Assessment of the cumulative effects of restoration activities on water quality in Tampa Bay, Florida

Introduction

Despite considerable investments over the last four decades in coastal and estuarine ecosystem restoration (Diefenderfer et al. 2016), numerous challenges still impede comprehensive success. In the Gulf of Mexico (GOM), chronic and discrete drivers contribute to the difficulty in restoring and managing coastal ecosystems. For example, the synergistic effects of widespread chronic coastal urbanization and climate change impacts will likely limit future habitat management effectiveness (Enwright, Griffith, and Osland 2016). Competing management and policy directives for flood protection, national commerce and energy development complicate and prolong efforts to abate coastal hypoxia and other coastal water quality issues (Rabotyagov et al. 2014; Alfredo and Russo 2017). Disputes surrounding fair and equitable natural resource allocation often result in contentious implementation plans for the long-term sustainability of coastal resources (GMFMC 2017). And, discrete tropical storm (Greening, Doering, and Corbett 2006) and large-scale pollution events (Beyer et al. 2016) often reset, reverse or delay progress in restoring coastal ecosystems. These factors contribute to a complex setting for successful implementation of ecosystem restoration activities within the GOM.

Notwithstanding these challenges, the difficulty in rigorously monitoring and understanding an ecosystem's condition and restoration trajectory at various spatial and temporal scales further constrain rigorous observations of restoration success (Hobbs and Harris 2001). The lack of long-term environmental monitoring is a primary impediment to understanding pre- versus post- restoration change (Schiff et al. 2016) – while also impeding the recognition of any coastal ecosystem improvements derived from prolonged management, policy and restoration activities. Where long-term coastal monitoring programs have been implemented, a broader sense of how management, policy and restoration activities affect coastal ecosystem quality can be attained

(Borja et al. 2016). Utilizing lessons-learned from environmental monitoring programs, new frameworks are starting to emerge to better understand and facilitate the implementation of coastal restoration ecology from a more informed perspective (Bayraktarov et al. 2016; Diefenderfer et al. 2016).

A very large, comprehensive and concerted effort to restore Gulf of Mexico coastal ecosystems is currently underway (GCERC 2013, 2016). Primary funding for this effort stems from the legal settlements resulting from the 2010 Deepwater Horizon oil spill. Funding sources include: early restoration investments that were made immediately following the spill, resource damage assessments resulting from the spill's impacts (NRDA, 2016), a record legal settlement of civil and criminal penalties negotiated between the responsible parties and the US government with strict US congressional oversight (RESTORE Act), and matching funds from research, monitoring and restoration practitioners worldwide. These funds, equating to >$20B US, present the Gulf of Mexico community an unprecedented opportunity to revitalize regional restoration efforts that will span multiple generations (GCERC 2013, 2016). Consequently, the restoration investments being made with these funds will be highly scrutinized. Better understanding the environmental outcomes of past restoration investments will help identify how, where and when future resources should be invested so that the Gulf Coast community can achieve the highest degree of restoration success.

Because of the difficulties in demonstrating restoration success, new tools are needed to help guide and support the implementation of GOM restoration activities. Here, we present an empirical framework for evaluating the influence of multiple restoration project types on water quality improvements within a GOM estuary. The framework helps synthesize routine, ambient monitoring data across various spatio-temporal scales to demonstrate how the cumulative effects of coastal restoration activities contribute towards broad estuarine water quality improvements. Data on water quality and restoration projects in the Tampa Bay area (Florida, USA) were used to demonstrate application of the analysis framework. Tampa Bay is the second largest estuarine embayment in the GOM and has been intensively monitored since the mid-1970s. The ecological context of water quality changes in the Bay is well-described (Greening et al. 2014) and a comprehensive history of restoration projects occurring in the watershed is available, making Tampa Bay an ideal test case for demonstrating and applying a new evaluation framework. The water quality and restoration datasets were evaluated to identify: 1) the types of restoration activities that contribute to the greatest improvements in water quality, and 2) the time frames over which water quality benefits may be elucidated from synergistic restoration activities. Changes in chlorophyll-a concentrations, a proxy for negative eutrophication effects within Tampa Bay (Greening et al. 2014), were used as the success metric to evaluate estuarine restoration activities. The final product is an open-source, decision support tool that will help restoration practitioners evaluate alternative scenarios for implementing future restoration strategies.

Methods

Study area

Tampa Bay is located on the west-central GOM coast of the Florida peninsula, and its watershed is one of the most highly developed regions in Florida (fig. 1). More than 60 percent of land within 15 km of the Bay shoreline is a mix of urban and suburban uses (SWFWMD 2011). The Bay has been a focal point of economic activity since the 1950s and currently supports a mix of industrial, domestic, and recreational activities. The watershed includes one of the largest phosphate production regions in the country, which is supported by port operations primarily in the northeast portion of the Bay (Greening et al. 2014). Water quality data have been collected since the 1970s when environmental conditions were highly degraded. Nitrogen loads into the Bay in the mid-1970s have been estimated as 8.9 x 10^6 kg year-1, most of which came from untreated wastewater effluent (Greening et al. 2014). In addition to reduced aesthetics, hypereutrophic environmental conditions were common and included elevated chlorophyll-a concentrations, increased occurrence of harmful algal species, low concentrations of bottom water dissolved oxygen, low water clarity, reduced seagrass coverage, and reported declines in fishery yields for both sport and recreational species. Advanced wastewater treatment operations were implemented at municipal plants by the early 1980s. These efforts were successful in reducing nutrients loads to the Bay by as much as 90%.

Current water quality in Tampa Bay is dramatically improved from historical conditions. Most notably, seagrass coverage in 2016 was reported as 16,857 hectares baywide, surpassing the restoration goal of coverage in the 1950s (Sherwood et al. 2017). These changes have occurred in parallel with reductions in nutrient

