tampa Bay region, with nearly 700 miles of shoreline[2] and 3.2 million residents - many of whom live near Tampa Bay or the Gulf of Mexico - is highly vulnerable to the potential effects of sea level rise (SLR). Citizens, emergency managers and regional leaders have been accustomed to thinking of coastal hazards in terms of the episodic effects of hurricanes or coastal storms; however, it is also important for local governments and regional agencies to consider the long-term, sustained effects of SLR on real property, natural habitats, and our ability to sustain growth in the regional economy.

The Tampa Bay regional economy is closely tied to both the Gulf of Mexico and Tampa Bay. It is valued at $170 billion, with $51 billion directly influenced by the bay itself[3]. In a report recently published by the World Bank, Tampa was identified as one of the ten coastal metropolitan areas most vulnerable to sea level rise and subsequent flooding. The report rated cities in terms of the overall cost of potential damage and assumed that no adaptation strategies would be implemented in response to SLR[4]. Regional measurements show that the Tampa Bay region is already experiencing sea level rise and there is broad scientific consensus that this trend will continue on into the next century. Cities that choose not to implement adaptation strategies, including those in the Tampa Bay region, may experience the following conditions which will likely incur substantial social and economic costs:

- Flooding of streets, homes, businesses, hospitals, schools, emergency shelters, etc.,
- Shoreline and beach erosion,
- Impacts to the operations of coastal drainage systems,

[2] http://www.tbrpc.org/mapping/pdfs/sea_level_rise/Tampa%20Bay%20-%20Sea%20Level%20Rise%20Project%20Draft%20Report%20without%20maps.pdf
[3] https://tbeptech.org/TBEP_TECH_PUBS/2014/TBEP_04_14_%20FinalReport_Economic_Valuation_of_Tampa_Bay_Estuary.pdf
[4] http://www.worldbank.org/en/news/feature/2013/08/19/coastal-cities-at-highest-risk-floods

- Impairment of coastal water supplies including saltwater intrusion of groundwater and threats to coastal water treatment facilities and infrastructure, and
- Shifts in habitats and reduced ecosystem services.

The economic costs of inaction in the face of SLR must be weighed carefully against the potential (and equally substantial) costs of implementing adaptation strategies, technological solutions and infrastructure investments. However, local governments in the Tampa Bay region should feel confident that there are viable opportunities for implementing adaptation strategies that increase the region's resilience to sea level rise and other coastal hazards. These opportunities benefit from a common projection of regional SLR that enables coordinated planning and policy efforts to protect public safety, health, and quality of life; providing the scientific rationale for the most appropriate projection(s) of SLR in the Tampa Bay region is the purpose of this recommendation.

The Tampa Bay Climate Science Advisory Panel (CSAP), formed in spring 2014, is an ad hoc network of scientists and resource managers working in the Tampa Bay region (Pinellas, Hillsborough, Manatee, and Pasco counties). The goal of the advisory panel is to develop recommendations for local governments and regional agencies as they make decisions about responding to climate change and associated SLR. The CSAP has assessed the best available scientific data to determine a regional set of SLR projection scenarios through 2100. With this shared projection, local governments can coordinate, develop, and implement appropriate coastal adaptation and risk reduction strategies. This document briefly explains the technical methods used to produce SLR projections and offers the CSAP's rationale for the most appropriate SLR projections to use for planning and policymaking throughout the Tampa Bay region.

TECHNICAL METHODS AND RECOMMENDATIONS

Estimates of future SLR are typically expressed by plotting or tabulating a quadratic function. This function is used because it is the simplest function that can effectively capture a wide range of possible SLR scenarios, including constantly increasing, rapidly increasing or even decreasing sea levels. Defining a specific SLR scenario requires three numbers: a datum, the point in time sea level is defined to be zero; a rate of change, how rapidly sea level is changing (increasing or decreasing) at time zero; and a projection, the amount global sea level is expected to change between time zero and some point in the future[5].

Both the datum[6] and the rate of change[7] are defined using present day observations from a tide gauge proximate to the region of interest. Local rates of sea level change reflect a variety of factors, including vertical land motion (subsidence or uplift), changes in estuarine and shelf hydrodynamics, regional oceanographic circulation patterns, and hydrologic cycles (river flow). So, while global measurements and projections are important for estimating SLR, local measurements and projections are needed for realistic local planning efforts. For the Tampa Bay region, the CSAP recommends using data collected from the tide station located near downtown St. Petersburg as the basis for adjusting the first two parameters that are needed to predict regional SLR. The St. Petersburg tide station[8] has the longest reliable period of record (1946 to present) in the region and is consistent with other nearby tide stations,

[5] Most often, this point in the future is the year 2100. However, this does not mean that we only know what the predicted sea level will be in 2100. The quadratic function can show possible sea levels at any point along the curve, between now, 2100 and beyond.
[6] http://tidesandcurrents.noaa.gov/datums.html?id=8726520
[7] http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8726520
[8] http://tidesandcurrents.noaa.gov/stationhome.html?id=8726520

including one located in the Gulf of Mexico at Clearwater[9]. Data measured at the St. Petersburg tide station shows that water levels in Tampa Bay have increased approximately 6.6 inches or approximately 1 inch/decade (see Figure 1).

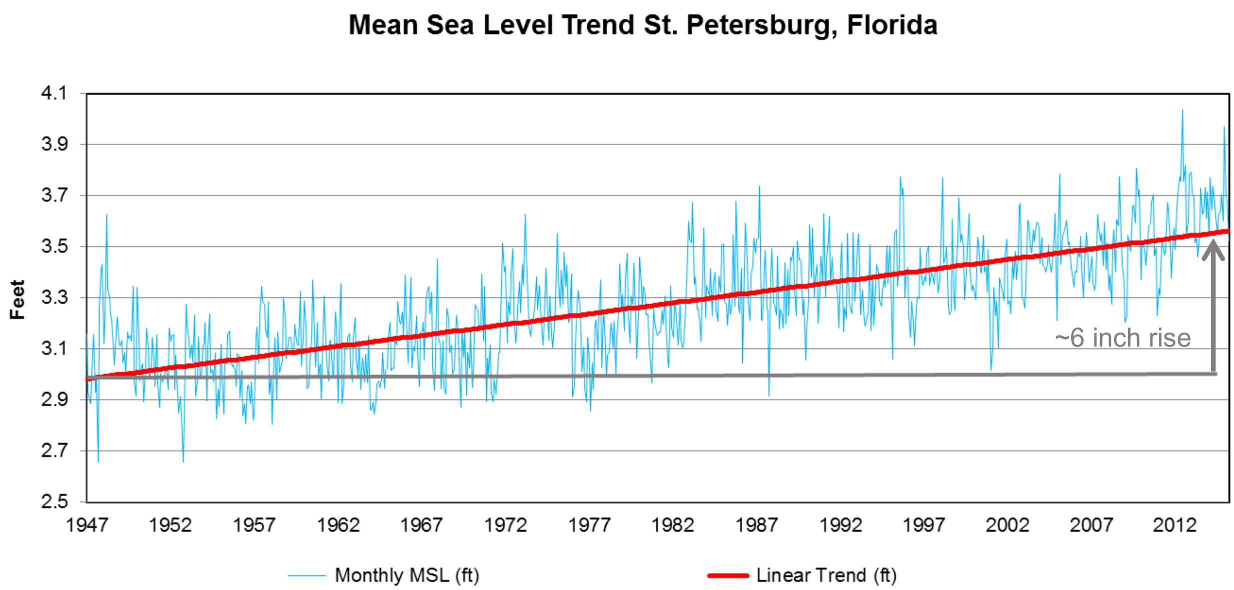

Figure 1. Mean Sea Level Trend in St. Petersburg (MLLW), Florida, NOAA Tide Gauge #8726520

