Evaluating Effectiveness of Wetland Restoration in the San Francisco Bay

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ABSTRACT

The majority of restoration projects nationwide remain unevaluated for their effectiveness post-implementation, which hinders understanding of restoration trajectories. In the San Francisco Bay Area, some restoration organizations that are working to restore degraded wetlands can benefit from further analysis of their monitoring data. This project examines the composition of plant communities in the transition zones of restored wetland projects by Save the Bay (STB), a San Francisco bay area nonprofit. I synthesized the vegetation monitoring data collected at STB's restoration sites following the Wetlands Regional Monitoring Program (WRMP) protocol to (1) investigate the plant composition of sites that have been restored, and (2) analyze the efficacy of soil treatment at the sites. I found that native cover is significantly increasing on average across all study sites, although there was significant variation in vegetation composition between sites and over time. I also found that soil treatment had a significant correlation with increasing native cover, and some soil treatments are more effective than others. These analyses have helped to inform Save The Bay on focus areas for upcoming restoration work, and best restoration techniques for increasing native plant cover.

KEYWORDS

wetland, tidal marsh, restoration, transition zone, vegetation, monitoring, San Francisco Bay

INTRODUCTION

Ecological restoration aims to improve ecosystem health for the benefit of native biota and human society (Alexander et al. 2016). Over the past three decades, increased incentives for restoration nationwide have led to major shifts in the types of restoration projects installed, the goals that they aim to achieve, and the ways in which they are implemented (Bernhardt et al. 2007, Christian-Smith and Merenlender 2010). However, due to monetary and institutional limitations, very few restoration projects are subject to detailed or systematic monitoring and evaluation processes post-implementation (Kondolf 1995). Furthermore, the few restoration projects that are evaluated often display high rates of failure or reveal disconnects between the goals and achievements of the project (Kondolf 1995, Christian-Smith and Merenlender 2010, Moreno-Mateos et al. 2012). Comprehensive analysis of regional restoration initiatives could help to improve restoration projects (Bernhardt et al. 2007).

The San Francisco Bay Area is a hub of heavily disrupted and strictly managed ecosystems, with an extensive network of conserved and restored lands adjacent to major urbanization (Shellenbarger et al. 2013). Tidal wetlands are one of the main habitats that have been severely affected by such urbanization. Around 90% of the region's tidal marsh habitat has been filled in the past 150 years, which has sparked a diverse array of wetland restoration projects (Callaway et al 2013, Shellenbarger et al. 2013). Specifically in the SFBA, restoration projects have shifted since the 1990s from smaller scale projects to implement large-scale tidal wetland restoration as an important component in restoring key processes for the entire ecosystem of the estuary (Williams and Faber 2001). The SFBA is now home to the second largest wetland restoration project in North America: the South Bay Salt Pond Restoration Project (SBSPRP) (Cloern and Jassby 2012, South Bay Salt Pond Restoration Project 2009).

In these restored wetlands, the ecological importance of the wetland transition zone has gained recognition among the regional restoration community (Collins and Goodman-Collins 2010). The transition zone between the marsh and upland habitat is a critical refuge for wildlife, such as the endangered Salt Marsh Harvest Mouse and California Clapper Rail (Thomson and Kakouros 2013). Wetland transition zones in the SF Bay can provide flood control and mitigate impacts of sea level rise by providing a buffer area between developed land and tidal waters (Ackerly et al. 2012, Beller et al. 2013). Furthermore, vegetative cover of transition zones can strongly indicate the success of a restored wetland in re-establishing habitat for native species (Collins and Goodman-Collins 2010). Therefore, analysis of the vegetative cover at existing transition zone restoration projects can inform restoration practice where extensive projects are planned (Collins and Goodman-Collins 2010, Grenier et al. 2015).

Now, transition zone restoration projects across the SFBA are monitored following protocols such as the Wetlands Regional Monitoring Protocol. Such data on wetland transition zones has become especially relevant in the San Francisco Bay in the effort to conserve the ecosystem services that wetlands offer (Beller et al. 2013). However, although monitoring data may be collected annually, not all of the local restoration organizations have the capacity to analyze their monitoring data. Save the Bay, an SFBA restoration organization, could benefit from an analysis of their extensive database of monitoring data to better understand the progress of their restoration efforts.

My research project explores the following two questions: (1) How do Save the Bay's restored transition zone projects change over time in established native plant habitat within individual sites and across sites? (2) How do soil treatments affect the establishment of native plant cover in transition zones? I analyzed Save the Bay's monitoring data to answer these questions.

METHODS

Study System

Save the Bay (STB) has seven major ongoing restoration project sites: Creekside Marsh, Martin Luther King Jr. (MLK) Regional Shoreline, Eden Landing Ecological Reserve, Ravenswood Pond, Palo Alto Baylands, Faber-Laumeister Tract, and Bair Island. These restoration sites are all located in different parts of the San Francisco Bay, and are on land that used to be tidal salt marsh habitat before industrialization. In each restoration project, the planting efforts were focused on the transition zone of the tidal marsh ecosystem. Many of these transition zone restoration sites take place on top of bayfill, meaning there is no influence from previous ecological history in the soils or surrounding conditions. This makes them novel ecosystems post-restoration, which are an emerging focus in restoration ecology as the influence of human infrastructure on ecological restoration becomes increasingly common (Ehrenfeld 2000). Restoration at each of these sites is carried out by engaging volunteers from the local community to plant native vegetation, a process which is overseen by Save the Bay staff.

