Appendix K. SFSU Vegetation Studies

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3.8 Intertidal Vegetation Establishment

Draft Executive Summary

Introduction

Intertidal wetland vegetation in mature marshes of the San Francisco Estuary (SFE) tends to occur along three shoreline zones (low marsh, middle marsh, and high marsh) characterized by (1) duration of inundation associated with low (longest) to high (shortest) intertidal elevation and (2) level of soil salinity (lowest where tidal inundation is most frequent and highest where tidal inundation is infrequent, and evaporation concentrates salts in the upper zone). California cord grass (*Spartina foliosa,* SPFO) dominates the lower zone, perennial pickleweed (*Sarcocornia pacifica,* SAPA) is abundant in the middle zone, and various salt tolerant species occupy the upper zone characterized by less duration of inundation and the highest salinities (e.g., annuals such as brass buttons [*Cotula coronopifolia,* COCO] and spearscale [*Atriplex prostrata,* ATPR]).

We found these plant distribution patterns to characterize the emergent vegetation at Sears Point at surprisingly fine spatial scales; however, an additional factor in newly establishing tidal marshes that has not been well studied is (3) a local disturbance regime that appears to be driven primarily by wind-wave and tidal current energy that influences vegetation establishment and persistence on shoreline sites that accumulates sediment through deposition versus those that lose sediment through scouring events. This factor has not been rigorously studied in the SF Estuary, presumably because newly formed tidal marshes, especially large tidal marshes, have not often been formed naturally during the past century. Rather, relatively small restored tidal wetlands have been observed by various consultant scientists who have not generally focused on this factor. Sears Point provided the opportunity to observe the importance of dynamic sediment disturbance patterns on vegetation establishment at an early stage in a large-scale tidal marsh restoration project. This collaborative study, benefitting from the engagement of various scientists and science-focused students, mostly from San Francisco State's Estuary and Ocean Science Center (EOS Center), has drawn attention to this third factor as an important element for consideration in future large-scale tidal restoration in the SFE.

Study Overview

The study began in early 2016 by Margot Buchbinder, an MA graduate student of Dr. Kathy Boyer. Margot's major focus was on the question of whether planting cord grass on mounds might improve their resistance to wind-wave erosion. By late 2016, the SF Bay NERR (based at the EOS Center) was contracted by the Sonoma Land Trust to monitor the project over the next five years. One focus of this monitoring was the intertidal zone of which vegetation establishment was a major goal (30 acres of intertidal vegetation within five years). Other associated studies on issues such as sediment accretion of the tidal basin and shoreline erosion are covered elsewhere in this report. A special feature of the project involved the creation of artificial shoreline "pannes" (seasonal ponds) along the North and Northeast shoreline and vegetation in these pannes was also a focus. Although the North and Northeast shorelines are the highest priority for protection, this study also was intended to cover the entire circumference of the intertidal shoreline and, to the extent possible, the mounds as well. Finally, an additional goal was to provide adaptive management guidance to the Land Trust based upon restoration trajectories observed during the study.

Given the size and scope of the project, and the dynamic nature of the environmental changes that emerged over short time scales, it soon became apparent that we should explore a number of methods to best capture changes in vegetation over time. These stressed the use of remote sensing technology supplemented by ground-based survey work, site photography, and limited special quantitative studies. Extensive survey work began in February 2017 and continued in March, April, May, June, August, and October (total of 13 site visits). This included two visits by Kathy Boyer's restoration class, work with Julian Meisler and Grad Assistant Ryan Anderson to repeat photo points, a drone flight by Dr. Jerry Davis and students (Geography and Environment at SF State), RTK GPS work by Margot Buchbinder and a USGS colleague, former EOS Center grad student Karen Backe, to scope additional mound planting of SPFO, and associated analyses. A poster session on the Sears Point project was also organized in October 2017. In 2018, RTK surveys were conducted around the entire periphery of the shoreline and, in March, SPFO mound plantings were done by the Invasive Spartina team on selected mounds based upon the earlier RTK survey work. Additional RTK survey work was conducted in April. Estimates of vegetation cover based on this work were computed for the 22 segments of shoreline that were surveyed. In October 2018, Kathy Boyer and her class conducted the first phase of a comparison between vegetation on the south shoreline of the west levee versus north shoreline (see below).

Work in 2019 slowed down as this was intended to be an interim year before the final assessment in 2020. Nevertheless, some important work occurred. In March, a second round of SPSF mound planting was accomplished by Invasive Spartina. Additional survey work was done in September and a seminar on the project was given at the formal EOS Center Seminar Series on September 25. In October a second year's worth of data was collected by Kathy Boyer's graduate seminar students focused on a comparison of shoreline vegetation along the southern (more protected) versus northern (less protected) levee. Additionally, we participated in preliminary discussions focused on the design for a remediation project to repair the levee bank wave erosion damage along the north section of the West levee and the North levee. Due to Covid restrictions, planned activities in 2020 were suspended and consequently final vegetation studies have not been carried out.

Findings from this study so far include:

<u>Acres of vegetative cover</u>

According to the of 2019 preliminary estimate of Dan Gillenwater, the total acres of vegetation cover was ~ 18.1 acres. This does not include mound vegetation and probably not the dependable annual cover of high marsh species like COCO (due to the date of the imagery), consequently this is likely to be an underestimate. It is also a good example of how acreage of vegetation cover is variable depending on the season and also on contingencies such as large storm events and other disturbances that can reduce vegetative cover temporarily.