The final parameter, projections of how much sea level will change globally over the next 100 years, is derived from experts engaged in climate science. Currently, there are two primary sources of information regarding sea level rise projections: the Intergovernmental Panel on Climate Change (IPCC) and the US National Climate Assessment (NCA). Although these assessments employ different methods (IPCC relies upon numerical process models; the NCA uses semi-empirical models), both produce estimates of SLR that are consistent with the other. This implies that the results obtained through either approach are robust and should provide practitioners with a higher degree of confidence in using the recommended projections for planning purposes.

The 2012 National Oceanic and Atmospheric Administration (NOAA) Technical Report, *Global Sea Level Rise Scenarios for the United States National Climate Assessment,* was produced as a coordinated, interagency effort to identify nationally agreed upon estimates for global SLR. The report synthesized the scientific literature on global SLR, included input from national experts in climate science, physical coastal processes and coastal management, and produced a set of four plausible SLR scenarios that can easily be adjusted for regional conditions throughout the United States. The projections included in the report will be reviewed every five years in concert with the NCA and the projections use the most current science available. For these reasons, the CSAP recommends that local governments and regional agencies use the set of four global SLR scenarios included in the NCA (hereinafter the NOAA SLR projections[10]), adjusted to local conditions, to inform adaptation and infrastructure planning efforts in the Tampa Bay region.

[9] http://tidesandcurrents.noaa.gov/stationhome.html?id=8726724&name=Clearwater Beach&state=FL

[10] NOAA led the multi-agency effort to inform the sea level portion of the NCA and produced the key technical report, so we will refer to these as the NOAA SLR projections.

Future SLR estimates can be calculated for the Tampa Bay region, integrating data from the local St. Petersburg tide gauge, using a flexible, well-supported tool developed by the United States Army Corps of Engineers (USACE)[11]. The tool takes the three parameters discussed above (datum, rate of change, projection) and produces the plots or tables that describe how sea level will change in the future, such as those included as Figure 2 and Table 1[12].

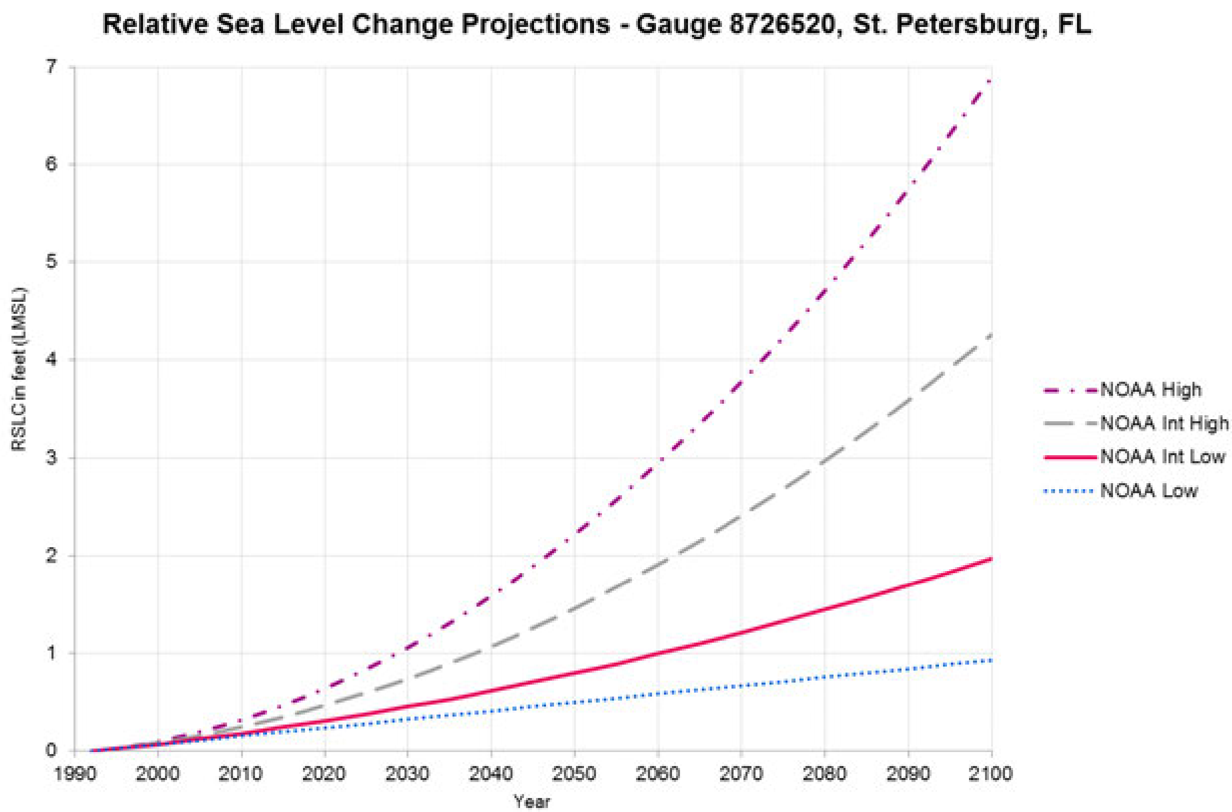

Figure 2. Graphic Relative Sea Level Change (RSLC) Scenarios for St. Petersburg, Florida, as calculated using the NOAA projections and regional corrections. (USACE, 2015)

The regionally adjusted NOAA SLR projections through 2100 (Table 1 and Figure 2) can be summarized as follows:

- *NOAA Low (0.93 feet)*: This is a linear continuation of the historically measured rate of sea level rise and is generally considered appropriate for use as a baseline comparison or in circumstances where there is a great tolerance for risk.
- *NOAA Intermediate Low (1.97 feet)*: This is based on global mean SLR projections from the IPCC 4th Assessment Report and primarily characterizes risks attributed to ocean warming.