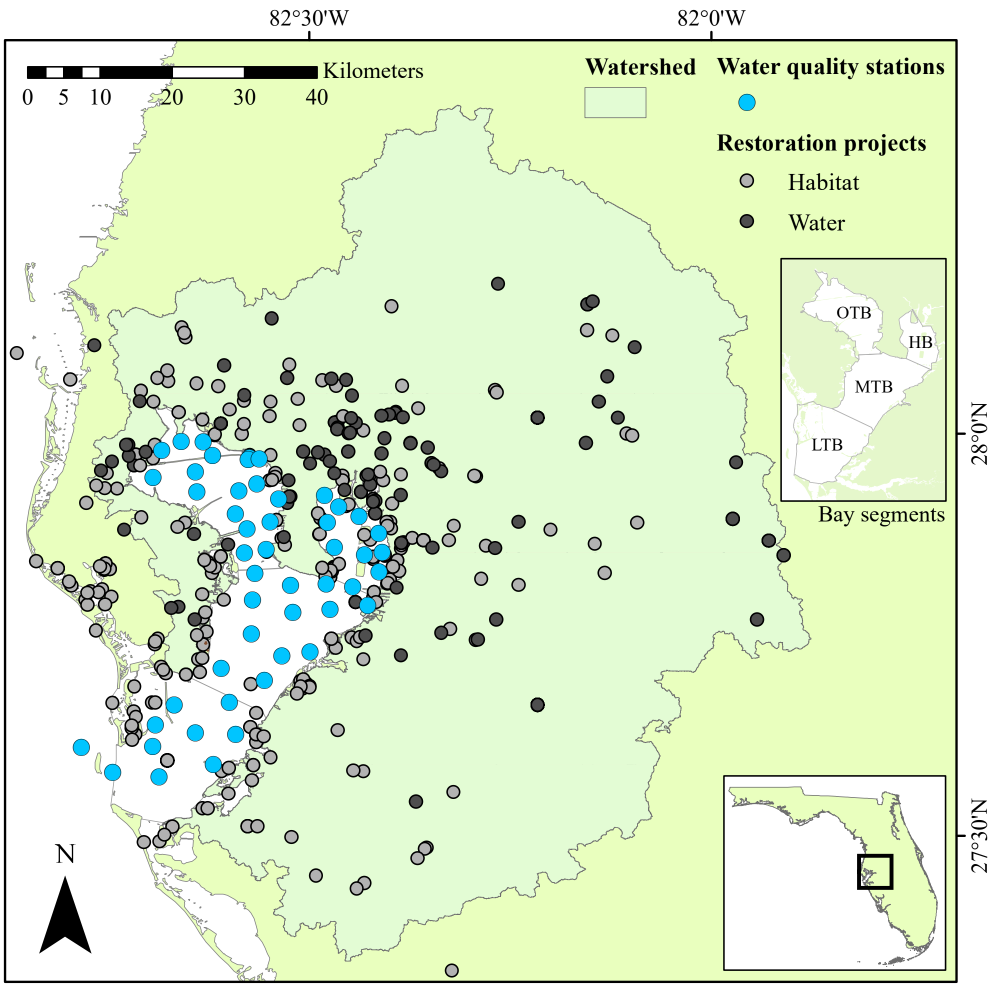

Figure 1: Water quality stations and restoration projects in the Tampa Bay area. Water quality stations have been monitored monthly since 1974. Locations of restoration projects represent 887 records that are generally categorized as habitat or water infrastructure projects from 1971 to present. Bay segments as management units of interest are shown in the upper right inset. HB: Hillsborough Bay, LTB: Lower Tampa Bay, MTB: Middle Tampa Bay, OTB: Old Tampa Bay.

loading (Poe et al. 2005; Greening et al. 2014), chlorophyll concentrations (Wang, Martin, and Morrison 1999; Beck and Hagy III 2015), and improvements in water clarity (Morrison et al. 2006; Beck, Hagy III, and Le 2017). Most of these positive changes have resulted from management efforts to reduce point source controls on nutrient pollution in the highly developed areas of Hillsborough Bay (Johansson 1991; Johansson and Lewis III 1992).

The cumulative and synergistic effects of nearly 900 additional management activities have also likely contributed to water quality improvements over the past 4 decades, yet no previous efforts have been made to quantify potential associations between these projects and water quality. Several hundred projects from both public and private entities have been completed since the 1971. These projects represent numerous voluntary (e.g., coastal habitat acquisition, restoration, preservation, etc.) and compliance-driven (e.g., stormwater retrofits, process water treatment upgrades, site-level permitting, power plant scrubber upgrades, improved agricultural practices, residential fertilizer use ordinances, etc.) activities. Although it is generally recognized that these projects have contributed to overall estuarine ecosystem improvements, their cumulative effects, relative to broad watershed-scale management efforts, are not well understood. Understanding how these projects affect adjacent estuarine water quality at various spatio-temporal scales will provide an improved understanding of the link between overall estuary improvements and specific restoration activities.

Data sources

Several databases were synthesized to provide a comprehensive history of restoration projects that have occurred in Tampa Bay and its watershed. The first dataset was obtained from the Tampa Bay Water Atlas (version 2.3, http://maps.wateratlas.usf.edu/tampabay/, TBEP (Tampa Bay Estuary Program) (2017)) maintained as a joint resource by the University of South Florida, the Tampa Bay Estuary Program (TBEP), and partners. This database included 253 projects from 1971 to 2007 that were primarily focused on habitat establishment, enhancement, or protection along the Bay's immediate shoreline or within the larger watershed area (e.g., restoration of salt marshes and mangroves, exotic vegetation control, conversion of agricultural lands to natural habitats, etc.). Information on more recent projects (2008-2017) acquired from the US

EPA's National Estuary Program Mapper (https://gispub2.epa.gov/NEPmap/) included an additional 265 projects. This database was limited to basic information, such as year of completion, geographic coordinates, general activities, and areal coverage. The last database was obtained from the TBEP Action Plan Database Portal (https://apdb.tbeptech.org/index.php) to describe locations of broader infrastructure improvement projects, structural best management practices, and policy-driven management actions. This database included 368 projects from 1992 to 2016 for county, municipal or industrial activities, such as implementation of best management practices at treatment plants, creation of stormwater retention or treatment controls, or site-specific controls of point sources.

For all restoration datasets, shared information included the location, year of completion, and project classification of the restoration activity. Because the types of projects differed, a classification scheme was developed that first described projects broadly as habitat or water infrastructure improvements and secondarily as a lower-level classification for habitat projects: enhancement, establishment, and protection; and water infrastructure projects: nonpoint source or point source controls. These categories were used to provide a broad characterization of restoration activities that were considered relevant for the perceived improvements in water quality over time. The five sub-categories (habitat enhancement, establishment, and protection; non-point and point source controls) were separately evaluated to describe the likelihood of changes in water quality associated with each type (described below). The final combined dataset included 887 projects from 1971 to 2017 (fig. 2). Projects with incomplete information (i.e., missing date) were not included in the final dataset.