Patterns of vegetative cover

The Gillenwater figure also provides important insights into the distribution of vegetative cover based upon geographic setting. Note the prominent gaps in vegetation along the North levee (S1-S7) and how vegetation is largely clustered in and around the pannes (primarily on the lee-side of the pannes). This illustrates how protection from wind-waves plays a key role in establishment and persistence. Photographic evidence also demonstrates how coarse-grained sediment is deposited in these lee-side sites creating somewhat protected germination and establishment conditions. Conversely, S8-S10 along the NE levee is protected from wind-waves and shoreline vegetation is dense, however, gaps in this cover represent the panne interiors in P8 and P9. For unknown reasons, these sites have been observed to not fill with water as much as pannes P1 – P7 along the North levee. This protected area and lack of persistent standing water apparently create ideal conditions for roosting waterfowl (particularly geese) which create so much persistent disturbance that they probably inhibit vegetative cover. The contrast between S13 (wind protected) and S14 (wind exposed) is also striking. Similar wind-wave exposure vegetation patterns exist to greater or lesser degrees around the site.

Another interesting pattern is the lack of vegetation at the junction of the East levee S12 and Southeast Levee S13 in the Whales Tale area. Wind-wave exposure is unlikely to cause this gap. However, this section of shoreline is at the head of a major engineered channel that may well bring a large volume of tidal water into this area every day. Another tidal current that may have an erosive shoreline effect is the one running alongside S7. Conversely, the tidal current that comes through the eastern breach at S17 may have created a counter-current strong enough to deposit large amounts of sediment and the tidal marsh vegetation at this site is the most extensive of any intertidal vegetation that has established in the entire basin (as revealed by the Gillenwater figure).

Succession of species over time

In 2016, SAPA appeared to be the early colonizer of favorable mid intertidal habitats. However, another very prominent high marsh annual was COCO. SPFO also was beginning to colonize the low intertidal areas. These patterns persisted in early 2017, however, two early succession species also became prominent by mid-2017, namely SADE in the low to mid intertidal and ELPA mats in the low intertidal. Several of the pannes at this time filled with water and were dominated by COCO and some unusual species such as *Plagiobothrys bracteosa,* a vernal pool plant. By 2018, SADE had become abundant in the middle marsh along with SAPA and along the Eastern levee, for example, greatly increased the vegetative cover of this area. Panne vegetation largely filled in with SAPA and COCO and ATPR were largely restricted. However, COCO and ATPR continued to be prominent in the high marsh zone. Another important intertidal species that occupies a zone between the low and mid marsh became more prominent (BOMA). Other species like FRSA, DISP, and JACA also became more prominent at various sites around the shoreline in 2018. By 2019 and 2020, patterns of intertidal vegetation were beginning to fill in wherever the disturbance regime seemed to permit. The early colonizers (SADE and ELPA) were still quite prominent as of 2020. The annual SADE in particular appears to have helped stabilize the shoreline and promoted colonization and expansion of the perennial SAPA.

Mound plantings

Although initial plantings of SPFO on the mounds were largely decimated by heavy wind-wave activity in April 2016, Ms. Buchbinder was persistent and replanted these mounds in 2017. Most re-plantings took and in 2018 and 2019 Invasive Spartina planted over 40 mounds considered at a suitable elevation. As emphasized in this report, the elevation of basin sediments has accreted dramatically over the past five years and mounds not planted appear to have eroded so, at low tide, the mounds are beginning to blend into the surrounding sediments leaving the planted mounds most visible. The concept originally was for the mounds to act as nuclei for marsh expansion when the basin sediments are consolidated enough and high enough to support expansion of the SPFO. This process appears well underway.

Role of off-shore dredged sediment placement

The West levee S22 shoreline is the site of an unintended "experiment". As part of the original design of the project, a channel was dredged from the west breach to the Petaluma River as a means of insuring that there would be adequate tidal exchange in the Sears Point basin. As a means of disposing of these dredged sediments, a cell was created near the western margin of the interior channel about half-way up the levee and these dredged sediments were deposited at this site. Consequently, the subtidal elevation sediments offshore from the southern half of the S22 shoreline started out at a significantly higher elevation than the northern half. We designed this class project to compare differences in intertidal plant composition, width of the shoreline vegetation, and height of the shoreline edge (a scarp where eroded) between these two shorelines. A summary of the results of this study is attached.

Although preliminary and not replicated, the findings are striking and very suggestive. In essence, the buffered southern shoreline presumably has been protected from wind-wave erosion and is twice as wide as northern section, more diverse, and its shoreline generally lacks a scarp compared to the northern section. This suggests that another approach to protecting the shoreline to promote intertidal vegetation establishment and prevent wind-wave erosion might be to use dredged sediments to construct subtidal deposits that buffer the shoreline.

Summary

Intertidal vegetation colonization of the shoreline defined by the Sears Point restoration has revealed some important insights. Early colonizers like SADE and ELPA arrived naturally without planting, as have most of the other intertidal species that have become established over the past five years. The goal of generating 30 acres of intertidal vegetation has not yet been met although the final analysis of this goal cannot be made due to the truncation of the study due to Covid.