[11] Although the CSAP recommends using the USACE Sea Level Change Curve Calculator Tool, this should not be confused with a recommendation of the USACE SLR projections. While the USACE SLR projections are similar to the results produced by the IPCC and NCA, they are derived from equations developed in 1987 (updated in 2013) for the National Research Council (NRC) report, *Responding to Changes in Sea Level; Engineering Implications* and do not reflect the best available science on the dynamics of ice melt.

[12] When using the USACE Sea Level Change Curve Calculator Tool, first select the "St. Petersburg, FL" gauge, then choose "NOAA" as the output agency and factor the projected SLC rate as "Regionally Corrected."

- *NOAA Intermediate High (4.26 feet)*: This is an average of the high end of ranges of global mean SLR reported by several studies[13] using semi-empirical approaches that attempt to characterize the complex relationships between observed sea level change, air temperature, and actual ice sheet loss.
- *NOAA High (6.89 feet)*: This is derived from a combination of estimated ocean warming from the IPCC 4th Assessment Report global SLR projections and a calculation of the maximum possible glacier and ice sheet loss by the end of the century.

Table 1. Relative Sea Level Change Scenarios for St. Petersburg, Florida in Feet above Local Mean Sea Level (LMSL).

Year	NOAA Low (Feet)	NOAA Int Low (Feet)	NOAA Int High (Feet)	NOAA High (Feet)
1992[14]	0.00	0.00	0.00	0.00
2025	0.28	0.38	0.60	0.84
2035	0.37	0.53	0.90	1.31
2050	0.50	0.80	1.46	2.22
2065	0.63	1.10	2.15	3.35
2075	0.71	1.33	2.68	4.23
2100	0.93	1.97	4.26	6.89

SUMMARY

Based upon a thorough assessment of scientific data and literature on SLR, the CSAP concludes that the Tampa Bay region may experience SLR somewhere between 6 inches to 2.5 feet in 2050 and between 1 to 7 feet in 2100. Given this range of uncertainty in future SLR, the CSAP encourages local governments and other agencies to use multiple scenarios in order to allow experts and decision makers the flexibility to consider a variety of contextual factors, including the expected lifespan of the project, project cost, and criticality of function, when developing adaptation strategies. Scenario planning offers opportunities to initiate actions now by balancing the costs of inaction against reasonable returns on investments made to infrastructure that may reduce future impacts and vulnerabilities. For example, decision makers may decide to plan for the NOAA Intermediate Low or Intermediate High scenarios when faced with projects with low to moderate risk tolerance such as temporary projects or infrastructure projects with a relatively short life cycle, while they may choose to plan for the NOAA High scenario in situations where there is little tolerance for risk (e.g. new infrastructure with a long anticipated life cycle such as a power plant, waste water treatment facility, or bridge) (NOAA, 2012). The level of adaptation planning necessary will be up to the planning entity and based on the acceptable level of risk and vulnerability.

[13] Grinsted et al. 2009; Jevrejeva et al. 2010; Vermeer and Rahmstorf, 2009; Horton et al. 2008 from NOAA Tech Memo OAR CPO, p. 12.

[14] The National Tidal Datum Epoch (NTDE) is calculated using tide gauge observations from 1983-2001. Therefore, 1992 (the mid-point) is used as the starting point for the projected curves.

The decision to use a common set of SLR scenarios throughout the Tampa Bay region will promote the efficient development of vulnerability assessment information, provide a platform for broad consensus that can facilitate political support at the local government level, enable increased inter-governmental sharing of policies, and serve as a resource for smaller local governments in the region that frequently look to their larger neighbors for planning and policy guidance. Furthermore, use of a regional set of scenarios for SLR will enable other entities, such as the CSAP, universities, regional agencies (e.g. Tampa Bay Estuary Program, Tampa Bay Regional Planning Council, Tampa Bay Water, Southwest Florida Water Management District) and others to develop decision support tools, best practices, and planning documents to inform policy, planning, and adaptation strategies for local governments and regional agencies managing transportation, infrastructure, water resources, and natural systems. The CSAP recommendations are intended to further these goals, but it is also important to acknowledge that scientific research is evolving. In order to keep up with the best available science, the CSAP advises that this recommendation be revisited, at minimum, every five years and sooner if significant scientific information on future SLR becomes available.

Local governments and other agencies planning for sea level rise in the Tampa Bay region should incorporate three key findings of the CSAP recommendation:

- Adaptation planning should employ a scenario-based approach that considers, at a minimum, location, time horizon, and risk tolerance.
- Projections of SLR should be consistent with present and future National Climate Assessment estimates and methods.
- Projections of SLR should be regionally corrected using the St. Petersburg tide gauge data.

A resilient Tampa Bay – one that acknowledges and responds to coastal vulnerabilities – is one that can support the economic, environmental, and cultural prosperity of this unique and highly valuable region.

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Regional Sea Level Rise Adaptation Planning in Tampa Bay, FL

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Introduction

Coastal communities surrounding Tampa Bay, including Tampa, St. Petersburg, Clearwater, and Bradenton, are low-lying and densely-populated.

By the Numbers
- 700 miles of coastline
- 3.2 million residents
- $170 billion regional economy
- $51 billion influenced by bay[1]
- Diverse cultural and natural resources

Figure 1. Map of Florida highlighting the Tampa Bay Regional Planning Council District

The region is highly susceptible to the effects of climate change and associated sea-level rise (SLR). A 2013 World Bank report[2] cited Tampa/St. Petersburg as the seventh most vulnerable urban region in the world, assuming it chooses not to implement adaptation strategies in response to SLR. Likewise, the 3rd National Climate Assessment (2014) identified Tampa Bay as one of three particularly vulnerable regions in Florida.

In 2014, local governments began to seek regional guidance related to SLR adaptation planning options. In response to requests, Florida Sea Grant and the Tampa Bay Regional Planning Council (TBRPC) initiated coordinated facilitated efforts to address adaptation planning in the four county area.

