Sears Point Tidal Marsh Restoration Project

Monitoring Report, Years 1 through 5
October 2015 to October 2020

March 31, 2022

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Executive Summary

Sonoma Land Trust opened the 940-acre Sears Point Tidal Marsh Restoration site to the tides on October 25, 2015. Since that time, the site has seen tremendous evolution from its subsided diked agricultural bayland beginnings towards its future as a vegetated tidal marsh. The early years of restorations like this are always dynamic, reflecting rapid changes in physical conditions and associated ecological functions, and Sears Point is entirely in line with these expectations. This report provides a detailed analysis of the site's development between October 2015- October 2020, with limited topics extending through 2021.

Regulatory compliance overview

Project permits established a small suite of performance objectives and targets. The site has met 5-year objectives for establishing transition zone habitat in the northeastern "fishtail" basin, establishing effective and well used public access trails atop the levee, and establishing long-term integrity of the flood control levee. The site did not meet its tidal marsh vegetation target of 30 acres though it is progressing toward it. The site also did not meet its transition zone habitat targets along the main basin northern levee and the northern half of the western separator levee. The fall 2021 construction of a nature-based levee shoreline protection adaptive management project and its partial rebuilding of eroded habitat levee is anticipated to remedy this issue. It is too soon to assess the objective of developing 940 acres of tidal marsh over 30 years, though the site is progressing satisfactorily at this early stage especially following the fall 2021 adaptive management action.

Highlights of positive progress and ecological functions

Accretion

The site has accreted about 3 million cubic yards of sediment through natural deposition in the 4.75 years from breach to the most recent (June 2020) site-wide LiDAR topographic survey. These numbers reflect a cumulative deposition rate of about 0.6 ft/yr across these four years, with incremental rates varying from a high of 0.6 ft/yr in the first 1.75 years to 0.4 ft/yr from 2018 to 2020. Deposition thickness averages about 2.5 ft with a maximum thickness of more than 4 ft.

Avian use

The site has been utilized extensively by resident and migratory shorebirds and waterfowl. Species assemblages and uses have changed as site elevations rose. In the early days, the deeper water attracted more diving ducks and pelicans with shorebirds found less often and only around the intertidal margins. As elevations rose, the emerging mudflats presented vast habitat extents for shorebirds and more narrow use by deeper water birds as suitable water depths had shorter durations. That being said, thousands of waterfowl have been observed each year during surveys, with Canvasbacks being the most abundant followed by Ruddy Duck, Greater Scaup, and Bufflehead. Dabbling ducks were present in lower numbers, led in abundance by Northern Pintail, American Wigeon, and Green-winged Teal. Least sandpiper, Dunlin, Willet, Western Sandpiper, American Avocet, Marbled Godwit, Black-bellied Plover, and Long-billed Dowitcher. were the most abundant shorebirds. Canada geese were observed nesting and raising broods in the early years but have not been observed more recently.

Fish use

One of the most striking (and expected) uses is by bat rays, evidenced by the thousands of foraging divets readily observable in air photos. Beyond that, fisherman are commonly observed on their boats in the site especially near the breaches, catching striped bass. Two sampling events were completed in May and October 2017, which yielded a total catch of 14,358 individual fish, with far higher fall abundance (12,766 fish) vs. spring (1,592 fish). Eighteen species total were collected along with three crustacean species. The fish community in spring was dominated by native Bay Goby, Starry Flounder, Topsmelt, and Pacific Staghorn Sculpin. Non-native gobies (Chameleon, Shimofuri, Shokihaze, and Yellowfin) and Striped Bass were also abundant. In fall, the native Topsmelt and Pacific Herring accounted for about 88 percent of the entire fish catch. Striped Bass was the most abundant non-native fish, followed by Chameleon and Yellowfin gobies. Two additional fish species, White Sturgeon (Green Sturgeon not likely) and Bat Ray, were visually observed by field crews but were never collected.

Large mammals

In the early years following the breach, river otters and seals were observed within the site, including a surfacing seal with a striped bass in its maw. Coyotes are frequently observed along the levees.

Establishing tidal marsh and ecotone vegetation

Tidally restored basins typically experience vegetation establishment early around the margins (levee slopes) where elevations are suitable. Sears Point is no exception. Where constructed slopes have remained stable, species including cordgrass, pickleweed, saltgrass, alkali heath, creeping wild rye and various other dicots have been establishing well, some through natural colonization and some through planting efforts. See below regarding areas of levee erosion. The Invasive Spartina Project (ISP) planted 57 of the interior marsh mounds and two of the sidecast ridges with native Pacific cordgrass, creating “nodes” of marsh spread within the site interior as elevations rise to suitable heights. As of June 2020, 19.7 acres of tidal marsh vegetation had established up to the high tide line, below the project goal of 30 acres. During the fall 2021 adaptive management project construction, and observations in early 2022 show active expansion of tidal marsh vegetation in many areas.

Nascent tidal channel development

Though still too early in the site evolution process to assess more than qualitatively, development of a tidal channel network has progressed positively. The constructed large subtidal channel has filled in considerably as expected – as the site accretes and tidal prism shrinks, these channels can be smaller to carry tidal flows effectively. Within the footprint of this channel, smaller channels remain. Numerous very small channels are forming off this main channel and connecting to the many moats around the marsh mounds, some may persist others may not. A few slightly larger channels are forming around the site, some associated with old farm ditches, some from scour into the farm field near the breaches, and some running alongside the levees. Channel development will be easier and more meaningful to assess in later years as the restored basin begins to have extensive vegetation establishment.

Highlights of challenges

Erosion of constructed "marsh mounds"

The most demonstrable early challenge was rapid erosion of the 490 constructed marsh mounds that were largely unvegetated substrate at time of breach. A graduate student at San Francisco State University's Estuary and Ocean Science Center, Margot Buchbinder, conducted her Masters research on these mounds. She documented their erosion, installed a variety of experimental treatments to test stabilization, and worked with the Invasive Spartina Project to plant a total of 49 mounds with native cordgrass between 2018 to 2021, with a portion of the total planted annually. The mounds lost 1.5 to 2 ft of elevation rapidly, within the first 1-2 years after tidal restoration. LiDAR data and field measurements show that the mounds planted earlier (in 2018) had a demonstrable positive effect on retaining and rebuilding mound elevations, suggesting the value of establishing marsh mound vegetation early. The lesson from this challenge is that vegetative stabilization before breach, as incorporated into the original restoration design, would likely be an effective erosion control measure. Vegetative stabilization would require 2 or more years of brackish water management within the site, controlled by pumps, tide gates or other methods.

Erosion of north and west habitat levees

The most significant challenge the project faced was extensive and ongoing erosion of the north and west habitat levees that faced the deeper parts of the restored basin. Constructed with 10:1 to 20:1 slopes, planted, and intended to provide ecotone habitats between tidal marsh and uplands, instead about two miles of levee suffered erosion, eating away at up to about 50 feet horizontal of the levee. The erosion events repeatedly impacted vegetation colonization – tidal marsh and low ecotone plants would colonize, begin to establish, then be eroded away. These problems led to construction of a large adaptive management project in fall 2021 that partially rebuilt the lower slopes of the habitat levee and installed nature-based features intended to provide shoreline erosion protection. The efficacy of these actions will be assessed in the coming years. Levee erosion did not occur in two notable locations – adjacent to the dredge spoil ponds in the southwest corner of the site as these bermed and higher initial elevations functioned as an effective wave break, and the northeastern "fishtail basin" that was sheltered from strong wind-wave action. The lesson from this challenge is that vegetative stabilization of the shoreline, marsh mounds, and the "floor" of the basin – the original design intention for shoreline erosion protection – should be implemented in advance of opening the site to the tides. A recent example where pre-breach vegetation community establishment took place is the Dutch Slough Restoration Project in eastern Contra Costa County. At Dutch Slough, 25,000 tule plugs and 50,000 shrubs and trees were planted. Sites like Sears Point would likely rely on passive colonization by water borne seeds.

Invasive and overly dominant native plant species interference with establishing diverse ecotone vegetation

Though SLT and others put in considerable effort to pursue "competitive exclusion" approaches to promote establishment of target diverse native plant communities along the habitat levees, persistent drought and atypical timing of rain events slowed and limited establishment. Oddly, the most successful establishment of a highly desirable plant species for its soil stabilization and ecological functions – creeping wildrye (*Leymus triticoides*) – occurred on the inland side of the north levee where inadvertent dispersal following construction thrived. One challenging native plant – coyote brush (*Baccharis pilularis*) – has proven to be too successful. Though it provides roosting and nesting habitat for passerine birds, it has spread so effectively (through plantings and natural colonization) that it occupies extensive coverage and excludes other desirable ecotone native vegetation. Extensive stands were thinned as part of the fall 2021 adaptive management project, with the harvested plants used beneficially as brush fencing.

1 Introduction

The Sears Point Restoration Project is located in southern Sonoma County, on the northern shore of San Pablo Bay (Figure 1). The restoration project, led by Sonoma Land Trust (SLT) in partnership with Ducks Unlimited, consisted of a variety of features intended to 1) promote development of emergent tidal marsh over time as sedimentation reverses subsided site elevations, 2) provide tidal flood protection to diked lands to the north, and 3) provide transition zone habitat along the newly constructed levee, known as a "habitat levee." Breaching of the historic Bayfront levee took place on October 25, 2015, restoring tidal action to the restoration site. Figure 2 presents the restoration design, and Figure 3 illustrates the as-built condition including variations from the project design. Table 1 provides the performance objectives being monitored for the project, as established in the permits. Table 2 provides the monitoring requirements established in the permits for assessing achievement of those performance objectives.

Monitoring, site experiments, plantings, and erosion adaptive management are being carried out by several entities:

1) ***Sonoma Land Trust*** – levee planting, photo monitoring
2) ***San Francisco Bay National Estuarine Research Reserve*** – Years 1-4 vegetation, air photos, elevation, geomorphology, and synthesis
3) ***Siegel Environmental and Gillenwater Consulting*** – Year-5 vegetation, tides, air photos, elevation, geomorphology, synthesis
4) ***Daniel Edelstein Consulting*** – bird monitoring
5) ***Dixon Marine Services*** – levee adaptive management construction, ecotone levee sod transplant
6) ***Ducks Unlimited*** – levee erosion monitoring
7) ***Hanford ARC*** – ecotone levee planting
8) ***Helix Environmental Planning, Inc.*** – fish use across the restoration site
9) ***Invasive Spartina Project*** – cordgrass planting and monitoring
10) ***Ducks Unlimited*** – cordgrass planting and monitoring
11) ***Pacific Watershed Associates*** – ecotone levee planting
12) ***San Francisco State University*** – marsh mound research plantings and erosion
13) ***Shelterbelt Builders*** – invasive species monitoring and management
14) ***Spye General Engineering*** – ecotone levee and cordgrass planting
15) ***STRAW –*** ecotone levee planting
16) ***U.S. Army Corps of Engineers*** – baseline topography

This *Years 1 through 5 Monitoring Report* for the Sears Point Tidal Marsh Restoration Project provides the cumulative findings to date, early assessment of project performance, and observations of site conditions and lessons learned.

This report is organized into the following sections:

- Section 2 provides an assessment of regulatory compliance performance to date
- Section 3 summarizes the site management actions undertaken by Sonoma Land Trust since restoration was completed between October 2015 and December 2021 (past Year 5 and included here to maintain a comprehensive record through time of this report preparation)
- Section 4 presents monitoring methods
- Section 5 presents monitoring results and discussion
- Section 6 discusses lessons learned to date

Sears Point Tidal Restoration Area

County Land Boundary

Sears Point
Site Location Map
Figure 1

Data: Sonoma Land Trust, watershed delineation by Camp Dresser & McKee | Aerial Imagery: (c) ESRI, i-cubed 15m eSAT | Map Date: May 2017 | Map Created by J. Kinyon, Sonoma Land Trust

Figure 2. Restoration Plan

100% DESIGN SET

BAR SCALE
0 500 1000 1500
US FEET

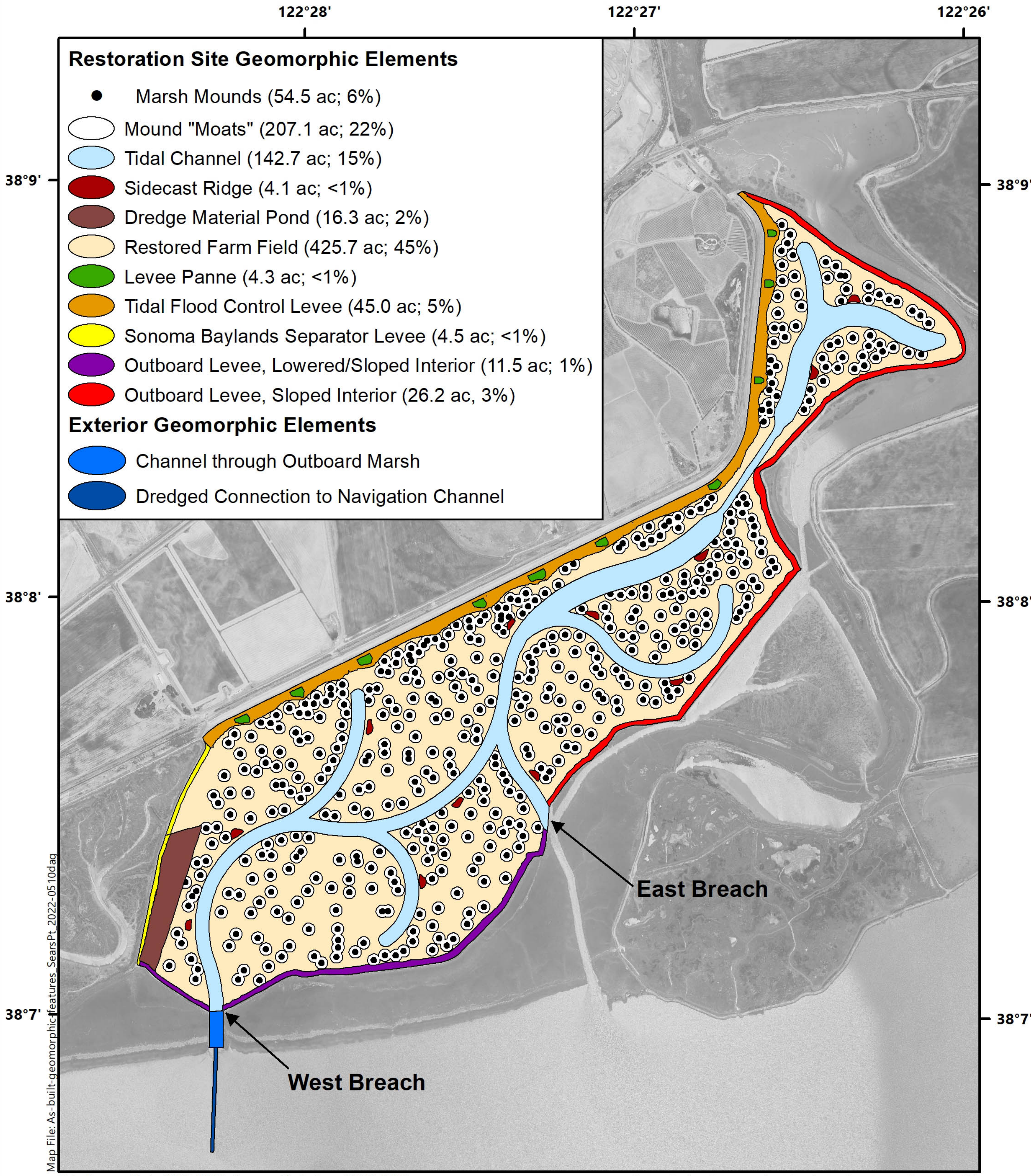
UNAUTHORIZED CHANGES & USES
THE ENGINEER PREPARING THESE PLANS WILL NOT BE RESPONSIBLE FOR, OR LIABLE FOR, UNAUTHORIZED CHANGES TO OR USES OF THESE PLANS. ALL CHANGES MUST BE IN WRITING AND MUST BE APPROVED BY THE PREPARER OF THESE PLANS.