However, even assuming the goal has not been met, the big lesson learned is that disturbance forces such as wind-wave erosion and high energy tidal currents in a large-scale restoration project like Sears Point need to be considered in both design and evaluation of project success, including intertidal vegetation establishment. Wind-wave erosion of the levees surrounding the shoreline is another important lesson. Current projects and research at Sears Point will help to assess how to plan for this key factor in intertidal vegetation establishment and persistence.

The Sears Point project is an excellent example of how the non-profit sector (including land trusts, conservation organizations like Invasive Spartina and the SF Bay NERR, and research and education institutions like the EOS Center) can collaborate and advance our understanding of how to best promote the values of intertidal vegetation to shoreline protection and wildlife habitat.

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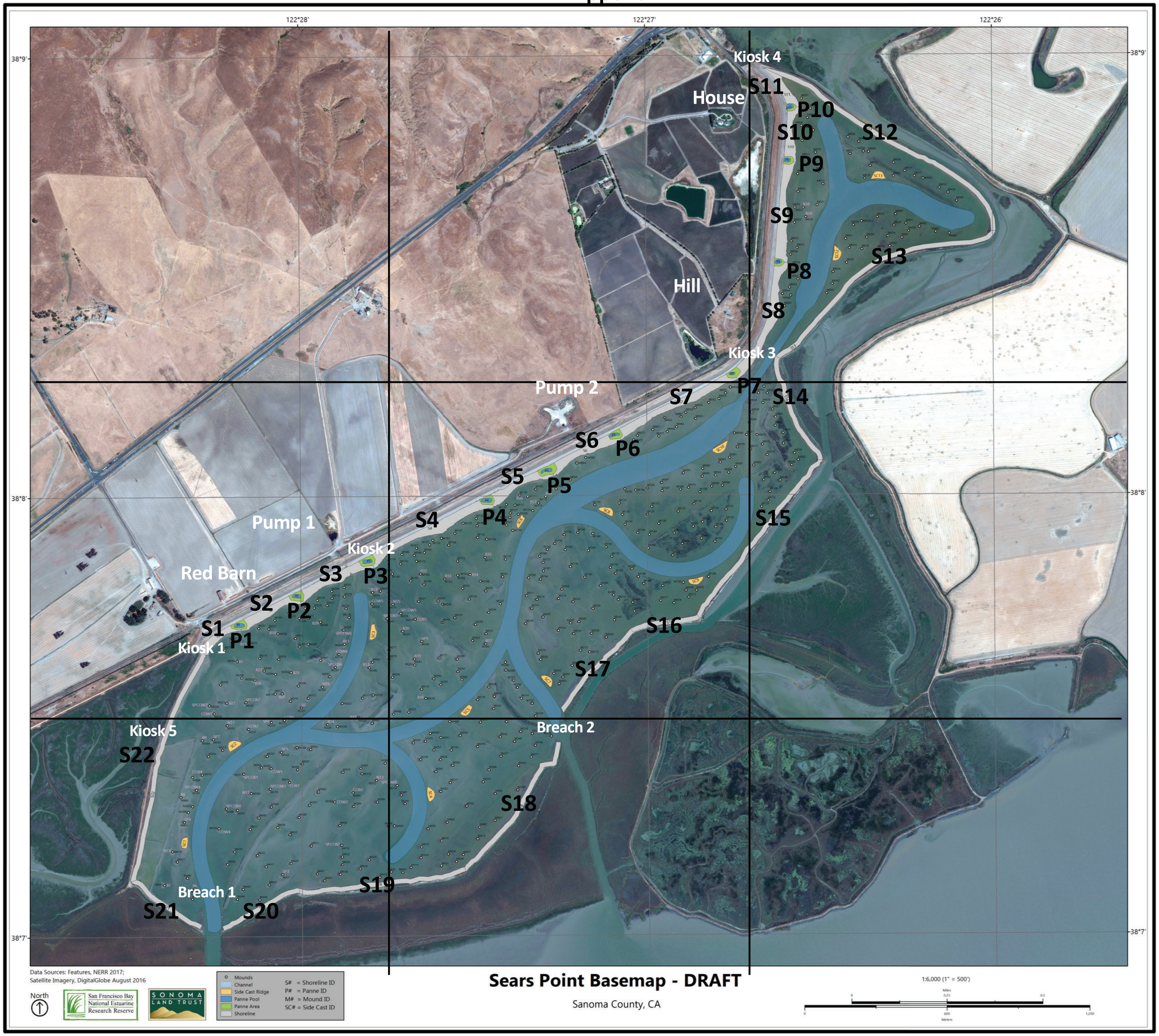