For this study, I focused on the three sites MLK Regional Shoreline in Oakland, Eden Landing in Hayward, and the Palo Alto Baylands (PAB) in Palo Alto due to their similar transition zone structure and composition (Table 1). Within each site, I included in my study one sub-site from MLK Regional Shoreline, two from PAB, and four from Eden Landing. These include MLK East Creek Slough South West (MLK ECS), PAB Byxbee Park (PAB BXB), PAB Compass Point Trail (PAB CPT), Eden A, Eden B, Eden D, and Eden E. There is variation among the restoration strategies and design in each of these three projects, however the underlying goal with each of these restoration sites is to provide habitat for native fauna and flora (Save the Bay 2010). There is also variation among the time period that these sites have been subject to restoration work, with some sites ranging from as early as the 1970's to 2015, and some sites have been restored more than once by different entities in that time period (Save the Bay 2010). However, this study focuses on the transition zones of restoration sites that Save the Bay has restored in the last decade. Furthermore, these sites and sub-sites differ in habitat conditions such as soil chemistry, salinity, transition zone size, and vegetation composition. Common species that have been planted to restore the transition zones at all of these sites include *Frankenia salina* or Alkali Heath and *Grindelia stricta* or Coastal Gumplant (Collins and Goodman-Collins 2010).

Table 1. Site Characteristics. Information taken from the Save the Bay website.

Site Name	**Size of STB Restoration**	**Year Restored by STB**	**Location Coordinates**	**Managed By**	**City and County**
MLK Jr. Regional Shoreline	50 acres	2000	37.7546 ˚N, -122.213 ˚W	East Bay Regional Park District	Oakland, Alameda County
Eden Landing Ecological Reserve	600 acres	2010	37.616 ˚N, -122.111 ˚W	California Department of Fish and Game	Hayward, Alameda County
Palo Alto Baylands	1,940 acres	2013	37.4581˚N, -122.103 ˚W	City of Palo Alto	Palo Alto, Santa Clara County

Within the Palo Alto Baylands are two experimental sites that I am studying to answer my second research question. These sites are located at Byxbee Park and Compass Point Trail (CPT), where restoration began in 2013. The experimental site consists of four treatment plots on the same levee: tilled soil, compost, compost and till, and a control plot. At Byxbee, the experimental area is 180 m in length, divided into four 45 m treatment plots, and the levee averages around 10 m in width. At CPT, the experimental area is around 60 m in length and the levee is around 10 m in width.

Figure 1a.

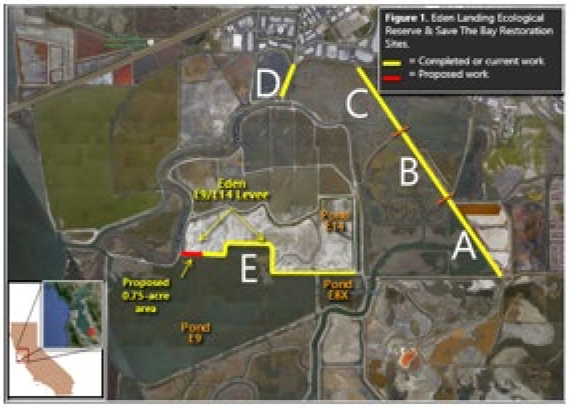

Figure 1b.

Figure 1c.

Figure 1d.

Figure 1(a-d). Study Sub-sites. (a) Sub-sites at Eden Landing Ecological Reserve, Eden A, B, C, D, and E, are lined in yellow. **(b)** The sub-sites at Palo Alto Baylands where the soil experiment was performed are displayed, with Compass Point Trail lined in yellow and Byxbee Park lined in red. **(c)** The sub-sites at Martin Luther King Jr. Shoreline are displayed, with East Creek Slough South West highlighted with a yellow line. **(d)** A map of all of STB's restoration sites. This study only considers Eden Landing, MLK Shoreline, and Palo Alto Baylands.

Data Collection

After restoration, monitoring data is collected annually in late summer by Save the Bay staff. Save the Bay's monitoring data for transition zones follows the Wetlands Regional Monitoring Protocol (WRMP). According to the protocol, the vegetation cover, maximum height, and presence of nonnative vegetation is measured at each site along strata characterized by four elevation zones of the sloping transition zone (Collins and Goodman-Collins 2010). A clinometer is used to set the backshore at each site from which the elevation zones will be set adjacent to (see Figure 2). Then, the width of the levee is measured and set. Levee width is divided into 4 evenly sized strata, which include intertidal, low, middle, and high elevation zones.

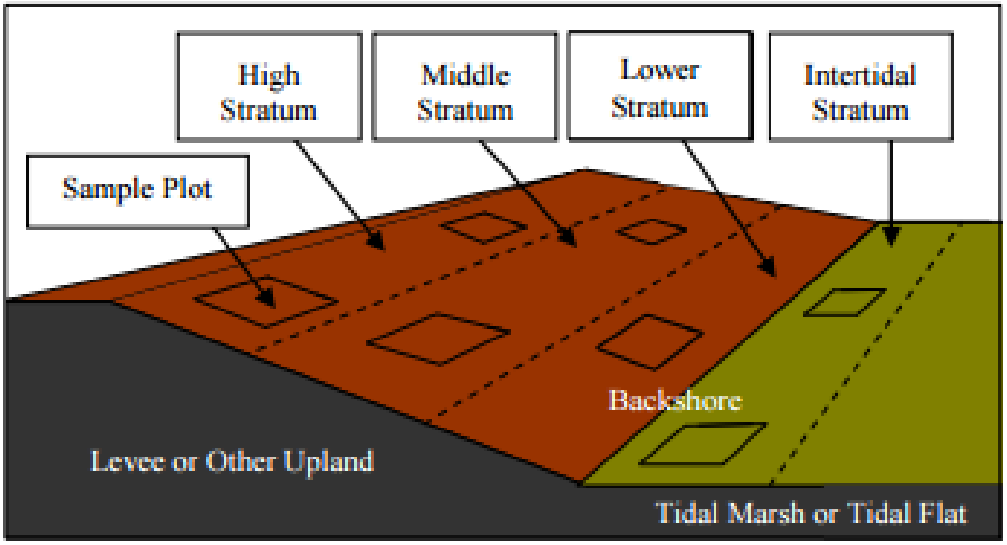

Figure 2. Monitoring Protocol. The transition zone is divided into four elevation strata from which quadrats are randomly sampled. (Collins and Goodman-Collins 2010)