REGISTERED PROFESSIONAL ENGINEER
AUSTIN G. PAYNE
NO. C71212
EXP. 06/30/13
CIVIL
STATE OF CALIFORNIA

REVISIONS			
REV. NO.	DESCRIPTION	DATE	APPROVED
5			
4			
3			
2			
1			

DUCKS UNLIMITED INC.
WESTERN REGIONAL OFFICE

PROJECT NO. US-CA-461-1		DESIGNED BY: AP
SEARS POINT WETLAND RESTORATION PROJECT OVERVIEW		DRAWN BY: JS
		SURVEYED BY:
		CHECKED BY:
DATE: 8.15.12	SHEET NO. 3 OF 32	APPROVED BY:	APPROVED BY:



Data Sources: Photo (NAIP, 2016); Geomorphic Features (NERR, 2020)

Sears Point Restoration Project, Sonoma County, CA

As-Built Project Geomorphic Elements

SONOMA LAND TRUST

Gillenwater GillenH2O Consulting

San Francisco Bay National Estuarine Research Reserve

1:24,000 (1" = 2,000' at letter size)

0 1,000 2,000 Feet

0 300 600 Meters

Figure 3

Table 1. Performance Objectives from San Francisco Bay Regional Water Quality Control Board (RWQCB), the Bay Conservation and Development Commission (BCDC) and the United States Army Corps of Engineers (USACE) Permits

Number	Objective	Agency
Source: Monitoring and Adaptive Management Plan, RWQCB Order No. R2-2013-0017		
PO-1	Development of 30 acres of predominately native tidal marsh vegetation over a 5-year period	RWQCB, USACE
PO-2	Development of approximately 940 acres of predominately native tidal marsh over a 30-year period	RWQCB, USACE
Source: Restoration Plan (Ducks Unlimited 2014) Project Goals Applicable to the Restored Baylands		
PO-3	Preserve and restore a large continuous band of tidal marsh along the Bayfront between the Petaluma River and Tolay Creek (Goal 1a). [For the purposes of Sears Point monitoring, this is interpreted to mean restore approximately 955 acres of tidal marsh at Sears Point over 30 years as defined in the BCDC permit project description.]	BCDC
PO-4	Establish a natural wetlands-uplands transition to the greatest extent possible and provide an upland buffer outside the baylands boundary (Goal 1b). [For the purposes of Sears Point monitoring, this is interpreted to mean create the habitat transition levee alongside the railroad alignment.]	BCDC
PO-5	Provide recreational opportunities, public access (including the Bay Trail), and environmental education compatible with protecting and restoring ecological and cultural resources (Goal 5). [For the purposes of Sears Point monitoring, this is interpreted to mean create the bay trail atop the new levee alongside the railroad alignment.]	BCDC
PO-6	To ensure public health and safety, including flood protection for Highway 37, Lakeville Highway, Reclamation Road, and the SMART railroad right of way, and mosquito abatement (Goal 7). [For the purposes of Sears Point monitoring, this is interpreted to mean ensure the long-term integrity of the new tidal flood control levee alongside the railroad alignment.	BCDC

Table 2. BCDC, RWQCB and Corps Permit Monitoring Requirements Through Year 5 and Relationship to Monitoring Purposes Fulfilled

Updated: 7/11/2016				Year						Monitoring Purposes Fulfilled		
Monitoring Activity	Frequency Years 1-5	Method Summary	Mandatory	Pre-Construction	1 2016	2 2017	3 2018	4 2019	5 2020	Effectiveness	Site Adaptive Management	Lessons Learned
BCDC (Permit M2012.022.00)	**4 monitoring events total in years 1, 5, 10, and 15**											
Monitoring Report	1x/req yr		Y									
Sedimentation	1x/req yr	Sed plates, pins or staff gauges until MSL+1'	Y							X		X
Tidal channel development	1x/req yr	Air photos + GIS analysis	Y							X	X	X
Vegetation	1x/req yr	Fixed photo stations, descriptive summary	Y							X	X	X
Avian surveys[1]	1x/req yr	USFWS, USGS, or Audubon methods	Y[2]							X		X
Invasive plant species eradication reporting[1]	NS	Field observations	Y							X	X	X
Field photo monitoring	NS	Once >10% veg cover, photos from 10 points	Y		(only after >10% veg cover)					X		X
RWQCB (Permit R2-2013-0017)	**Monitoring and Adaptive Management Plan**											
Reporting	1x/req yr		Y									
Field photo monitoring	1x/req yr	Fixed photo points	Y							X		X
Aerial or satellite photo		GE or other low cost	Y							X	X	X
Methylmercury[1,3]	TBD	Protocol TBD w/RWQCB	Y[3]									X
Birds	≤4x/yr	Frequency based on available funds	Y							X		X
Vegetation	Annual	Air photos + ground truthing	Y							X	X	X
SMHM and ornate shrew[1]	1x/req yr	Standard USFWS protocol	If habitat present							X		X
Invasive plant species management[1]	NS	Follow management program	Y							X	X	X
Tidal channel evolution	1x/req yr	Air photos + GIS analysis	Y							X		X
Sedimentation	1x/req yr	Sed plates, pins, erosion tables, LiDAR, veg	Y							X		X
Seasonal Wetlands[1]	1x/req yr	CRAM or equivalent	Y							X		
Corps (Permit 2011-00152N)	**Mitigation and Monitoring Plan**											
Reporting	1x/req yr		Y									
Same as RWQCB MAMP		Years 1 to 5 required	Y							X	X	X

Notes

1. Avian, invasive vegetation, small mammal, and methyl mercury monitoring at tidal restoration site, and seasonal wetlands monitoring, to be conducted separately from NERR monitoring. Findings to be included in NERR-prepared monitoring reports.

2. BCDC permit ambiguous on whether avian monitoring mandatory.

3. Methyl mercury monitoring plan must be developed upon request of RWQCB after it reviews results from nearby restoration sites.Thus, no monitoring at this time.

2 Regulatory Compliance Performance Assessment

Table 3 presents the project performance assessment of conditions five years following levee breach. The performance objectives were presented in Table 1.

Table 3. Summary of Project Performance Criteria Attainment at Year 5

Number	Agency	Performance Objective and Year-5 Assessment
PO-1	**RWQCB, USACE**	Development of 30 acres of predominately native tidal marsh vegetation over a 5-year period
Year-5 Assessment		**Not met – will need to reassess in the few years following fall 2021 adaptive management construction project to remedy erosion problem** • Vegetation in southern west separator levee and "fish tail basin" north levee establishing effectively • Vegetation along "main basin" north levee and northern reach of the west separator levee has been continuously establishing then partially lost due to levee erosion. This problem was addressed with fall 2021 construction of a major nature-based adaptive management project to reconstruct the lower slopes of the habitat levee and to provide erosion protection features • Eroded mounds also never established vegetation naturally. Invasive Spartina Project planted 58 of 490 mounds with *Spartina foliosa* between 2018-2021 and mound elevation data shows benefits of planting to promoting marsh elevations • Spartina planting in 2019, 2020, and 2021 along north levee and northern reach of west levee shorelines also beginning to take hold. • Natural accretion has raised site elevations near cusp to support vegetation • Expect more rapid progress in next few years as all the above factors take hold
PO-2, PO-3	**RWQCB, USACE, BCDC**	• Development of approximately 940 acres of predominately native tidal marsh over a 30-year period (RWQCB, USACE) • Preserve and restore a large continuous band of tidal marsh along the Bayfront between the Petaluma River and Tolay Creek. [Restore approximately 955 acres of tidal marsh at Sears Point over 30 years as defined in the BCDC permit project description.] (BCDC)
Year-5 Assessment		**Too early to assess** • Status: on positive trajectory, with high sedimentation rates and early vegetation colonization around the site perimeter and spreading outward from the planted mounds

Number	Agency	Performance Objective and Year-5 Assessment
PO-4	**BCDC**	Establish a natural wetlands-uplands transition to the greatest extent possible and provide an upland buffer outside the baylands boundary. [Create the habitat transition levee alongside the railroad alignment.]
Year-5 Assessment		**Met for north levee in "fish tail basin" and southern section of west separator levee** • Establishing effectively within the "fish tail basin" and west separator levee adjacent to dredge spoil ponds **Not yet met for north levee in "main basin" and northern section of west separator levee** Main basin northern levee and west separator levee north of dredge spoil ponds have not met this PO due to excessive erosion. Outcomes led to fall 2021 construction of nature-based adaptive management action to remedy this problem (Siegel Environmental 2022)
PO-5	**BCDC**	Provide recreational opportunities, public access (including the Bay Trail), and environmental education compatible with protecting and restoring ecological and cultural resources. [Create the bay trail atop the new levee alongside the railroad alignment.]
Year-5 Assessment		**Met** • Bay trail constructed • Interpretive signs at parking lot, levee-top bay trail entry point, far northeast levee turn around, and south along separator levee • Benches installed at all sign locations except parking lot Informal observations show extensive public use regularly
PO-6	**BCDC**	To ensure public health and safety, including flood protection for Highway 37, Lakeville Highway, Reclamation Road, and the SMART railroad right of way, and mosquito abatement. [Ensure the long-term integrity of the new tidal flood control levee alongside the railroad alignment.]
Year-5 Assessment		**Met** • Flood protection levee built to geotechnical specifications • Erosion of habitat levee did not encroach on the core flood protection levee. Habitat levee erosion remedied fall 2021 with a nature-based adaptation action

3 Management Actions through December 2021

Since the levee breach in October 2015, the Sonoma Land Trust and partners have undertaken a number of management actions. These actions are summarized in Table 4 and are described in the sections following, and all relate to vegetation.

Table 4. Management Actions Pre-Construction to Fall 2021

Action Date	Entity	Description	Intent/Purpose
Invasive Vegetation Control (see Section 3.1)			
Ongoing	USFWS Refuge	Herbicide control of invasive plant species on northern levee crest	Reduce potential for spread of noxious weeds
Research Spartina Plantings on Mounds (see Section 3.2)			
April 2016	SFSU graduate student	Experimental mound plantings of *Spartina foliosa*	Assess vegetation potential to protect mounds from erosion and promote sedimentation
Spartina Plantings on Mounds and Sidecast Ridges (see Section 3.3, Appendix F)			
March 2018	Invasive Spartina Project	Plant 35 mounds	Promote early establishment of native cordgrass and assist with mound stabilization
March 2019		Plant 11 mounds	
March 2020		Plant 12 mounds	
March 2021		Plant two sidecast ridges	
Cordgrass Plantings along Toe of North Levee (see Section 3.4, Appendix F)			
Late June-early July 2019	Baye, Ducks Unlimited, SLT	Planted *Spartina foliosa* along shoreline deposited mud edge, north levee, sourced from southeast corner of site; 2021 also between new brush fence	Component of nature-based strategy for addressing levee erosion
August 2020			
Sep 2021	Spye General Engineering		
Transition Zone Plantings on North and West Ecotone Levee Slopes (see Section 3.5, Appendix G)			
2014	SLT	Lime application to constructed north levee slopes	Reduce acidity from sulfate in reused diked bay mud soils
2014-2015, 2015-2016	SLT-hired farmer	Plant and harvest oat hay crops north and south slopes of north levee	Preclude weed establishment, stabilize bare soils
2015-2016	Hanford ARC	Creeping wildrye and salt grass planted bayside of north levee	Promote establishment of target ecotone vegetation

Action Date	Entity	Description	Intent/Purpose
2015-2016	STRAW	Planting 0.25 miles of north levee	Promote establishment of target ecotone vegetation
Feb 2018	Pacific Watershed Associates	Creeping wildrye planted bayside of north levee	Promote establishment of target ecotone vegetation
Dec 2018-Jan 2019	Pacific Watershed Associates	Creeping wildrye and salt grass planted bayside of north levee	Promote establishment of target ecotone vegetation
2018, 2019	STRAW	Plantings along western separator levee – Coyote brush, creeping wildrye	Promote establishment of wetland-upland transition plant communities and associated wildlife functions
Jan 2020	Spye General Engineering	Creeping wildrye planted bayside of north levee	Promote establishment of target ecotone vegetation
Nov-Dec 2021	Dixon Marine	Creeping wildrye sod transplant bayside of north and west levees	Promote establishment of target ecotone vegetation and support erosion control of regraded ecotone levee slopes

3.1 Invasive Plant Species Control

Sonoma Land Trust contracted Shelterbelt Builders to provide invasive species monitoring and management services at Sears Point. A report on the 2016 work is provided in Appendix J.

The USFWS Refuge carries out ongoing invasives control along the northern levee crest, addressing species such as *Dittrichia graveolens*, through herbicide application. The remainder of invasive plant species control has focused around competitive exclusion through active plantings of native vegetation (see Section 3.5). One such focus is a shift almost entirely from active control of invasive *Dittrichia graveolens* to suppression by competition using *Leymus triticoides* transplants.

The Refuge also noted the presence in 2021 of *Alternanthera phylloxeroides* or alligator weed. They are working with Brenda Grewell (USDA) to monitor its known locations.

3.2 Cordgrass Plantings on Research Study Mounds (SFSU Graduate Student)

The Sears Point restoration site utilizes marsh mounds to diffuse wave energy, facilitate mudflat sedimentation, and reduce erosion throughout the site. The original project design by the Wetlands and Water Resources, Inc. team (WWR et al. 2007) incorporated establishment of sacrificial vegetation on the marsh mounds and throughout the site's interior former farm fields prior to breaching the levee in order to protect the mounds from erosion following the return of tidal action to the site. For a variety of reasons, this was not completed before the breach and the mounds have experienced significant erosion, primarily due to wind-wave action since October 2015 (see Section 5.7), hindering their ability to achieve the above functions. An experiment was conducted by a San Francisco State graduate student (Ms. Margot Buchbinder) to determine whether planting native salt marsh vegetation on the mounds can protect them from further erosion and support sediment accretion, and whether protecting plantings with physical barriers to erosion can enhance this effect. Additionally, the experiment explored whether planting vegetation in the compacted mound sediments can make conditions more hospitable to invertebrates, enhancing the mounds' value for the return of normal ecosystem function as the restoration site progresses towards becoming a mature marsh.

The experimental installation occurred on 36 mounds in six different treatment groups, including vegetative, physical and control treatments. Vegetative treatments consist of planted plots of *Spartina foliosa* (hereafter Spartina), a native marsh plant characteristic of lower-elevation tidal marsh. Physical barrier treatments consisted of coir erosion logs oriented to intercept wind-waves (from the WNW) or tidal currents (from the primary breach to the SW). These treatments were crossed to produce six treatment types: Spartina alone, coir alone facing the prevailing winds, coir alone facing the breach, combinations of Spartina with coir facing the winds or the breach, and untreated control mounds (Figure 4). Sediment pins were installed at the apex of each mound and in each cardinal direction, 0.5 m lower than the apex. Experimental treatments were randomly assigned to mounds arranged in blocks to account for local differences in conditions throughout the site (Figure 5). The experiment was monitored quarterly during the growing season (spring, summer and fall) for erosion and vegetation establishment; and cores were taken to quantify soil properties and soil invertebrates, and trapping is conducted to characterize epibenthic mound communities.

The installation of the experiment began in April 2016. Seven blocks of six mounds were selected via aerial imagery (Google Earth) in locations dispersed throughout the southwestern portion of the site, and treatments were randomly assigned to mounds within each block. Sediment pins, coir and Spartina sourced from the Invasive Spartina Project's (ISP) propagation beds were installed on the mounds during this period. In late April, goose exclosures were installed on vegetated mounds after herbivory was observed within plantings. At that time, it was discovered that some mounds had lost Spartina plugs, coir logs, or both; some of these mounds had been planted just five days prior to this observed damage. All mounds were evaluated for destructive erosion, and mounds were rearranged throughout May to locations where plantings and coir logs could persist. Through this process, two entire blocks were removed, and one new block was created in an area evaluated to be more suitable for plantings. Some new vegetated mounds were planted with plugs salvaged from failed mounds, and additional mounds were planted in early June with new plants collected and transplanted directly from the Port Sonoma Marina, which was the original collection location of the plants sourced from ISP's propagation beds.