122°28'
122°27'
122°26'
38°9'
38°8'
38°7'
Kiosk 4
House
S11
P10
S10
S12
P9
S9
S13
P8
Hill
S8
Kiosk 3
Pump 2
P7
S7
S14
S6
P6
S5
P5
S4
P4
S15
Pump 1
Kiosk 2
Red Barn
S3
P3
S2
P2
S1
P1
Kiosk 1
S16
S17
Kiosk 5
Breach 2
S22
S18
S19
Breach 1
S21
S20
Data Sources: Features, NERR 2017;
Satellite Imagery, DigitalGlobe August 2016
North
San Francisco Bay National Estuarine Research Reserve
SONOMA LAND TRUST
Mounds
Channel
Side Cast Ridge
Panne Pool
Panne Area
Shoreline
S# = Shoreline ID
P# = Panne ID
M# = Mound ID
SC# = Side Cast ID
Sears Point Basemap - DRAFT
Sanoma County, CA
1:6,000 (1" = 500')
Miles
0
0.25
0.5
0
600
1,200
Meters

Appendix K-2

Sears Point MSC 709 Field Exercise
Fall 2019
M. Vasey

Comparison of Protected versus Unprotected Shoreline on Erosion and Vegetation Recruitment at the Sears Point Tidal Wetland Restoration Project in San Francisco Bay

Question

Does the offshore deposit of dredged sediment located along the southern shoreline of the separator levee (Shoreline 22) at Sears Point possibly protect the south shore from erosion and provide conditions that promote tidal wetland vegetation recruitment?

Hypotheses

H_0 - There is no significant difference between conditions in each of the contiguous shorelines (shoreline vegetation recruitment and erosion of the adjacent levee scarp). Consequently, offshore dredged sediment disposal does not appear to be buffering the south shore from erosion nor impacting its pattern of vegetation recruitment.

H_1 – There is a significant difference in patterns of shoreline vegetation recruitment and evidence of erosion along the north shore that is not protected from erosion as is the case for the southern shoreline.

Methods

A trail kiosk area conveniently is situated at the boundary between the dredged sediment cell to the south and an open, unprotected shoreline to the north (See Fig. 1). We placed a PVC pin at the boundary between the two shorelines. We then placed pins near the toe of the levee ~ every 25 m to the south and every 25 m to the north. These pins were labeled 1 at the southern-most point to 20 at the northern-most point. At each pin, we ran a transect line and used a meter stick to estimate the width of the vegetation (in m) from the toe of the levee to the farthest wetland vegetation away from the pin. We then measured the vertical height (in cm) from the toe of the levee to the top of its erosion scarp. We also measured the distance (in cm) from the pin to the base of the levee slope to track future erosion of the levee over time.

Finally, we used 0.25 m^2 quadrats starting at the pin and moving in a perpendicular direction towards the open water. Cover for each species in the quadrat was estimated. Quadrats were "leap frogged" to every other location along the transect (in essence, we sampled 0.25 m^2 for each 1m along the transect until we got to the end of the vegetation zone). We estimated cover for all plants and non-plants in the quadrat. Thus, we achieved a balanced design with 10 'gradsects' (Parker et al. 2011) along the southern shore and 10 along the northern shore.

The class sampled 14 gradsects on September 25, 2019 and M. Vasey completed the sampling of the additional 6 gradsects on October 4, 2019. Data was entered into an Excel spread sheet. As it was entered, it was curated by M. Vasey. The non-vegetated substrate (mud, wrack, algae, wood, tire) was lumped into "Bare". Using Excel, means, standard deviation, and standard error calculations were made for vegetation width and erosion scarp height in the south and north shorelines. A one tailed *t*-test was run on the width of the vegetation and the height of the erosion scarp for south and north shores. The number of plots for each shoreline was calculated and the total percent cover for each species and 'bare' were calculated based upon the number of plots in which they occurred. Plots along the gradsects were then grouped by position from start to finish along each shoreline to visualize potential zonation patterns. A table pertaining to these findings was created as were three bar graphs and a scatter plot comparing vegetation width of the shoreline in relation to degree of vertical scarp erosion.

Results

Figure 1 provides an overview of the Sears Point restoration site. The separator levee occurs in the lower left corner of the figure and the high elevation dredged sediment cell in the southern half of the levee is distinctly visible because its elevation is higher (reddish brown) than other sites in the restoration basin. Table 1 reflects the significant difference between the two shorelines. There were nearly twice the number of plots sampled to the south because the width of the vegetation was significantly wider than the vegetation to the north. Further, the height of the erosion scarp to the north was significantly greater than the south.

