Estuaries and Coasts

Assessment of the cumulative effects of restoration activities on water quality in Tampa Bay, Florida
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Abstract:	Habitat and water quality restoration projects are commonly used to enhance coastal resources or mitigate negative impacts of water quality stressors. Significant resources have been expended for restoration projects, yet much less attention has focused on evaluating broad regional outcomes beyond site-specific assessments. This study presents an empirical framework to evaluate multiple datasets in the Tampa Bay area (Florida, USA) to identify 1) the types of restoration projects that have produced the greatest improvements in water quality, and 2) over which time frames different projects may produce water quality benefits. Information on the location and date of completion of 887 restoration projects from 1971 to 2017 were spatially and temporally matched with water quality records at each of 45 long-term monitoring stations in Tampa Bay. The underlying assumption was that the developed framework could identify differences in water quality changes between types of restoration projects based on aggregate estimates of chlorophyll-a concentrations before and after the completion of different projects. Water infrastructure projects to control point source nutrient loading into the bay were associated with the highest likelihood of chlorophyll-a reduction, particularly for projects occurring prior to 1995. Habitat restoration projects were also associated with reductions in chlorophyll-a, although the likelihood of reductions from the cumulative effects of these projects were less than those from infrastructure improvements alone. The framework is sufficiently flexible for application to different spatiotemporal contexts and could be used to develop reasonable expectations for implementation of future water quality restoration activities throughout the Gulf of Mexico.

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Estuaries and Coasts

I am pleased to submit our manuscript, "Assessment of the cumulative effects of restoration activities on water quality in Tampa Bay, Florida," to be considered as a management applications paper in Estuaries and Coasts.

The ecological and management history of Tampa Bay, Florida has been well-described and is largely viewed as an environmental success story. A rich data set of nearly 900 restoration projects has been documented for Tampa Bay and its surrounding watershed, yet no efforts have been made to comprehensively link these data to water quality changes. A fundamental challenge for managers has been the evaluation of restoration success, particularly for understanding cumulative effects at the scale of an entire estuary. We present an empirical framework that links restoration projects to the known water quality improvements in Tampa Bay to quantify relative benefits associated with different restoration project types. This information is timely given the current investments in Gulf restoration as a result of BP settlement funds. Our framework provides a means of understanding the relative tradeoffs of different restoration projects, using Tampa Bay as an example, that could inform Gulf restoration efforts in other locations.

We are confident that readers of Estuaries and Coasts will find this information useful and appreciate the opportunity to publish our work in this venue. Please feel free to reach out should there be any questions about our submission.

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Assessment of the cumulative effects of restoration activities

on water quality in Tampa Bay, Florida

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Abstract

Habitat and water quality restoration projects are commonly used to enhance coastal resources or mitigate negative impacts of water quality stressors. Significant resources have been expended for restoration projects, yet much less attention has focused on evaluating broad regional outcomes beyond site-specific assessments. This study presents an empirical framework to evaluate multiple datasets in the Tampa Bay area (Florida, USA) to identify 1) the types of restoration projects that have produced the greatest improvements in water quality, and 2) over which time frames different projects may produce water quality benefits. Information on the location and date of completion of 887 restoration projects from 1971 to 2017 were spatially and temporally matched with water quality records at each of 45 long-term monitoring stations in Tampa Bay. The underlying assumption was that the developed framework could identify differences in water quality changes between types of restoration projects based on aggregate estimates of chlorophyll-a concentrations before and after the completion of different projects. Water infrastructure projects to control point source nutrient loading into the bay were associated with the highest likelihood of chlorophyll-a reduction, particularly for projects occurring prior to 1995. Habitat restoration projects were also associated with reductions in chlorophyll-a, although the likelihood of reductions from the cumulative effects of these projects were less than those from infrastructure improvements alone. The framework is sufficiently flexible for application to different spatiotemporal contexts and could be used to develop reasonable expectations for implementation of future water quality restoration activities throughout the Gulf of Mexico.

Key words: chlorophyll, Gulf of Mexico, long-term monitoring, restoration, Tampa Bay, trends

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 in the southeast United States (Enwright et al. 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 et al. 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.

In addition to these challenges, the difficulty of 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; Liang et al. 2019). The lack of long-term environmental monitoring is a primary impediment to understanding pre- versus post- restoration change (Schiff et al. 2016) and also impedes recognition of any coastal ecosystem improvements derived from prolonged management, policy and restoration activities. Long-term coastal monitoring programs can facilitate a broader sense

57   of how management, policy and restoration activities affect coastal ecosystem quality (Borja et

58   al. 2016). Utilizing lessons-learned from environmental monitoring programs, new frameworks

59   are starting to emerge to better understand and facilitate coastal restoration ecology (Bayraktarov

60   et al. 2016; Diefenderfer et al. 2016).

61   A very large, comprehensive and concerted effort to restore Gulf of Mexico coastal ecosystems

62   is currently underway (GCERC 2013; GCERC 2016). Primary funding for this effort is derived

63   from the legal settlements resulting from the 2010 Deepwater Horizon oil spill. Funding sources

64   include: early restoration investments that were made immediately following the spill, natural

65   resource damage assessments resulting from the spill's impacts (NRDA 2016), a record legal

66   settlement of civil and criminal penalties negotiated between the responsible parties and the US

67   government with strict US congressional oversight (United States vs. BPXP, et. al.), and

68   matching funds from research, monitoring and restoration practitioners worldwide. These funds,

69   equating to >\$20B US, present the Gulf of Mexico community an unprecedented opportunity to

70   revitalize regional restoration efforts that will span multiple generations (GCERC 2013; GCERC

71   2016). Consequently, the restoration investments being made with these funds will be highly

72   scrutinized. Better understanding the environmental outcomes of past restoration investments

73   will help identify how, where and when future resources should be invested so that the Gulf

74   Coast community can achieve the highest degree of restoration success.

75   Tampa Bay (Florida, USA) is the second largest estuarine embayment in the GOM and has been

76   intensively monitored since the mid-1970s (Greening et al. 2014; Sherwood et al. 2016). Nearly

77   900 public and private projects to improve water quality have been completed in Tampa Bay and

78   its watershed over the past 4 decades, yet no previous efforts have been made to directly quantify

79   potential associations between these activities and estuarine water quality. These projects

80   represent numerous voluntary (e.g., coastal habitat acquisition, restoration, preservation, etc.)

81   and compliance-driven (e.g., stormwater retrofits, process water treatment upgrades, site-level

82   permitting, power plant scrubber upgrades, improved agricultural practices, residential fertilizer

83   use ordinances, etc.) activities. Although it is generally recognized that these projects have

84   contributed to overall estuarine ecosystem improvements, their cumulative effects, relative to

85   broad watershed-scale management efforts, are not well understood. Understanding how

86   implementation of these projects is associated with adjacent estuarine water quality at various

87   spatio-temporal scales will provide an improved understanding of the link between overall

88   estuary improvements and specific restoration activities.

89   Because it is difficult to demonstrate restoration success, new tools are needed to help guide and

90   support GOM restoration. Here, we present an empirical framework for evaluating the influence

91   of restoration projects on water quality improvements within Tampa Bay. The framework helps

92   synthesize routine, ambient monitoring data across various spatio-temporal scales to demonstrate

93   how coastal restoration activities cumulatively affect estuarine water quality improvement. Data

94   on water quality and restoration projects in the Tampa Bay area were used to demonstrate

95   application of the analysis framework. Water quality and restoration datasets were evaluated to

96   identify: 1) the types of restoration activities that most improve water quality, and 2) the time

97   frames over which water quality benefits resulting from restoration may be resolved. Changes in

98   chlorophyll-a concentrations, a proxy for negative eutrophication effects within Tampa Bay

99   (Greening et al. 2014), were used as the success metric to evaluate estuarine restoration

100 activities.