During this time, coir logs were also reinstalled or replaced on several mounds due to degradation and relocation due to wind-waves and erosional forces. In July, one final Spartina mound was found to have completely eroded, and a new mound was planted adjacent to the existing block. The experimental mound map was finalized at this point (Figure 5). In August 2016, continuing degradation of some coir logs in combination plots with Spartina appeared to physically damage and threaten plantings, and all coir logs were removed from combination treatments with coir facing the breach. No changes were made to experimental mounds after August 2016; as such, Spartina densities and coir presence are subject to change into the future due to erosional forces.

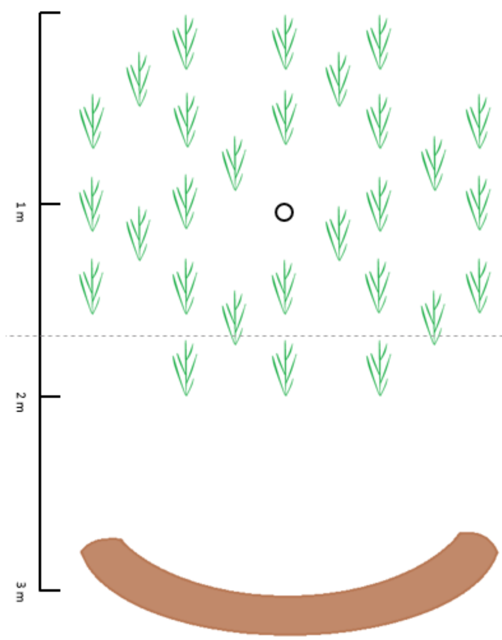


Figure 4. Diagram of Experimental Planting Plots on Marsh Mounds
*Plots all include a sediment pin (***o***), but may have either Spartina (green), coir (brown), both, or neither. Orientation of the plots varied with coir direction and presence. Source: Buchbinder 2018*

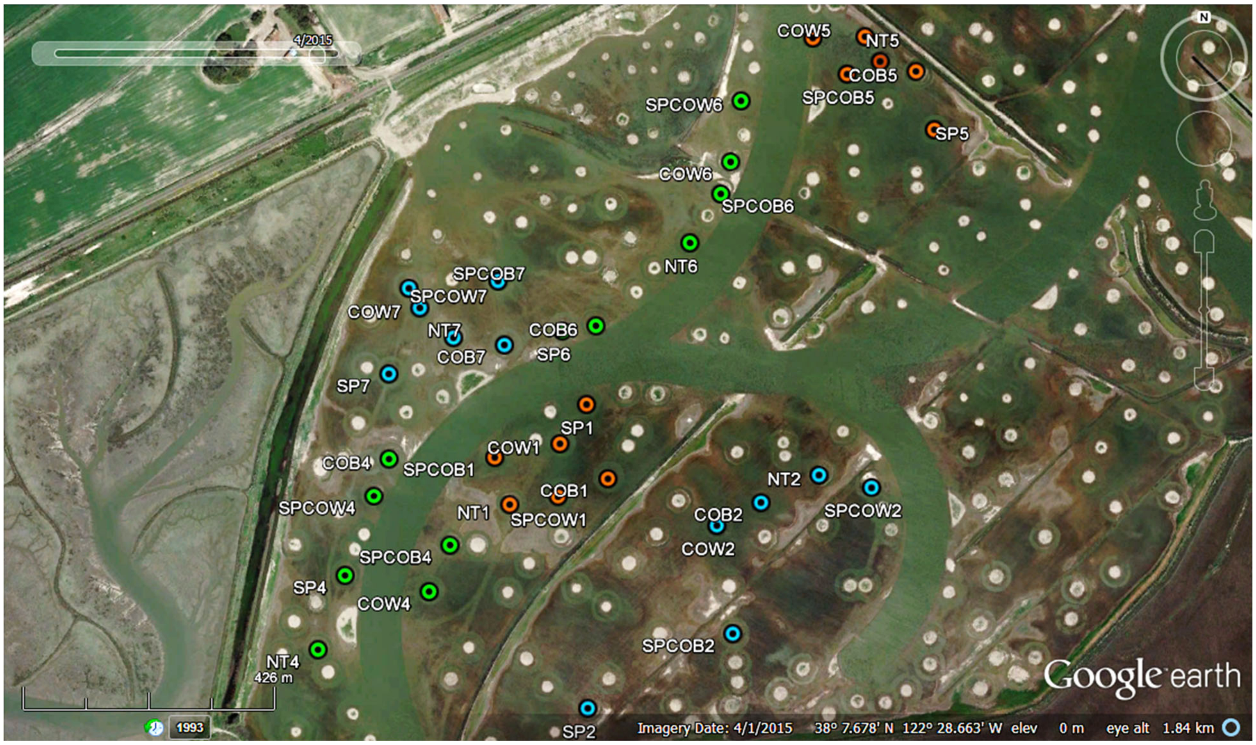


Figure 5. Map of Planted Mounds for Experiment

3.3 Cordgrass Plantings on Additional Mounds (Invasive Spartina Project)

From 2018 to 2020, the Coastal Conservancy's Invasive *Spartina* Project (ISP) planted more than 4,000 plugs of native *Spartina foliosa* on 59 previously unplanted mounds and sidecast ridges. At a meeting at the Benson Center on 1/18/2018, Mike Vasey (SF Bay NERR), Julian Meisler (SLT), Jeanne Hammond (ISP/OEI) and Margot Buchbinder (SFSU) discussed priorities for planting by ISP at Sears Point. The primary objective of plantings was determined to be for the successful establishment of native cordgrass on more islands throughout the site. Therefore, planting goals were focused on areas with high accretion or optimal elevations (> 1.2 m NAVD88) where planting success was anticipated to be higher. Maximizing potential genetic diversity by using a minimum of four cordgrass source populations, following standard ISP protocols, was also prioritized.

In 2018 (3/7-3/8/2018), ISP planted native *Spartina* on 34 mounds located in three primary planting areas; two located near the breach in the SW portion of the site, and one located in the fishtail basin in the NE of the site. Each planted mound contained 30 Spartina plugs planted into six 0.25 m^2 subplots, with three donors represented per mound, for a total of 1020 plugs planted from four source donors (Port Sonoma Marina, Golden Gate Fields, Tennessee Valley, and Napa River). All planted mounds were at an elevation of 1.2 m NAVD88 or higher, and were caged to prevent goose herbivory.

In 2019 (3/12/2019), ISP planted 600 native *Spartina* plugs on 11 mounds using a similar design, but with a varying number of plots per mound. Plugs in 2019 were sourced from three donors (American Canyon, Port Sonoma Marina, and Seminary Cove).

In 2020 (2/14/2020), ISP planted native *Spartina* plugs on 12 mounds using a similar design, but with a varying number of plots per mound. Plugs in 2020 were sourced from ISP locations in American Canyon, Napa River, Sonoma, Tennessee.

In 2021 (3/17/2021), ISP planted 2,386 native *Spartina* plugs on two of the "side cast ridges". Plugs in 2021 were sourced from four ISP locations in American Canyon, Coyote, Napa River, and Sonoma.

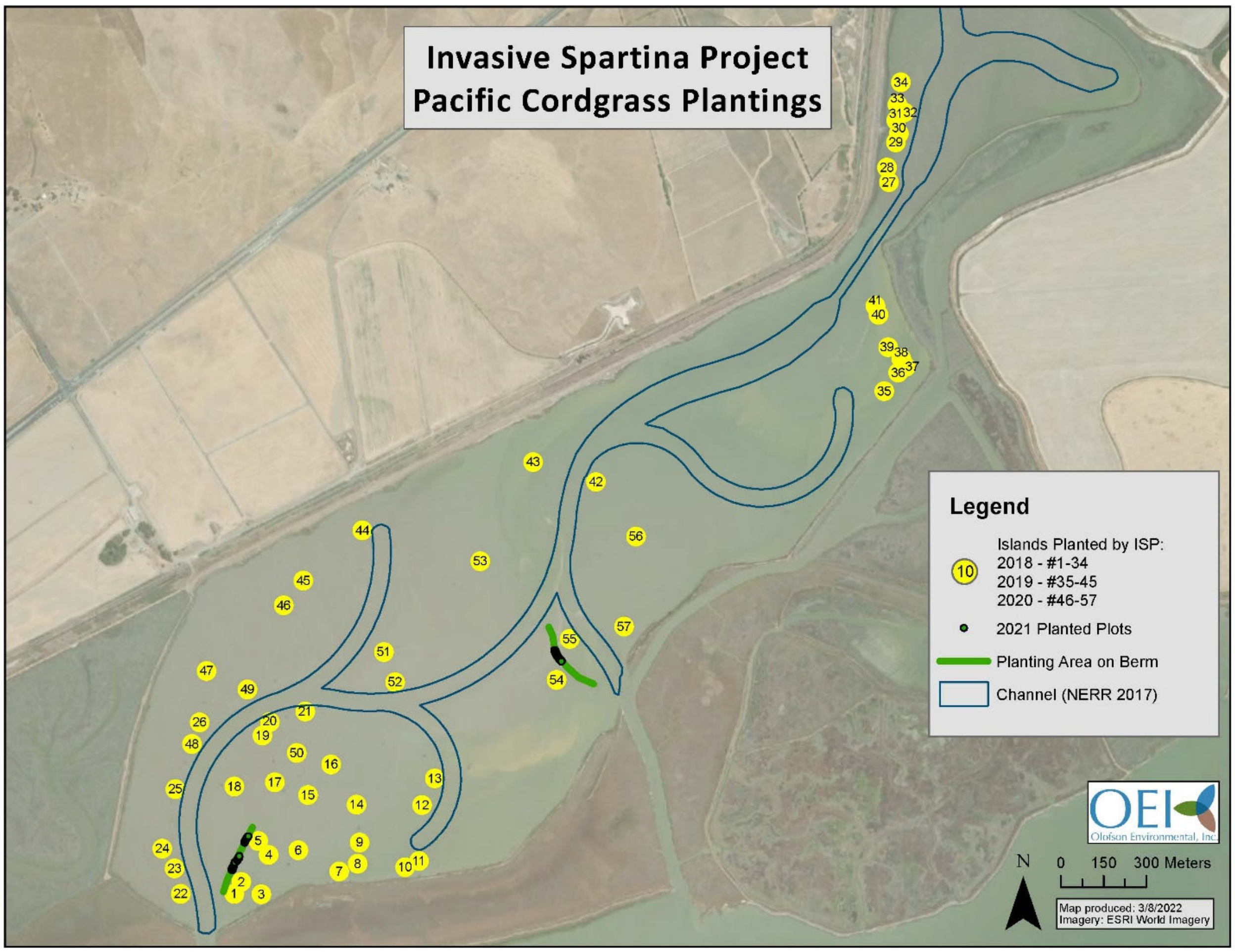


Figure 6. Map of Planted Mounds by Invasive Spartina Project, 2018-2021
Source: Invasive Spartina Project

3.4 Cordgrass Plantings of North Levee Lower Shoreline, 2019 to 2021

As part of the levee erosion adaptive management project, plantings of cordgrass along the toe of the northern levee took place in three rounds, once each in 2019, 2020, and 2021. The intent of these plantings is two-fold to jump-start establishment and spread of cordgrass: to promote the wave attenuation functions of more dense stands of cordgrass, and to hasten establishment of the ecological functions of cordgrass. See Appendix F for more details on these planting efforts.

2019 Plantings

In late June and early July 2019, SLT volunteers trained by Peter Baye planted approximately 1,800 transplants of Pacific cordgrass (*Spartina foliosa*) in several “cells” along the northern levee, with each cell being bound by one of the habitat levee tidal pannes (Figure 7). Cordgrass planting consisted of two rows of plugs spaced about 7 ft (2 m) apart. These plantings were the first phase of the revegetation component of constructing a nature-based shoreline erosion protection adaptive management action on the Sears Point northern levee shoreline. This first planting phase was intended in part to test the viability of rapid, large-scale transplanting of tidal wetland vegetation, with subsequent plantings intended for 2020 if this planting effort proved viable.

The transplant source stands came from on site. Because of the concern about invasive cordgrass, sourcing for these transplants came solely from the southwest corner of Sears Point where natural recruits had been establishing. To verify that these source areas were the native species, field phenological characteristics and genetic testing were performed. Dr. Peter Baye carried out the phenological assessment in October-November 2018, when pigment and phenology contrasts with hybrids (greener later, senescing to orange-tan rather than pale straw). No morphological indicators of hybrids were evident. The Invasive Spartina Project subsequently conducted genetic testing this source area and confirmed the native cordgrass determination.

2020 Plantings

Plantings were completed between July 31 and August 28, 2020. Cordgrass was planted in two lines bayward of the 2019 plantings. The upper of the two lines was planted throughout the areas shown in Figure 7B and the lower line, about 2m bayward, was planted in cells 1, 3, 4, and 5 of the north levee and along a portion of the west levee. A small number of plugs were planted on unvegetated marsh mounds nearshore of cells 2, 4 and 5 and in the accreted mudflat of cell 5 (Figure 7C). These latter plugs were to test whether mature plugs could establish in these isolated areas. This round of planting also included testing of fertilizer application (20-0-0 high nitrogen fertilizer) to assess hypothesis that SF Bay is not nutrient limited.

2021 Plantings

Plantings were completed between September 20 to 24, 2021, while the levee erosion adaptive management project was under construction. Plantings were installed in cells 3 through 7 (Figure 7). All were planted with Pacific cordgrass in locations where prior years’ planting had not survived and, at cells

6 and 7, cordgrass plantings were placed between and above the newly installed brush fences. Cell 7 also had plantings of alkali bulrush (*Bolboschoenus maritimus*) near the wood-anchored logs installed as part of the levee erosion adaptive management project. Cordgrass transplants came from the west levee and alkali bulrush transplants came from collection pond for the western pump station in the diked baylands just north of the northern levee.

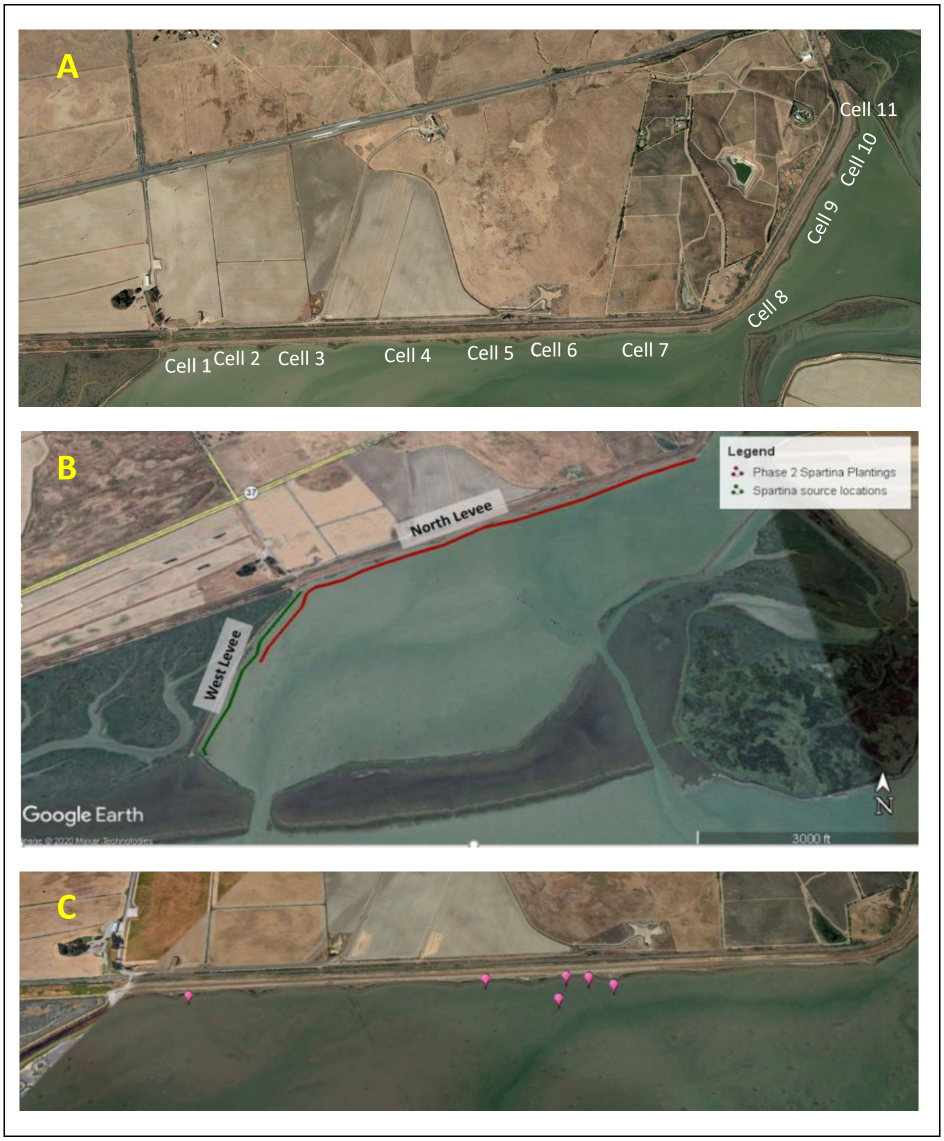


Figure 7. Planting Locations of Pacific Cordgrass Along the Northern Levee, 2019, 2020, 2021
(A) Cells planted in 2019 and some cells planted in 2021. (B) Extent of planting 2020 and source area for cordgrass transplants. (C) Locations of 2020 plantings on mounds and accreted mudflats.