Figure 2. (a) Infrastructure at Risk-Belcher Road, Pinellas (b) Planning Consultations (c) Street flooding in St. Petersburg caused by saltwater infiltrating stormwater system

Methods

Climate Science Advisory Panel (CSAP)

- ❖ Facilitator-UF/IFAS Extension, Florida Sea Grant
- ❖ Membership- Scientists
  - ❖ Federal Agencies
  - ❖ Universities & Academic Consortia
  - ❖ Local & Regional Governments
- ❖ Objective- *Collaboratively develop recommendations for local governments and regional agencies as they make decisions about responding to climate change and SLR.*

CSAP Timeline of Activities

Date	Action Item
January 2014	Sea Level Rise Project Inventory
January 2014	Presentation to Pinellas Board of County Commissioners
March 2014	Invited members to serve on CSAP
April 2014-January 2015	Monthly Meetings of CSAP • Expert Speakers, Literature Review, Facilitated Discussion
August 2014	Presentation to Hillsborough Board of County Commissioners
May, Oct, Dec 2014	Planning & Science Updates to TBRPC ONE BAY Resilient Communities Working Group
February – April 2015	Presentations to Manatee Directors, Environmental Protection Commission of Hillsborough Climate Group, City of Tampa, Manatee Council of Governments

ONE BAY Resilient Communities Working Group

- ❖ Facilitator- Tampa Bay Regional Planning Council
- ❖ Membership- Practitioners
  - ❖ Policy Makers
  - ❖ Municipal & County Planners
  - ❖ Emergency & Floodplain Managers
- ❖ Objective- *Improve the regional capacity of the area to withstand uncertainty and adverse impacts associated with sea level rise and other coastal hazards.*

ONE BAY Timeline of Activities

When	Action Item
Winter 2014	Requests from local governments for SLR coordination
April 2014	Apply for NOAA CRest Grant to facilitate regional SLR planning efforts (supported by 4 counties, various regional entities and the cities of Tampa, Clearwater and St. Petersburg)
June 2014	Awarded NOAA CRest Grant (2 year term)
May 2014-May 2015	Quarterly meetings of ONE BAY Resilient Communities Working Group • Invited speakers highlighted case studies and success stories assessing vulnerability and planning for SLR • Conducted informal needs assessment of local governments

Results

- Inventory of SLR research projects underway in Tampa Bay Region (February 2014)
- The **CSAP** has drafted *Recommendation for a Unified Projection of Sea-Level Rise in the Tampa Bay Region* (available June 2015) to inform future decision support tools and best practices promoted through **ONE BAY**.
- **ONE BAY** has published a website that serves as a clearinghouse for regionally-relevant SLR resources.
- **ONE BAY** partnered with the Department of Homeland Security to develop a tool simulating the decision-making process for critical infrastructure resilience.

Conclusions

The CSAP and ONE BAY groups are working in tandem to establish the positive feedback loops between researchers and practitioners that promote the pragmatic application of scientific data in public policy .

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DEVELOPMENT OF A MULTIYEAR IMPLEMENTATION PLAN: THE PINELLAS COUNTY EXPERIENCE

Andrew P. Squires

ABSTRACT

The RESTORE Act of 2012 allocates 80% of the Clean Water Act penalties from the Deepwater Horizon oil spill to the Gulf Coast Restoration Trust Fund. The Trust Fund is allocated to five funding components including the Direct Component allocation that provides funds directly to each of 23 Gulf coast Florida counties. As of March 2015, Pinellas County had received a Direct Component allocation of $1,548,320.71 to fund projects. In January 2014, Pinellas County began a collaborative process with a citizen-based stakeholder group to develop a Multiyear Implementation Plan (MYIP) for submittal to the U.S. Treasury. A Treasury-approved MYIP is required by each county prior to applying for project-specific Direct Component grant funding. The stakeholder group assisted staff in the development of the MYIP through a series of publicly-noticed meetings over a 17-month period. An open competitive process was used to select and rank projects for MYIP inclusion. The end product was a MYIP with County Commission approval and broad stakeholder support that included the four highest ranked projects meeting Treasury guidelines and requirements. The Direct Component funding process will be compared to other RESTORE Act funding components, and the specific steps of the county's process to develop the MYIP will be discussed.

INTRODUCTION

The Resources and Ecosystem Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast Act of 2012 (RESTORE Act) was passed by Congress on June 29, 2012 and signed into law by President Obama on July 6, 2012. The RESTORE Act allocates 80% of the Clean Water Act (CWA) penalties from the Deepwater Horizon oil spill to the Gulf Coast Restoration Trust Fund (Trust Fund).

CWA administrative and civil penalties related to the oil spill will go into the Trust Fund based on the following allocation:

- (35%, Pot 1) Direct Component – 35% to be split equally among the five Gulf Coast States.
- (30%, Pot 2) Council –Selected Restoration Component – 30% to the Gulf Coast Restoration Council to develop and implement the Comprehensive Plan applicable to all five states.
- (30%. Pot 3) Spill Impact Component – 30% to the Gulf Coast States.
- (2.5%, Pot 4) Research, Observation, and Monitoring Component – 2.5% to the National Oceanic and Atmospheric Administration Gulf Restoration Science Program.

- (2.5%, Pot 5) Centers of Excellence Research Grants Component – For Florida, 0.5% to the Florida Institute of Oceanography to administer competitive grants.

Pinellas County requested ideas (since June 2014) and received 17 proposals (from November 6, 2014 to February 6, 2015) for Direct Component (Pot 1) funded projects within the county and/or its adjacent bay, coastal and Gulf waters that will benefit the Gulf of Mexico ecosystem. As of March 2015, $1,548,320.71 of Direct Component funding was available to Pinellas. The settlement between the Justice Department and British Petroleum (BP) is expected to allocate an additional $8 to $8.5 million to the county over a 15-year period.

The U.S. Department of Treasury (Treasury) Interim Final Rule issuing regulations for the Trust Fund became effective October 14, 2014. For the Direct Component activity grant application, at a minimum (per 31 CFR Part 34.303, application procedure) the county must:

- Submit a Multiyear Implementation Plan (MYIP) describing each activity it seeks to fund.
- For each activity, the plan must include a narrative description demonstrating:
  - the need, purpose, and objectives;
  - how the activity meets all funding eligibility requirements;
  - the activity location, budget, milestones, and projected completion dates;
  - criteria used to evaluate success criteria;
  - how at least a 45-day public review and comment period was provided; and
  - how each activity was adopted following public input.
- Include supporting information in each grant application that:
  - proposed activities meet statutory eligibility requirements, and
  - each activity to protect or restore natural resources is based on best available science.

DEVELOPMENT OF PROJECT SELECTION AND RANKING PROCESS

In November 2013, county staff presented a RESTORE Act update to the Board of County Commissioners (Board) with a summary of completed Pot 1 related activities. The Board approved the composition of a proposed 17-member RESTORE Act Working Group to assist staff in 1) refining county-specific goals and priorities drafted by the in-house advisory committee, 2) developing a project selection and ranking process, and 3) selecting and ranking a set of recommended projects to county staff to include in the MYIP. The Working Group included individuals from cities (3), non-governmental organizations (8), academia (3), Florida Department of Environmental Protection (1), Tampa Bay Water (1), and the seafood restaurant business (1).

Seven public meetings between county staff and the Working Group were held from January through May 2014 to establish project goals and priorities and a project selection and ranking process. During the meetings, the Working Group: 1) approved their Charter; 2) heard presentations on the Sunshine Law, elements of the county's comprehensive plan, county economic priorities, and county assistant attorney summaries of the RESTORE Act and Treasury rules; 3) developed and approved project goals, and 4) developed and approved the project selection and ranking process.