Water quality data in Tampa Bay have been consistently collected since 1974 by the Environmental Protection Commission of Hillsborough County (Sherwood et al. 2016; TBEP (Tampa Bay Estuary Program) 2017). Data were collected monthly at forty-five stations using a water sample from mid-depth or a monitoring sonde depending on the parameter. Monitoring stations are fixed and cover the entire bay from the uppermost mesohaline sections to the lowermost euhaline portions that have direct interaction with the GOM. Water samples at each station are laboratory processed immediately after collection. Measurements at each site include temperature (^{o}C), Secchi disk depth (m), dissolved oxygen (mg/L), conductivity (μOhms/cm), pH, salinity (psu), turbidity (Nephalometric Turbidity Units), chlorophyll *a* (chl-*a*) (μg/L), total nitrogen (mg/L),

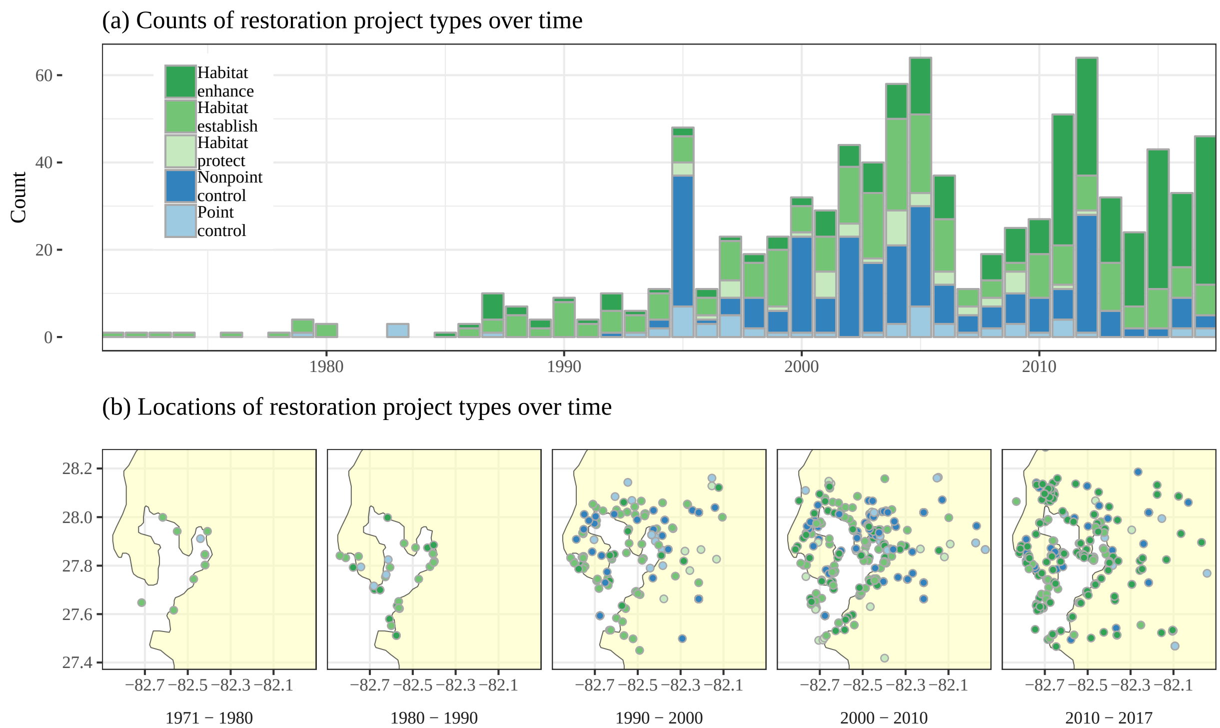

Figure 2: Counts (top) and locations (bottom) of restoration project types over time in the Tampa Bay watershed. Restorations were categorized as water infrastructure (blue; nonpoint source controls, point source controls) and habitat (green; enhancements, establishments, protection) projects. The compiled restoration database included records of 887 project types and locations from 1971 to 2017.

and total phosphorus (mg/L). For the models, all measurements of salinity, total nitrogen, and chl-*a* were combined for a total of 515 monthly observations of each parameter at each station.

Data synthesis and analysis framework

Combining the restoration and water quality datasets was a critical part of developing the analysis framework. Each dataset described events or sampling activities with unique dates and locations and a simple synoptic pairing of restoration projects with water quality data was not possible. To address this challenge, observations in each dataset were spatially and temporally matched using an approach designed to maximize the potential of identifying a unique effect of the restoration projects on changes in water quality. Water quality monitoring sites were matched to the closest selected restoration projects and changes in the water quality data were evaluated relative to the completion dates of the selected projects.

The matching between the two datasets began with a spatial join where the Euclidean distances between each water quality station and each restoration project were quantified. The spatial matches were used to create a ranking of project sites from each water quality station based on distance. The distances were also grouped by the five restoration project types (i.e., habitat protection, nonpoint source control, etc.) such that the closest n sites of a given project type could be identified for any water quality station (fig. 3).

For each spatial match, temporal matching between water quality stations and restoration projects was obtained by subsetting the water quality data within a time window before and after the completion date of each restoration project (fig. 4). For the closest n restoration sites for each of five project types, two summarized water quality estimates were obtained to quantify a before and after estimate of chlorophyll associated with each project. Time windows that overlapped the start and end date of the water quality time series were discarded. The final two estimates of the before and after effects of the five types of restoration projects at each water quality station were based on an average of the n closest restoration sites, weighted inversely by distance from the monitoring station.