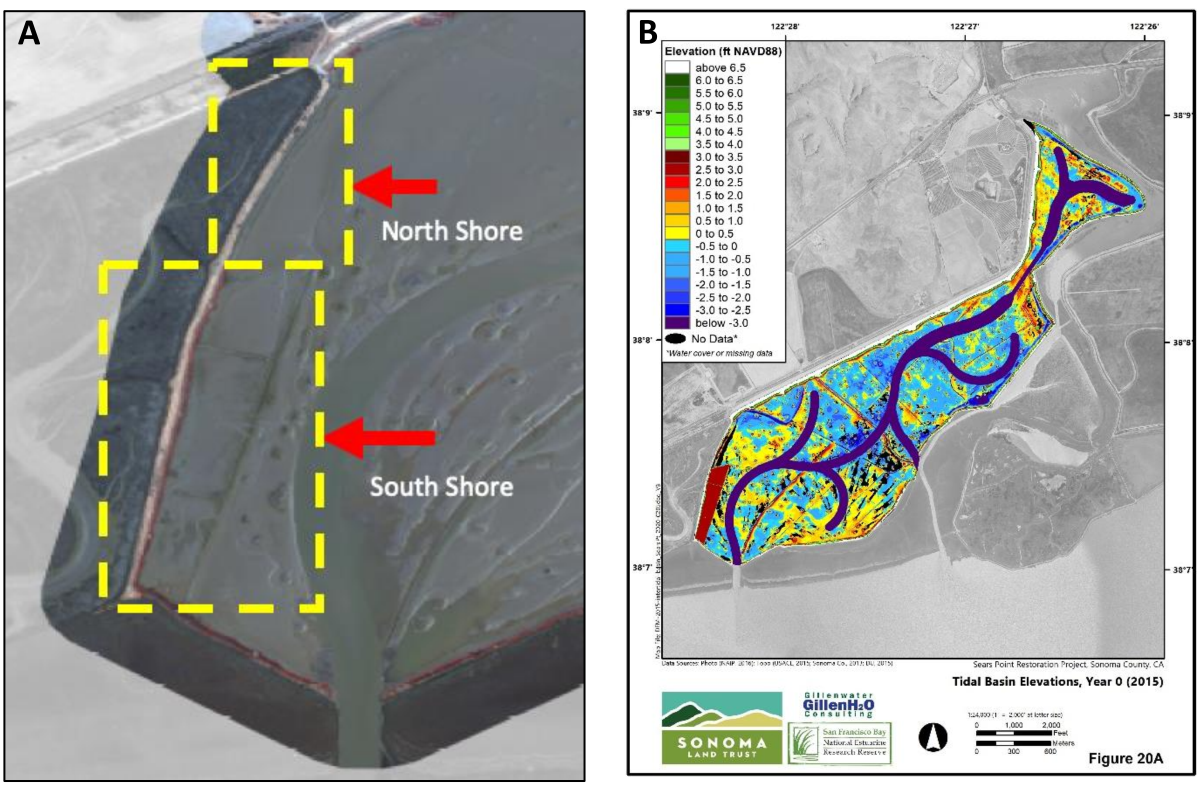

Fig. 1 Sears Point Southwest Levee Air Photo (A) and As-Built Topography (B). Infra-red aerial photo from 2018 shows South Shore and North Shore. Note thicker band of vegetation along south shore. DEM of restoration site on right shows separator levee to the far left. Brownish red area (south shore) is the higher elevation dredged sediment disposal site. North shore lacks off-shore dredged-sediment cell and is of similar low elevation as the rest of the site. Image incorporates LiDAR data from time of breach in October 2015.

In terms of species composition, Fig. 2 suggests that the dominant species for each shoreline are quite similar, as is the presence of 'bare' cover. Yet, because of the greater number of plots on the south shore, there is almost twice the cover of inter-tidal vegetation in dominant species like pickleweed SAPA (*Sarcocornia pacifica*) and saltgrass DISP (*Distichlis spicata*) in the south versus the north. Both cord grass SPFO (*Spartina foliosa*) and alkali bulrush BOMA (*Bulboschoenus maritimus*), which typically grow lower in the intertidal area, are also proportionately more abundant. The relatively even proportion of "Bare" along each shore

Table 1: Sears Point Comparison of Southern (Protected) versus Northern (Unprotected) Shoreline 22.

Shoreline 22 (Separator levee)	Number of Gradsects	Number of Plots (0.25 m^2)	Mean Width of Vegetation (± SE)	Mean Height of Erosion Scarp
South Shoreline	10	87	9.78 ± 0.64	9.5 cm ± 2.14
North Shoreline	10	46	5.32 ± 0.54	48.0 cm ± 4.96
Significance P value	NA	NA	t = 0.000002; p < 0.001	t = 0.0000005; p < 0.001