Methods

Study area

Tampa Bay is located on the west-central GOM coast of the Florida peninsula. Its watershed is among the most highly developed regions in Florida (Figure 1). More than 60 percent of land-use within 15 km of the Bay shoreline is urban or suburban (SWFMD 2018). The Bay has been a focal point of economic activity since the 1950s and currently supports a mix of industrial, private, 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 8.9×10^6 kg/y, largely from wastewater effluent (Greening et al. 2014). In addition to reduced aesthetics, hypereutrophic environmental conditions were common and included elevated chlorophyll-a and harmful algae, and reduced bottom water dissolved oxygen, water clarity, and seagrass coverage. Fishery yields were purportedly depressed for both commercial and recreational species during this time, although fisheries practices (i.e., widespread Bay trawling and gill-netting) likely contributed to declines. Advanced wastewater treatment operations were implemented at municipal plants by the early 1980s, reducing nutrient loads to the Bay by as much as 90%.

Current water quality in Tampa Bay is dramatically improved from the degraded historical condition. Most notably, seagrass coverage in 2016 was reported as 16,857 hectares baywide, surpassing the goal of restoring coverage to levels that occurred in 1950 (Sherwood et al. 2017).

122 Reductions in nutrient loading (Poe et al. 2005; Greening et al. 2014), chlorophyll-a

123 concentrations (Wang et al. 1999; Beck and Hagy 2015), and improvements in water clarity

124 (Morrison et al. 2006; Beck et al. 2018) have also preceded the seagrass recovery. Most of these

125 positive changes have resulted from management efforts to reduce point source controls on

126 nutrient pollution in the highly developed areas of Hillsborough Bay (Johansson 1991; Johansson

127 and Lewis III 1992). These controls allowed nutrient and chlorophyll-a targets to be met by the

128 early 1990s. However, numerous smaller-scale projects that have occurred since then have not

129 been thoroughly evaluated. These smaller projects, including watershed-focused efforts (Lewis et

130 al. 1998), have likely had a supporting role in maintaining the earlier water quality improvements

131 observed after water infrastructure upgrades.

Data sources

133 Several databases were combined to document restoration projects in Tampa Bay and its

134 watershed. Data from the Tampa Bay Water Atlas (version 2.3,

135 http://maps.wateratlas.usf.edu/tampabay/, TBEP 2017) documented 253 projects from 1971 to

136 2007 that were primarily focused on habitat establishment, enhancement, or protection along the

137 Bay's immediate shoreline or within the larger watershed area. Examples include restoration of

138 salt marshes and mangroves, exotic vegetation control, and conversion of agricultural lands to

139 natural habitats. Information on an additional 265 recent (2008-2017) projects was acquired from

140 the US EPA's National Estuary Program Mapper (https://gispub2.epa.gov/NEPmap/). This

141 database provides only basic information, such as year of completion, geographic coordinates,

142 general activities, and areal coverage. Data from the Tampa Bay Estuary Program (TBEP)

143 Action Plan Database Portal (https://apdb.tbeptech.org/index.php) documented locations of

144   infrastructure improvement projects, structural best management practices, and policy-driven

145   stormwater or wastewater management actions. This database included 368 projects from 1992

146   to 2016 for county, municipal or industrial activities, such as implementation of best

147   management practices at treatment plants, creation of stormwater retention or treatment controls,

148   or site-specific controls of industrial and municipal point sources.

149   For all restoration datasets, shared information included the project location, year of completion,

150   and classification of the restoration activity. Because the types of projects varied, we developed

151   and applied a classification scheme that first described projects broadly as habitat or water

152   infrastructure improvements and secondarily as a lower-level classification for habitat projects:

153   enhancement, establishment, and protection; and water infrastructure projects: nonpoint source

154   or point source controls. These categories were used to provide a broad characterization of

155   restoration activities that were considered to contribute to improvements in water quality over

156   time. The five sub-categories (habitat enhancement, establishment, and protection; nonpoint and

157   point source controls) were separately evaluated to describe the likelihood of changes in water

158   quality associated with each type (methods described below). The final combined dataset

159   included 887 projects from 1971 to 2017 (Figure 2). Projects with incomplete information were

160   not included in the final dataset.

161   Water quality data in Tampa Bay have been collected consistently since 1974 by the

162   Environmental Protection Commission of Hillsborough County (Sherwood et al. 2016; TBEP

163   2017). Data were collected monthly at forty-five stations using a water sample or monitoring

164   sonde at bottom, mid- or surface depths, depending on parameter. The locations of monitoring

165   stations were fixed and cover the entire bay from the uppermost mesohaline sections to the

166   lowermost euhaline portions that have direct interaction with the GOM (Figure 1). Mid-depth

167   water samples at each station are laboratory processed immediately after collection.

168   Measurements at each site include temperature (°C), Secchi disk depth (m), dissolved oxygen

169   (mg/L), conductivity (μOhms/cm), pH, salinity (psu), turbidity (Nephalometric Turbidity Units),

170   chlorophyll-a (μg/L), total nitrogen (mg/L), and total phosphorus (mg/L). For the analysis, all

171   measurements of salinity, total nitrogen, and chlorophyll-a were combined for a total of 515

172   monthly observations of each parameter at each station.

Data synthesis and analysis framework

174   Water quality monitoring sites were matched to the closest selected restoration projects and

175   changes in the water quality data were evaluated relative to the completion dates of the selected

176   projects. The matching between the two datasets began with a spatial join wherein the Euclidean

177   distances between each water quality station and each restoration project were quantified. The

178   restoration projects closest to each water quality station were identified using the distances

179   between projects and water quality stations. The distances were also grouped by the five

180   restoration project types (i.e., habitat protection, nonpoint source control, etc.) such that the

181   closest n sites of a given project type could be identified for any water quality station (Figure 3).

182   For each spatial match, temporal matching between water quality stations and restoration

183   projects was obtained by subsetting the water quality data within a time window before and after

184   the completion date of each restoration project (Figure 4). For the closest n restoration sites for

185   each of five project types, two summarized water quality estimates were obtained to quantify a

186   before and after estimate of chlorophyll-a associated with each project. The before estimate was

187   the average of observations for the year preceding the completion of a project and the after

188   estimate was the average of observations for a year period that occurred after a defined window

189   of time upon completion of a project. Time windows that overlapped the start and end date of the

190   water quality time series were discarded. The final two estimates of the before and after values of

191   the five types of restoration projects at each water quality station were based on an average of the

192   n closest restoration sites, weighted inversely by distance from the monitoring station.

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

194
$$\Delta WQ = \frac{\sum_{i=1}^{n} \widehat{wq} \in win + proj_{i,dt}}{n \cdot dist_{i \in n}} - \frac{\sum_{i=1}^{n} \widehat{wq} \in proj_{i,dt} - win}{n \cdot dist_{i \in n}} \qquad (1)$$

195   where ΔWQ was the difference between the after and before averages for each of n spatially

196   matched restoration projects. For each i of n projects ($proj$), the average water quality ($\widehat{wq}$)

197   within the window (win) either before ($proj_{i,dt} - win$) or after ($win + proj_{i,dt}$) the completion

198   date (dt) for project i was summed. The summation of water quality before and after each

199   project was then divided by the total number of n matched projects, multiplied by the distance of

200   the projects from a water quality station ($dist_{i \in n}$). This created a weighted average of the before-

201   after estimates for each project that was inversely related to the distance from a water quality

202   station. A weighted average by distance was used based on the assumption that restoration

203   projects farther from a water quality station will have a weaker association with potential

204   changes in chlorophyll-a. The total change in water quality for a project type was simply the

205   difference in weighted averages. This process was repeated for every station (Figure 5). Overall

206   differences between project types were evaluated by ANOVA F-tests, whereas pairwise

207   differences between project types were evaluated by t-tests with corrected probability values for

208   multiple comparisons.

209   One of the key assumptions of our approach is that restoration projects will benefit water quality

210   through a change in chlorophyll-a. We make no assumptions about the expected magnitude of an

211   association given that the model does not describe a specific mechanism of change. However, we

212   hypothesized that the magnitude of chlorophyll-a changes varies by project type, and number of

213   projects or length of time window evaluated. An expected outcome is that qualitative statements

214   can be made about the relative differences between projects types, particularly regarding how

215   more projects of a particular type could benefit water quality and within what general time

216   windows a change might be expected (Diefenderfer et al. 2011).