The Board adopted the following Direct Component goals providing that the project and programs, to the extent feasible: 1) provide and/or contribute to countywide and/or regional environmental and/or economic benefits, and (2) utilize a collaborative approach emphasizing environmental stewardship and sustainable practices.

- All projects must benefit the Gulf of Mexico ecosystem through one or more of the Gulf Coast Ecosystem Restoration Council's five goals:
    1. Restore and Conserve Habitat,
    2. Restore Water Quality,
    3. Replenish and Protect Living Coastal and Marine Resources,
    4. Enhance Community Resilience, and
    5. Build and Revitalize the Gulf Economy.
- Projects may also support, further, or implement goals as identified in the Future Land Use and Quality Communities; Natural Resource Conservation and Management; Coastal Management; Recreation, Open Space and Culture; and Economic Elements of the Pinellas County Comprehensive Plan.

Projects and programs must meet one or more RESTORE Act required eligible activities:

1. Restoration/protection of natural resources, ecosystems, fisheries, marine wildlife habitats, beaches, and coastal wetlands,
2. Mitigation of damage to fish, wildlife, and natural resources,
3. Implementation of Federally-approved marine, coastal, or comprehensive conservation management plan, including fisheries monitoring,
4. Workforce development and job creation,
5. Improvements to or on State parks in coastal areas affected by Deepwater Horizon oil spill,
6. Infrastructure projects benefitting the economy or ecological resources, including port infrastructure,
7. Coastal flood protection and related infrastructure,

8. Promotion of Gulf Coast Region tourism, including recreational fishing,
9. Promotion of the consumption of seafood harvesting from the Gulf Coast Region, and
10. Planning assistance.

The recommended Working Group project priorities were to:

1. Protect and restore native habitats,
2. Provide stormwater quality improvements,
3. Create policies, programs, and/or mechanisms to remediate environmental and/or economic damages,
4. Protect against future environmental and/or economic vulnerability,
5. Provide climate change/sea-level rise planning, adaptation and/or related community engagement,
6. Provide flood and storm protection to infrastructure and other publically owned assets that consider resilience and changing sea levels,
7. Implement or further actions in the Pinellas County Post Disaster Redevelopment Plan.
8. Diversify and improve the economy including tourism, and
9. Promote sustainable recreational fishing and consumption of seafood dependent on Gulf ecosystem, and/or protect or promote working waterfronts.

The county Direct Component project goals and priorities were incorporated into the selection and ranking criteria as shown below. Eleven criteria were selected with a point range assigned to each for a total number of possible points from 6 to 27.

1. (1-3 points) Value of project in meeting Restoration Council goals.
2. (1-2 points) Number of Restoration Council goals clearly addressed.
3. (1-3 points) Value of project in meeting RESTORE Act eligible activities.
4. (1-2 points) Number of RESTORE Act eligible activities clearly addressed.
5. (0-3 points) Value of project in meeting RESTORE Act Pinellas County priorities.
6. (0-3 points) Number of RESTORE Act county priorities clearly addressed.
7. (1-3 points) Provide countywide and/or regional benefits?
8. (0-1 points) Utilizes a collaborative approach incorporating partnerships.
9. (0-2 points) Will strongly support and further County Comprehensive Plan Element goal attainment as identified in the overarching project goals.
10. (1-3 points) Long-term project benefits.
11. (0-2 points) Matching Funds.

PROJECTS SELECTED FOR FUNDING

A project selection subcommittee of five Working Group members and three county staff reviewed the 17 proposals submitted totaling $9,289,082 of requested funds. Five projects were initially recommended for funding. The two highest ranked projects were to be fully funded, and the third through fifth ranked projects were recommended for partial funding. The number one ranked project was a proposal by the Tampa Bay Estuary Program (TBEP) to fund $100,000 of a future Tampa Bay Environmental Restoration Fund (TBERF) project. The U.S. Treasury informed county staff that they would not accept a MYIP unless the project is identified and details are clearly described, such as specific milestones, costs, and success criteria. Consequently, staff could not recommend funding this project since the project specifics would not be known until 2016. The third ranked project's funding level was reduced from $415,910 to $233,930 to cover the first two years of an originally proposed 5-year project. The Working Group, with additional county staff input, recalculated a proposed funding level of $942,646 to $479,490 for the forth ranked project. This cost revision aligned with the ranking subcommittee's recommendation to fund the first two project phases (years 1-3) and to adjust the "administrative" percentage from 10% to 3% per RESTORE Act requirements. Finally, the subcommittee's total funding level recommended for the proposed projects, excluding the top ranked TBEP project, still exceeded the total funding available. Consequently, staff lowered the fifth ranked project's funding recommendation from $617,402 to $534,890 so the total funding amount requested ($1,548,310) did not exceed the total funding amount available ($1,548,320.71). The final four projects to be submitted for funding to the Treasury are listed below.

- PROJECT 1. PINELLAS COUNTY ASSESSMENT OF VULNERABILITY TO THE IMPACTS OF SEA LEVEL RISE & INFRASTRUCTURE RESILIENCY PLAN - *Pinellas County Planning Dept,* project duration 3 years, $300,000 (Mean Ranking Score 22.00)

  Project Components:

  - Create a Geographical Information System-based support tool incorporating the latest sea level rise scenarios, topography, and locations of existing/planned infrastructure (transportation, utilities, public safety) within Pinellas County,
  - Develop adaptation and mitigation strategies based on scenarios related to timelines and predicted changes,
  - Perform an economic analysis to facilitate long-term sustainability and cost: benefit driven decision making, and
  - Identify and prioritize key projects eligible for infrastructure sales tax funding.

- PROJECT 2. COASTAL OCEAN MONITORING & PREDICTION SYSTEM (COMPS) - *USF College of Marine Science,* project duration 2 years, $233,930 (Mean Ranking Score 21.86)

  Project Components:

  - Reestablishes a moored buoy observing station off Pass-a-Grille Beach,
  - Measurements of winds, waves, currents, temperature, relative humidity, barometric pressure, sea surface temperature, and salinity, and
  - Provide publicly available real-time data.
  - Data use examples include:
    - The prediction of coastal inundation by hurricane storm surge and waves,
    - Harmful algal bloom tracking & prediction,
    - Understanding of gag grouper recruitment,
    - Database development of wave and current information for ongoing/future modeling needs, and
    - Providing coastal marine weather and atmospheric conditions to user groups.