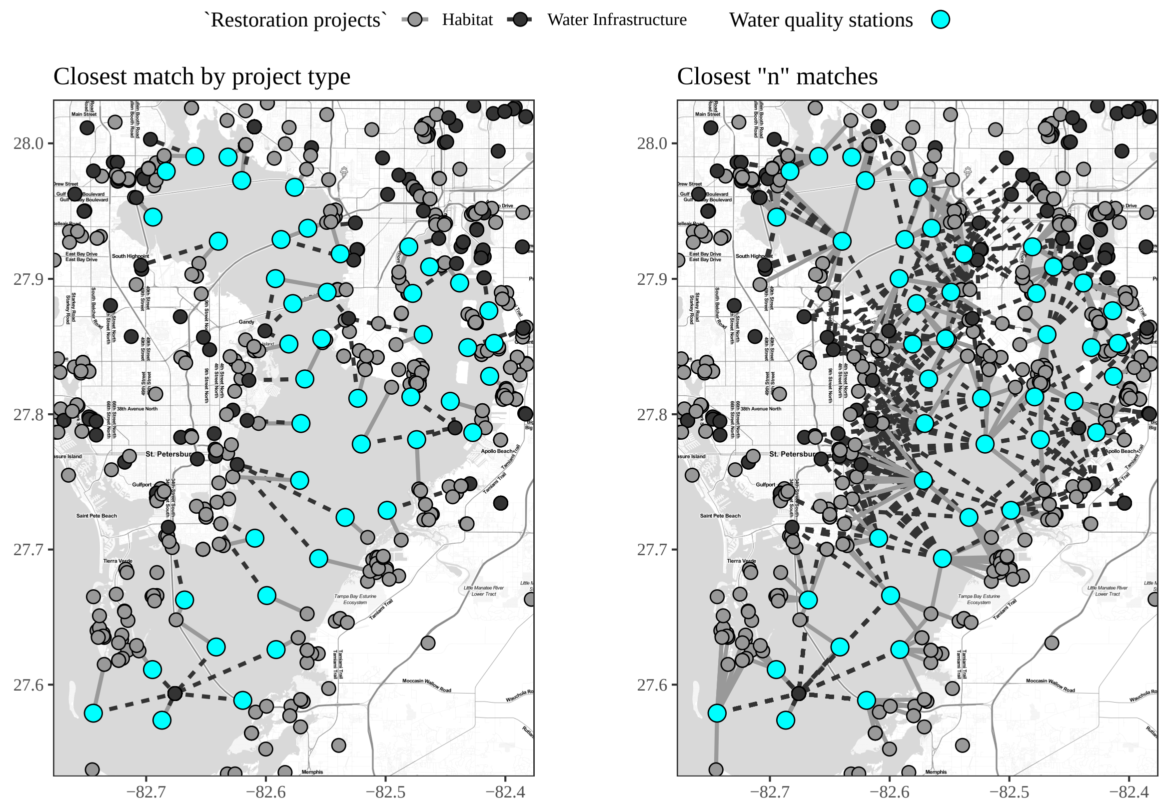

Figure 3: Spatial matching of water quality stations with restoration projects. Spatial matches of each water quality station (blue dots) with habitat (solid line to grey dots) and water infrastucture (dashed line to black dots) projects are shown as the closest single match by type on the left and the "n" closest matches on the right. The spatial matches were made for the five restoration project types within the broader habitat and water categories shown in the figure.

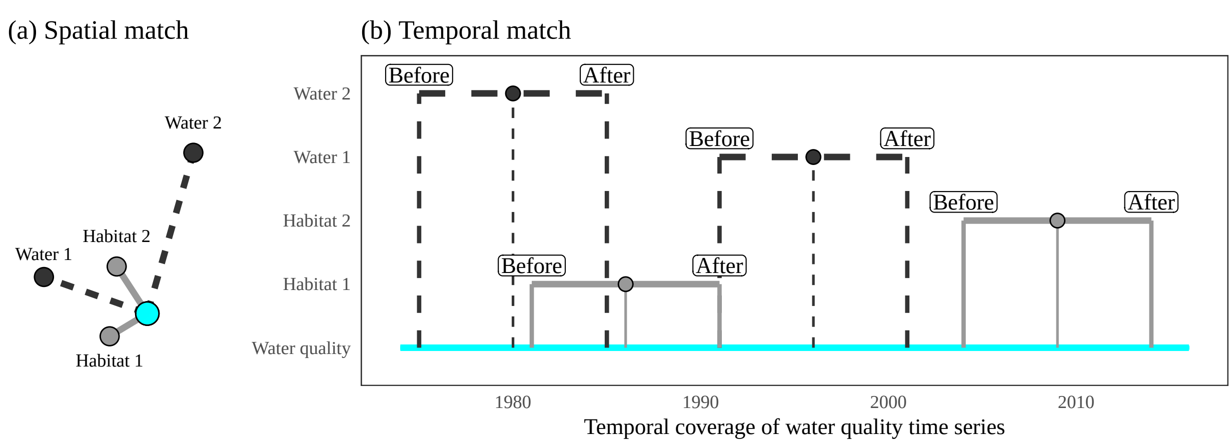

Figure 4: Temporal matching of restoration project types with time series data at a water quality station. The restoration project locations that are spatially matched with a water quality station (a) are used to create a temporal slice of the water quality data within a window of time before and after the completion date of each restoration project (b). Slices are based on the closest "n" restoration projects by type (n = 2 in this example) to a water quality station. The two broad categories of habitat and water infrastructure projects are shown in the figure as an example, whereas the analysis evaluated all five restoration sub-categories.

Change in water quality relative to each type of restoration project was estimated as:

$$\delta WQ = \frac{\sum_{i=1}^{n} \hat{wq} \in win + proj_{i,dt}}{n \cdot dist_{i \in n}} - \frac{\sum_{i=1}^{n} \hat{wq} \in proj_{i,dt} - win}{n \cdot dist_{i \in n}} \tag{1}$$

where δWQ was the difference between the after and before averages for each of n spatially matched restoration projects. For each i of n projects ($proj$), the average water quality ($\hat{wq}$) within the window (win) either before ($proj_{i,dt} - win$) or after ($win + proj_{i,dt}$) the completion date (dt) for project i was summed. The summation of water quality before and after each project was then divided by the total number of n matched projects, multiplied by the distance of the projects from a water quality station ($dist_{i \in n}$). This created a weighted average of the before-after effects of each project that was inversely related to the distance from a water quality station. A weighted average by distance was used based on the assumption that restoration projects farther from a water quality station will have a weaker association with potential changes in chlorophyll. The total change in water quality for a project type was simply the difference in weighted averages. This process was repeated for every station and a graphical example of eq. (1) is shown in fig. 5

There are key assumptions made by the above approach regarding how the analysis was conducted and what information is obtained from the result. First, our spatial-temporal matching of water quality data with restoration projects is strictly associative where the general assumption is that restoration projects will benefit water quality through a decrease in chlorophyll. We make no assumptions about the expected magnitude of an association given that the model does not describe a mechanism of change. However, a general expectation is that chlorophyll changes will be different by project type and this association will vary as a function of distance and evaluated time windows. An expected outcome is that qualitative statements can be made about the relative differences between projects types, particularly regarding how more projects of a particular type could benefit water quality and within what general time windows a change might be expected.