217   The model was also designed to quantify cumulative relationships of restoration projects with

218   water quality at different spatial scales. In eqn. (1), the association of a restoration type with

219   chlorophyll-a is estimated for one water quality station, whereas estimates from several water

220   quality stations can be combined to develop an overall description of a particular restoration type

221   as it applies to an areal unit of interest, potentially over broad regional scales. For example,

222   estimated associations of point source control projects with each water quality station in the bay

223   can be combined to develop an overall narrative of how these projects could (assuming a causal

224   relationship) influence environmental change across the entire Bay. Estimates across stations

225   were evaluated to describe associations in baywide improvements from various restoration

226   project types throughout the watershed. Estimates were also evaluated by individual bay

227   segments that have specific management targets for chlorophyll-a concentration (Florida Statute

228   62-302.532, Janicki et al. 1999). Stratification by bay segments provided an alternative context

229   for interpreting the results based on areal differences between segments and how restoration

230   projects varied in space and time.

231   The analysis of each project type was bounded by two key parameters in eqn. (1). These include

232   n, the number of spatially-matched restoration projects used to average the cumulative estimate

233   of each project type, and win, the time windows before and after a project completion date that

234   were used to subset a station's water quality time series. These boundaries affected our ability to

235   characterize each restoration project type with water quality changes. Identifying values that

236   maximized the difference between before and after water quality measurements was necessary to

237   quantify how many projects were most strongly associated with a change in water quality, the

238   time within which a change is expected, and the magnitude of an expected change between

239   project types. We evaluated different combinations of five or ten year time windows from the

240   date of each project completion and the five or ten closest projects to each water quality station.

241   All analyses were conducted with customized scripts created for the R statistical programming

242   language (RDCT 2018).

Testing effects of restoration dates and location

244   Because of the documented improvements in water quality in Tampa Bay, a concern with our

245   approach is that any association between restoration projects and chlorophyll-a may result from

246   correlations between the two parameters, confounding a true demonstration of water quality

247   improvements in relation to restoration activities. To address this challenge, estimated changes in

248   chlorophyll-a were evaluated in response to temporal and spatial matching with restoration

249   projects, as above, but with random date and location assignments for each restoration project.

250   An expected outcome of randomization is that no differences are observed between project types

251   and that all associations between projects and chlorophyll-a changes should reflect the

252   continuous decline of chlorophyll-a over time, as observed in the independent water quality

12

253   record. In other words, our null model is that the estimated effects of restoration projects are

254   simply those that can be evaluated from the raw data - slicing the observed time series by

255   arbitrary dates and evaluating before/after averages is expected to reflect the continuous decline

256   of chlorophyll-a in the raw data. Alternatively, differences between project types and changes in

257   chlorophyll-a that are different from the long-term decline would provide evidence that our

258   framework is robust.

259   **Results**

260   **Water quality observations**

261   Chlorophyll-a in Tampa Bay decreased over the forty-year record consistent with documented

262   changes (Wang et al. 1999; Greening et al. 2014; Beck and Hagy 2015) (Table 1). Median

263   concentrations were highest from 1977 to 1987 (median 13.40 μg/L at low salinity stations <26.5

264   psu, 7.30 μg/L at high salinity stations >26.5 psu). Declines were monotonic throughout the

265   period of record with the largest reductions occurring during the first twenty years (34%

266   decrease), followed by consistent but smaller reductions in concentrations later in the time series.

267   A 34% decrease at low salinity stations and a 30% decrease at high salinity stations was

268   observed between the periods of 1977-1987 to 1987-1997. Seasonally, chlorophyll-a

269   concentrations were highest in the late summer/early fall periods (median 13.80 μg/L at low

270   salinity stations, 7.23 μg/L at high salinity stations, across all years). Total nitrogen

271   concentrations had similar trends as chlorophyll-a, although a steady decline was observed

272   across the entire time series rather than primarily in the first two decades in contrast to

273   chlorophyll-a (Poe et al. 2005; Greening et al. 2014). An exception for total nitrogen was

274   observed at high salinity stations where concentrations were relatively constant at approximately

275   0.55 mg/L from 1987 to 2007. Seasonally, total nitrogen concentrations peaked in the late

276   summer/early fall period.

277   The monotonic decline in chlorophyll-a concentrations was coincident with the increases in the

278   number and types of restoration projects in the watershed, where the number of documented

279   projects especially increased after 2000 (Figure 2). For the entire record, 275 (31% of total)

280   habitat enhancement, 259 (29%) habitat establishment, 45 (5%) habitat protection, 248 (28%)

281   nonpoint source, and 60 (7%) point source control projects were documented. Individual point

282   source controls early in the record were those that occurred in the historically polluted upper

283   Hillsborough Bay and adjacent to the city of St. Petersburg (Johansson 1991; Johansson and

284   Lewis 1992; Lewis et al. 1998). Prior to 1995, only 11 water infrastructure projects (three

285   nonpoint control, eight point source controls) were documented in the database, whereas 70

286   habitat projects were recorded (50 habitat establishment, 20 habitat enhancement). Nearly ten

287   times as many restoration projects were completed in 1995 to present (806 total), with notable

288   increases in the number of nonpoint source controls (245) and habitat protection projects (45).

Associations between restoration projects and water quality change

290   Before employing our analytical approach, we evaluated temporal trends in water quality and

291   possible drivers of water quality change to develop an analytical baseline for comparison. A

292   simple analysis of water quality measurements versus the cumulative number of restoration

293   projects over time showed a decrease in both total nitrogen and chlorophyll-a with additional

294   restoration effort. Analysis of median water quality estimates across all monitoring stations for a

295   given year versus the cumulative number of restoration projects as of that year showed that water

296   quality was related to the number of projects for all project types (based on linear models, $\alpha =$

297   0.05; Figure 6). Associations with number of projects were relatively strong for total nitrogen

298   and relatively weaker for chlorophyll-a across project types. Decreases in total nitrogen were

299   most strongly associated with water infrastructure projects for nonpoint source ($F = 65.5, df =$

300     $1,23, p < 0.005$) and point source controls ($F = 60.8, df = 1,21, p < 0.005$), as expected.

301   Habitat protection projects were also strongly associated with decreases in total nitrogen ($F =$

302     $34.8, df = 1,14, p < 0.005$). For chlorophyll-a, the strongest associations were observed with

303   habitat establishment ($F = 20.8, df = 1,35, p < 0.005$) and point source control ($F =$

304     $13.7, df = 1,22, p < 0.005$) projects. A marginally significant association was observed

305   between chlorophyll-a and cumulative habitat protection projects ($F = 4.6, df = 1,14, p =$

306   0.049).

307   One limitation of the above analysis is that the number of restoration projects increased over

308   time and responses due to restoration were potentially confounded with temporal changes

309   resulting from other factors. Similarly, effects of different project types are confounded when

310   both types increased over time (Figure 6). Although significant associations were observed with

311   improvements in water quality and increasing cumulative number of projects, the comparisons in

312   Figure 6 do not provide a means to distinguish effects of different project types. For example, the

313   separate effects of habitat establishment and point source projects on chlorophyll-a reductions

314   cannot be separated through simple linear analyses because both increase over time, i.e., an

315   association of chlorophyll-a with one project type could be an artifact of an association with

316   another project type. Likewise, a weak association (e.g., habitat protection and chlorophyll-a)

317   does not provide strong evidence that a particular project type is unimportant for water quality

318   improvements, given that the simple analysis may lack sufficient power to detect an association.

319   Our approach that uses spatial-temporal matching between restoration projects and water quality

320   stations is meant to overcome these challenges.

321   Baywide estimates of the effects of restoration projects using spatial-temporal matching

322   depended on the year window sizes and number of nearby restoration projects matched to each

323   water quality station (Figure 7). Estimated associations of different projects types with

324   chlorophyll-a at individual stations are shown in the left maps and the baywide aggregate

325   associations across all stations for a given project type in the right plots. Station points in the left

326   maps correspond to the change estimate for the year window and closest project type selections

327   for each project type that were obtained through the steps in Figure 5 and eqn. (1). Stations

328   outlined in black have significant results based on t-tests of the mean estimates of chlorophyll-a

329   relative to zero change. The plots on the right are based on the baywide distributions of the

330   estimated water quality changes for all stations for the corresponding project types in the maps

331   on the left. The plots on the right also include statistical summaries for 1) an analysis of variance

332   (ANOVA) F-test to compare the distribution of water quality changes between project types, 2)

333   individual t-tests for each project type to evaluate changes that were different from zero, and 3) a

334   multiple comparison test denoted by letters to identify which project types had changes that were

335   different from each other.