- PROJECT 3. A VERY HIGH RESOLUTION ESTUARY CIRCULATION NOWCAST/FORECAST MODEL FOR TAMPA BAY & VICINITY – *USF College of Marine Science,* project duration 3 years, $479,490 (Mean Ranking Score 21.14)

  Project Components:

  - Develop and implement an automated, internet-based, daily nowcast/forecast system of high resolution water circulation in Tampa Bay and vicinity (Boca Ciega Bay, Intracoastal Waterway, inlets, Sarasota Bay, adjacent Gulf of Mexico),
  - Model previously developed and vetted through peer-reviewed literature, and
  - State-of-the-art 3-dimensional circulation model.
  - Applications will aid:
    - Safe and efficient navigation,
    - Water quality assessments and predictions,
    - Pollutant and harmful algae tracking and prediction, and
    - Understanding coastal /ocean ecosystem drivers and interrelated processes.
- PROJECT 4. FT. DE SOTO PARK DUNE WALKOVERS – *Pinellas County Office of Management & Budget*, project duration 3-years, $534,890 (Mean Ranking Score 20.80)

  Project Components:

- Design, permitting, and construction of 2-3 dune walkovers at Ft. De Soto Park
- About 540 linear feet of walkovers to be built between the Gulf Pier parking lot northward to the North Beach parking lots, and
- Walkovers to funnel beachgoers to selected entry points.
- Benefits:
    - Preserve and protect sensitive dune habitats, sea turtle and shorebird nests,
    - Provide disabled access to beach,
    - Enhance natural sand accretion, and
    - Defend against storm and tidal influx.

MYIP REVIEW AND APPROVALS

In June 2015, the Board agreed to place the draft MYIP out for the required 45-day public review period. A news release was distributed to local media outlets on June 29, 2015 inviting the public to review and provide comments through August 20, 2015. Notices soliciting comments were also sent to the county's 24 city government offices, the Tampa Bay Estuary Program's listserv of e-mail addresses, and to individuals affiliated from over 20 stakeholder organizations.

Seventy-seven comments were received as either letters or e-mails. There was very strong public support for the projects proposed. All those sending in comments were in favor of one or more MYIP projects with one exception. The one exception was from a local environmental consultant who supported the resiliency and dune walkover projects (Projects 1 and 4 as listed above) but opposed inclusion of the two USF ocean-science projects (Projects 2 and 3). A summary of comments received are shown in Table 2. On September 24, 2015, the Board approved submittal of the MYIP to the Treasury for their review and comments. The MYIP was submitted to the Treasury for their review on October 1, 2015.

NEXT STEPS

Upon Treasury approval of the MYIP, project-specific grant applications for federal assistance must be submitted to the Treasury for review and approval. Upon approval of each funding application, funding agreements for each approved project will be developed and executed so project work can begin. The set of approved projects in this initial MYIP are expected to begin in late spring or summer 2016. As the Direct Component Trust fund allocation for Pinellas grows over time from BP settlement payments, the county anticipates repeating the established process to solicit new projects for inclusion in an updated MYIP for funding consideration by the Treasury.

ACKNOWLEDGEMENTS

Special thanks to Lindsay Cross of the Tampa Bay Estuary Program for facilitating the many public meetings and to coworkers Kelli Levy, Liz Freeman, David McCrea, Brendan Mackesey, Debbie Chayet, and Chris Moore for their comments and assistance during the process. Finally, completion of the MYIP would not have been possible without guidance and input provided by the Working Group members: Mayor Bob Minning, Carlos Frey, Elliot Shoberg, David White, Jessica Koelsch, Peter Clark, Elizabeth Fetherston, Cathy Harrelson, Mark Rachal, Mike Colby, Dennis O'Hern, Frank Chivas, Tracy Harris, Mark Hafen, Ernst Peebles, Mark Luther, Bob McConnell, and Randy Runnels.

IMPLEMENTING THE RESTORE ACT IN FLORIDA: THE STATE EXPENDITURE PLAN

Doug Robison

ABSTRACT

Overview of the Florida State Expenditure Plan - Following the Deepwater Horizon oil spill Congress passed the Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economy of the Gulf Coast Act (RESTORE Act) that provides a mechanism to hold the responsible parties financially accountable for restoring the Gulf. Signed into law in 2012, the Act is expected to generate unprecedented funding for both ecological and economic restoration of the Gulf Coast. Among the five affected states Florida is unique with regard to the prominent role of its 23 Gulf Coast counties, as well as the large geographic extent of its coastline and the associated diversity of coastal ecosystems and communities. This paper will focus specifically on the Spill Impact Component of the Act, and how that component will be executed in Florida through the development of the Florida State Expenditure Plan by the Gulf Consortium. The types of projects, programs and activities eligible for funding under the Spill Impact Component will be reviewed, and priorities applicable to Tampa Bay will be discussed.

WLERA - WESTERN LAKE ERIE RESTORATION ASSESSMENT

Justin A. Saarinen and Kurt P. Kowalski

ABSTRACT

Restoring coastal wetlands are a cross-cutting integrated solution to protect and restore the largest freshwater ecosystem in the world. The WLERA provides a data-driven definition for the restorability of coastal, diked, and potential coastal wetlands in Western Lake Erie, informed by autonomous surveys (lidar), time series (30-year lake levels), current mapping efforts (C-CAP, NWI), and expert formulation (meetings). The geospatial model is a restorability surface covering the continuous coastal landscape in 1 m^2 increments between the Detroit River, Michigan and Black River, Ohio. These small areas are assigned a normalized score between 0-100, with 100 being more restorable, and can be aggregated to summarize any irregular area (parcel) or group of areas (refuge units) to asses restorability. A supporting geodatabase was developed and includes 1) polygon feature areas that represent current and potential wetlands with relevant attribution, 2) linear features representing dikes, and a hydrologic flow network attributed with level of disconnection, and 3) point features representing other hydrologic control features such as culverts and water-control structures.

We are developing derivative models that incorporate longer term field observations to assess individual ecosystem service benefits of alternative futures of coastal wetland restoration. With relevant GLRI projects as the basis of cost per hectare, we projected out restoration funding scenarios based on reduced and increased levels. With disaggregated WLERA index values, we generated 4 future restored coastal wetland landscapes then applied published measurements of phosphorus mass retention in functional WLE wetlands to present a range of total phosphorus retention per year for alternative restoration future as compared to the total phosphorus load. The preliminary results of this project will contribute to alternative economic valuation studies of ecosystem services associated with coastal wetlands, supporting alternative restoration decisions of researchers, managers and planners.

COMMUNITY CONNECTIONS CREATE BAY IMPROVEMENT

Misty Cladas, Ernie Franke, George Heinrich and Nestor B. Ortiz, Jr.

ABSTRACT

The Tampa Bay Estuary Program (TBEP) involves the public in the restoration and education of Tampa Bay using the Bay Mini-Grant and Give-A-Day for the Bay Programs. TBEP started the Bay Mini-Grant program in 1993 to empower the local community to become Bay stewards. Since 2000, funding has come from sales of the Tampa Bay Estuary specialty license plate and in 2014 had awarded $1.5 million to 292 different recipients. Grant projects recommended for funding by TBEP's Community Advisory Committee, include creating the popular Boating and Angling Guides, environmental programs for children, and lake and pond restorations by homeowner associations. TBEP brings the community into the environmental arena through volunteer workdays. Give-A-Day for the Bay work days are held six times a year on Saturday mornings at parks and preserves within the watershed. Volunteer activities include removing invasive plants, planting native plants and trash and debris removal. Since 2010, 1,308 volunteers have worked 5,232 hours on 107.5 acres around Tampa Bay. This volunteer force, calculated into actual dollars represents $118,064.10 worth of time donated to improving Tampa Bay over a five-year period. A healthy Bay is important and involving the local community in protecting and restoring Tampa Bay will continue to be a top priority.