An additional assumption is that the model was designed to describe cumulative effects at different spatial scales. In eq. (1), the association of a restoration type with chlorophyll is estimated for one water quality station, whereas estimates from several water quality stations can be combined to develop an overall description of a particular restoration type as it applies to an areal unit of interest. For example, estimated associations

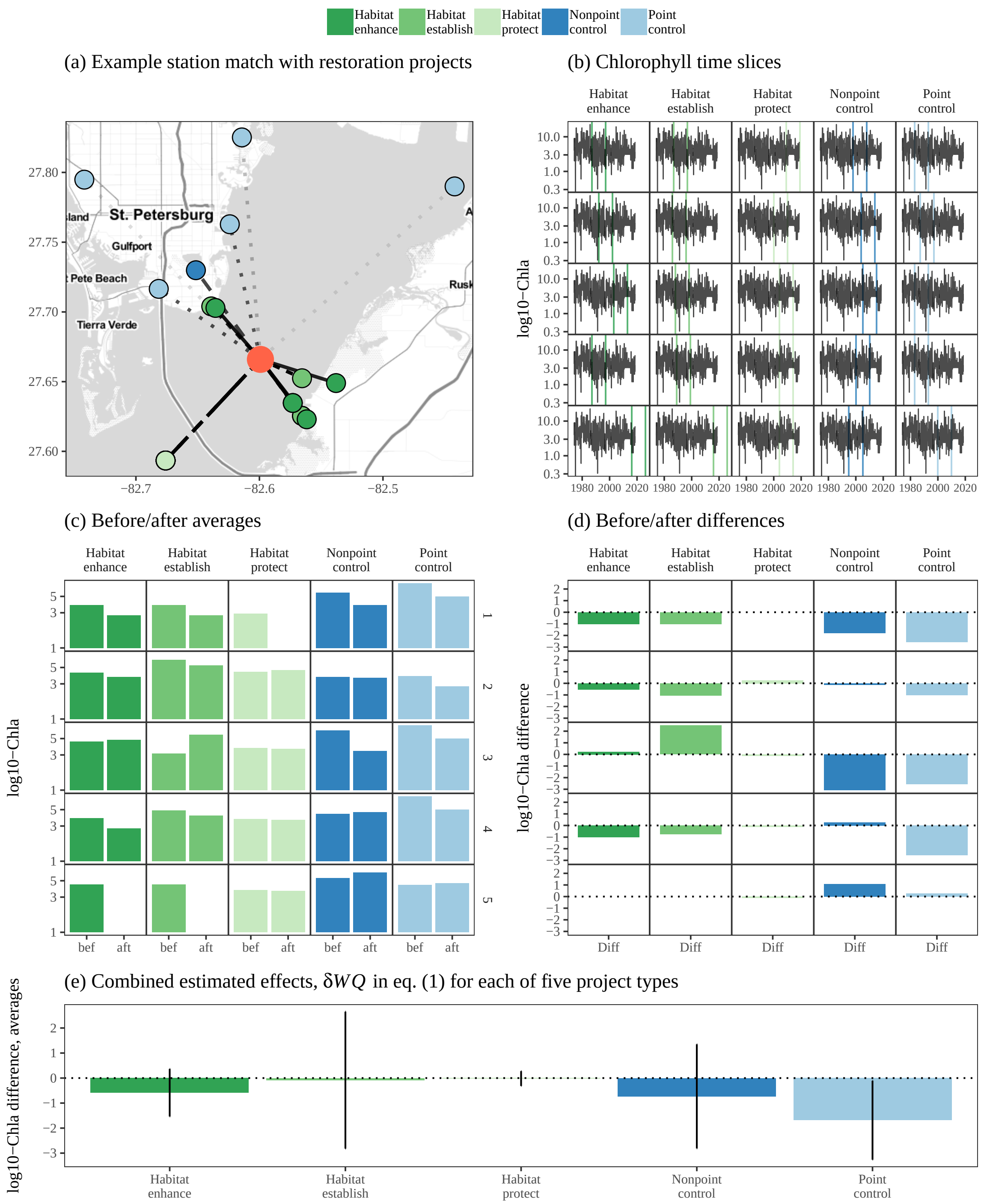

Figure 5: Steps to estimate cumulative effects of water quality changes at a single station relative to a selected number of projects and time windows. Subplot (a) shows station 23 in Middle Tampa Bay matched to the five nearest restoration projects for each of five types. The time slices of the water quality observations for +/- ten years before and after the completion of each project are shown in (b), ordered from near to far. The before/after water quality averages for the slices are shown in (c) and the differences between the two are shown in (d). Finally, the weighted averages for the five closest matches by project type are shown in (e) with 95% confidence intervals.

of point source control projects with each water quality station in the bay can be combined to develop an overall narrative of how these projects could positively effect environmental change in the bay. The examples in figs. 3 to 5 are focused on individual stations to demonstrate core principles of the approach. Estimates across stations were evaluated to describe baywide effects of restoration project types and by individual bay segments that have specific management targets for chlorophyll concentration (Florida Statute 62-302.532, Janicki, Wade, and Pribble 1999). This approach was used given the uneven distribution of restoration projects in space and time relative to the known changes in water quality that has been documented in the different Bay segments (Greening et al. 2014).

Finally, parameters in eq. (1) affected the synthesis of the datasets which directly controlled the ability to characterize associations of each restoration project type with water quality changes, 1) n, the number of spatially-matched restoration projects used to average the cumulative effect of each project type, and 2) win, the time windows before and after a project completion date that were used to subset each water quality time series. Identifying values that maximized the difference between before and after water quality measurements was necessary to quantify how many projects were most strongly associated with a change in water quality, the time within which a change is expected, and the magnitude of an expected change between project types. All analyses were conducted with the R statistical programming language (RDCT (R Development Core Team) 2018).

Results

Observed data

Observed water quality trends in Tampa Bay showed a long-term decrease in Chlorophyll-a over the forty-year record consistent with documented changes (Wang, Martin, and Morrison 1999; Greening et al. 2014; Beck and Hagy III 2015) (table 1). Median concentrations were highest in the earlier period of record from 1977 to 1987 (median 13.40 μg/L at low salinity stations, 7.30 μg/L at high salinity stations). Declines were consistent throughout the period of record with the largest reductions occurring during the first twenty years

Table 1: Summary of total nitrogen and chlorophyll-a observations from monitoring stations in Tampa Bay. Minimum, median, and maximum observed values for low and high salinity conditions are shown for seasonal and annual aggregations of water quality observations at all monitoring stations (See fig. 1). Low or high salinity is based on values below or above the long-term baywide median (26.5 psu). JFM: January, February, March; AMJ: April, May, June; JAS: July, August, September; OND: October, November, December.