336   For site-specific estimates of water quality changes, longer time windows and more project

337   matches with each monitoring station increased observations of significant associations (i.e.,

338   more black circles in the maps in Figure 7d, compared to Figure 7a). This was particularly true

339   for habitat protection projects where no significant associations were observed for the 5 year

340   window, 5 closest projects combination, but twelve stations had significant associations for the

341   10 year window, 10 closest projects combination. A similar trend was observed for point source

342 control projects where more stations had more significant reductions in chlorophyll-a with the 10

343 year window, 10 closest projects. For nonpoint source projects, the greatest number of stations (n

344 = 13) with significant improvements in water quality was observed for the 5 year window, 10

345 closest projects combination. Associations of habitat enhancement and habitat establishment

346 projects with water quality stations were inconsistent, with some sites showing an increase or

347 decrease that varied by the year window, closest project combinations. Spatial patterns among

348 stations regarding associations with different project types were also not clear, although point

349 source controls were more commonly associated with improvements in mid-bay stations (Middle

350 Tampa Bay segment, see Figure 1).

351 The estimated baywide effects for each project type showed that point source controls were more

352 strongly associated with reductions in chlorophyll-a than the other project types (Figure 7, right

353 plots). This association was particularly strong for the ten year window combinations (Figure 7c,

354 d), where the results suggested an overall baywide reduction in chlorophyll-a of approximately 2

355 μg/L, depending on the number of projects implemented (median change across all sites:

356 reduction of 2.7 μg/L for 10 years, 5 closest projects and 1.6 μg/L for 10 years, 10 closest

357 projects). Nonpoint source controls were also significantly associated with chlorophyll-a

358 reductions, but only when a large number of projects were implemented (10 closest project

359 combinations, Figure 7b, d). Additionally, the magnitude of nonpoint source control reductions

360 were less than point source controls (reduction of 0.7 μg/L for 5 years, 10 closest projects and

361 0.5 μg/L for 10 years, 10 closest projects). Habitat protection projects were also significantly

362 associated with baywide changes for all year window, closest project combinations, with the

363 largest estimated reduction of 1μg/L for the 5 year window, 5 closest projects combination.

364 Habitat enhancement and establishment projects were not strongly associated with baywide

365   changes in chlorophyll-a, with the exception of habitat establishment for the 10 year window, 10

366   closest projects combination (0.9 μg/L reduction).

367   The above analysis was repeated for individual bay segments to identify spatial variation in

368   associations of restoration projects with water quality changes. This analysis also demonstrated

369   the flexibility in how the approach can be tailored to better understand effects of restoration in

370   different spatial contexts. Table 2 provides similar information as the plots on the right side of

371   Figure 7, where results are presented similarly but for each of four bay segments (HB:

372   Hillsborough Bay, LTB: Lower Tampa Bay, MTB: Middle Tampa Bay, OTB: Old Tampa Bay,

373   Figure 1) for each year window, closest projects combination. As for the baywide result, point

374   source controls were most consistently associated with reductions in chlorophyll-a, particularly

375   for ten year window combinations. Nonpoint source controls were also important, although

376   significant associations with chlorophyll-a changes were limited to the Middle and Old Tampa

377   Bay segments. The importance of habitat protection projects for different bay segments varied by

378   year window, closest project combinations. Habitat establishment projects were most strongly

379   associated with changes in each bay segment for the 10 year window, 10 closest projects

380   combination, with the exception of Hillsborough Bay where the relationship was not significant.

381   Chlorophyll-a changes in Lower Tampa Bay were significantly associated with habitat

382   enhancement and establishment projects for the 5 year window, 10 closest projects combination.

383   **Effects of random restoration dates and locations**

384   A comparison of the baywide results (Figure 7, right side) to results from simulations where

385   dates and locations were randomized for each restoration project suggested that the framework in

386   eqn. (1) is robust. The same year windows and closest project combinations were evaluated as

387   above (i.e., 5/10 year windows, 5/10 closest projects), but with 1000 simulations where the date

388   and location of each restoration were randomized (i.e., random draw from uniform distribution of

389   years from 1971 to 2017, random draw from uniform distribution of latitude and longitude based

390   on the bounding box of the study area). Nearly all of the simulated results suggested that each

391   project was associated with a decline in chlorophyll-a (Table 3, values in bold, mean < 0). This is

392   consistent with our null hypothesis that randomization would simply reflect the long-term

393   decline in chlorophyll-a that is apparent in the observed water quality records. Some differences

394   were observed in the 5 years, 5 projects combination where no change (mean = 0) was the most

395   observed outcome from the simulations. These inconsistencies with our null hypothesis may be

396   the result of using relatively small windows and project combinations, i.e., slicing the data too

397   thin to detect the long-term decline in chlorophyll-a.

398   The "Actual" and "Agreement" columns in Table 3 indicate the estimated changes for each

399   project using the actual restoration dates/locations and if the result agrees with those from the

400   random simulations. In support of the alternative hypothesis, nine of the rows in the

401   "Agreement" column indicate a result different than a consistent decline in chlorophyll-a

402   expected under the null hypothesis. Compared to random simulations, different results were

403   more often observed for habitat enhancement and habitat establishment projects, where the

404   simulated results most often suggested a decrease and the actual results suggested no change in

405   chlorophyll-a. Nonpoint and point source control projects were in agreement with simulated

406   results, although this does not provide sufficient evidence that the results from the actual data are

407   incorrect. Because the null hypothesis under randomization suggests projects will be associated

408   with water quality improvements based on the independent chlorophyll-a time series, an

409   observed decline in chlorophyll-a in relation to actual restoration projects could still suggest a

410   signal rather than a false positive result. There is no way of identifying type I errors with the

411   current dataset, although the differences from the null results for habitat enhancement and

412   establishment projects do suggest the framework is robust.

413   **Discussion**

414   The results support several conclusions that are consistent with recognized, long-term changes in

415   water quality in Tampa Bay. Water infrastructure projects related to point and nonpoint source

416   controls were consistently associated with improved water quality. The record of restoration

417   projects included key point source nutrient controls that occurred primarily in upper Tampa Bay

418   (Hillsborough Bay) and that were successful in reducing nutrient loads during the first two

419   decades of observation (Johansson 1991; Johansson and Lewis 1992; Greening et al. 2014).

420   These outcomes were expected and the ability of the results to clearly demonstrate these long-

421   term associations provided a proof of concept for the overall approach. Moreover, efforts

422   focused on mitigating effects of nonpoint sources of pollution were more common in the latter

423   half of record after 1990 and our results provide evidence that these projects have been effective

424   in improving water quality baywide, as well. Nonpoint source control efforts broadly described

425   several activities that included, among others, street sweeping, education/outreach efforts, and

426   various best management practices for stormwater, agricultural, and wetland management

427   programs. The ability to document effects of nonpoint control efforts on water quality relative to

428   end-of-pipe controls is challenging (Hassett et al. 2005; Meals et al. 2010; Liang et al. 2019) and

429   the results suggest that our approach is capable of detecting improvements in water quality from

430   these projects when many are implemented.

431 Habitat restoration projects were also associated with reductions in chlorophyll-a, although to a

432 lesser magnitude than water infrastructure projects. Our categorization of habitat projects as

433 enhancement, establishment, and protection were developed to better understand potential effects

434 on water quality related to the type and intensity of actions for each group. Specifically, the

435 categories represented extremes from low to high intensity effort, where protection was low

436 effort (e.g., direct land acquisition), establishment was highest effort (e.g., mangrove/seagrass

437 plantings, creation of oyster reefs), and enhancement was moderate effort depending on the

438 activity (e.g., hydrologic restoration for wetlands, exotic species control). Categorization by

439 effort combined with the associated estimates of water quality improvements provides a coarse

440 cost-benefit analysis (e.g., Spurgeon 1998). For example, habitat protection was consistently

441 linked to chlorophyll-a reductions independent of year windows and number of projects. The

442 effort for land acquisition is minimal relative to the other habitat restoration projects.