3.5 North and West Levee Ecotone Plantings, 2014 through 2021

The following presents a chromoly of efforts to establish transition zone and upland vegetation on the levee at Sears Point. See Appendix G for more information and maps of planting locations.

Fall 2014

- The first lift of the levee was complete. To reduce the threat of erosion and invasive species colonization, SLT contracted with a local farmer to sow a hay crop on the levee. The hay crop was harvested in May 2015.

Fall 2015

- Second and final lift of levee completed. Following soil analysis, SLT spread and incorporated 175 tons of lime into the north and west levees for the purpose of increasing low soil pH associated with reuse of buried bay mud soils that run risk of triggering acid sulfate soil conditions that can impair vegetation establishment. Existing pH was 3.4 on average. Dump trucks were used to spread the lime and a shallow disc for incorporation into the soil.
- SLT drill seeded ~8 acres of the inboard and ~6 acres of the outboard slopes of the north levee adjacent to the vineyard (in the fishtail) using a native species mix combined with a sterile hybrid erosion control grass. SLT also transplanted giant wildrye into the outboard slope. Source of giant wildrye transplants was CDFW preserve located east of Tolay Creek near Sonoma Raceway.
- SLT seeded the remainder of the levee, inboard and outboard (~34 acres), with a second hay crop. Hay seeding extended from near crest of levee down to several feet above wrack line. The crop was harvested in May 2016.

Fall 2016

- Spread and incorporated 125 tons of lime into inboard and outboard slopes of north levee from near the bend in levee to western terminus. Hay crop was seeded into this area.
- Mule ears (*Wyethia angustifolia*) and hayfield tarweed (*Hemizonia congesta* ssp. *lutescens*) seed, both harvested from Sears Point Ranch, were hand broadcast in areas not seeded with hay.

Winter 2016/17

- With students from local elementary schools, STRAW planted creeping wildrye and several forb species along 0.25 miles of westernmost portion of the north levee.
- Save the Bay staff volunteered to install creeping wildrye and several forb species along 0.2 miles of the north levee, beginning where STRAW left off and extending eastward.
- Hanford ARC was contracted to harvest and transplant creeping wildrye (*Leymus triticoides*) and saltgrass (*Distichlis spicata*) above and below the wrack line along the entire outboard of the north levee and adjacent to the drainage ditch on the inboard bench. Creeping wildrye was

harvested north of Highway 37 at the western boundary of the North Parcel seasonal wetlands enhancement project. Salt grass was harvested from the ditch on the northern side of the ecotone levee towards the west end of the levee. See Appendix G-1.

Winter 2017/18

- STRAW planted native grasses and forbs along several sections of the west levee. See Appendix G-4.
- In February 2018, Pacific Watershed Associates planted over 4,000 plugs of creeping wildrye on the outboard slopes of the north levee and watered them three times. Creeping wildrye and salt grass were planted at the lower levee slopes, with one plant installed every 5 ft for the entire levee length. Plants were also installed around the ecotone levee marsh pannes. Creeping wildrye was also planted in vertical rows from the levee top down to the high water line, between the eastern stormwater pump east to the “fish tail” basin. All plant plugs were harvested from the Lakeville Highway-Highway 37 intersection and from a drainage ditch north of the railway line near the rail crossing. See Appendix G-2.

Winter 2018/19

- In December 2018/January 2019, Pacific Watershed Associates planted 7,590 plugs of creeping wildrye and 1,700 plugs of salt grass on the outboard slope of the north levee. Creeping wildrye was planted in 30-plant patches at levee mid-elevations for the entire levee length. Salt grass was similarly planted, in 20-plant patches between the eastern stormwater pump east to the “fish tail” basin. Salt grass was placed just below the creeping wildrye. All creeping wildrye and salt grass was harvested from a large existing stand within the fenced area of the eastern stormwater pump (Pump 2) and from a drainage ditch north of the railway line near the railroad crossing, respectively. See Appendix G-3.

Winter 2019/20

- In January 2020, Spye General Engineering planted creeping wildrye on the outboard side of the northern ecotone levee. A total of 7,470 plugs were planted between the patches planted in December 2018-January 2019. These mid-levee plantings consisted of 30-plant patches. Plants were harvested from the Pump 2 source plants. See Appendix G-5.

Fall 2021

- In November-December 2021, as part of the levee erosion adaptive management project constructed in fall 2021, Dixon Marine Services transplanted creeping wildrye sod along the entire work area of the western levee and portions of the northern levee where construction activities heavily disturbed the lower levee slopes. Transplants were sourced from extensive patches located the north side of the ecotone levee near the vineyard pond adjacent to the "fishtail" basin of the site. Different than the previous rounds of individual plug plantings, this transplant effort excavated dry-dormant sods approximately 0.5 ft thick (concentrated zone of root and rhizome mats) from borrow source stands by a long-reach excavator and stacked on a flat-bed truck during cool, overcast weather conditions or morning hours (to minimize desiccation injury). Harvested sods were immediately trucked to planting sites. On the north levee, a short-reach excavator cut a shallow pit, and crews manually placed a sod fragment about 2 ft in diameter in the pit. The excavator shallowly buried (2-5 inches) the sod by pushing loose soil over it with the teeth of the bucket and tamping it (light compaction) with the back of the bucket. On the west levee, sods were deposited on the levee slope and worked into the topsoil by multiple passes of a box grader, followed by light track-walking by heavy vehicles for compaction. See map of transplanting areas in Appendix G-6 (transplant areas equal the scarp grading segments).

4 Monitoring Methods

4.1 Air photos

Air photos compiled for monitoring include commercial satellite images (no control of timing relative to tides), purpose-ordered fixed-wing aircraft (control over timing relative to the tides), and monitor-operated unmanned aerial vehicles (UAV or drones) (control over timing relative to the tides). These photos are used to extract early-stage restoration changes to the extent that features are visible relative to tidal submergence.

4.2 Field Photos

In 2013, Sonoma Land Trust established eight photo monitoring stations at the Sears Point tidal marsh restoration site. At each station, staff used a compass to develop between one and four repeatable photo views. Photo monitoring took place between 2013 and 2018. These photos are presented in Appendix B.

4.3 Topography

Different methods were utilized to develop the baseline (as built) topography and the post-restoration topography.

4.3.1 As-Built Topography

No as-built topographic surveys were performed. To develop an as-built surface, the SF Bay NERR utilized three data sources of varying vertical accuracy to yield the "best available" baseline as-built topography. Table 5 summarizes and Figure 8 shows the data sources used to construct baseline topography.

Data source 1: September 2015 Ground-Based LiDAR Survey, U.S. Army Corps of Engineers

The Corps collected these data as part of a wind wave study it was conducting at the Sears Point and Hamilton Air Field restoration projects.

Their methods are as follows, provided via email on July 11, 2016 from Bryan Herring (Research Civil Engineer, Field Data Collection and Analysis Branch Coastal and Hydraulics Laboratory Engineering Research Development Center U.S. Army Corp of Engineers) and on June 28, 2016 from Austin Payne (Civil Engineer, Ducks Unlimited):

- **Survey Date**: September 2015.
- **Elevation Control**: The Sears Point data was collected in NAD83, California Zone 2, USFT and NAVD88, USFT. The collection method was done by multiple scan positions using a VZ-2000. At each scan position two targets where used to traverse the site. For each target location used to "tie" in the scan positions, a rapid static position on the target was collected using a Trimble R8.

The base station used to triangulate the position was setup on the sears point site and a control point near Hamilton Bay was used to verify the position of the base station. The LIDAR data was processed using the proprietary software of Riegl Laser Scanners, RiSCAN Pro. It was filtered using the RiSCAN Pro octree filter at 5usft in the x, 5usft in the y, and 1usft in the z.

- **LiDAR Data Collection and Processing**: The data was collected using a Riegl VZ-2000 LIDAR scanner. The accuracy of the instrument is 5-8mm at 2000m, but as low as 2mm closer to the instrument. The data was georeferenced, so the accuracy of the data is 2cm as this is the highest accuracy of RTK (GPS). The resolution of 5x5x1 (x,y,z) is an octree filter used by the LIDAR software used to process the data. This is an interpolated grid resolution. This filter procedure is done by using an octree structure. That structure is based on a cube which is divided into 8 equally sized cubes which are again divided and so on. The division into sub cubes is done on demand by filling the points into the octree and stopped as soon as a given minimum cube size is reached. After generation of the octree, one cube contains one point, which is the center of gravity of the averaged points in general representing a larger number of points. Simply, this is a grid process that reduces the number of points to 5x5 in the horizontal and only a reduction of every one foot in the vertical. The original data set prior to the gridding process is ~100 million points.

Data Source 2: Sonoma County 2013 LiDAR

The Sonoma County Agricultural Preservation and Open Space District and the Sonoma County Water Agency undertook the "Sonoma County Vegetation Mapping and LiDAR Program" to map the county's topography, physical and biotic features, and diverse plant communities and habitats. It flew LiDAR for the county in 2013 and produced a 1-m digital surface model. These data and full descriptions of their acquisition and processing are available at the Sonoma Veg Map website[1].

This LiDAR data acquisition took place prior to construction work at Sears Point and thus has direct applicability only to areas that were not disturbed by earthwork activities.

Data Source 3: Restoration Engineering Design Plans "As Builts"

Ducks Unlimited prepared the engineering design plans for the Sears Point Restoration Project. DU (2016a,b) also prepared a version of "as-built" drawings which documented changes from the original design.

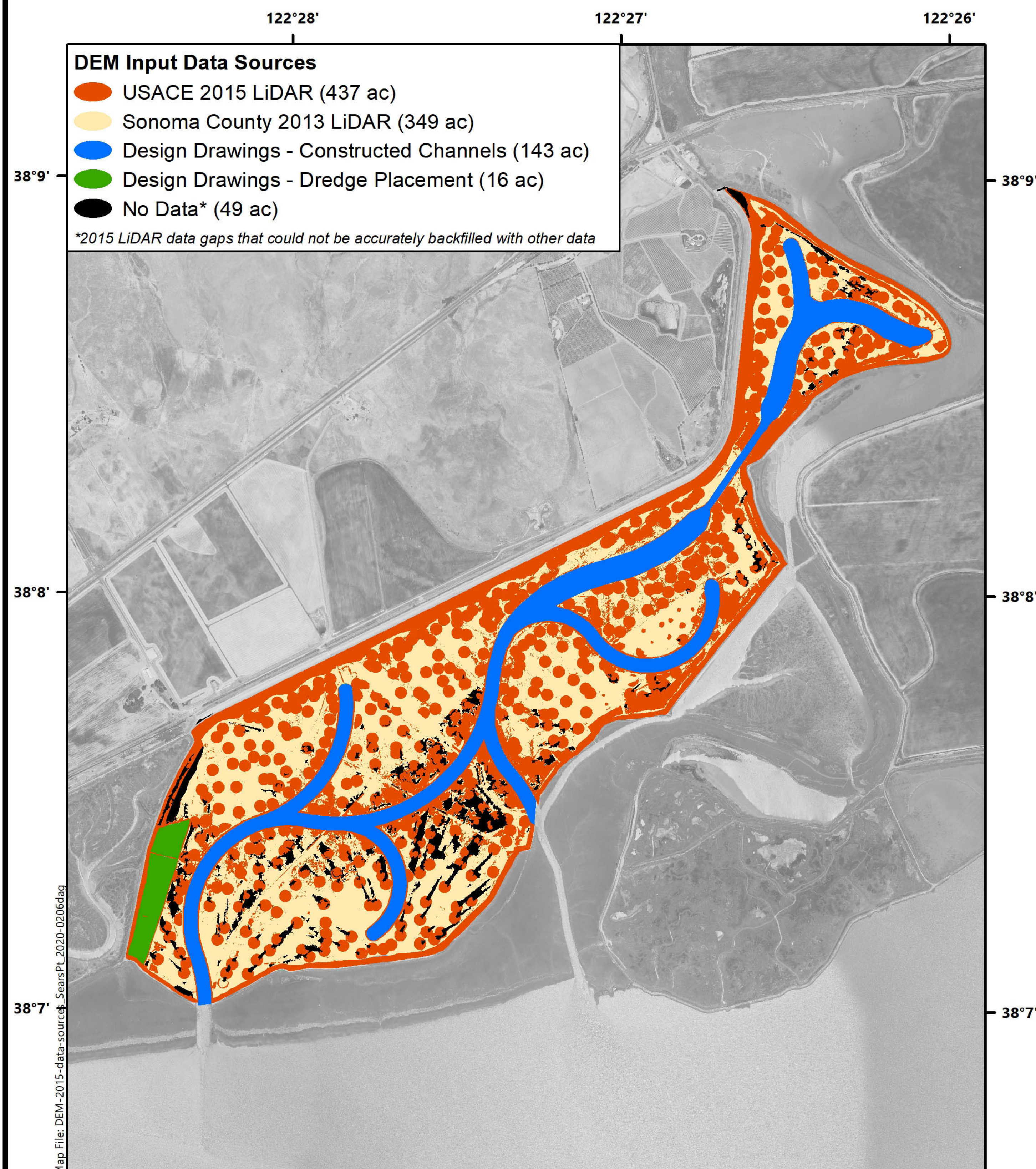
[1] http://sonomavegmap.org/

Table 5. Baseline Topography Data Sources

Data Source	Areas Utilized	Elevations Used
USACE 2015 ground-based LiDAR	Mounds and surrounding soil borrow, levees, some disturbed interior areas	As provided by USACE
Sonoma County airborne LiDAR	Undisturbed site interior	As provided by Sonoma County
Ducks Unlimited Engineering Plans “As Builts”	Constructed channels, dredge placement area	• -5 ft NAVD88 for constructed channels • +3 ft NAVD88 for dredge placement areas
No data could be established	Areas with dense vegetation that blocked reliable LiDAR data acquisition, “shadows” of some constructed mounds	

Building the As-Built Digital Elevation Model

To generate the baseline digital elevation model, available data described above were combined to create an ArcGIS Terrain. Areas that were further than 4m from a LiDAR datapoint were removed from the digital elevation model. Areas with brush were removed from the Terrain by manually delineating brush polygons based on the baseline air photo (Appendix A – Figure A-1) and the digital elevation change model (comparing USACOE 2015 and LiDAR flight in 2017). The Terrain was exported to a raster at 1m resolution to generate the final DEM product.