The protocol uses stratified random-sampling to allocate 1 m^2 sample quadrats along elevation strata. Randomly selected points are taken along a transect and are measured in quadrats at the center of each stratum. At these points, species present in the 1m^2 quadrat are recorded as well as the percent cover and maximum height at each. The protocol then calls for the use of a species area curve to determine the number of quadrats measured per stratum. After the first three quadrats are sampled, the data is plotted onto a species area curve and quadrats must be collected until the curve plateaus. For many of the sites, four quadrats were observed per elevation zone. Some sites have more, depending on the length of the levee and the species area curve. At the Byxbee soil experiment site, these measurements were recorded separately for each of the four treatment plots.

I focused my study on monitoring data that had been collected by Save the Bay using the WRMP over the past five years. I specifically looked at three distinct time periods of restoration. Monitoring data from the sub-sites Eden A, Eden D, and MLK ECS SW was studied during the five-year period of 2011-2015 while data from the sub-sites Eden B and Eden E were studied over the two-year period of 2014-2015. The soil treatment experiment study looks at the monitoring data collected between 2014-2016 at the Palo Alto Baylands sub-sites. I assisted with collecting 2016 monitoring data in the field. I extensively reorganized and cleaned up all of the vegetation monitoring data, which had many gaps and inconsistencies, before using it in my analysis.

Analysis

Across All Sites

I compared percent native and nonnative cover between the studied sub-sites at Eden Landing and MLK Shoreline. I ran a mixed effects model analysis on R to test the correlation of the mean native percent cover over time between the sub-sites while accounting for both fixed effects and random effects. The log percent native cover was tested as a dependent variable for correlation with year as a fixed effect, and with zone, sub-site, and site as random effects. I also observed the species composition in total in 2015 across all sub-sites. I compared directional trends of change taken from the individual site temporal analysis over the five-year period and the two-year period, depending on the monitoring data available for each sub-site and the date of initial restoration.

At Each Site

To gain a fuller understanding of each respective restoration project, I analyzed plant community composition across time at each individual sub-site. These sub-sites include Eden Landing A, B, D, and E, as well as MLK Shoreline ECS SW. I looked at the low, middle, and high elevation zones where most restoration efforts are concentrated, ignoring the intertidal zone because it is often confounded by existing vegetation in the marsh plain. At each site, I obtained the mean percent native cover, nonnative annual grasses, other nonnative species, and bare ground of all three elevation zones combined. I used R to perform a one-way linear regression to test the significance of percent native cover over time and between zones. I also obtained the overall plant species composition and observed how the species composition changed over time. To better understand the temporal dynamics of restoration success, I then ran a historical analysis and plotted how these variables changed over the past five years. I compared mean percent cover for native species, nonnative annual grasses, other nonnative species, and bare ground from either the five-year period or the two-year time period of study. I then observed the different trajectories of change in vegetation cover over time.

Soil Treatment Experiment

In 2013, Save the Bay set up experimental plots at Byxbee Park and Compass Point Trail in the Palo Alto Baylands to determine the effectiveness of three soil treatments in contributing to successful restoration of the native vegetation cover. There was a control plot, a tilled plot, a composted plot, and a composted and tilled plot. The soil treatment of compost and tilling and the native plantings were carried out by volunteers with oversight from Save the Bay staff. I analyzed the monitoring data collected from both of these plots from 2014 to 2016 and used ANOVA in R to determine if any treatment established significantly more native cover than the others. I performed an ANOVA for both experimental sites separately and then combined to account for any differences between sites. I also compiled the species composition for the site and observed how it changed over time along with cover types bare ground, native cover, nonnative annual grass, and nonnative other.

RESULTS

Across All Sites

There was a significant change in percent native cover over time across all study sites. The mixed model showed that across all the restoration sites, native cover significantly increased between 2011 and 2015 (p=0.0000, t=4.8830, SE=0.0237). The average percent native cover in 2015 at all study sites is 36.81%, with a standard deviation of 18.98% (Figure 3). Some of the most common native and nonnative species across all sites in 2015 were nonnative annual grass, *Grindelia stricta*, *Salicornia pacifica*, and *Mesembryanthemum nodiflorum*. View Appendix 1 for a detailed chart of the species composition of all sites in 2015.