443 Conversely, habitat enhancement was not strongly associated with baywide improvements in

444 water quality and such projects may require more intensive effort and monitoring assessments to

445 understand and contribute towards downstream water quality benefits. Based on these results,

446 habitat protection may be a more immediate and efficient approach than other types of habitat

447 restoration projects, especially if the primary restoration objective is to quickly improve

448 downstream water quality.

449 Our results also provide an approach to identify an expected range of time and number of

450 projects that are associated with potential improvements in water quality (Diefenderfer et al.

451 2011). This information was included as an explicit component in eqn. (1) to quantify tradeoffs

452 for different restoration activities based on how results varied by time and effort, similar to the

453 categorization for habitat projects. Monitoring water quality improvements after a short period of

454   time since project completion and with fewer projects (e.g., 5 year window, 5 closest projects)

455   may be more efficient than those where improvements are observed after longer periods of time

456   and with more projects (e.g., 10 year window, 10 closest projects), dependent on the project type.

457   Given this logic, both habitat protection and point source controls could potentially provide the

458   greatest measured water quality benefits for the least cost, whereas other projects provide lesser

459   improvements, require more time to confer water quality benefits (e.g., full maturation of a

460   habitat enhancement/establishment site), and require more projects to be implemented to

461   contribute to significant water quality improvements (e.g., implementing many nonpoint source

462   controls across a watershed). However, this approach assumes that immediate downstream water

463   quality improvements with minimal effort are the primary restoration objectives and implicitly

464   discounts the long-term effects that may or may not persist for a given project type or regional

465   restoration challenges. Likewise, other restoration objectives may be a primary driver for

466   pursuing a particular project type (e.g. increasing biodiversity, improving fish and wildlife

467   habitats, etc.).

468   Conclusions from our approach may also be sensitive to system hysteresis. An initial

469   improvement of water quality associated with a particular project may be obfuscated by chronic

470   degraded conditions, if additional restoration projects that directly address the underlying

471   problem are not pursued (i.e., Scheffer et al. 1998; Borja et al. 2010). As an example, habitat

472   enhancement projects were associated with improvements in Lower Tampa Bay only during the

473   five year window when ten projects were implemented; reductions in chlorophyll-a were not

474   shown to persist at the ten year window.

Assumptions and limitations

There are several assumptions and limitations of our approach that affect the interpretation of the results. These assumptions and limitations are a reflection of 1) the inherent uncertainty in quantifying baywide effects of restoration projects that vary considerably in mechanisms affecting water quality (e.g., Baird 2005; Borja et al. 2010), and 2) explicit construction of the approach to best account for this uncertainty. Because we do not know the true effect of restoration projects, the results can be interpreted as worst- or best-case descriptions depending on how much certainty is reflected in the estimates. At worst, we provide an approach that can identify the closest restoration projects that have occurred near a water quality monitoring site and a means to compare water quality between project types. We consider this valuable information for managers even if there is considerable uncertainty in the estimates of change; there are currently no tools that match restoration projects to water quality records in Tampa Bay. At best, we provide a decision support tool that provides managers with an expectation of water quality benefits associated with restorations actions, and an estimate of time required for improvements to be observed (Diefenderfer et al. 2011). Both kinds of information are critical to inform and sustain environmental restoration programs.

The value of our approach to quantify cumulative effects of restoration activities on improving water quality is likely between the worst- and best-case scenarios outlined above given the confidence that can be invested in the conclusions. The ability of our model to support previously and well-described changes in water quality in response to key management interventions (e.g., improvements from point source controls, Greening et al. 2014; Beck and Hagy 2015) provides additional assurance and weight of evidence that our approach improves

497   our understanding of restoration effectiveness beyond basic relationships presented in Figure 6.

498   Operating under this assumption, an explanation of how the results could be interpreted to guide

499   management is required to minimize extrapolation of conclusions beyond a reasonable level of

500   confidence in what the approach provides (i.e., a levels-of-evidence reasoning, Diefenderfer et

501   al. 2011).

502   As an example, a practitioner could use the following logic derived from our approach to guide

503   future restoration efforts. Figure 7 suggests that point source controls were responsible for an

504   approximate baywide chlorophyll-a reduction of 2 μg/L. These results were observed at the 10

505   year window and 5 (and 10) closest project combinations. What exactly does this information

506   suggest and what expectations can be derived regarding the likely effects of future point source

507   control efforts? First, an inaccurate conclusion is that baywide chlorophyll-a would be reduced

508   by 2 μg/L after ten years, if five projects are implemented in the future. A more correct

509   interpretation is that, historically, the aggregate effect of point source control projects for a

510   "typical" station at any point in the record and location in the bay has been a reduction of 2 μg/L

511   after about ten years in response to 5-10 projects, all of which were completed at different times.

512   Importantly, this latter interpretation assumes causal relationships between the projects and

513   changes in chlorophyll-a. This description is also understandably vague, but it provides context

514   of an expectation relative to other types of projects, particularly in narrative terms. For example,

515   the aggregate effects of habitat establishment projects were most apparent for the ten year

516   window, ten closest projects combination. With this information, qualitative conclusions about

517   the relative effects of point source control versus habitat establishment can be made. Point source

518   control projects are "more effective" in improving downstream water quality because

519   improvements are expected "quicker" and with "fewer" implemented projects, as applied to a

520 "typical" water quality station that could be at any location in the bay. Similar but alternative

521 conclusions could be made in different spatial contexts (e.g., "typical" stations in Hillsborough

522 Bay, Table 2).

523 The flexibility and simplicity of the approach to quantify associations between restoration

524 projects and water quality was purposeful given the constraints of the data. Although the

525 compiled restoration databases included additional information on effort (e.g., acreage restored),

526 these data were not consistently collected and our approach was constrained to the most basic

527 information about each project (i.e, type, completion date, and location). Explicit monitoring of

528 project effectiveness pre- and post-completion is atypical (Neckles et al. 2002; NASEM 2017)

529 and our minimal dataset describing the when and where for each project is a more available

530 description of restoration efforts across systems, especially in historic contexts. Within these

531 constraints, the model was strictly associative and any conclusions do not provide a mechanistic

532 explanation. These limitations in our associative approach were apparent in some of the results.

533 Specifically, significant increases in chlorophyll-a associated with particular projects and

534 year/site combinations were observed (e.g., Figure 7d, three sites for habitat enhancement).

535 These trends are contrary to expectations and highlight shortcomings where the simple design

536 may not have adequately accounted for improvements in downstream water quality (e.g., full

537 ecosystem maturation of a restoration site). Our aggregated estimates using all stations to

538 describe a baywide association were partly meant to reduce the influence of some of these

539 spurious results.

540 The simplicity of our approach also means that it is highly adaptable to novel contexts. A

541 primary goal of this study was to develop a decision support tool that could be applied

542 elsewhere. We used Tampa Bay as an example where the outcome was partially known and a

543   rich dataset was available, affording us a prior expectation of the results. Application to

544   additional systems would require, at minimum, water quality observations spanning multiple

545   years and a similar dataset of restoration projects. Our categorization that described relevant

546   water and habitat related restoration projects was specific to Tampa Bay, but our approach can

547   include different project definitions and specificity depending on the types of activities that may

548   have occurred and the expected benefits for water quality in a different system. Similarly, the

549   flexibility of our approach to accommodate different year windows and number of projects

550   provides a diagnostic that is sensitive to both the restoration effort expressed in a dataset and

551   how the potential associations could be interpreted. Lastly, we demonstrated flexibility in the

552   spatial context from estimated changes at discrete locations to entire system-wide responses.

553   Although there is uncertainty associated with these interpretations (noted above), the ability to

554   accommodate different spatial contexts means the approach can be readily applied to different

555   systems or management questions at various scales - from a single monitoring station to a

556   regional monitoring network.