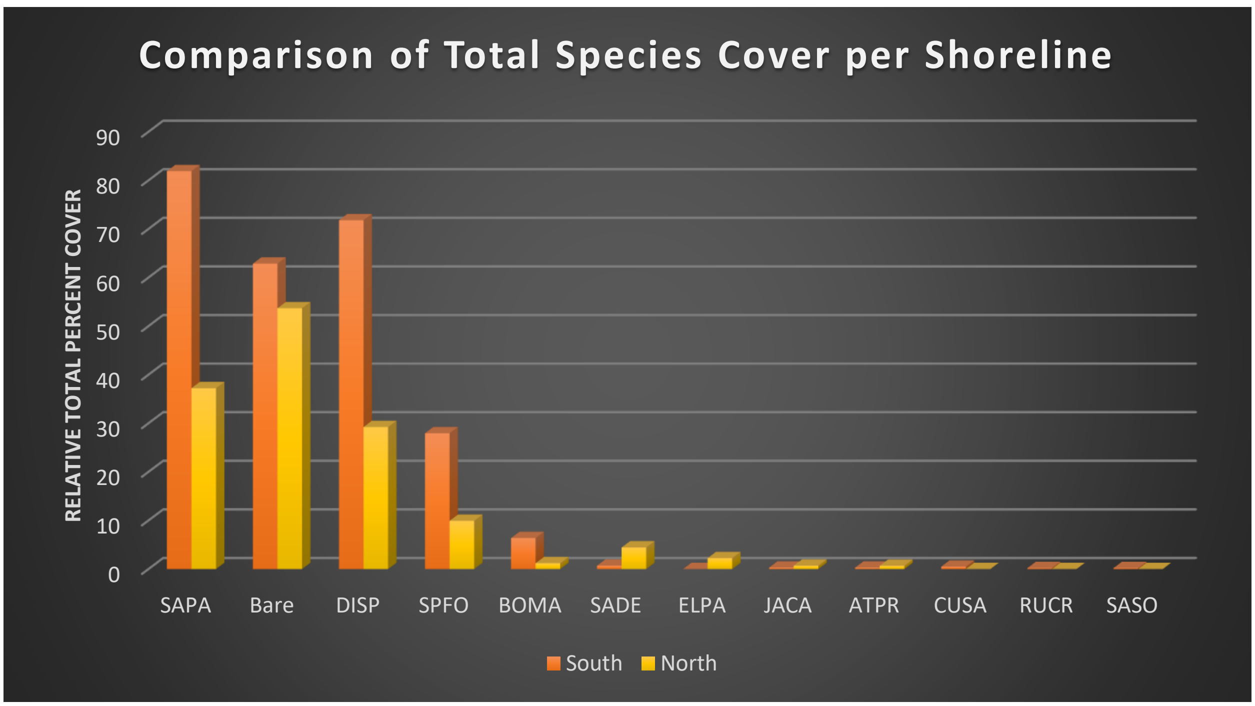

Fig. 2. Total cover for each taxon per shoreline. Acronyms along the X axis reflect species (or Bare). Numbers along the Y axis reflects the total cover (m^2) for each species relative to the number of plots in which they occur (sum of the average cover per plot X number of plots per shoreline). Total cover per shoreline in part represents the greater number of plots in the south versus the north (see Table 1 & Table 2).

reflects the greater presence of bare in gradsects on the northern shore. Further, note that annual pickleweed SADE (*Sarcocornia depressa*) is proportionately more abundant along the north shore. Typically, annual pickleweed precedes perennial pickleweed (SAPA) as a colonizer so, again, this is to be expected. Finally, several herbaceous species are more prominent on the south shore than the north, possibly reflecting the greater area of intertidal habitat in which to colonize. One large patch of dwarf spikerush ELPA (*Eleocharis parvula*) is in the north. It often occurs in bare areas in the low intertidal and appears to be an early colonizer that is replaced eventually by SPFO.

The gradsects along the south shore reveal incipient zonation despite the narrow width of the intertidal vegetation between the levee and the open water (Fig. 3; Table 1). Note that pickleweed (SAPA) and salt grass (DISP) dominate cover over the first five meters. Bare is relatively low. Alkali bulrush (BOMA) has low cover but is intermediate, occuring from S2 through S7 (where it is more prominent in the wetter end at S6 and S7). The low intertidal species of cord grass (SPFO) is picked up toward the wetter end of the gradient and dominates the low intertidal between S8 – S10. Meanwhile, the amount of "Bare" area (mud, algae, etc.) is much higher towards the bayward end of the gradient.

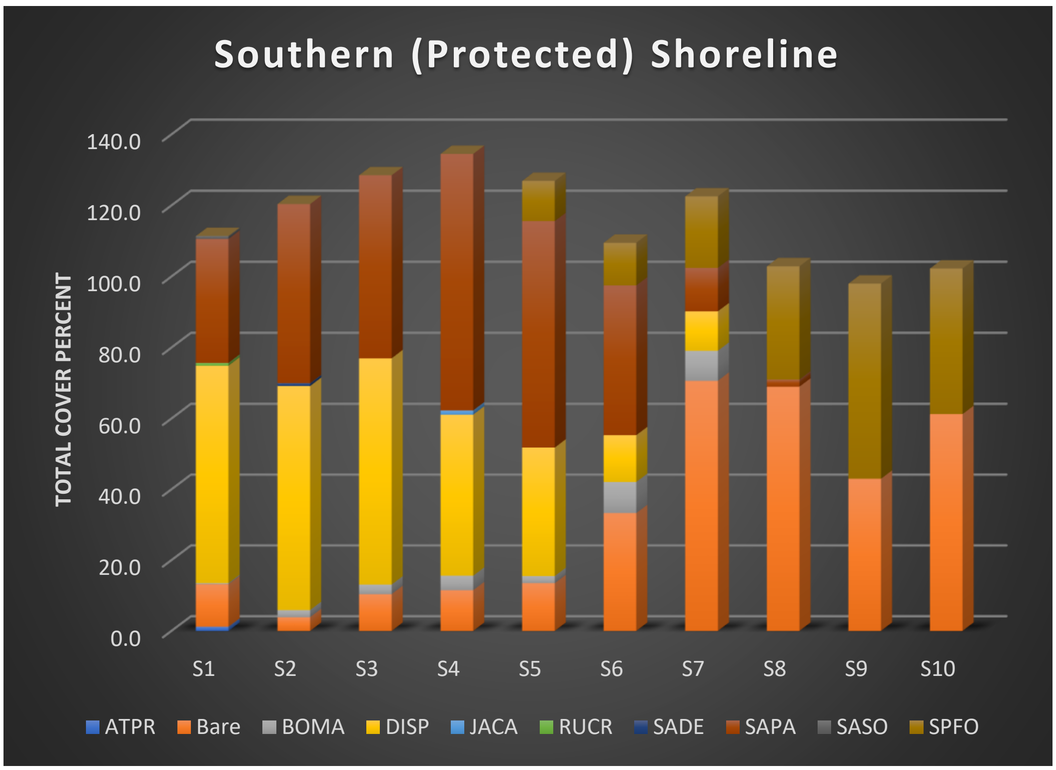

Fig. 3. Distribution of species and bare from S1 (adjacent to the toe of the levee) to S10 at the outer edge of the gradsect.