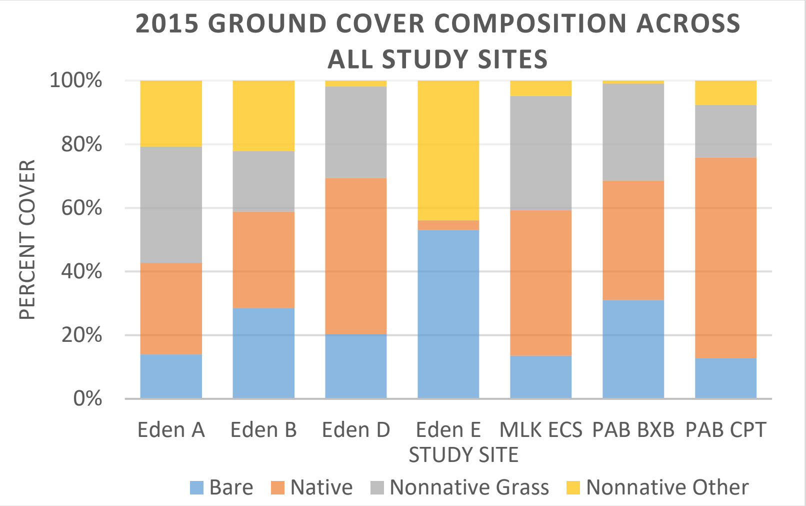

Figure 3. Vegetation Cover in 2015. Percent cover of bare ground, native vegetation, nonnative grass, and nonnative other at all study sites in 2015.

Looking at the total change in native cover over time during the study period revealed much variance in the temporal trends of each site. On average, the sites studied over 5 years from increased in native cover by 28.50% (SD=20.18%, Figure 4). Sites studied over a two year period (2014-2015) on average decreased -0.924% (SD=8.28%).

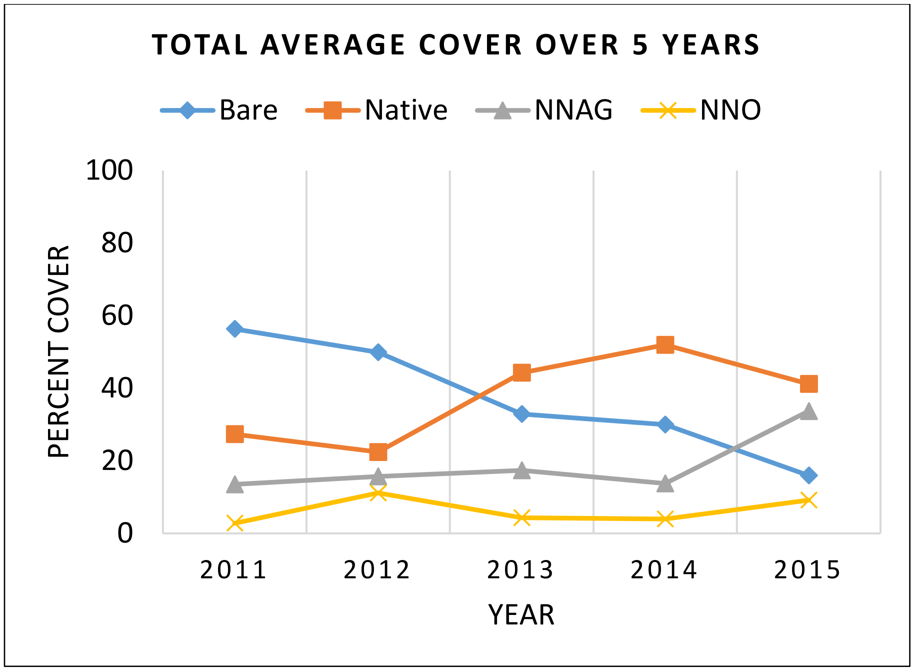

Figure 4. Total Site Cover Over Time. This graph averages the percent covers at the three sites studied for a five-year period (Eden A, Eden D, and MLK ECS. NNAG=Nonnative Annual Grass, NNO=Nonnative Other species

At Each Site

There was a significant correlation between the year and the percent native cover for Eden A, Eden D, and MLK ECS, which shows that there is significant change in vegetation cover composition at these sites over time. View the results of the linear regression between year and percent native cover in Table 2, as well as descriptive statistics of this temporal analysis for each site.

Table 2. Statistical results of the linear regression. Significant p-values are marked with an asterisk (*).

Site Name	Average Percent Native Cover (2015)	Adjusted R^2 value	P value	Standard Error
Eden A	28.79177	0.2549	0.0000 *	4.164
Eden B	30.46396	0.0534	0.0816	24.31
Eden D	49.06385	0.2882	0.0000 *	1.763
Eden E	3.026762	0.05947	0.0562	2.760
MLK ECS	45.74054	0.07402	0.0009 *	2.094

Each site had different temporal trends of ground cover since either 2011 or 2014, depending on date of restoration (Figure 5). At Eden A and MLK ECS, there is an observed decrease in native cover between 2014-2015. We can see trends of a general steady increase in native cover at MLK and Eden D over the five year period.