557   ## Conclusions

558   A long-term record of restoration activities and water quality data in Tampa Bay provided the

559   foundation to develop a novel decision support tool for coastal restoration practitioners and

560   managers. This new tool provided 1) a unique process to understand the associations between

561   past restoration projects and known changes in water quality, and 2) establishes, under certain

562   assumptions, an expectation of water quality improvements that could result from future

563   restoration activities contingent upon the level of investments in different activities and the

564   necessary time to monitor any observed downstream water quality benefits at local to watershed

565   scales. Overall, we demonstrated a baywide association of water quality changes to different

566   restoration activities that varied by project type, while refining parameters for estimating the

567   results, including the spatial context of interpretation. The flexibility of our approach has

568   potentially broad application and extension within the Gulf Coast restoration and management

569   community.

570 # Supplement

571   Data analysis frameworks and manuscript source materials available at

572   DOI:10.5281/zenodo.2539623.

573 # Acknowledgments

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591 **Figures**

592

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.

(a) Counts of restoration project types over time

(b) Locations of restoration project types over time

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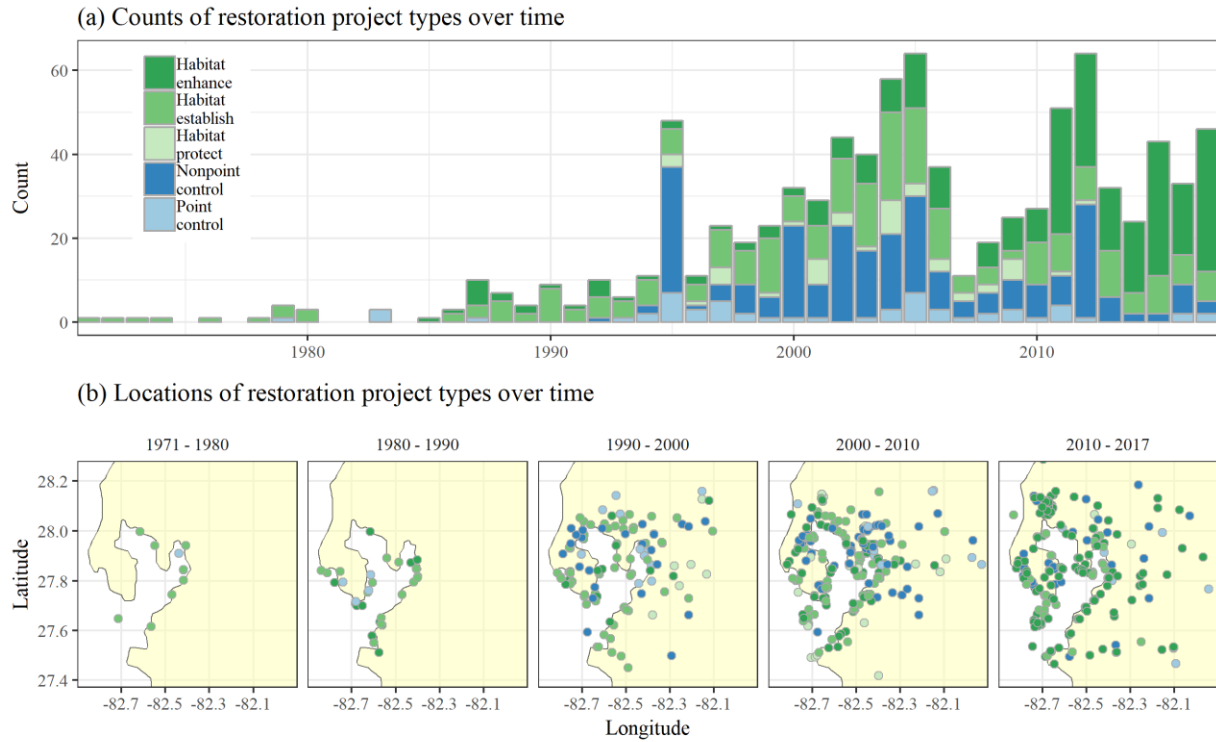
Figure 2 Counts (top) and locations (bottom) of restoration project types over time in the Tampa

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.

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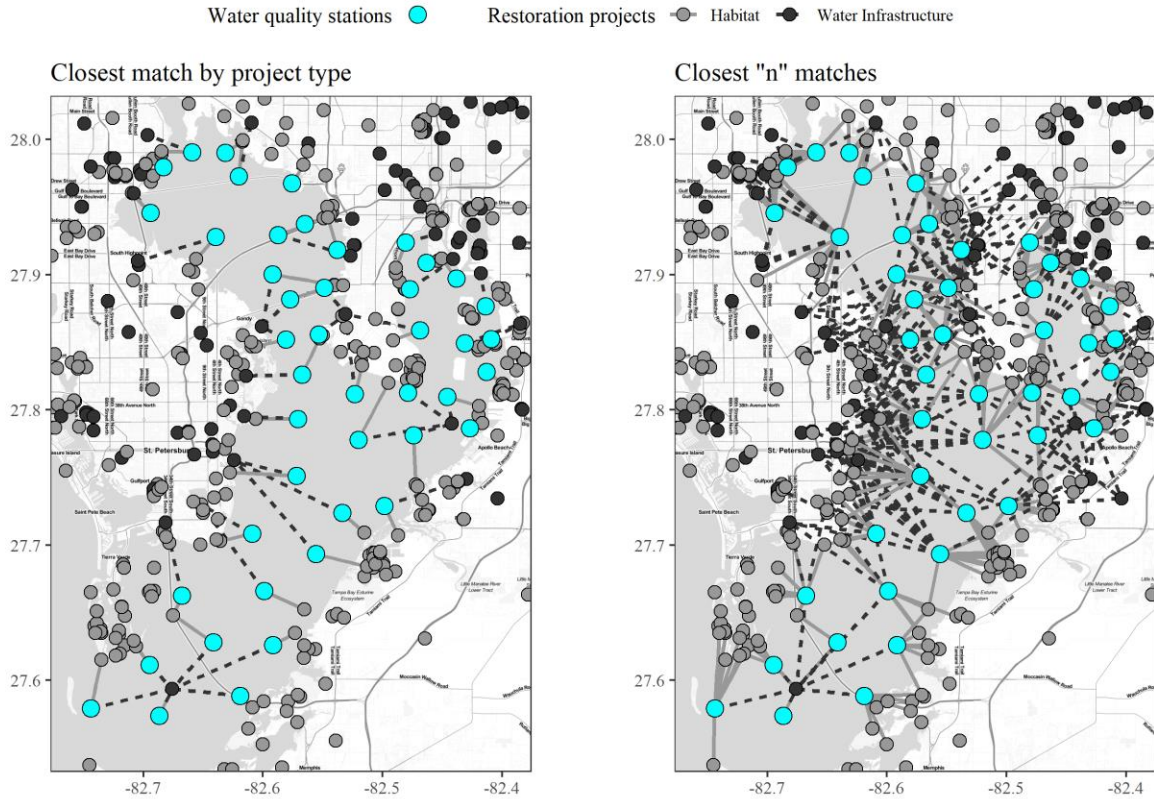
Figure 3 Spatial matching of water quality stations with restoration projects. Spatial matches of

each water quality station (blue dots) with habitat (solid line to grey dots) and water

infrastructure (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.