Gradsects along the north shore (Fig. 4 below) also demonstrate some zonation but not as clear a pattern as along the more well-vegetated southern shoreline. The vegetation is more compressed and distribution patterns are less clear. A large proportion of bare is near the edge of the levee. N2 and N3 have less bare and more SAPA and DISP. The proportion of bare increases in the north from N4 to N6 but only in N6 does cord grass and bare dominate. The occurrence of dwarf spikerush ELPA far out at N7 reflects its adaptation to the lower intertidal zone.

In summary, these vegetation patterns tend to reinforce the difference between the south shore and the north shore. The south shore appears to be more well-established and zonation patterns are more discrete. The vegetation of the south shore has probably been established for a longer period of time. Conversely, the north shore is still in the process of being sorted, suggesting that it is more recently established. These patterns are consistent with past observations.

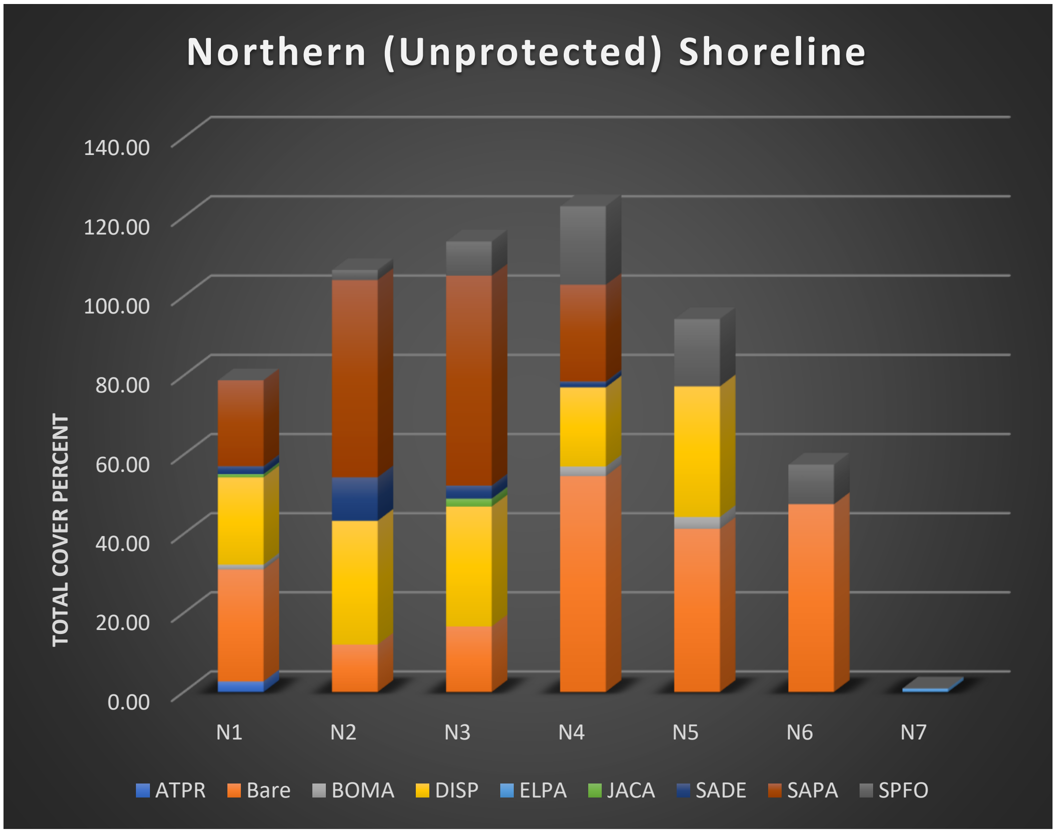

Fig. 4. Distribution of species and bare from N1 (adjacent to the toe of the levee) to N6 at the outer edge of the gradsect.

One further question that can be addressed with these data is represented in Fig. 5. The question is: if the southern shoreline is less eroded than the north, is this more likely because the vegetation is buffering the shore or because the offshore sediment deposit itself is the likely buffer. Of course, it's probably true that the offshore sediment deposit set up the more favorable conditions for vegetation recruitment but, even so, are the erosion scarps more highly correlated with vegetation width or not?

Fig. 5 explores this relationship through a scatter plot. Within each reach, there is considerable variability in scarp height and vegetation width and no discernable relationship between scarp height and vegetation width. In comparing the north and south reach, there is a significant difference – the north reach has narrower vegetation and taller scarp height relataive to the south reach. From an erosion protection standpoint, the south reach with broader vegetation and the dredge sediment placement has had a significant benefit on reducing levee erosion.