Time period	**Total nitrogen**			**Chlorophyll-a**		
	Min	Median	Max	Min	Median	Max
Low						
JFM	0.00	0.46	2.69	0.12	5.30	114.40
AMJ	0.03	0.59	3.03	0.20	8.40	183.40
JAS	0.02	0.64	3.02	0.50	13.80	266.60
OND	0.03	0.57	4.14	0.00	10.00	192.14
1977-1987	0.02	0.88	3.03	0.10	13.40	266.60
1987-1997	0.05	0.73	4.14	0.00	8.78	192.14
1997-2007	0.00	0.54	2.89	0.12	7.86	261.90
2007-2017	0.03	0.42	2.75	0.50	7.40	220.60
High						
JFM	0.03	0.43	1.65	0.00	3.20	55.80
AMJ	0.02	0.48	1.95	0.10	5.40	74.90
JAS	0.03	0.54	3.16	0.10	7.23	333.40
OND	0.02	0.43	2.43	0.00	4.67	142.90
1977-1987	0.02	0.57	1.92	0.30	7.30	136.80
1987-1997	0.02	0.54	2.43	0.00	5.11	142.90
1997-2007	0.02	0.56	3.16	0.00	4.80	72.30
2007-2017	0.03	0.33	1.80	0.80	3.70	333.40

(34% decrease), followed by consistent but smaller reductions in concentrations later in the time series. A 34% decrease at low salinity stations and a 30% decrease at high salinity stations was observed between the periods of 1977-1987 to 1987-1997. Seasonally, chlorophyll concentrations were highest in the late summer/early fall periods (median 13.80 μg/L at low salinity stations, 7.23 μg/L at high salinity stations, across all years). Similarly, total nitrogen concentrations had similar trends as chlorophyll, although a consistent decline similar in magnitude was observed across all four decades (Poe et al. 2005; Greening et al. 2014). An exception for nitrogen was observed at high salinity stations where concentrations were relatively constant at approximately 0.55 mg/L from 1987 to 2007. Seasonally, nitrogen peaked in the late summer/early fall period.

The consistent decline in chlorophyll concentrations were opposite to the observed trends in the number and types of restoration projects in the watershed. As shown in fig. 2, less projects were observed early in the record, whereas a majority were completed after the year 2000. Individual point source controls early in the record were those that occurred in the historically polluted upper Hillsborough Bay (Johansson 1991; Johansson and Lewis III 1992). Prior to 1995, only 11 water infrastructure projects (three non-point control, eight point source controls) were found in the database, whereas 70 habitat projects were observed (50 habitat establishment, 20 habitat enhancement). From 1995 and on, nearly ten times as many restoration projects were observed in the record (806 total) with notable increases in the number of nonpoint source controls (245) and habitat protection projects (45). For the entire record, 275 (31% of total) habitat enhancement, 259 (29%) habitat establishment, 45 (5%) habitat protection, 248 (28%) nonpoint source, and 60 (7%) point source control projects were observed.

Relationships of restoration projects with water quality

A simple comparison of water quality measurements versus the cumulative number of restoration projects over time showed a decrease in both total nitrogen and chlorophyll with additional restoration. Figure 6 shows median water quality estimates across all monitoroing stations for a given year against the total number of cumulative restoration projects for the current and all preceding years. Significant relationships were observed between water quality and number of projects for all project types ($\alpha = 0.05$), although the strength of association varied. Overall, stronger assocations with number of projects were observed for total nitrogen and relatively weaker assocations were observed for chlorophyll. Decreases in total nitrogen were most strongly associated with water infrastructure projects for nonpoint source ($F = 65.5, df = 1, 23, p < 0.005$) and point source controls ($F = 60.8, df = 1, 21, p < 0.005$), as expected. Habitat protection projects were also strongly associated with decreases in total nitrogen ($F = 34.8, df = 1, 14, p < 0.005$). For chlorophyll, the strongest associations were observed with habitat establishment ($F = 20.8, df = 1, 35, p < 0.005$) and point source control ($F = 13.7, df = 1, 22, p < 0.005$) projects. A weak but marginally significant association was observed between chlorophyll and habitat protection projects ($F = 4.6, df = 1, 14, p = 0.049$).

An obvious limitation of the above analysis is the confounding effect of almost all restoration projects increasing through time. Although significant assocations were observed with improvements in water quality and increasing cumulative number of projects, the comparisons in fig. 6 do not provide a means to distinguish effects of different project types. For example, the separate effects of habitat establishment and point source projects on chlorophyll reductions cannot be separated through simple linear analyses because both increase

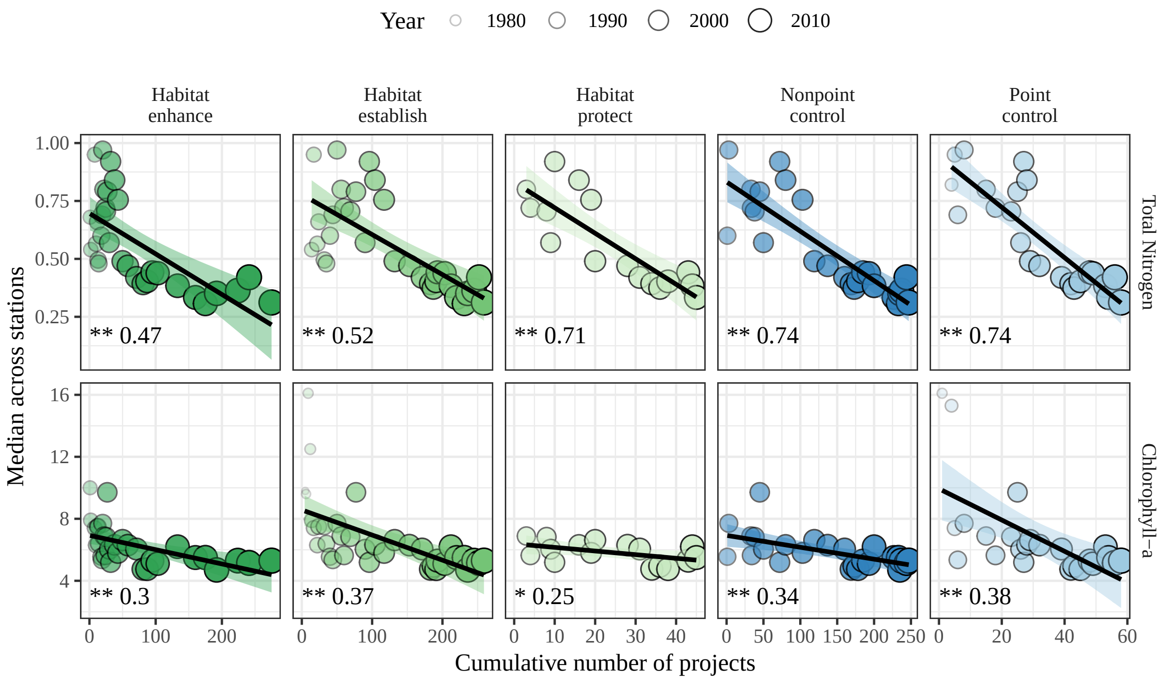

Figure 6: Relationships between cumulative number of restoration projects over time and water quality observations in Tampa Bay. The plot shows median total nitrogen (mg/L) and chlorophyll (μg/L) across all monitoring stations for each year against the cumulative number of projects for all preceding years. Points are sized and shaded by year to show the progression of water quality and number of projects over time. Summary statistics are shown in the bottom left corner as the significance of the linear regression and R-squared value. *p > 0.05 ns, p < 0.05 *, p < 0.005 ***

over time. An assocation of chlorophyll with one project type could b an artifact of an assocation with another project type. Likewise, a weak assocation (e.g., habitat protection and chlorophyll) does not provide strong evidence that a particular project type is unimportant for water quality improvements. Our formal approach that uses spatial-temporal matching between restoration projects and water quality stations is meant to overcome these challenges and results from the simple analysis above provides a basis of comparison for how our approach could lead to new insights.