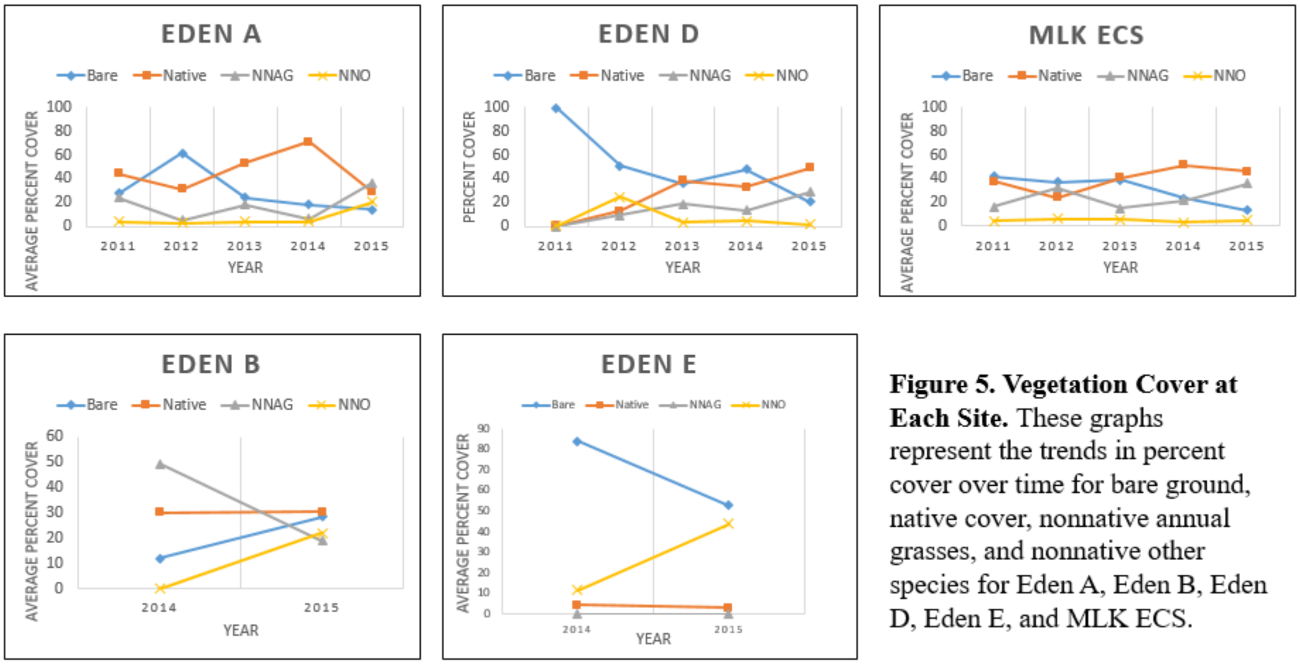

Figure 5. Vegetation Cover at Each Site. These graphs represent the trends in percent cover over time for bare ground, native cover, nonnative annual grasses, and nonnative other species for Eden A, Eden B, Eden D, Eden E, and MLK ECS.

Each site displays a unique palette of plant species that is present, although there is common overlap among a few sites. The change in species composition over time for each individual site is visualized in Table 3.

Table 3. Native species composition at each site across time. View Appendix 2 for the full-length scientific names of the species represented by a four-letter code here.

Year	**Site**	ARCA	ATTR	BAGL	BAPI	DISP	ELTR	ERFA	ESCA	EUOC	FRSA	GRST	JACA	MIAU	NAPU	SAPA	SCCA	SYCH
2011	Eden A	0	7	10	0	48	0	0	0	0	2128	1686	2	0	0	891	0	0
	Eden B	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Eden D	0	0	0	0	0	0	0	0	0	15	0	0	0	0	1	0	0
	Eden E	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	MLK ECS	0	11	0	25	77	0	0	0	0	0	222	12	0	0	890	0	0
2012	Eden A	0	1	37	0	12	0	0	0	0	556	161	8	0	0	41	0	0
	Eden B	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Eden D	11	6	6	0	3	32	0	12	37	118	205	0	0	0	49	1	0
	Eden E	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	MLK ECS	9	5	0	0	117	0	0	2	2	1	307	4	3	0	432	13	0
2013	Eden A	0	0	0	0	52	0	0	0	0	954	942	22	0	0	1257	10	0
	Eden B	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Eden D	0	0	1	0	0	179	0	0	0	151	404	0	0	0	111	0	0
	Eden E	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	MLK ECS	16	1	54	0	282	6	0	0	95	0	252	0	6	0	305	6	1
2014	Eden A	0	10	0	0	147	0	0	0	0	608	251	0	0	0	331	0	0
	Eden B	0	0	0	0	0	0	0	0	0	127	0	0	0	0	246	0	0
	Eden D	11	0	1	0	0	160	0	0	1	26	551	0	0	0	5	0	0
	Eden E	0	0	1	0	8	0	0	0	0	76	0	6	0	0	0	0	0
	MLK ECS	55	7	54	50	216	10	1	0	42	5	720	0	1	0	230	0	2
2015	Eden A	0	0	0	0	26	1	0	0	0	286	22	0	0	0	225	0	0
	Eden B	0	5	12	0	1	7	0	0	0	339	41	0	0	0	1657	0	1
	Eden D	5	0	1	0	0	63	0	0	11	6	790	0	0	65	81	0	0
	Eden E	0	2	3	0	17	3	0	0	0	195	5	6	0	0	27	0	0
	MLK ECS	11	0	12	0	141	60	0	0	96	1	686	15	0	0	261	0	0

Soil Treatment Experiment

The ANOVA proved that soil treatment has a significant correlation with percent native cover at both sites overall (p=0.0374, F=2.945). There was also a significant correlation between percent native cover and the experimental sub-site (p=0.0000, F=39.887). There was not a significant correlation between percent native cover and elevation zone (p= 0.8085, F=0.213).