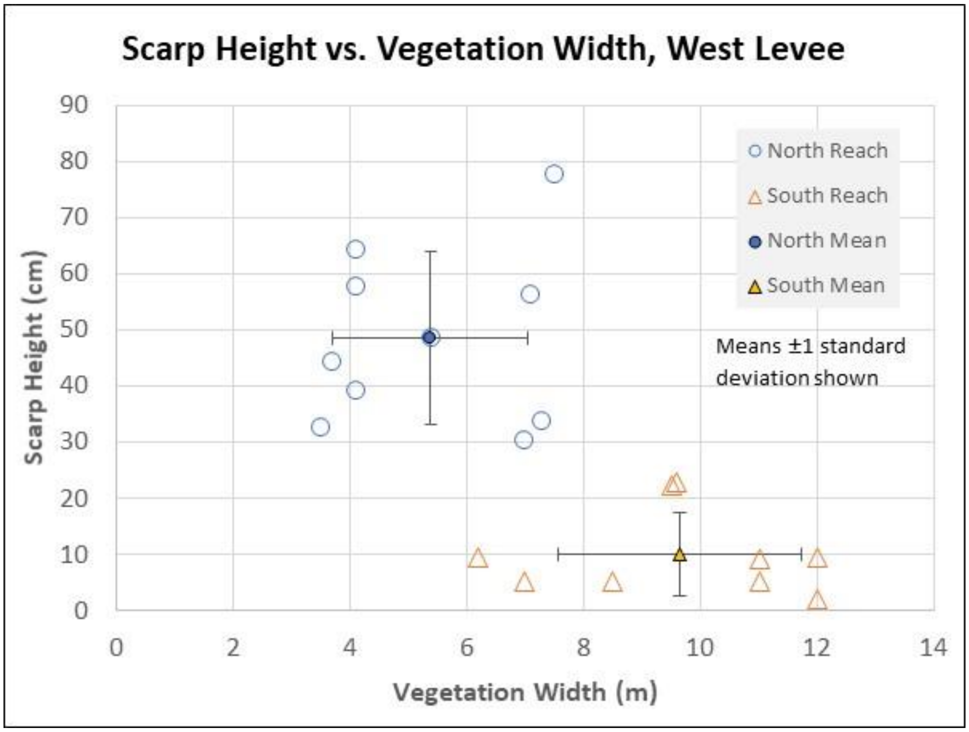

Fig. 5. Scatter plot depicting the relationship between width of vegetation and height of the erosion scarp.

Discussion

The Sears Point tidal restoration project was designed to be a relatively low cost, large scale restoration project with numerous design features that were intended to counter expected severe processes such as wind-wave erosion and forceful tidal currents. One of the design features included dredging a channel from the main breach to the channel of the Petaluma River to enhance natural sedimentation into the Sears Point basin. A consequence of this design feature was deposition of a large amount of dredged sediments into a cell that was constructed along the southwestern shoreline of the project near the breach. Placement of this dredged sediment was not “intended” to have an ecological effect. Thus, inadvertently, a “natural” experiment was set-up that was launched in October 2015 when the main channel was breached.

As part of routine monitoring of the Sears Point restoration project, it was observed that the southern protected shoreline appeared to be successfully recruiting intertidal vegetation and south shore levee is not eroding as much as the unprotected north shore. This raised the question: does the offshore cell of dredged sediments provide protection for the southern shoreline from severe erosion processes that occur along other constructed shorelines at Sears Point? We took advantage of the MSCI 719 class to test the hypothesis that the dredged sediment protection of the south shore has been buffered by this off-shore sediment deposit.

This unintended experiment along the separator levee at Sears Point provided the class and the SF Bay NERR the opportunity to explore a potential future innovative feature that could potentially be implemented in large tidal wetland projects that recognize the need for shoreline protection in the face of severe erosive physical processes (mainly wave-erosion and strong tidal currents). This analysis suggests that strategically-placed dredged sediments near shore buffered these processes, allowing inter-tidal vegetation to recruit successfully along its protected shoreline, and generally this protection appears to have prevented severe erosion of the bay-ward face of the separator levee. It further appears that a vegetation buffer *per ce* is not sufficient to prevent levee erosion, however, this should be further investigated. Thus, a planned off-shore dredged sediment treatment along certain shoreline areas could potentially help to buffer these shorelines while not requiring the extensive (and expensive) amount of dredged sediment deposition that is currently anticipated for use to raise basin-wide elevation in the future.

Table 2 List of species depicted in Figs. 2-4

CODE	SPECIES	COMMON NAME
ATPR	*Atriplex prostrata*	spearscale
BARE	Mud, wood, algae, wrack, etc.	
BOMA	*Bolboschoenus maritimus*	Alkali bulrush
DISP	*Distichlis spicata*	Salt grass
ELPA	*Eleocharus parvula*	Dwarf spikerush
JACA	*Jaumea carnosa*	Jaumea
SADE	*Salicornia depressa*	Annual pickleweed
SAPA	*Salicornia pacifica*	Perennial pickleweed
SPFO	*Spartina foliosa*	Cord grass

Reference

Parker, V.T., Schile, L.M., Vasey, M.C. and Callaway, J.C., 2011. Efficiency in assessment and monitoring methods: Scaling down gradient-directed transects. *Ecosphere*, *2*(9), pp.1-11.