THE SUWANNEE COOTER (*PSEUDEMYS CONCINNA SUWANNIENSIS*) IN THE ALAFIA RIVER: DETERMINING THE DISTRIBUTION, STATUS, AND CONSERVATION NEEDS OF A DISJUNCT TURTLE POPULATION

George L. Heinrich, Timothy J. Walsh and Dale R. Jackson

ABSTRACT

The Suwannee cooter, *Pseudemys concinna suwanniensis*, the largest member of the speciose turtle family Emydidae, is known to occur in at least 18 rivers that drain into the northeastern Gulf of Mexico along the northwest coast of Florida, from just west of Tallahassee to just south of Tampa. The southern distribution and status of this state-protected subspecies is uncertain and hence of conservation concern. A distributional gap of ~79 km occurs between the Weeki Wachee River and Alafia River (southernmost documented occurrence). We reviewed known museum specimens and historical records, and summarized everything known about this subspecies in the Alafia River, from the first specimens collected by Auffenberg and co-workers in 1953 to a nest of hatchlings documented in 2014. This now published work was the impetus for an ongoing survey to determine the distribution and status of the Suwannee cooter in the Alafia River. Located within one of the world's most important and highly degraded phosphate mining regions, this river has a long history of anthropogenic disturbance. It is critical to monitor this ecosystem carefully for existing and potential threats to both aquatic habitat and adjacent upland nesting areas of Suwannee cooters to assure that appropriate conservation and management activities are in place to protect what may be an important peripheral population.

VOLUNTEERS FOR STORMWATER RETENTION PONDS

Ernie Franke

ABSTRACT

How would you feel if you woke each morning to a stagnant stormwater retention pond? Most of us, at some point in our lives, have wondered just how much difference we can make in the world. That's what happened with the pond just outside my front door at the Shores of Long Bayou (SLB) Condominiums. Although I call it "my pond," it's really a stormwater retention pond, designed to capture nutrients from lawns, roads and parking lots before entering Florida's waterways. The pond had been neglected for many years, and required chemical controls to contain invasive weeds. Condo owners didn't want "raw" nature, preferring something closer to a golf-course setting, but the pond had gravitated more to a "Love Canal" look. When pressed with the demands of condo owners, the Home-Owners association (HOA) manager faces a dilemma between using professional help or volunteer labor. The professional lake and pond service offers expert help using chemicals to control weeds and algae. Chemicals act faster and are more economical, but suffer from environmental and erosion problems. Volunteers offer a manual, biological, more environmentally-compliant approach to pond management. Mimicking what we see at city, county and state parks, we need a combination of volunteers and professionals to save money and maintain our environment.

Over the past six years of attending and presenting at Lake/Pond Education Days, we have noticed many groups seeking instructions for rejuvenating their retention ponds in an urban environment. These Tampa Bay groups are home-owners and condominium owners with a common retention pond, seeking solutions to their problems on a limited budget. Special problems faced in the urban environment are esthetics, multiple ownerships, condo cooperation and a "non-yardwork attitude". Because the owners are not bio-engineers, they are seeking specific guidance, hence the development of Conservation Modules (CMs) with step-by-step, illustrated instructions..

INTRODUCTION

Many of our retention ponds were initially constructed to control flooding and fluctuations in stormwater run-off. As volunteers, we wanted to focus on two dynamics, both the result of an increasing population in Florida. Today, with the threat of red-tide and the rampant use of fertilizers in an urban environment, retention pond emphasis has switched to the task of removing nutrients before entering the estuary. Secondly, animal life has been displaced. We searched for a method of improving the coalescence in an urban environment. This led to our interest in turtle basking islands and providing a habitat for the common moorhen. SLB has ten stormwater retention ponds and two large lakes in its 77-acre nature reserve. The HOA manager must decide between using professional and volunteer help in maintaining these lakes and ponds. In most cases, it's a matter of size. Professionals concentrate on lawns, lakes and invasive out-of-control species, often employing power tools. At the volunteer level, ponds and trails are maintained using safer hand-tools such as pruning shears and shovels. Volunteers are excellent at removing paper and plastic from the environment, as shown by all successful Adopt-A-Block, -Mile, -Pond, -Shoreline and -Trail programs. Volunteers contribute their time, which could be very costly at the professional level. The answer is a combination of professional and volunteer efforts.

Figure 1. Map of Shores of Long Bayou

APPROACH

Volunteers come with an attitude - an attitude of service. We need to set an atmosphere for them - where we provide information and encouragement, financial help and recognition. And finally, we need to act to prevent frustration of not accomplishing anything. People feel a part of a project when they know what's going on and knowing why. Because transforming a pond is a long-term affair, it's important to transfer your vision of how the pond will look in the future. Working in the pond gives you a great chance to meet neighbors who know you as the "pond guy." You also get to watch the animals around you, especially during mating season. When baby black fluff-balls follow their mama moorhen across the pond, you'll find yourself proudly sharing photos of your "pond grandkids". Along with improving the appearance for the people who live nearby, a top priority for our campus is providing a haven for waterfowl. Across Florida, there has been significant habitat lost to development.

CONSRVATION MODULES (CM)

The Tampa Bay Estuary Program (TBEP) recently awarded SLB a mini-grant to develop several conservation modules. Much of the information is available on the internet, but hasn't been collected together and applied to the urban retention pond. Because we have ten retention ponds and two lakes on our 77-acre campus, we have field-tested and documented techniques of hydrilla control, Brazilian pepper-tree removal, muck removal, habitat restoration and conservation awareness. Conservation modules (Franke 2015a) are web-posted PowerPoint / PDF presentations, an easily-editable format to add future experiences. These modules provide a retrievable, paper-less reference, available for posting on State, County and Local websites, vetted by the website owners. We have also posted our modules on our condominium website (SLB Website 2015), which informs, co-ordinates and invites volunteers. Just as community blogging and YouTube instructional videos have blossomed over the years, we expect conservation modules to be useful tools for the Do-It-Yourself owners of stormwater retention ponds for creating conservation-awareness, habitat restoration and pond rejuvenation.

CM #1: Turtle Islands Provide a Haven in a Condo Setting

While stopping to take a picture of one of the many turtle basking islands that we built, I noticed a dozen cars also pulled over to the side of the road behind me. "What is he taking a picture of?" turned into "It's an alligator, Get my camera or cell-phone out!"