Baywide estimates of the potential effects of restoration projects using spatial-temporal matching differed depending on the year windows and number of closest restoration projects that were matched to each water quality station. The results are shown in fig. 7 where the estimated associations of different projects types with chlorophyll at individual stations are shown on the left maps and the aggregate assocations across all stations for a given project type are shown in the right plots. That is, station points in the maps correspond to an estimate for the year window and closest project type selections for each project type that were obtained through the steps in fig. 5 and eq. (1). Water quality stations outlined in black show where the estimated change is significant (i.e., the standard error lines in the botom plot of fig. 5 do not include zero, green points where chlorophyll was lower, red points where higher). The plots on the right are based on the distributions of the estimated water quality changes for each station for the corresponding project types in the maps on the left. The plots on the right also include statistical summaries for 1) an analysis of variance (ANOVA) F-test to compare the distribution of water quality changes between project types, 2) individual t-tests for each projct type to evaluate changes that were different from zero, and 3) a multiple comparison test denoted by letters to identify which projects types had changes that were different from each other.

For site-specific estimates of water quality changes, a slight trend of longer time windows and more project matches with the number of monitoring stations that had significant changes was observed (i.e., more black circles in the maps fig. 7d, compared to fig. 7a). This was particularly true for habitat protection projects where no significant associations were observed for the 5 year window, 5 closest projects combination, but twelve stations had significant assocations for the 10 year window, 10 closest projects combination. A similar trend was observed for point source control projects where more stations had more significant reductions in chlorophyll with the 10 year window, 10 closest projects. The largest number of stations ($n = 13$) with significant improvements in water quality for nonpoint source projects was observed for the 5 year window, 10 closest projects. Associations of habitat enhancement and habitat establishment projects with water quality stations were inconsistent, with some sites showing an increase or decrease that varied by the year window, closest project combinations. Spatial patterns among stations regarding associations with different project types were not clear, although point source controls were more commonly associated with mid-bay stations (Middle Tampa Bay).

The estimated baywide effects for each project type showed that point source controls were more strongly associated with reductions in chlorophyll than the other project types (fig. 7, right plots). This assocation was particularly strong for the ten year window combinations (fig. 7c, d), where the results suggested an overall baywide reduction in chlorophyll of aproximately 2 μg/L (based on the median change across all sites, reduction of 2.7 μg/L for 10 years, 5 closest projects and 1.6 μg/L for 10 years, 10 closest projects).

Nonpoint controls were also significant but only when more projects were considered. Habitat protection was also important at all combinations, habitat establish only important with more projects and time, whereas habitat enhancement had a negligible association no matter the comparison parameters.

Segment results in table 2.

Discussion

A long-term record of restoration activities and water quality data in Tampa Bay provided the foundation to develop a novel decision support tool for coastal restoration practitioners and managers. This new tool provides an improved process to understand the expected water quality improvements that could result from future restoration activities contingent upon the level of cumulative investments made toward divergent activities and the required monitoring to understand downstream water quality benefits at local to watershed-wide scales. This tool has broad application and extension within the Gulf Coast restoration and management community. However, several reservations on its application were discovered.

- 2004-2017, nonpoint source and habitat protection appears to have the largest effect on chlorophyll-a