Data Sources: Photo (NAIP, 2016); Data sources (NERR, 2020)

Sears Point Restoration Project, Sonoma County, CA

Data Sources for Baseline (2015) Topography

SONOMA LAND TRUST

Gillenwater GillenH2O Consulting

San Francisco Bay National Estuarine Research Reserve

1:24,000 (1" = 2,000' at letter size)

0 1,000 2,000 Feet

0 300 600 Meters

Figure 8

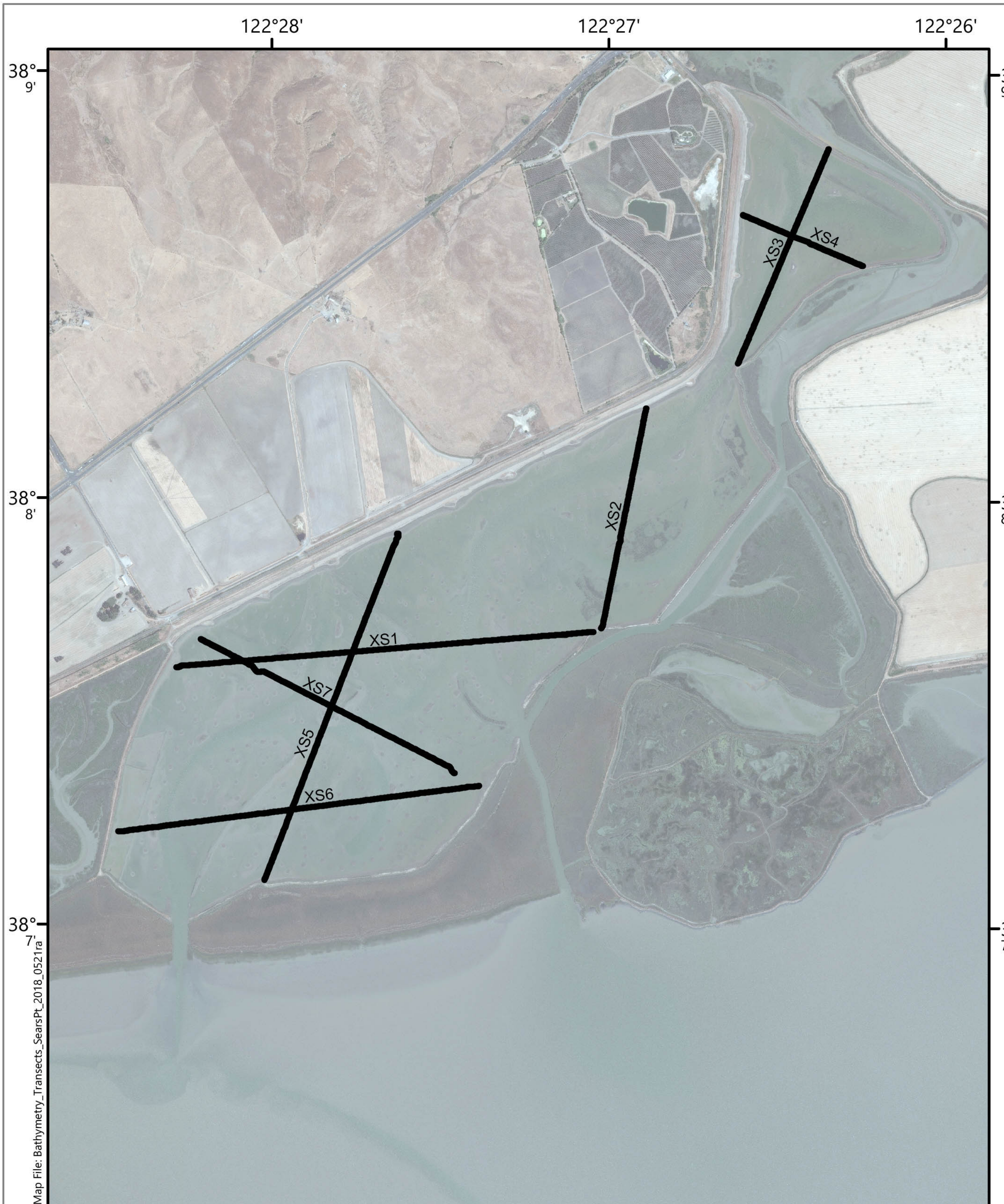
4.3.2 Post Restoration Topography

Airborne collection of LiDAR data was performed in **June 26, 2017, June 16, 2018, and June 7, 2020** via contract to Quantum Spatial. Method details are described in their data reports (Appendix C). Data were collected at a spring low tide in order to have as much of the site exposed from tidal submergence as possible. The 2018 and 2020 LiDAR were accompanied by 4-band ortho-imagery, while the 2017 LiDAR was collected without an orthoimage, to save costs.

Each LiDAR flight was scheduled to take place with as low tide as possible within an acceptable time from late morning to early afternoon to minimize sun reflection angles. Flight scheduling is constrained by fog and low clouds and by availability of aircraft with the necessary equipment which are mobilized from outside the San Francisco Bay Area. (Flights are most cost effective for SLT when combined with other related work in the region carried out by other parties, which allows aircraft mobilization costs to spread across multiple data acquisition efforts.) Standing water is present wherever site elevations are below tide levels at the time of the flight. The subtidal constructed channels are always underwater and thus are “no data” areas. Other areas holding water at low tide include the soil borrow areas around many of the mounds, depressions forming through natural deposition, and naturally forming deeper channels. Consequently, all LiDAR data sets have some “no data” areas and these areas vary across years.

4.4 Bathymetry

A small boat-based bathymetric survey of six transects across the site (Figure 9) was collected in February 2017 during the extreme high tides that took place that month. Bathymetric survey methods are presented Appendix D. Data from these transects will be compared to the USACE baseline topographic survey to yield sedimentation data.



Data Sources: Bathymetry, CLE Engineering 2017

Bathymetric Elevation Transects, Sears Point

Sonoma County, CA

Feet: 0, 2,000, 4,000

Meters: 0, 480, 960

1:24,000 (1" = 2,000' at letter size)

North

San Francisco Bay National Estuarine Research Reserve

SONOMA LAND TRUST

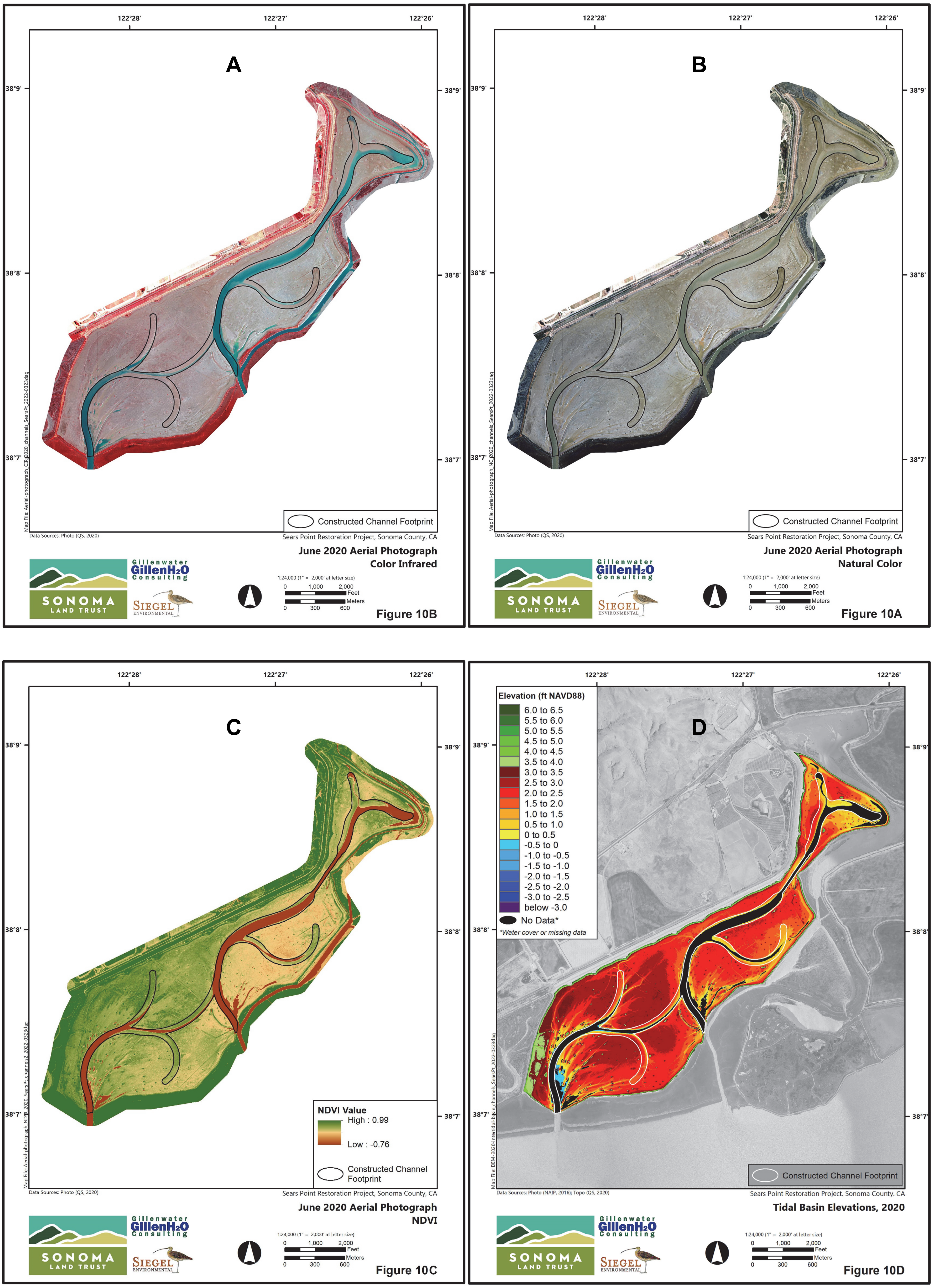
Figure 9

4.5 Tidal Channel Development

Tracking the development of tidal channels in an accreting mudflat environment in advance of vegetation establishment is both challenging and perhaps premature. Remote sensing techniques rely upon spectral signature differences which are fairly subtle in the mudflat stage that is Sears Point at present. Heads-up digitizing is the alternative method. One consideration with this approach is deciding what channel size to capture, as the smallest nascent channels (rivulets really) can be numerous and not particularly significant at this stage of restoration evolution.

Figure 10 compiles the four data sources that can inform channel development – the natural color and color infrared (CIR) air photos, the NDVI map software-generated from the CIR image, and the LiDAR-based DEM. For each of these data sets we overlaid the outline of the large constructed subtidal channel for reference.

Given the still-early stage of marsh evolution and the complexity of mapping tidal channel development, for this monitoring period this assessment consisted of a limited heads-up digitizing approach that focused on channels developing off the constructed large subtidal channel (Section 5.5).



Mapping tidal channels during the mudflat stage of restoration is very challenging, as remote sensing automated techniques have very little spectral differences to draw from. These four data sets – the air photo in natural color (A) and color infrared (CIR) (B), the NDVI (normalized difference vegetation index) derived from the CIR (C), and the LiDAR-based DEM (D) – illustrate this challenge and guide the heads-up digitizing method if employed. Also challenged by need to decide what channel size to digitize.

Fig-12_DEMC_Baseline-2020_2022-0317sws

Sears Point Tidal Marsh Restoration Project
Sonoma County, California

Input Data for Assessing Tidal Channel Development
Figure 10

4.6 Marsh Mound Plantings

Monitoring of the marsh mound plantings was conducted quarterly during the growing season (summer, spring and fall) from summer 2016 through summer 2017 by the SFSU graduate student.

Relative elevation change was assessed on all experimental mounds through the use of erosion pins, which were installed in spring 2016. Erosion pins consisted of 1.5-meter PVC that was driven vertically into the ground until 0.5 – 0.7 m remained exposed. A single pin was installed on the apex of each mound, and four additional pins were installed along the slopes of each mound in all cardinal directions. Slope pins were positioned 0.5 m lower in elevation than the apex pin (distance from the center of the plot varied by individual mound grade). Pins were measured from the surface of the sediment to the top of the pin; measurements were completed upon installation in addition to each quarterly timepoint. Erosion increases the distance from the ground surface to the top of the pin, and deposition decreases that distance. Precise pin elevations were determined in August 2017 using a Real-Time Network (RTN) GPS unit (Leica Viva).

Vegetation monitoring was conducted at each timepoint for vegetated mounds. Total shoot counts were conducted when plots were sparse or unevenly vegetated; when plots were evenly and densely vegetated, shoot counts were conducted within a randomly placed 1 m^2 quadrat (low-density plot), or 0.25 m^2 quadrat (high-density plot). Plant canopy height was determined by measuring and taking the mean of the five tallest shoots from the plot. When flowering shoots were present, these were measured separately from vegetative shoots.

Sediment cores were taken from within each plot using a 5-cm diameter PVC corer to 10-cm depth. Cores for sediment analyses were split in the field into two sections containing the top 3- and bottom 7-cm of soil for further analyses. Cores were processed in the laboratory for bulk density, percent moisture, grain size, and percent organic matter. Carbon and nitrogen content were assessed for summer 2017 samples only. Cores for infaunal invertebrates were returned to the laboratory and sieved to 2 mm, 1 mm, and 500 µm. Macro-organic matter (MOM) was retained from the 2- and 1-mm sieves, dried and weighed. Infaunal invertebrates we collected from the 500 µm sieve, preserved in 10% buffered formalin, stored in 70% ethanol, and later identified to the lowest taxonomic group possible.

In fall 2017, an additional experiment was conducted to assess flow reduction by Spartina on planted mounds. Plaster dissolution blocks were deployed in the interior and exterior of plots for 14 days, and flow was assessed by the mass of plaster lost over that period, with higher mass loss indicating higher flow and lower mass loss indicating lower flow. Sediment pins were measured during deployment and retrieval, and vegetation measurements were taken during block deployment including shoot counts, maximum shoot height, and vegetated area.

In fall 2019, goose exclosures were removed and mounds were monitored. Shoot density was measured using a 0.25 m^2 quadrat randomly placed within the original planting area, and vegetated area was estimated by measuring the maximum length of the *Spartina* patch and the width of the patch perpendicular to the length; area was calculated as the area of an ellipse.

Monitoring of plantings by the Coastal Conservancy's Invasive *Spartina* Project was completed in the fall of each year (**10/29/2018 and 11/18/2019**). Survivorship of originally planted plugs was tracked during monitoring in the first year after planting. In 2019, *Spartina* patches on 33 of the 34 mounds planted in 2018 were mapped instead, as original plots and plugs could no longer be tracked due to *Spartina* expansion.

4.7 Marsh Mound Erosion

Monitoring of marsh mound erosion was conducted with two separate methods:

- **Erosion pins on subset of mounds.** The first method utilized the installation of erosion pins on a subset of the mounds included within the study of the SFSU graduate student (Figure 17). Pins were installed on the apex of mounds following methods described above (section 4.5). Pins were installed in October 2015 just prior to levee breaching, and then measured quarterly from December 2015 to March 2018. Precise pin elevations were measured in August 2017 using an RTK GPS (Leica Viva). Mound elevations were extrapolated across monitoring timepoints by adjusting elevation by change in pin height.
- **LiDAR data comparison.** The second method compared elevations of all mounds between the baseline September 2015 pre-breach as-built elevations and the June 2017 aerial LiDAR elevation survey.

4.8 Levee Erosion

Erosion of the northern and western levees was monitored in two manners. Ducks Unlimited collected topographic data on 52 levee cross sections in 2017 (Appendix E1) and they reoccupied 27 of these cross sections in 2018 (Appendix E2). Cross sections were surveyed with survey-grade Real-Time Kinematic Global Positioning System (RTK-GPS) methods and using reference benchmarks established near the Refuge headquarters for project construction. Siegel Environmental extracted levee slope data from the 2018 LiDAR utilizing ArcGIS tools, setting levee slopes greater than 17 percent as the minimum steepness criterion to locate levee erosion. Constructed levee slopes varied between 5 to 10 percent, and the intent was to map more significant erosion that may need to be addressed through adaptive management actions being examined by SLT with Siegel Environmental under contract.