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(a) Spatial match (b) Temporal match

Temporal coverage of water quality time series

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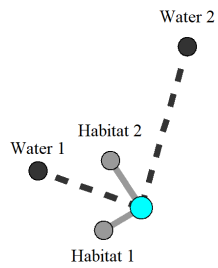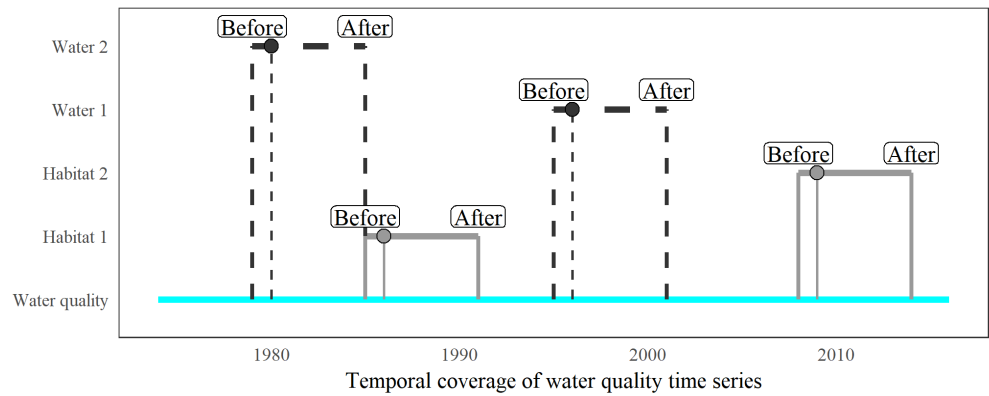
Figure 4 Temporal matching of restoration project types with time series data at a water quality

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 categories.*
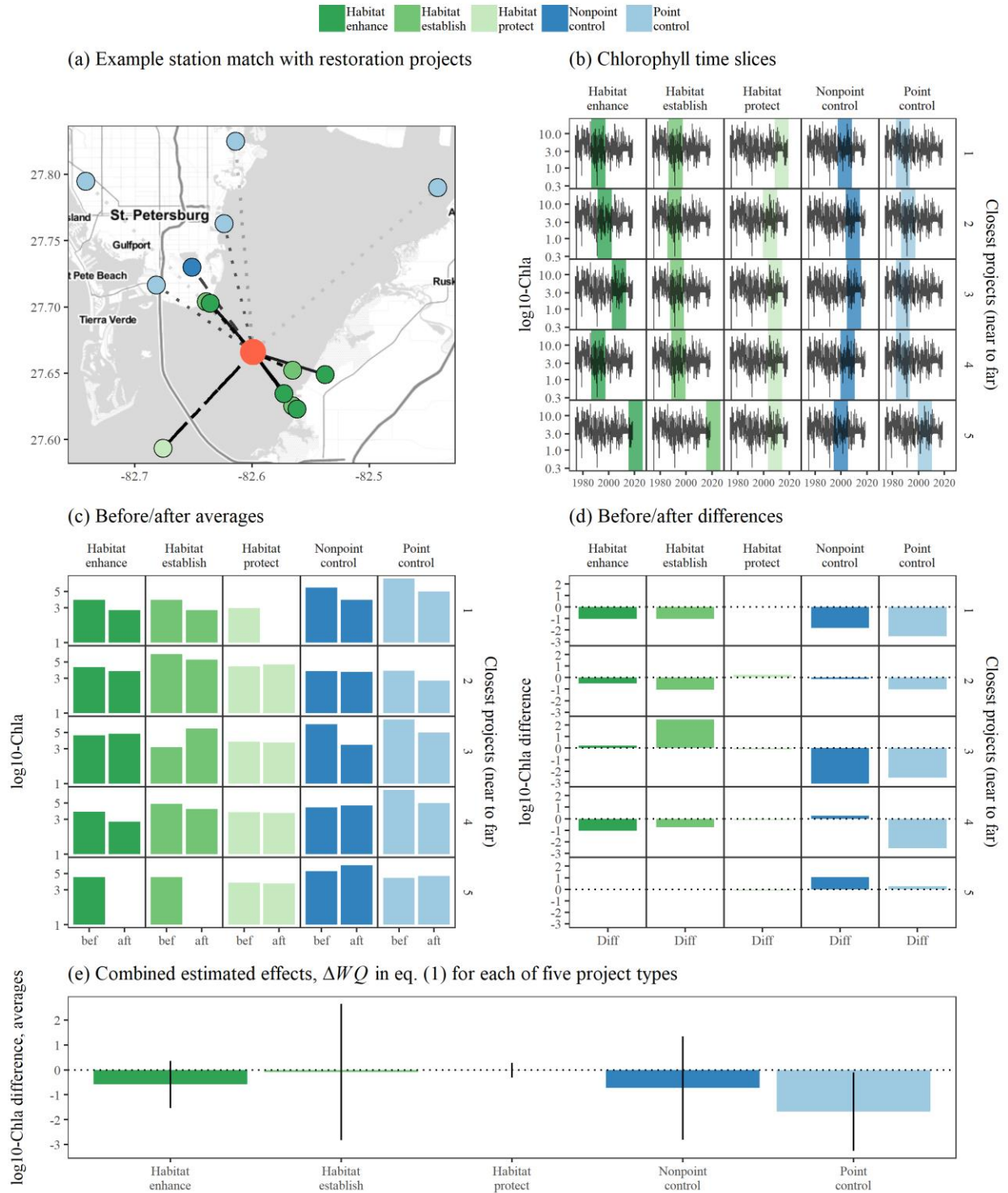
Figure 5 Steps to estimate cumulative water quality changes at a single station associated with a

selected number of projects and time windows. Subplot (a) shows a station in Middle Tampa Bay

622   *matched to the five nearest restoration projects for each of five types (some are co-located). The*

623   *time slices of the water quality observations for one year prior and ten years after the completion*

624   *of each project are shown in (b), ordered from near to far. The before/after water quality*

625   *averages for the slices are shown in (c) and the differences between the two are shown in (d).*

626   *Finally, the weighted averages for the five closest matches by project type are shown in (e) with*

627   *95% confidence intervals.*

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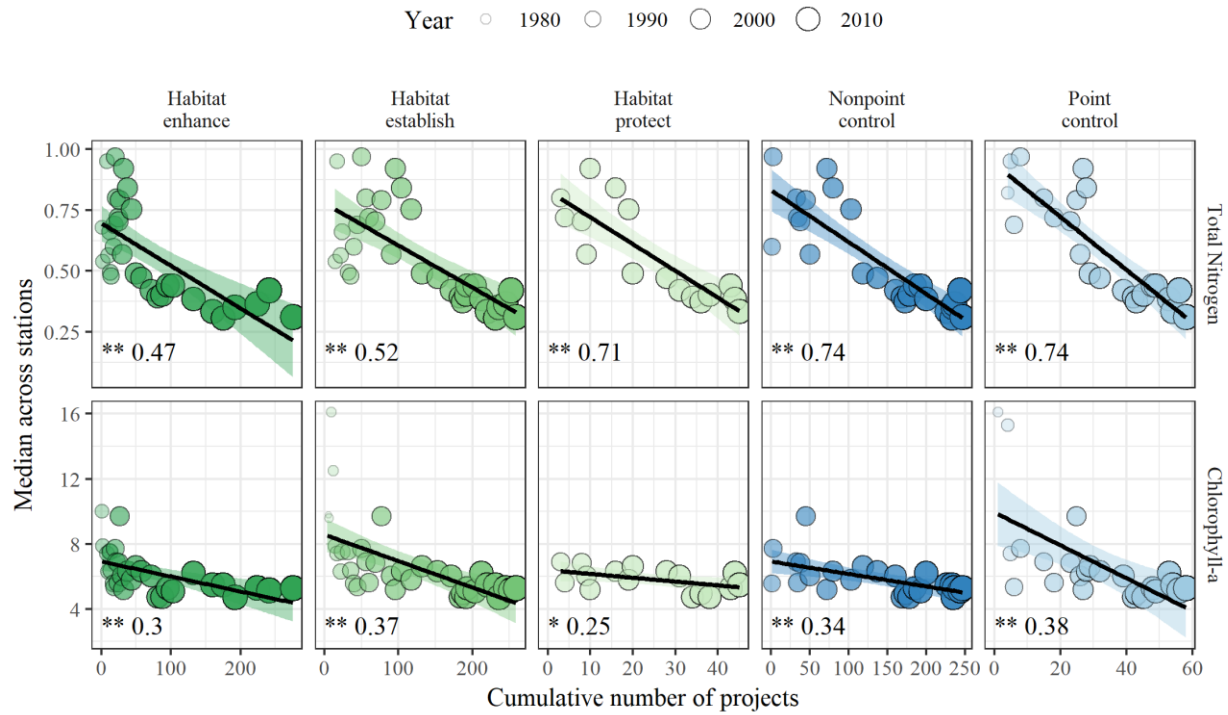
Figure 6 Relationships between cumulative number of restoration projects over time and water

quality observations in Tampa Bay. The plot shows median total nitrogen (mg/L) and