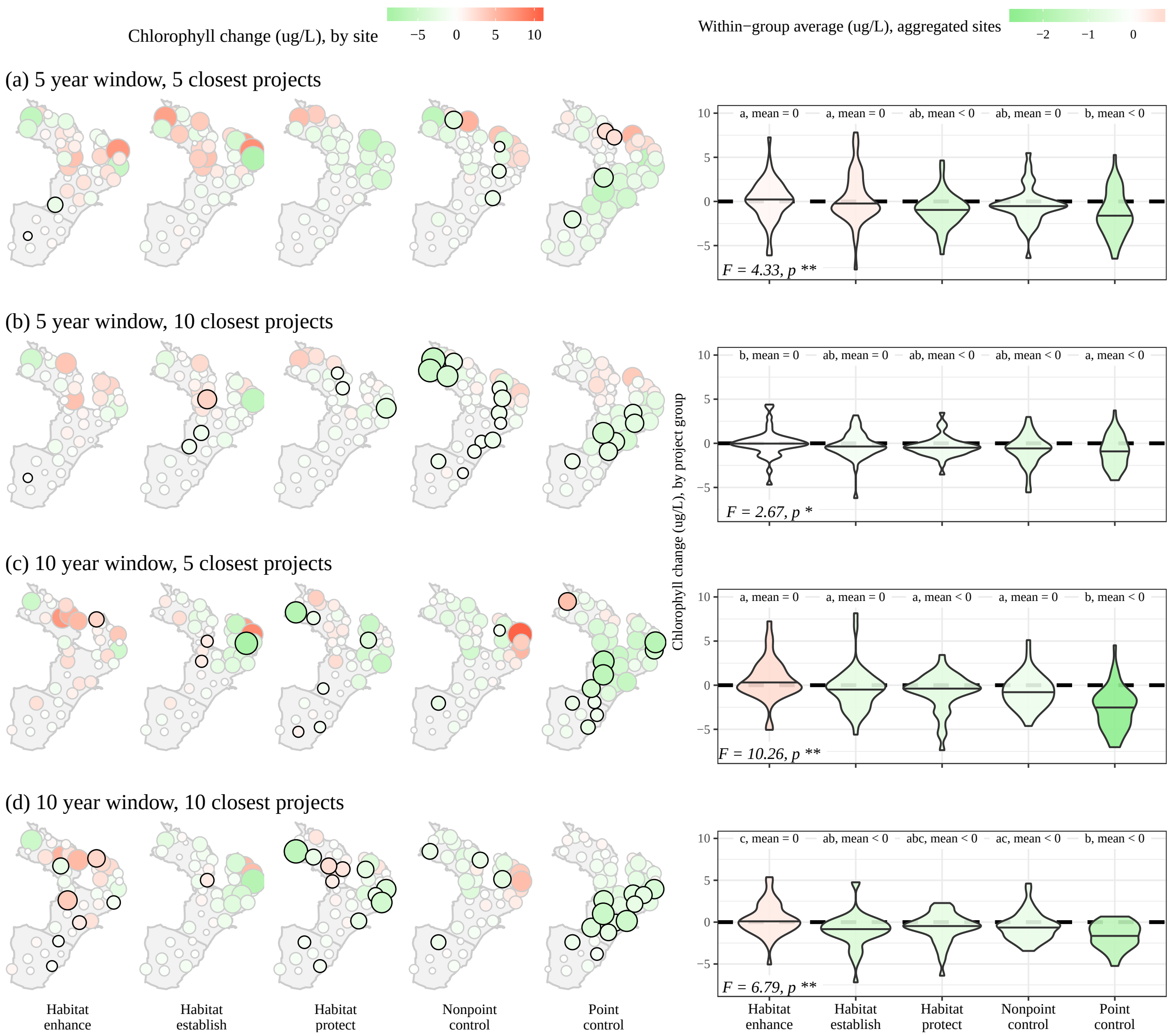

Figure 7: Associations of restoration projects with chlorophyll changes at all sites in Tampa Bay from 1974 to 2017. Associations were evaluated based on different year windows (5, 10) since completion of restoration projects and number of closest restoration projects (5, 10) to each monitoring station (subfigures a-d). The left plots show the estimated changes at each site (green decreasing, red increasing) for each restoration project type, with significant changes at a site outlined in black. The right plots show the aggregated site changes for each project type. Overall differences were evaluated by ANOVA F-tests (bottom left corner), whereas pairwise differences between project types were evaluated by t-tests with corrected p-values for multiple comparisons. Chlorophyll changes by project types within each subfigure that are not significantly different share a letter and significance of the within-group mean relative to zero is also shown.

Table 2: Associations of restoration projects with chlorophyll changes for different segments of Tampa Bay from 1974 to 2017. Associations were evaluated based on different year windows (5, 10) since completion of restoration projects and number of closest restoration projects (5, 10) to each monitoring station within each segment. Overall differences in chlorophyll changes between restoration project types by segment and year/project number combinations were evaluated by ANOVA F-tests, whereas pairwise differences between project types were evaluated by t-tests with corrected p-values for multiple comparisons. Chlorophyll changes by project types that are not significantly different share a letter and significance of the within-group mean relative to zero is also shown.

Bay segment		**Restoration projects**				
	ANOVA	Habitat enhance	Habitat establish	Habitat protect	Nonpoint control	Point control
5 years, 5 projects						
HB	$F = 1.09$, *ns*	a, 0	a, 0	a, < 0	a, 0	a, 0
LTB	$F = 17.37$, **	a, 0	a, 0	a, 0	a, 0	b, < 0
MTB	$F = 13.5$, **	b, 0	ab, 0	a, < 0	ab, < 0	c, < 0
OTB	$F = 1.5$, *ns*	a, 0	a, 0	a, 0	a, 0	a, 0
5 years, 10 projects						
HB	$F = 0.66$, *ns*	a, 0	a, 0	a, 0	a, 0	a, 0
LTB	$F = 2.64$, *ns*	ab, < 0	ab, < 0	ab, < 0	a, 0	b, < 0
MTB	$F = 18.75$, **	a, 0	a, 0	a, < 0	a, < 0	b, < 0
OTB	$F = 3.11$, *	ab, 0	a, 0	ab, 0	b, < 0	a, 0
10 years, 5 projects						
HB	$F = 2.9$, *	ab, 0	ab, 0	ab, < 0	a, 0	b, < 0
LTB	$F = 6.13$, **	a, 0	a, 0	a, 0	ab, 0	b, < 0
MTB	$F = 14.11$, **	a, 0	a, 0	a, 0	a, 0	b, < 0
OTB	$F = 3.15$, *	b, 0	ab, 0	ab, 0	a, < 0	a, < 0
10 years, 10 projects						
HB	$F = 2.42$, *ns*	a, 0	a, 0	a, 0	a, 0	a, < 0
LTB	$F = 1.78$, *ns*	a, 0	a, < 0	a, < 0	a, 0	a, < 0
MTB	$F = 11.79$, **	a, 0	a, < 0	a, 0	a, 0	b, < 0
OTB	$F = 2.35$, *ns*	b, 0	ab, < 0	ab, 0	a, < 0	ab, < 0

HB: Hillsborough Bay, LTB: Lower Tampa Bay, MTB: Middle Tampa Bay, OTB: Old Tampa Bay. $p > 0.05$ *ns*, $p < 0.05$ *, $p < 0.005$ **

levels. This effect is not clear until after 5 years of monitoring and with the evaluation of multiple projects. When fewer restoration activities were taking place in the Bay (i.e. 94-04) a greater monitoring time frame was necessary to identify the benefits of restoration activities (>5 years).

- From 1974 - 1994, chlorophyll changes were most distinct in relation to water infrastructure projects, particularly for low salinity regions in the bay. The effect was more apparent with increasing time from the completion of a project and with evaluation of multiple projects. Habitat projects did not have a noticeable effect although, these were limited to later in the time period.
- Our analysis of the different year window, number of matches provided an approach to separately evaluate the effect of temporal signals and spatial signals on water quality improvements. Explain...
- What can we really say with this analysis? Above this text, describe in bullet points the key conclusions, but here we can describe what they really mean, e.g. why did some sites have reduction in water quality with projects? These are noisy relationships.... Our approach provides a tradeoff between the noise and ability to disentangle cumulative effects but it's messy. The figures on the right in figure 7 provide one approach to identify the signal to wash out what may be errors.
- It is inherently difficult to determine any downstream water quality benefits from enhancement no matter how many sites or years. Enhancement is primarily activities such as invasive species removal which is not done with the primary goal of improving water quality.
- How can this be used to guide coastal wq management in the Gulf?
  - Demonstrate the benefit of Long Term monitoring
- How can this be used to inform or prioritize restoration activities in the Gulf?
- What are the limitations of our analysis?
- How can the analysis be applied in other locations?

Limitations of analysis

- More restoration projects later in the time series could be from inconsistent data collection early in the time series
- Associative by design - does not empirically link cause and effect, actual relationships are very complex

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