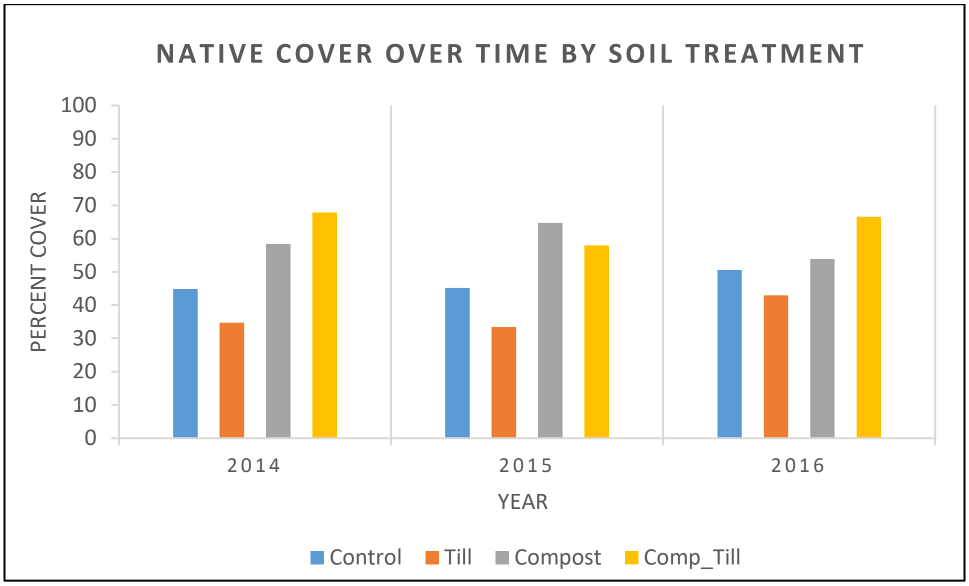

Figure 6. Soil Experiment Results. Percent native cover for each treatment over the experimental three year period.

At the Byxbee experimental site, the tilled plot had the lowest native cover, and the compost and till plot had the highest native cover. The compost plot had the lowest nonnative annual grass cover. View Table 4 for the variation in native cover between experimental plots. The most abundant species in the entire site include nonnative annual grass, *Artemisia californicus*, *Salicornia pacifica*, and *Grindelia stricta*.

At the CPT experimental site, the compost and till plot had the highest native cover by a margin of 0.705% over the compost plot in 2016. The till plot had the lowest percent native cover and highest percent cover of nonnative annual grass in 2016. View the cover composition between treatment plots in Table 5.

Table 4) Byxbee Percent Covers By Treatment. Percent cover of the four cover categories at the Byxbee site are presented by year and treatment plot.

Year	Treatment	BARE	NATIVE	NNAG	NNO
2014	Control	59.78495	23.11828	16.88172	0.215054
2014	Till	79.62963	3.703704	16.33987	0.326797
2014	Compost	55.67338	32.55567	11.24072	0.530223
2014	Compost and Till	32.03883	55.44768	12.51348	0
2015	Control	39.09774	37.80881	22.6638	0.429646
2015	Till	47.64957	16.13248	34.18803	2.029915
2015	Compost	22.86036	53.37838	23.64865	0.112613
2015	Compost and Till	14.45026	43.66492	41.04712	0.837696
2016	Control	27.97927	27.52591	41.83938	2.65544
2016	Till	40.52502	15.34044	34.94668	0.902379
2016	Compost	11.90789	28.97319	33.02812	0
2016	Compost and Till	10.16692	53.64188	36.11533	0

Table 5) Percent Covers By Treatment. Percent cover of the four cover categories at the Compass Point Trail site are presented by year and treatment plot.

Year	Treatment	BARE	NATIVE	NNAG	NNO
2014	Control	22.2467	66.62996	10.57269	0.550661
2014	Till	25.10965	65.78947	8.991228	0.109649
2014	Compost	14.45523	84.25027	1.294498	0
2014	Compost and Till	14.38923	80.33126	4.761905	0.517598
2015	Control	8.845739	52.64293	15.21036	23.30097
2015	Till	14.164	50.79872	32.05538	2.981896
2015	Compost	15.0641	76.17521	8.226496	0.534188
2015	Compost and Till	13.47594	72.29947	10.26738	3.957219
2016	Control	10.72165	73.71134	15.56701	0
2016	Till	7.683864	70.58178	21.73436	0
2016	Compost	5.901639	78.9071	14.97268	0.218579
2016	Compost and Till	4.530744	79.61165	15.21036	0.647249

DISCUSSION

Across transition-zone restoration projects, I found that native cover is generally increasing at most sites despite persistent drought conditions. The ways in which vegetation cover changed over time is different for each site, and site-specific conditions can reveal a better understanding of the trends in vegetation cover change. Soil treatments proved to significantly increase vegetation cover, especially the composts and till plot.

Save the Bay's transition zone restoration projects vary in vegetation composition. There are many factors that contribute to the establishment of native cover at each site. There are also specific restoration practices that significantly influence the effectiveness of a restoration project in restoring native vegetation cover. This section will explore these factors and their nuances in depth.

Multiple Site Analysis

The mixed effects model showed that there was significant positive change over time in native cover across all sites, with a small standard error. There is wide range of species that can be found among sites, with each site having its own unique plant palette. Most sites had more native cover than other cover types, which is a sign that sites are maintaining a relatively high percent native plant cover. This observation can indicate the proximity of the restoration projects reaching their goals. However, a quantitative goal was not defined for these sites, as often happens in restoration projects (Bernhardt et al. 2007). Defining an effective measure of the success of a restoration project involves a lot of complication, but Save the Bay could benefit from this practice. Until that goal is defined, however, we can interpret the higher abundance of native cover over nonnative cover averaged across all study sites as a mark of restoration success.

Individual Site Analysis

At each site, I observed a range of cover distributions and will explore in depth what may have caused these results at each site. In general, trends in vegetation cover can be influenced by soil conditions among sites, the size of the sites, and the initial site conditions prior to restoration especially as novel ecosystems, all of which vary among the study sites (Moreno-Mateos et al. 2012). Soil is an especially variant factor in the context of SFBA wetlands because so many restored sites are novel ecosystems built on top of bayfill (Ehrenfeld 2000). The history of active management also varies between sites, which may explain the difference in temporal trends between sites.