Who doesn't like to watch wildlife? Turtles tend to sun themselves on the shoreline or on storm-water ramps. They quickly slip back into the water when strollers pass by. Construction of a durable island in a retention pond provides turtles with a water barrier from viewers. It helps for the community to "see" the wildlife present in the retention pond, enhancing conservation awareness.

CM #2: Combating the Invasion of Brazilian Pepper-Trees

Shortly after José Gaspar raided the west coast of Florida, Brazilian pepper-trees were introduced into Florida in the mid-1800s as ornamental plants. Today, every fourth tree in the Tampa Bay area is a Brazilian pepper, but we don't celebrate their invasion. Pepper-trees are invasive, with no natural enemies in Florida. With impenetrable canopies and unruly branches, Brazilian peppers hog sunlight and space, causing indigenous plants to wither and die. Their shallow roots promote soil erosion, displacing mangroves and disrupting fish-breeding habitats. And when you think it couldn't be worse, pepper trees are in the same family as poison ivy, poison oak, and poison sumac, which can cause allergic reactions.

Brazilian peppers started to encroach on the mangroves in our estuary system. TBEP offered a mini-grant to groups willing to combat this invasion, encouraging the formation of coalitions of combatants. Starting with a mini-grant of $3,000, the wetlands project grew to $8,500 when the SLB and Long Bayou condo associations partnered together to improve the nature reserve. An individual unit owner donated an additional $4,400 to remove pepper-trees in one section of the reserve. Thus TBEP's initial seed money grew by a factor of four in a short time. The Shores has come a long way to achieving a "pepper-free" campus within a few years.

Eradication involves cutting each tree down to the stump and applying poison to kill the roots. Not only was there giving of money, but gifts-in-kind and volunteer labor as well. Clean mulch was readily available. At minimum wage rates, volunteers donated an equivalent of $2,000 to the original mini-grant, transforming the forest of peppers into a picnic area. They needed a little guidance and direction, and beamed with pride over the improvement in their reserve.

CM #3: Freshwater Clams Micro-Filter Stormwater Retention Ponds

Consider the honeybee - alone she is able to gather a few drops of nectar and pollinate a few flowers. Together the hive produces gallons of rich honey and pollinates entire crops. Now picture the freshwater clam, the size of a fingernail, able to micro-filter ten cups of water each day. Expand that to a colony of Asian clams (Corbicula fluminea) which can macro-filter an entire stormwater retention pond. Today we look for renewable resources in harmony with the earth. The freshwater clam continuously filters the nutrients from retention ponds, helping reduce the growth of algae - all without man adding any energy (Franke 2015b).

Many of our retention ponds were initially constructed to control flooding and fluctuations in stormwater run-off. Today, with the threat of red-tide and the rampant use of fertilizers in an urban environment, emphasis has switched to the task of removing nutrients before entering the estuary. Freshwater clams have been shown (Cohen etal 1984; Phelps 1994), to decrease the nutrient level in stormwater retention ponds by micro-filtering the water, decreasing algae blooms. Freshwater clams multiply rapidly to perform mass filtering of bottom nutrients. In the Potomac River, Asian clams have produced a substantial decrease in phytoplankton and in water turbidity.

A dilemma exists between using chemicals for algae control and a chemical-free, biological approach using freshwater clams to remove nutrients. The addition of freshwater clams to a retention pond may not instantly cure algae problems. Asian clams are merely a tool in the integrated pond maintenance tool-box, including aquatic plants.

Asian clams are sold in the aquarium trade, where they are known as “pygmy" or “gold-luck" clams, for cleaning aquariums by removing algae. They have invaded entire U.S. Southeast (USGS Map 2015), including every river and stream in Florida, inhabiting the shallow, sandy bottoms of lakes and streams. They form an important functional component of freshwater ecosystems, as an important food source for many fish, birds and reptiles. Colonies serve as indicators of water quality and overall health of aquatic ecosystems.

We have successfully used Asian clams to micro-filter six stormwater retention ponds to remove nutrients and decrease algae growth. A simple calculation shows that an entire pond (0.3 acres) can pass through the micro-filtering within a day. Osprey Pond, which has been chemically-free maintained for five years, has grown a colony of freshwater clams from a few patchy colonies to now occupying the outer third of the pond (littoral zone). Using a measured density of 100 clams per sq. ft, there are close to one-half million clams present. Given an Asian clam filtration rate of 100 ml/hr/clam (Lauritsen 1986; Phelps 1997; Widdows 2001), we find that the entire pond can be micro-filtered in about one day. As they would say in Vaudeville, "That's a lot of clams!".

CM #4: Florida-Native Water Lilies to Remove Muck

Some people pay big money for mud-baths, but we offer it for free! What more can you want: exercise, sauna and mud-bath? We use the roots of Florida-native water lilies to bundle the muck in the bottom of each stormwater retention pond. We then wait for the root-ball to surface, and gather these five-to-ten pound mud-balls and toss them on the shore. This both de-mucks the pond and builds up the banks.

CM #5: Forming Moorhen Breeding Islands

As wildlife habitats shrink with urban development, we must provide alternate freshwater habitats for waterfowl. The common moorhen is an abundant bird with a global population that likely numbers several million, but is currently endangered due to destruction and lack of good habitat. In many places human-modification of the landscape to create reservoirs and artificial wetlands has actually increased the amount of habitat available to the common moorhen (Franke 2015c). In the coastal regions of Florida, condominiums have lakes and ponds that serve as retention areas for stormwater run- off control. We have duplicated their nesting habitat within the urban condominium setting by forming small breeder islands within several stormwater retention ponds. The advantage of forming these islands is isolation. The moorhen loves to have the security of an island it can call its own. Condo people love to keep track of their moorhens. Water forms a barrier for both raccoons and people. Everyone wins. We've bred over twenty sets of moorhens over the past three years.

CM #6: Grass Carp to Combat Hydrilla Invasion

If you maintain a retention pond in the Tampa Bay area, you will be fighting hydrilla (Hydrilla verticillata). This invasive aquatic plant can take-over an entire pond in just one season. Hydrilla removal requires a combination of manual and chemical control, before adding grass carp. The conservation module guides the pond-owner through the permitting process with the Fish and Wildlife Commission (FWC).

LOCAL ADOPT-A-POND PROGRAM

Within our 77-acre condominium campus, we have ten ponds and two lakes. The lakes are maintained by a professional service, while most of the ponds are maintained by volunteers. Volunteers have transformed chemically-maintained ponds into natural, pleasant, stormwater retention ponds that remove nutrients before reaching the Tampa Bay estuary. Southwest Florida Water Management District (SWFWMD), the regional governmental agency that permits all stormwater retention ponds in our region, desires to see greater than 35% of the pond covered with aquatic plants for nutrient-absorption.

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