4.9 Intertidal Vegetation Establishment

Remote Sensing-Based Mapping. Mapping the extent of intertidal vegetation establishment in 2020 was done using remote sensing methods. The June 2020 4-band aerial image of the site was used as the basis for the vegetation mapping. A normalized difference vegetation index (NDVI) layer was created from the 4-band image in ArcGIS Pro 2.9 to aid in the identification of dense, live (i.e. green) vegetation. Based on inspection of the NDVI layer and the native aerial image, NDVI values above 0.25 appeared to represent intertidal marsh vegetation rather well. However, some potential vegetation signatures were missed by the NDVI classification, while some areas of algae on the intertidal mudflats were classified as vegetation. As the NDVI classification alone did not satisfactorily represent intertidal vegetation colonization, it was determined that digitizing the vegetation polygons by hand would be the most accurate and reliable method.

The NDVI layer and the aerial image, using both natural color and color infrared renderings, were used to guide the heads-up digitization of vegetation polygons in ArcGIS Pro 2.9. Areas that appeared to represent intertidal marsh vegetation, based on review of the three image renderings, were digitized as polygons at a scale of 1:300 (1" = 25 ft). The minimum vegetation patch size captured was generally 20 ft^2 (5' diameter). Only intertidal vegetation below the 8 ft NAVD88 contour line was digitized. Brown (dormant) vegetation at the upland margins was not captured, nor were obvious coyote brush patches at the margins. The total acreage of all digitized vegetation polygons was calculated to determine the intertidal vegetation cover in 2020.

Field surveys. Field vegetation sampling focused on the west levee as part of SFSU Professor Kathy Boyer's wetlands ecology class, with some additional effort at the levee pannes. Sampling along the west levee included a PVC central marker placed at the junction between the dredged soil cell to the south and the open shoreline to the north. Ten PVC pins were placed every 25 meters to the north and south of this demarcation point and each team of students ran a transect at least 10 m perpendicular to the levee and out into the low intertidal zone. A $25m^2$ quadrat was placed every meter along the transect and all species present were identified and cover was estimated (including bare mud, algae, and wrack). At each pin, height of the levee erosion scarp was measured if one existed.

4.10 Transition Zone Vegetation

As described in the management activities section above (Section 3.5), several plantings and invasives control efforts took place along the northern and western levee slopes within and above the transition zone between 2014 prior to levee breach through 2021 as part of the levee erosion adaptive management project. As such, this area underwent vegetation "resets" a number of times. Each of these plantings efforts were in response to intentionally temporary approaches (e.g., oat hay crops), observations of underperforming outcomes (e.g., drought conditions impairing creeping wildrye establishment), and extending effective plantings more broadly. Consequently, transition zone vegetation monitoring fell mainly to qualitative observations of vegetation bands along the levee slope – relative species composition and processes and factors that may be acting on that composition. SFSU and the SF Bay NERR did establish some vegetation transects but a variety of factors including the above led to them not being utilized at a level for monitoring reporting.

4.11 Birds

Avian monitoring took place from 2016 to 2021 by Daniel Edelstein and Kate Freeman on behalf of SLT. Survey methods and results are in Appendix H. Survey methods are summarized here.

Survey Locations

Survey stations, affixed with permanent markers, were located at equidistant points along the site's levee (part of the San Francisco Bay Trail), paralleling the north shore of San Pablo Bay (Figure 11).

Survey protocol

Surveys were conducted by volunteer citizen scientists, all of whom completed classroom and on-site training prior to the field season. A lead monitor executed each survey, with the support of 1–6 additional monitors to assist in bird identification and recording.

Monitors conducted ten minute fixed-radius point counts at 12 survey stations. At each survey station, observers counted all shorebirds, ducks, and rails within a 0.1-mile (160 meter) radius, recording species and counts on a datasheet. Weather conditions and habitat characteristics were also documented at the beginning of each point count.

Point counts were scheduled to occur at moderate low tides (below two feet) and moderate high tides (above five feet). Each day of surveying included a visit to all 12 survey stations. Surveys occurred twice per season, from fall 2016 through summer 2019, for a total of 24 surveys. All datasheets were shared with the United States Fish and Wildlife Service (USFWS) and entered into the California Avian Data Center (CDAC) online database.

Summary metrics

We summarized point count data by calculating total abundance, mean abundance, bird species richness, and diversity using all detections within 160m, excluding flyovers. Mean abundance per point for a species was estimated as the average of counts across all visits to a point in a given season or year. If a species was not detected at a point it was assigned a count of zero prior to averaging (Salas et al. 2010). Total mean abundance of all species for the entire site was calculated per season, averaged across all visits at each point count location. Standard deviations were calculated across all point count locations, for all species combined, with the number of point count stations as the sample size (Salas et al. 2010). We estimated species diversity using a transformation of the basic Shannon index H` (N1= eH`). To understand our results in the context of existing SF Bay waterbird data we grouped observations into feeding guilds (State of the Estuary 2015). We used the following guilds to investigate population dynamics: diving and dabbling ducks, shorebirds, herons and egrets, and rails. Diving ducks include Bufflehead, Canvasback, Common Goldeneye, Ruddy Duck, Scoter (Black, White-winged, and Surf scoter), and Scaup (Greater and Lesser scaup). Dabbling ducks include American Wigeon, Gadwall, Green-winged Teal, Mallard, Northern Pintail, and Northern Shoveler (State of the Estuary 2015).

Figure 11. Avian Survey Monitoring Locations

4.12 Sedimentation

Sedimentation was measured by difference calculations between the baseline elevations and the 2017, 2018 and 2020 LiDAR topographic data sets, performed in ArcGIS. “No data” values in each of these data sets (due to incomplete baseline data collection and the presence of water during the LiDAR flights) results in no sedimentation data between time periods in some areas. The elevation difference calculations yield maps of sedimentation as well as elevations for each “cell” in the data which we then used to generate histograms representing acreage of sedimentation amounts for each time period. Dividing sedimentation amounts by the time interval then allowed calculation of sedimentation rates.

4.13 Fish

Dual-method sampling was conducted in the spring (May) and fall (October) of 2017. Each sampling event was conducted over a period of five days and consisted of both stationary (n = 18) and transect (n = 24) surveys that were designed to cover the various subtidal habitat types within the Project. These habitat types included:

Subtidal Habitat Type	Sampling Methods and Locations
Sidecast ridges	• Stationary monitoring sites – S1, S2, S3 • Transect monitoring sites – T1, T2
Marsh mounds	• Stationary monitoring sites – S4, S5 • Transect monitoring sites – T5, T8
Levee transition slope	• Stationary monitoring sites – S8, S9 • Transect monitoring sites – N/A
Flooded remnant terrestrial vegetation	• Stationary monitoring sites – S6, S7 • Transect monitoring sites – T6, T7
Rootwads	• Stationary monitoring sites – N/A • Transect monitoring sites – T3, T4

Sampling at both stationary and transect surveys consisted of sampling first with the ARIS (Model 1800, 0.7 – 35-meter range), immediately followed by the deployment of traditional sampling gear (i.e., beach seine and otter trawl). In both cases, the ARIS continued to operate throughout the traditional sampling efforts to characterize fish avoidance behavior and relative capture efficiency. Water quality measurements were collected at each site prior to sampling.

See Appendix I for further descriptions.

5 Monitoring Results and Discussion

5.1 As-Built Geomorphic Features

The project constructed five distinct geomorphic features: levees, channels, mounds, side-cast ridges, and pannes, as well as the marsh plain to accrete by natural sediment deposition (Figure 3). These features have been identified through a combination of heads-up digitizing from 2016 aerial photograph, engineering construction drawings, and the as-built topography. Levee areas were delineated by the 1ft (low side) and 9ft (high side) contour lines of the as-built topography. Panne areas were manually delineated based on NAIP 2016 imagery and the as-built topography. Side cast ridges were manually delineated based on the Digital Globe 2016 satellite image. Channels were based on the Ducks Unlimited construction drawings and modified using the April 1, 2015 pre-breach Google Earth image (Figure A-1). This data set will be used to compare evolution of the channels, mounds, sidecast ridges, and levees.

5.2 Air Photos

Several air photos have been acquired for Sears Point (Table 6). All air photos are found in Appendix A.

The as-built air photo is from Google Earth, flown April 1, 2015 (Appendix A – Figure A-1). This photo precedes the October 2015 levee breach but follows winter rains and thus has standing water in the excavated large channel network. All the constructed marsh mounds, sidecast ridges, and the habitat levee are visible in the image. Some mounds were removed after April 1, 2015 and in advance of the levee breach. These alterations were captured in the U.S. Army Corps of Engineers September 2015 LiDAR survey.

The post-breach photos vary in their data collection. Some are purchased from commercial satellite stock, some are taken with low-cost methods, some are orthorectified imagery collected in conjunction with collecting LiDAR topographic data.

Table 6. Inventory of Aerial Photographs

Date	Band[1]	Figure No.	Time	Tide (ft MLLW)	Years > Breach	Platform[2]	Resolution	Vendor[3]
Apr 1, 2015	NC	A-1	NA	NA	Baseline	S	NA	GE
Jul 6, 2016	NC	A-2	18:41	4.1	0.73	FW	27cm	TA
Jul 21, 2016	CIR	A-3	17:26	4.6			30 cm	
Aug 23, 2016	NC	A-4	12:22	1.3	0.86	S	NA	DG
Nov 17, 2016	BW	A-5	~15:00	6.7	1.09	S	BA	DG
Aug 2017 (north levee only)	NC	A-6	NA	NA	1.80	UAV	8.4 cm	SFSU
	FC	A-7						
	NDVI	A-8						
Sep 9, 2017	NC	A-9	NA	NA	1.90	FW	26 cm	TA
	CIR	A-10						
Jul 16, 2018	NC	A-11	NA	~-0.8[4]	2.75	FW	15cm	QS
	CIR	A-12						
	NDVI	A-13						
Aug 16, 2019	NC	A-14	09:40	0.2	3.84	FW	23cm	PAS
Oct 9, 2019	NC	A-15	NA	NA	3.99	FW	16cm	PAS
	CIR	A-16						
	NDVI	A-17						
Jun 7, 2020	NC	A-18	NA	~-1.4[4]	4.62	FW	15cm	QS
	CIR	A-19						
	NDVI	A-20						
Jun 16 & 30, 2022 (north and west levees)	NC	A-21	NA	Below MTL	5.65	UAV	2.5	ED
Dec 9, 2022 (north and west levees)	NC	A-22	~11:00-12:00	2.7	6.13	UAV		SFEI

Notes:

1) *Image band: NC = Natural Color, CIR = Color Infrared, BW = Black and White, NDVI = Normalized Difference Vegetation Index, FS = False Color*
2) *Platform: S = satellite, FW = fixed wing aircraft, UAV = unmanned aerial vehicle ("drone")*
3) *Vendor: TA = Terravion, GE = Google Earth, DG = Digital Globe, QS = Quantum Spatial, PAS = Pacific Aerial Survey, ED = Envirodrones, SFEI = San Francisco Estuary Institute*
4) *Air photos flown with LiDAR data collection do not have reported time stamps, however noted in data report that flown at lowest tide*

5.3 Field photos

Baseline field photographs are included in Appendix B. These photographs were taken at pre-established fixed photograph monitoring points which are reoccupied after construction.
Appendix B provides:

- a table of all photo points with descriptions
- a map of the photo stations with bearing to show the photo direction
- photos from 2013-2017 showing changes at the site

5.4 Tidal Basin Topography and Accretion

Basin topography and accretion are assessed through four digital elevation models (Section 5.4.1) – pre-breach as-built (developed from multiple data sources) and three fixed-wing airborne LiDAR data sets – and one round of site elevation measurements (Section 0).

5.4.1 Marsh Plain Net Accretion from LiDAR Data

The four DEM data sets represent as-built (year 0), June 2017 (year 1.75), June 2018 (year 2.75), and June 2020 (year 4.75). Figure 12 presents these four DEMs of site topography. Net accretion is determined as the elevation differences over time between these four DEMs. “Net” refers to the integration of processes of elevation gain (accretion) and elevation loss (consolidation and compaction of accreted sediments, loading of the underlying ground surface, and any erosion that may have occurred). Monitoring has not separated out any of these individual processes. Figure 13 shows the net accretion across the four time intervals – breach to June 2017 (1.75 yr), June 2017 to June 2018 (1 yr), June 2018 to June 2020 (2 yr), and baseline to June 2020 (4.75 yr). Figure 14 presents the histograms of this accretion – the area of each depth interval of accretion, shown for the time increments between each data set and cumulatively since breach, and it shows the average annual accretion rates during each plotted time interval. Table 7 provides the net volume of accreted sediments, from as-built to each year of LiDAR data and cumulative from as-built to June 2020.

Each data set contains areas with no data (see Section 4.3) originating from gaps in baseline data due to data collection methodology and from tidally submerged areas at the time of LiDAR data collection (all were flown at low tide). The geographic extent of no data is generally different across data sets, with the subtidal constructed channel consistently having no data due to submergence. These no-data areas have two consequences for assessing marsh accretion. First, underestimates of accretion (or erosion) extent and magnitudes result when making comparisons across data sets due to non-overlapping areas of no data. Second, sedimentation within the large, subtidal constructed channel becomes far more evident in the latest data set when compared only to the pre-breach data, as large areas of this accreted channel were exposed when the LiDAR was flown.

These elevation and elevation change data reveal a number of findings:

1) **Accretion volumes.** The site has net accreted approximately 3 million cubic yards of sediment in the 4.75 years from breach to the June 2020 LiDAR elevation survey. Based on the June 2020 LiDAR, there is another approximately 5.5 MCY of sediment needed to bring the site to MHHW, so the site has filled roughly one-third its volume in its first 4.75 years.

2) **Accretion rates**
    a) **Average annual accretion rates by each incremental time period** (first 1.75 yr, next 1 yr, following 2 yr) decreased from 0.60 ft/yr to 0.53 ft/yr then to 0.40 ft/yr. This decline from one time increment to the next is as expected – the higher site elevations reach, the less time they are submerged by the tides and thus time for sedimentation to occur.
    b) **Average annual accretion rates from breach to each later time period** stayed fairly constant at 0.60 ft/yr, with a slight drop to were 0.57 ft/yr from breach to June 2020. These cumulative time periods average out changes within each time increment and also reflect a more rapid filling of the constructed large subtidal channel as time progressed. This increase in channel accretion is likely due to the decreased tidal prism of the restoration site as it fills with sediment.

3) **Accretion depths.** Table 8 shows the percent area of the site for each half-foot increment of accretion, assessed as cumulative time since breach (i.e., 2015 baseline to the three DEMs of 2017, 2018, and 2020). As noted above, each DEM has some "no-data" areas which originate for different reasons and as a result differ between DEMs. Thus, comparing to baseline for each year minimizes the effect of these no-data areas. These data show progressively greater percentage of the site has greater accumulation amounts over time (see also Figure 14).
    a) From baseline to 2017, average accumulation was approximately 1 ft.
    b) From baseline to 2018, average accumulation was approximately 1.7 ft.
    c) From baseline to 2020, average accumulation was approximately 2.7 ft.
    d) Of particular note is accretion within the large constructed tidal channel that was constructed to -5 ft invert elevation. The LiDAR elevation data is ground surface only and here does not penetrate the water surface. Elevations below low tides at time of LiDAR flights have no data and thus accretion is only detected once it rises above the low tide level. Thus, there is a large jump in the 2020 data for greater than 4 ft of accretion, as channel accretion became detectable. See further discussion below.