We can parse out trends between the sites that were studied for the five-year period (Eden A, Eden D, and MLK ECS SW) and a two-year period (Eden B and Eden E). At Eden A, there was an overall increase in native cover, reaching a peak of 74% in 2014, which is the highest observed native cover among all sites. However, there is a subsequent decrease in native cover in 2015, which is observed at MLK ECS SW as well. This is possibly the result of the statewide drought, which might improve the conditions for nonnative annual grasses to colonize over the struggling native vegetation (Armstrong and Huenneke 1993). Considering that the site started out completely bare in 2009 before restoration, and that very little active management has been performed at the site in recent years, the abundance of native cover demonstrates progress.

Eden D is the only site with a continued steady increase in native cover throughout all of the years. The current most abundant species at Eden D is *Grindelia stricta,* which demonstrates the drastic changes this site has undergone since restoration. There was a steady decrease in bare ground throughout the years as the site started with 100% bare ground in 2011. There remained low percentages of nonnative other species, although nonnative annual grasses increased steadily throughout the years. Before restoration, Eden D consisted primarily of nonnative mustard species. It was then plowed and replanted for restoration, and has been actively managed by volunteers and Save the Bay staff ever since. This active management is a probable cause of the high proportion of native cover. The steady increase of native cover over time can be interpreted as showing the most progress towards restoration goals out of all study sites.

At East Creek Slough South West in MLK Regional Shoreline, there seems to be very effective native cover restoration. The native cover has the highest proportion in 2015 (45.47%), and displays an overall increasing trend over the years. This is likely because East Creek Slough is a heavily managed site, and Save the Bay hosts many volunteer events to maintain the site. Nonnative annual grass was the most abundant species category (35.87 %) in 2015, which is relatively high compared to other sites in 2015, with *Grindelia stricta* as the second most common species.

At the two-year sites, it is more difficult to interpret significant trends, especially because there was no statistically significant correlation between vegetation cover and time. At Eden B, both years have a stable percent native cover (30.4%), while nonnative annual grasses decreased dramatically in 2015 (-31%). This may be a result of the very recent restoration planting, and we may need to wait a few years to see a more drastic change in native cover. Before restoration, Eden B mostly consisted of nonnative annual grasses. In the two years observed, nonnative annual grass decreases to around half its original value. There was also some active management of the site performed by staff which included pulling weeds and planting more native plants. This may be a preliminary factor in the observed decrease in nonnative annual grasses.

Eden E is another new site with only a few years' data, limiting our ability to draw any long term conclusions. The site is hyper saline and was completely bare prior to restoration, which commenced after the site was plowed. It displays unique results compared to the other sites in that there is no nonnative annual grass found in any of our quadrats in both years, because the conditions are too saline. However, there is significantly more nonnative other species that native species for both years (40% more nonnative) and a large proportion of bare ground (53%) in 2015. This implies that once the site conditions were improved to be suitable for plant colonization, nonnative species outcompeted the planted native species. The dominant species is *Mesembryanthemum nodiflorum* or Slenderleaf Iceplant, which can thrive in saline conditions.

Soil Treatment Experiment

The soil treatment experiment showed that the combination of compost and tilling had the highest native vegetation cover in 2016 for both CPT and Byxbee sites when observed separately. However, looking at which treatment had the highest percent cover averaged over the past three years shows that the compost only treatment is also effective. At both experimental sites, the margin between the compost treatment and the compost and tilling treatment was small, and combining the data from both sites shows a similar trend. Knowing that soil treatment has a significant effect on increasing native cover, Save the Bay can choose which soil treatment might make the most sense for a site based on resources available. It is likely that compost will be much easier to implement and have a similar effectiveness as tilling or both compost and tilling. The choice of which soil treatment to use may also depend on the site-specific soil conditions of a restoration project (Zink and Allen 1998).

Synthesis

Average percent native cover across these sites is indicative of overall progress. There are many potential explanatory variables for the change in cover percentages over time at each site, and in this study we can only speculate over significant points of temporal change. Sites with active management have higher native cover than sites with no management. Soil treatment can significantly increase the native cover at restoration sites. However, these conclusions must take into account the limitations of our study.

Limitations and Future Directions

There are a number of limitations to this study and a few recommendations for future investigation on the subject. Firstly, the way we define "effectiveness" and "progress" restoration can be very subjective if no clear goals are defined. There is a need for clarification about the role of nonnative annual grasses in measuring the effectiveness of a restoration project, and how we let their presence influence our analysis of the site. In many cases, nonnative grasses are very widespread and resilient, and often times close to being naturalized in California, therefore very difficult to permanently remove from sites (Armstrong and Huenneke 1993). If we were to look at the effectiveness of restoration while ignoring the nonnative grasses, the narrative of the results would really change.

There are many factors that may influence the native vegetation cover I have not accounted for in this study. I had originally intended on observing the relationship between vegetation composition and a series of active management factors, such as the number of plants planted, the number of volunteer hours spent managing the site, the gallons of water used for irrigation, and the pounds of weeds pulled. However, the data for these factors had a lot of discrepancies and missing information, so it was insufficient for an analysis. In order for a deeper understanding of the correlation between specific active management practices and vegetation cover, this data must be recorded carefully and prioritized for future analyses. Furthermore, the soil chemistry of each site can be considered more deeply in future studies for a detailed understanding of the causes of variation in plant species composition at each site (Callaway et al. 1990, Zedler 2000).