chlorophyll-a (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 (stars) and R-squared value. p > 0.05 ns,

p < 0.05 *, p < 0.005 **
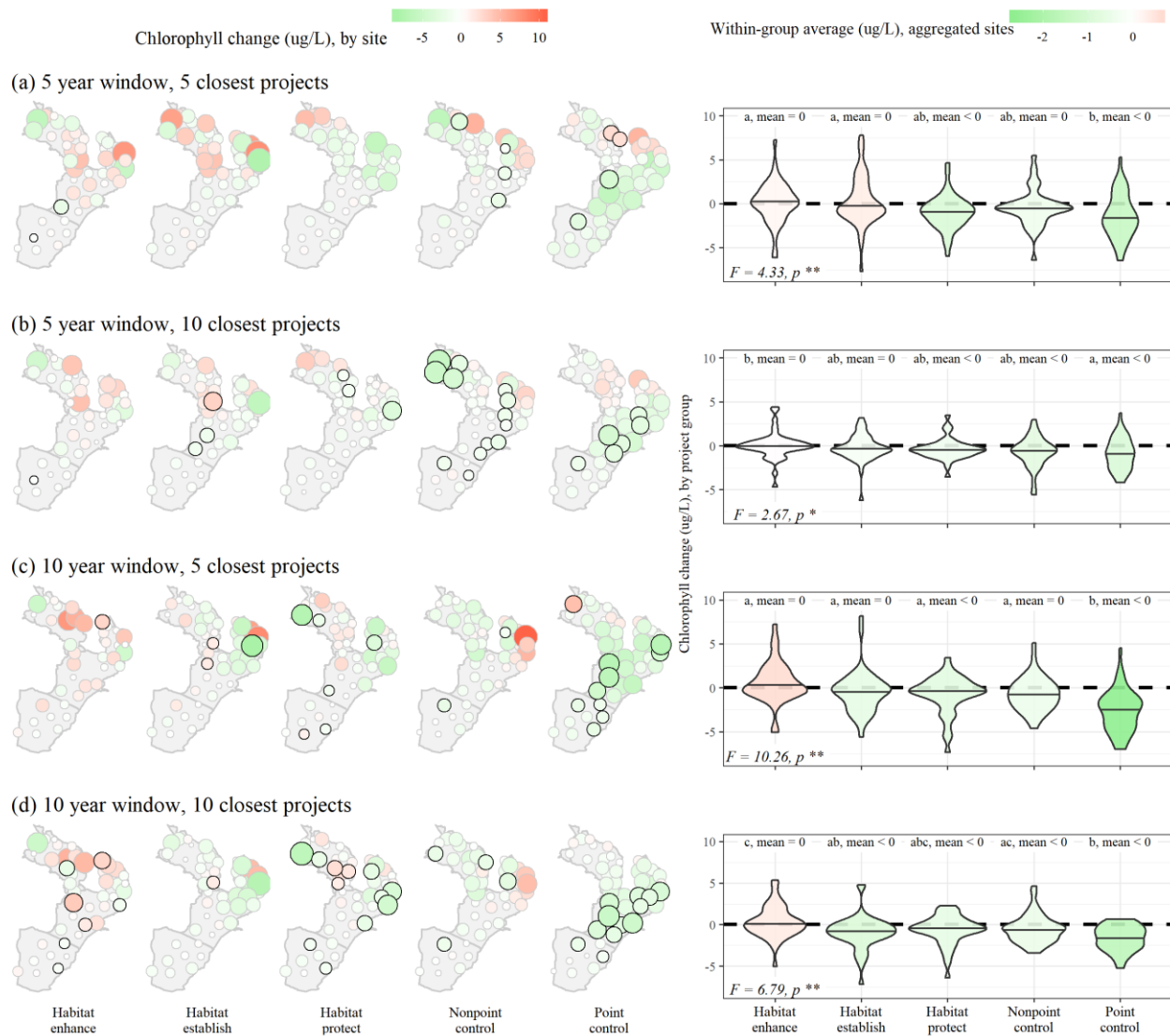
Figure 7 Associations of restoration projects with chlorophyll-a changes at all sites in Tampa
Bay. Associations were evaluated based on different year windows (5, 10) since completion of
restoration projects and number of closest restoration projects (5, 10) to each monitoring station
(subfigures a-d). 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
between project types were evaluated by ANOVA F-tests (bottom left corner, right plots),
whereas pairwise differences between project types were evaluated by t-tests with corrected p-

646 *values for multiple comparisons. Chlorophyll-a changes by project types within each subfigure*

647 *that are not significantly different share a letter and significance of the within-group mean*

648 *relative to zero is also shown.*

649

Tables

		Total Nitrogen			Chlorophyll-a		
Salinity	Time period	Min	Median	Max	Min	Median	Max
lo	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
hi	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

659   *Table 2: Associations of restoration projects with chlorophyll-a changes for different segments*

660   *of Tampa Bay (Figure 1). Associations were evaluated based on different year windows (5, 10)*

661   *since completion of restoration projects and number of closest restoration projects (5, 10) to*

662   *each monitoring station within each segment. Overall differences in chlorophyll-a changes*

663   *between restoration project types by segment and year/project number combinations were*

664   *evaluated by ANOVA F-tests, whereas pairwise differences (shown as letters) between project*

665   *types were evaluated by t-tests with corrected p-values for multiple comparisons. Chlorophyll-a*

666   *changes by project types that are not significantly different share a letter (comparisons are only*

667   *valid within rows) and significance of the within-group mean relative to zero is also shown. HB:*

668   *Hillsborough Bay, LTB: Lower Tampa Bay, MTB: Middle Tampa Bay, OTB: Old Tampa Bay. p*

669   *> 0.05 ns, p < 0.05 *, p < 0.005 ***

			Restoration project				
Combination	Bay segment	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

Combination	Bay segment	ANOVA	Habitat enhance	Habitat establish	Habitat protect	Nonpoint control	Point control
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

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Table 3 Results comparing water quality associations for random date and location assignments

of restoration projects to those from real data. The columns "mean < 0", "mean = 0", and

"mean > 0" show the proportion of results for 1000 simulations of random dates and locations

where the estimated effect had an overall decrease in observed chlorophyll-a (mean < 0), no

change (mean = 0), or increase in chlorophyll-a (mean > 0). The actual estimate of the

association with chlorophyll-a change from observed data for restoration projects is also shown.

The agreement column shows whether the actual estimate is in agreement (y: yes, n: no) with the

most frequently observed result from the random simulations (bold).

Combination	Restoration project	mean < 0	mean = 0	mean > 0	Actual	Agreement
5 years, 5 projects	Habitat enhance	0.44	**0.51**	0.06	mean = 0	y
	Habitat establish	0.47	**0.49**	0.04	mean = 0	y
	Habitat protect	**0.49**	0.38	0.14	mean < 0	y
	Nonpoint control	0.45	**0.5**	0.05	mean = 0	y
	Point control	**0.49**	0.4	0.11	mean < 0	y
5 years, 10 projects	Habitat enhance	**0.59**	0.38	0.04	mean = 0	n
	Habitat establish	**0.61**	0.36	0.04	mean = 0	n
	Habitat protect	**0.58**	0.32	0.1	mean < 0	y
	Nonpoint control	**0.59**	0.37	0.04	mean < 0	y
	Point control	**0.57**	0.31	0.12	mean < 0	y
10 years, 5 projects	Habitat enhance	**0.82**	0.17	0	mean = 0	n
	Habitat establish	**0.82**	0.18	0	mean = 0	n
	Habitat protect	**0.79**	0.18	0.04	mean < 0	y
	Nonpoint control	**0.81**	0.18	0.01	mean = 0	n
	Point control	**0.75**	0.22	0.03	mean < 0	y
10 years, 10 projects	Habitat enhance	**0.92**	0.08	0	mean = 0	n
	Habitat establish	**0.94**	0.06	0	mean < 0	y
	Habitat protect	**0.83**	0.14	0.02	mean < 0	y
	Nonpoint control	**0.94**	0.06	0	mean < 0	y
	Point control	**0.87**	0.12	0.01	mean < 0	y

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