4) **Spatial differences in accretion**
    a) **The western portion of the main basin has accreted to the highest elevation**. The eastern breach and its subtidal channel (Figure 3) may be acting as a hydrodynamic

barrier, slowing flows from the west breach when they reach the eastern channel and resulting in increased rates of sediment deposition. Elevations in the west basin in 2020 are mostly between 2-3’ versus 1.5-2.5’ in the eastern basin and 0.5-2.5 in the fishtail (see Figure 12-D).

b) **The “fishtail basin” has had the least accretion**, though portions of the large constructed subtidal channel have filled in considerably. This basin is the furthest distance from either breach, so sediment transported into the site will have already deposited closer the inlets.

c) **The dredge spoils ponds** in the southwest corner of the site dropped in elevation initially, likely due to consolidation of placed sediment. By 2020 they had accumulated sediment and were the highest elevation portion of the site, up to the 3.5-4’ elevation range.

d) **The large constructed subtidal channel has accreted extensively.** This channel, about 143 acres, was constructed to -5’ elevation. Accretion could only be detected once channel elevations had reached the lowest tides during aerial LiDAR, around -1’, so early subtidal accretion was not detected. By June 2018, the channel had accreted roughly 120,000 cubic yards, or about 8% of total net accretion, and about 13% of the channel had accreted to low or higher elevations. By June 2020, the channel had accreted roughly 375,000 cubic yards, or about 13% of total net accretion, and about 41% of the channel had accreted to low or higher elevations (Table 9). During this same time period, the surface area of the channel that was below low tide (i.e., still subtidal) reduced from 143 ac at construction to 84 acres in June 2020 (Figure 16 and Table 9).

5) **Scour has occurred just inside and to the northeast of each breach.** Closest to the subtidal channel, scour has deepened the farm field to subtidal elevations below the tide levels when LiDAR was flown. Once away from the channel edge, scour was less, up to about 1 ft. This scour reflects the velocity of incoming tidal flows associated with the large tidal prism through each breach, and the direction of scour likely combines alignment of the channel outside the restoration site and some influence of prevailing wind directions.

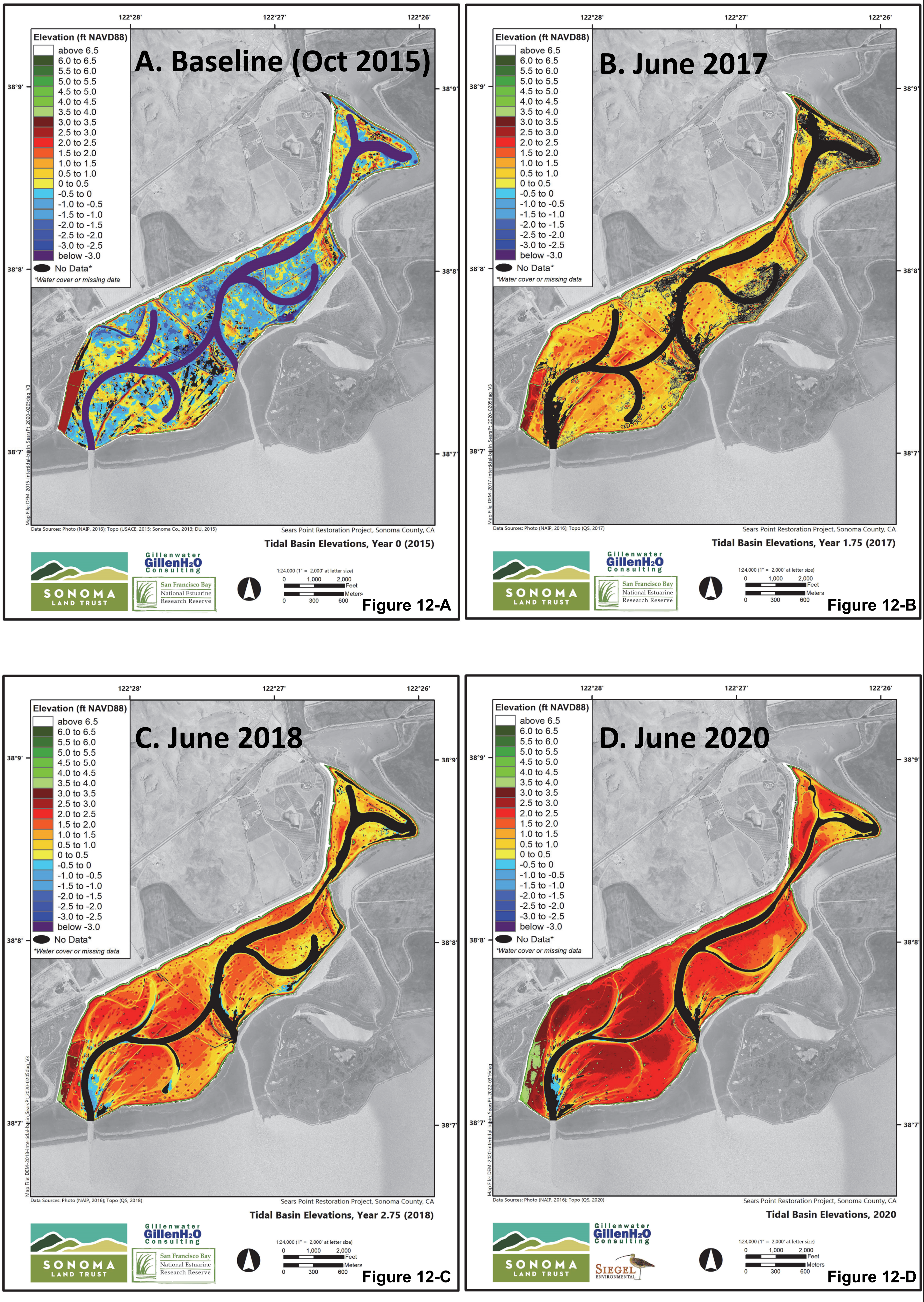


Fig-12_DEM_Baseline-2020_2022-0323sws

Sears Point Tidal Marsh Restoration Project
Sonoma County, California

Tidal Basin Elevations
Years 0 (2015), 1.75 (2017), 2.75 (2018), and 4.75 (2020)
Figure 12

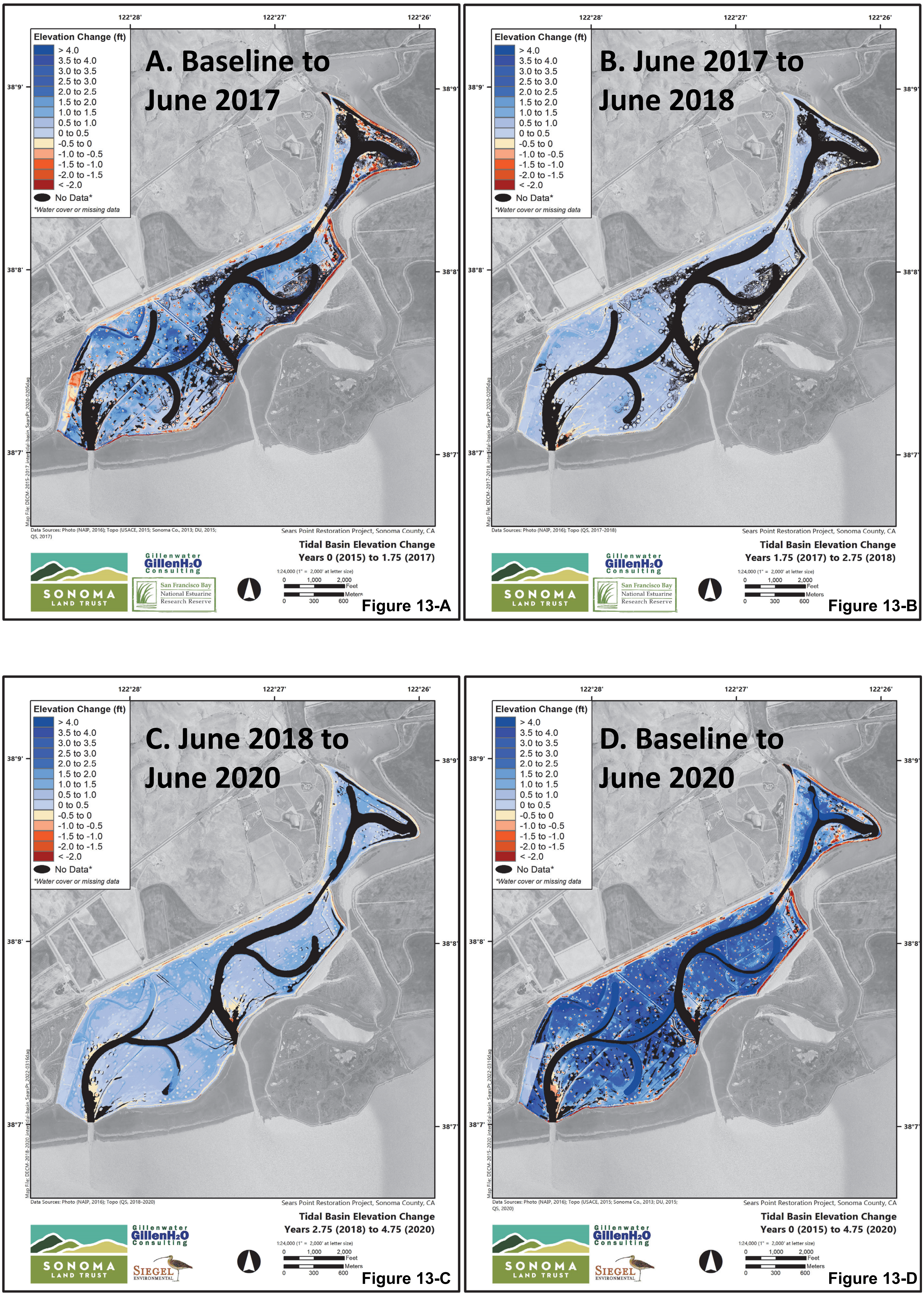


Fig-12_DEMC_Baseline-2020_2022-0317sws

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Sears Point Tidal Marsh Restoration Project
Sonoma County, California

Tidal Basin Elevation Change to 2020
Figure 13

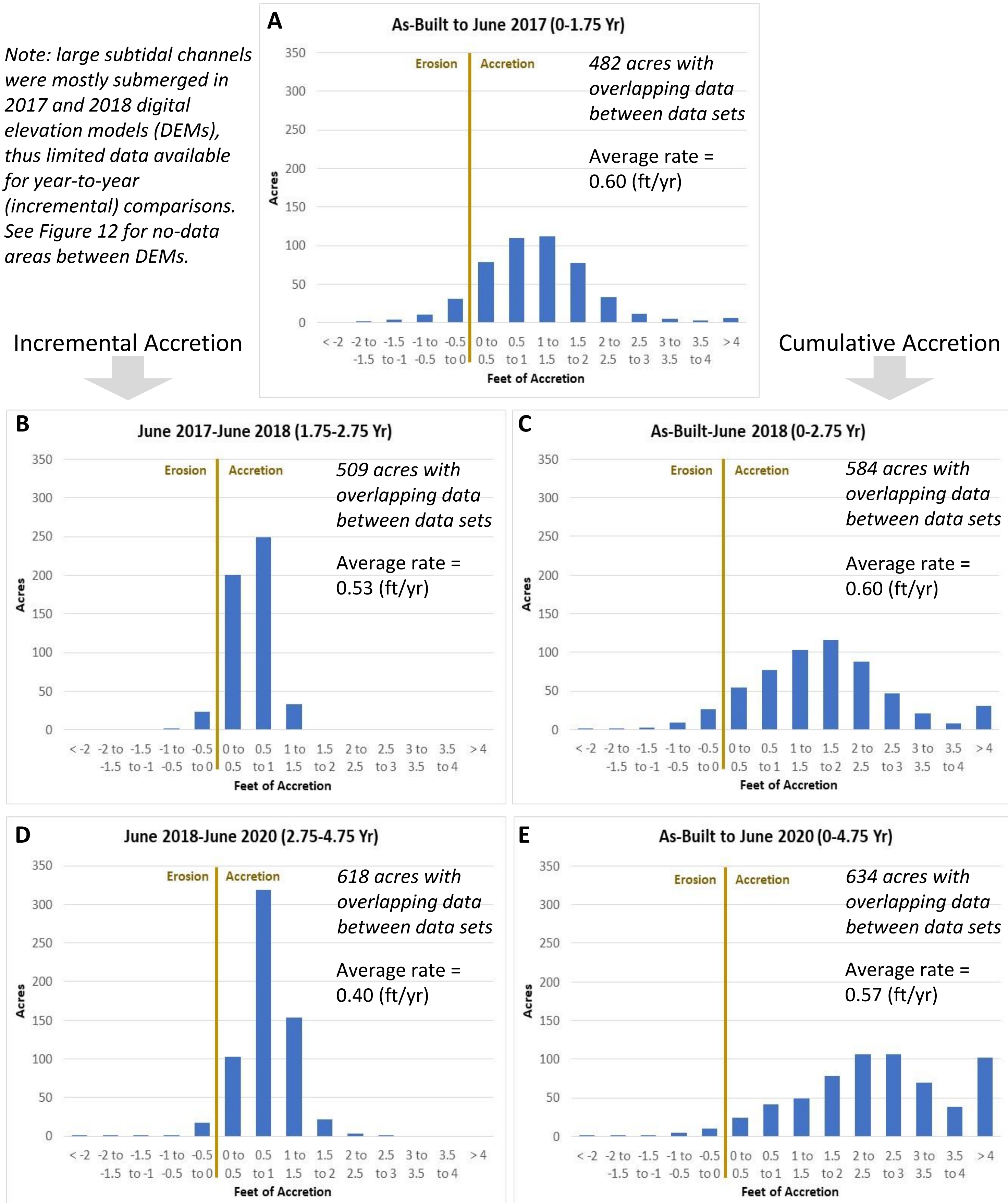

Fig-14_Accretion Histograms_2022-0512sws

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Sears Point Tidal Marsh Restoration Project
Sonoma County, California

Tidal Basin Accretion Quantities and Rates
Breach to June 2020
Figure 14

Table 7. Net Erosion and Accretion Volumes Below High Tide Line to June 2020

Time Interval	Net Accreted Sediment Volume (CY)[1,2]	Net Erosion Volume (CY)[3]
Baseline to June 2017, 1.75 yr	940,000	135,000
June 2017 to June 2018, 1 yr	475,000	17,000
June 2018 to June 2020, 2 yr	870,000	18,000
Baseline to June 2020, 4.75 yr (cumulative)[4]	2,935,000	110,000

Notes:

1. *These net volumes slightly underestimate the total, due to areas of no data in each of the four DEM data sets*
2. *Due to different "no data" locations*
3. *Erosion represents all levees enclosing the site – north, west, and outboard. Assumed that all eroded sediment redistributed internally within the restoration site, but not assessed.*
4. *Cumulative volume is measured difference between the June 2020 and baseline DEMs, not the sum of the incremental DEM differences. This approach minimizes effects of no-data areas in each separate DEM.*

Table 8. Percent of Site by Accretion Amount

Elevation Change (ft)	Cumulative Time 2015-2017	Cumulative Time 2015-2018	Cumulative Time 2015-2020
Erosion			
< -2	0.2%	0.1%	0.1%
-2 to -1.5	0.3%	0.2%	0.1%
-1.5 to -1	0.9%	0.5%	0.2%
-1 to -0.5	2.3%	1.6%	0.7%
-0.5 to 0	6.3%	4.6%	1.6%
Accretion			
0 to 0.5	16.2%	9.3%	3.8%
0.5 to 1	22.7%	13.2%	6.6%
1 to 1.5	23.2%	17.6%	7.8%
1.5 to 2	16.1%	19.8%	12.4%
2 to 2.5	6.8%	15.0%	16.8%
2.5 to 3	2.3%	7.9%	16.7%
3 to 3.5	1.0%	3.5%	11.0%
3.5 to 4	0.6%	1.3%	6.1%
> 4	1.2%	5.2%	16.2%

1. *Each DEM has "no data" areas and those areas differ between years, so percentage comparisons between intervals is approximate*

Table 9. Accretion within the Constructed Tidal Channel

Elevation (ft NAVD88)	2015		2017		2018		2020	
	Ac	%	Ac	%	Ac	%	Ac	%
Subtidal	142.6	100%	142.6	100%	124.0	87%	84.1	59%
-1 to -0.5					0.4	0%	0.4	0%
-0.5 to 0					2.3	2%	1.6	1%
0 to 0.5					8.8	6%	7.3	5%
0.5 to 1					5.6	4%	13.6	10%
1 to 1.5					1.3	1%	11.2	8%
1.5 to 2					0.3	0%	12.7	9%
2 to 2.5					0.0	0%	10.5	7%
2.5 to 3					0.0	0%	1.1	1%

5.4.2 Marsh Plain Accretion from Field Measurements

On March 16, 2017, M Buchbinder and M Vasey led a wetland ecology class in collecting 89 sediment depth samples in order to estimate maximum, minimum, and average deposition across the northwest corner of the site (Figure 15). Maximum depth was 88 cm (2.9'), minimum was 12 cm (0.4'), and the average depth was 43.6 cm (1.4'). Depths of accumulated sediment appears to be highest towards the shoreline and in the matrix zone surrounding mounds in wind shadow environments. It appears that the mounds are stimulating rapid sedimentation (such as mound “shadows”), as was part of their design intention.