The WRMP that STB uses does not provide permanent plots that can be revisited and measured each year, which disrupts the continuity in the monitoring data. Therefore, the results may be slightly skewed due to the variation in quadrats measured each year, because they do not detail how a specific quadrat is actually changing over time.

In future monitoring endeavors, Save the Bay should set up permanent quadrats to be measured repeatedly to add a more continual dimension to the analysis. Future analyses should also investigate other factors that might be influencing the vegetation cover including specific active management practices.

Conclusions

This study has identified which restoration practices can help increase native vegetation cover as well as summarized the current state of STB's restoration sites. Tidal wetland transition zone restoration projects in the SF bay could benefit from a clearer understanding of their current vegetation composition. This can be achieved by regularly monitoring and actively analyzing the vegetation cover at restoration sites. Understanding the status of restoration projects and the factors that influence the vegetation cover across all sites can help guide future restoration projects in the SFBA. There is an increasing urgency of wetland restoration in the face of sea level rise and biodiversity loss, whereas effective and well-informed restoration practices can help to mitigate the negative impacts of the environmental threats to the region (Moreno-Mateos et al. 2012).

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APPENDIX

Appendix 1. Species composition across all sites in 2015.

	Eden A	Eden B	Eden D	Eden E	MLK ECS	PAB BXB	PAB CPT
ABIOTIC	272	1947	424	4533	382	1151	482
ACCO	0	0	0	0	8	0	0
ACMI	0	0	0	0	0	8	0
ARCA	0	0	5	0	11	280	115
ARDO	0	0	0	1	0	35	0
ATLE	0	0	0	0	0	100	100
ATSE	2	0	0	3	0	0	0
ATTR	0	5	0	2	0	0	0
BAGL	0	12	1	3	12	23	111
BAPI	0	0	0	0	0	80	321
BRNI	37	597	0	0	0	14	9
CAED	0	0	0	0	0	0	0
CAPY	0	14	0	0	0	1	21
COCO	0	0	0	0	0	0	11
CYDA	0	0	0	0	26	0	0
DISP	26	1	0	17	141	37	0
ELPO	0	0	5	0	0	0	0
ELTR	1	7	63	3	60	87	116
ERNU	0	0	0	0	16	0	0
ERCI	0	0	0	0	0	5	0
ERFA	0	0	0	0	0	365	0
ESCA	0	0	0	0	0	4	0
EUOC	0	0	11	0	96	42	123
FRSA	286	339	6	195	1	101	81
FOVU	0	0	1	0	0	3	0
GRST	22	41	790	5	686	76	400
HOBR	0	0	0	0	0	5	0
JACA	0	0	0	6	15	0	0
LIRA	0	0	0	0	0	0	0
MECR	0	0	0	0	0	0	0
MEIN	0	30	18	0	0	0	244
MENO	232	562	1	3737	0	0	0
MEPO	10	6	2	0	0	0	0
MIAU	0	0	0	0	0	115	0
NAPU	0	0	65	0	0	21	0
NNAG	710	1300	599	1	1016	1133	615

PAIN	0	0	10	0	0	0	0
PIEC	0	0	0	0	0	0	0
PLCO	0	3	0	0	0	0	0
RASA	0	0	0	0	1	0	0
RUCR	0	0	0	0	0	3	0
SAPA	225	1657	81	27	261	0	950
SASO	121	293	1	24	3	6	0
SCCA	0	0	0	0	0	15	37
SOAS	1	13	0	0	0	0	1
SYCH	0	1	0	0	0	0	0
TRMA	0	0	0	0	6	0	0
VISA	0	0	0	0	88	0	0

Appendix 2. Species scientific name and four-letter codes.

ABIOTIC	Bare ground or water	ELTR	*Elymus triticoides*
ACCO	*Acmispon corniculatus*	ERNU	*Eriogonum nudum*
ACMI	*Achillea millefolium*	ERCI	*Eriogonum cinereum*
ARCA	*Artemisia californica*	ERFA	*Eriogonum fasciculatum*
ARDO	*Artemisia douglasiana*	ESCA	*Eschscholzia californica*
ATLE	*Atriplex lentiformis*	EUOC	*Euthamia occidentalis*
ATSE	*Atriplex semibaccata*	FRSA	*Frankenia salina*
ATTR	*Atriplex triangularis*	FOVU	*Foenniculum vulgare*
BAGL	*Baccharis glutinosa*	GRST	*Grindelia stricta*
BAPI	*Baccharis pilularis*	HOBR	*Hordeum brachyantherum*
BRNI	*Brassica nigra*	JACA	*Jaumea californica*
CAED	*Carpobrotus edulis*	LIRA	*Limonium rammosissimum*
CAPY	*Carduus pycnocephalus*	MECR	*Mesembryanthemum crystallinum*
COCO	*Cotula coronopifolia*	MEIN	*Melilotus indica*
CYDA	*Cynodon dactylon*	MENO	*Mesembryanthemum nodiflorum*
DISP	*Distichlis spicata*	MEPO	*Medicago polymorpha*
ELPO	*Elytrigia pontica*	MIAU	*Mimulus aurantiacus*
NAPU	*Nassella pulchra*	RUCR	*Rumex crispus*
PAIN	*Parapholis incurva*	SAPA	*Salicornia pacifica*
PIEC	*Picris echioides*	SASO	*Salsola soda*
NNAG	Nonnative annual grass	SCCA	*Scrophularia californica*
PLCO	*Plantago coronopus*	SOAS	*Sonchus asper*
RASA	*Raphanus sativus*	SYCH	*Symphyotrichum chilense*
TRMA	*Triglochin maritima*	VISA	*Vicia sativea*