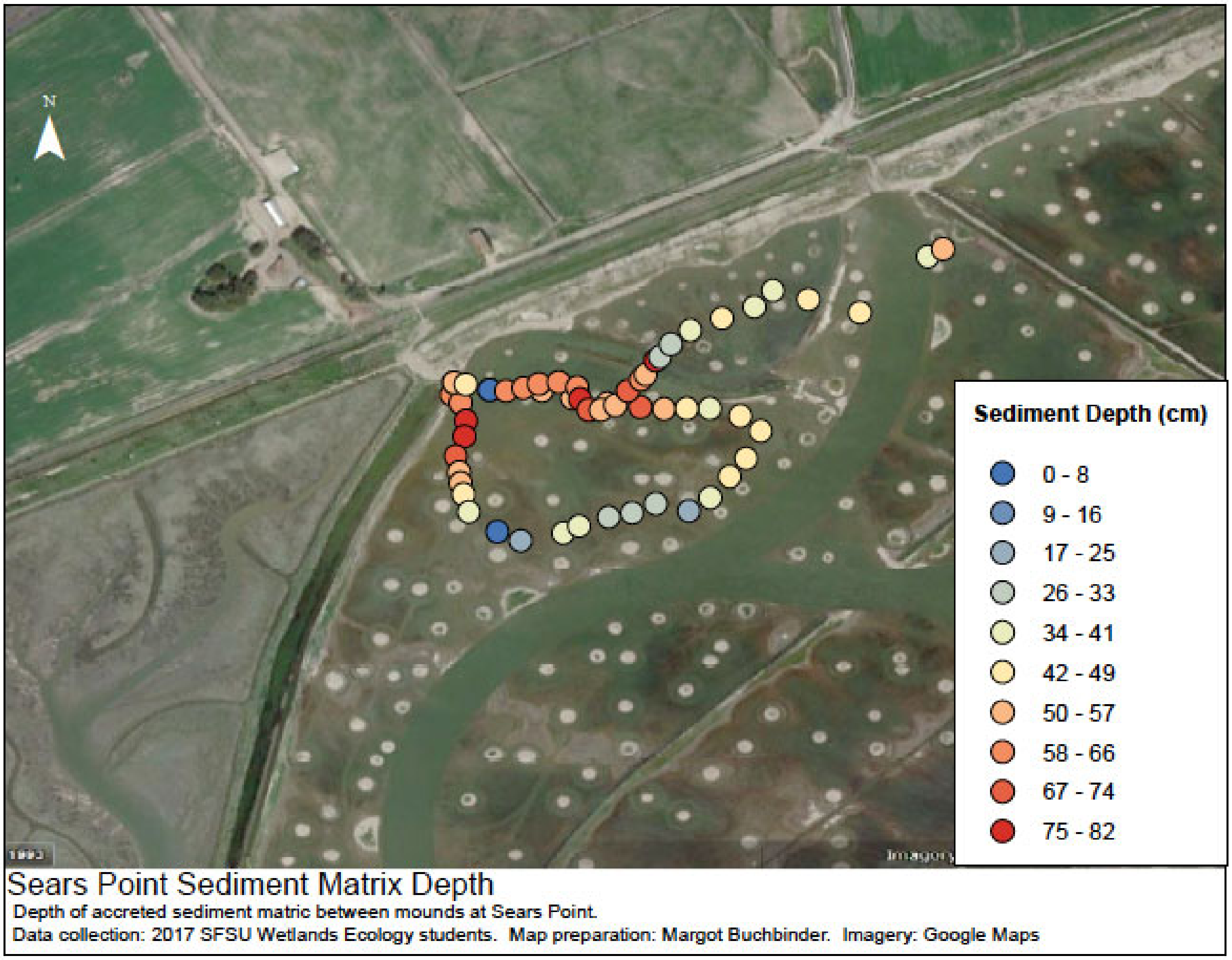


Figure 15. Sedimentation Depth in Northwest Corner, April 2017 (6 Months Post-Breach)

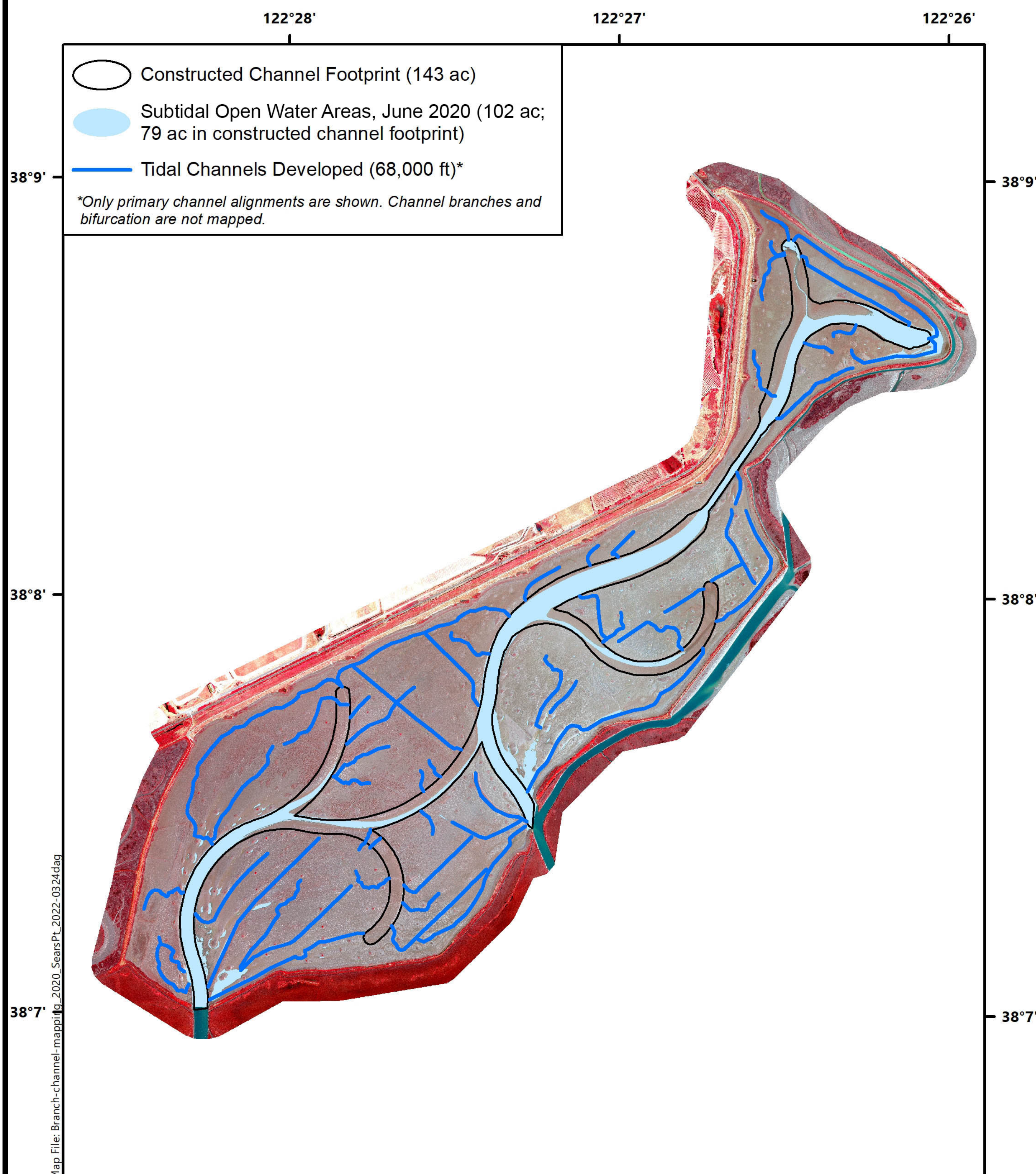
5.5 Tidal Channel Development

Figure 16 shows the mapping of tidal channel development derived from the June 2020 aerial imagery and LiDAR data (see input data in Figure 10). As noted in the methods description (Section 4.5), mapping tidal channels at the currently developing mudflat stage at Sears Point was done with heads-up digitizing and focused on channels connecting to the constructed large subtidal channel.

Key findings on tidal channel development:

1) The constructed large subtidal channel has silted in considerably and thus shrunk (see Section 5.4 and Figure 13D). Its constructed footprint was 143 ac and its subtidal footprint as of June 2020 had reduced to 79 ac, a 45% reduction. Net sedimentation volumes are at least 375,000 cubic yards (accretion below low tide not visible in the LiDAR, see Section 5.4.1). Within the constructed footprint, smaller and in some locations sinuous channels are forming (e.g., very far northeast end within the fishtail basin).

2) Tidal channels forming in the accreting mudflat exhibit a few patterns and total about 13 miles in aggregate length:
    a. Some channels with evolving sinuous geomorphology are forming throughout the site
    b. Some channels fairly straight in planform are forming near each levee breach, these channels are fairly indistinct
    c. Some channels retain pre-existing straight agricultural ditches planform
    d. Some channels retain borrow ditch planform along the toe of the outboard levee
3) Subtidal areas outside the constructed large subtidal channel remain near the two breaches and at the far northeast end in the fishtail basin, and subtidal areas have expanded near each breach (see Figure 13).



Data Sources: Photo (QS, 2020); channels (GillenH2O, 2022)

Sears Point Restoration Project, Sonoma County, CA

Tidal Channel Development
June 2020

Gillenwater GillenH2O Consulting

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1:24,000 (1" = 2,000' at letter size)

0 1,000 2,000 Feet

0 300 600 Meters

Figure 16

5.6 Marsh Mound Plantings

Planting Efforts by SFSU Graduate Student

As mentioned in Section 3.2, in April 2016, Ms. Buchbinder, a graduate student in Dr. Kathy Boyer's lab at the Romberg Tiburon Campus, began her experimental project involving marsh mound plantings as part of her MA research project. The purpose of the study is to assess the potential for plantings of *Spartina foliosa* and wind-wave buffers (coirs) to prevent mound erosion. After implementing the design, by May 2016, there had been major disruption to the coirs and plugs of *Spartina* were lost from the mounds. Based on weather data from the CIMIS weather station located at nearby Black Point[2] extremely high wind events occurred during this time. Subsequent efforts to re-establish *Spartina* plantings also included the installation of Canada Goose exclosures. Efforts were made to re-establish the coir buffers but periodic heavy wind events made this relatively impossible. The original design was modified to include six blocks and efforts to maintain the coir buffers eventually was abandoned.

Results from the planting experiment showed that although Spartina was effective at changing conditions at the site, this process was time-intensive. Spartina was able to increase macro-organic matter (MOM) content in the soil, but the addition of MOM did not manifest itself for a year after planting. Additionally, Spartina growth was not sufficient to drive additional changes in soil development such as bulk density or organic matter. However, increases in Spartina-driven MOM, as well as mounds exhibiting higher densities, were associated with significant impacts of Spartina presence on mound stabilization in fall 2017, when control mounds were found to erode while Spartina mounds remained stable. When assessing flow in fall 2017, mounds with larger vegetated areas had lower flow inside the plot and experienced elevation gain rather than loss, compared to mounds with smaller vegetated areas which experienced lower flow as well as elevation loss. These results indicate that although impacts of Spartina may take time to manifest, plantings can have a positive effect on mound stabilization in the long term. As these impacts become more pronounced with increased vegetated area and stem density, and planted plots are continuing to expand and develop over time, we expect to see magnified effects over time.

Despite initial difficulties in establishing and maintaining plantings on the marsh mounds, Ms. Buchbinder found that plantings that persisted through the initial high-energy period of spring-summer 2016 were very likely to persist over the course of the experiment. By fall 2017 almost half the planted mounds had shoot densities over 200 shoots m^{-2}, and four mounds had densities exceeding 400 shoots m^{-2}. Additionally, vegetative expansion occurred in almost all cases, with vegetated areas exceeding the original 4 m^2 in most cases. The persistence and expansion of Spartina on these mounds indicates that it could be used effectively if allowed to establish under less erosive conditions. The efficacy of this method is confirmed by the success of subsequent ISP plantings in spring 2018 and 2019.

[2] www.cimis.water.ca.gov

Ms. Buchbinder led a survey of the marsh mound plantings with SF Bay NERR staff (M. Vasey and A. Deck) in March 2017. We noted that several *Spartina* plots have survived, however, others have eroded away. The plots that have survived may be providing some protection against mound erosion. Nevertheless, it appears that wind wave action in the Sears Point lagoon is extremely intense and may be too extreme for most vegetation to survive on the marsh mound surfaces at this time. One hopeful sign is that a dominant wetland species in the North Bay region, alkali bulrush (*Bulboschoenus maritimus*), has established voluntarily on some of the mounds and, according to recent observations, on adjacent intertidal mudflats (P. Baye, personal observation). It is possible that this species might be an alternative for mound planting to Spartina, which appears to be vulnerable to the erosive action of heavy wind waves. Or, possibly planting cordgrass and alkali bulrush on intertidal mudflats could promote marsh plain vegetation at the site.

In observations from the shoreline on April 28, 2021, it appears that some of the side-cast ridges are revegetating naturally. For the most part, vegetation along these features appears to be pickleweed (*Sarcocornia pacifica*).

In fall 2019, monitoring of vegetated mounds from the SFSU graduate student project indicated that 14 of the original 18 experimental planted mounds continued to have established *Spartina*. *Spartina* density ranged from 248 – 604 shoots m^{-2} and patch size ranged from 28 – 72 m^2, indicating that *Spartina* presence was maintained or expanded on all but one mound since fall 2017.

Monitoring conducted by ISP in 2019 indicates that 33 of the 34 mounds planted in 2018 are characterized by good survivorship and expansion of the *Spartina* plots, such that individual plugs and plots from the original plantings can no longer be tracked. A single mound from that group, located nearest to the SW breach, has surviving plugs, but these are persisting rather than expanding. Plug survivorship among the mounds planted in 2019 was 64% and exhibited a spatial gradient, with the four westernmost mounds having higher survivorship (84%) than the eastern mounds. Although the cause for this gradient is not fully understood, observations of the sediment indicate that it is possible that the lower survivorship on the eastern mounds may be due to less suitable substrate (pers. comm Jeanne Hammond, 1/23/2020). The possible causes of these differences has not been assessed and may also relate to different mound elevations.

5.7 Marsh Mound Erosion

Erosion of the marsh mounds was monitored in two ways:

1) Ground-based monitoring, via erosion pin and topographic surveys by the SFSU graduate student.
2) Remotely sensed monitoring, from the LiDAR-derived DEM and digitized polygons of the constructed marsh mounds.

5.7.1 Marsh Mound Erosion from Ground-Based Monitoring

Mound erosion pins were examined approximately every three months from December 2015 until March 2018. In that time, over 30 cm (one foot) of erosion occurred on mounds that were sampled (without vegetation) (Figure 18). Some mounds developed a "tear drop" effect presumably reflecting wind-wave and current patterns of erosion and deposition.

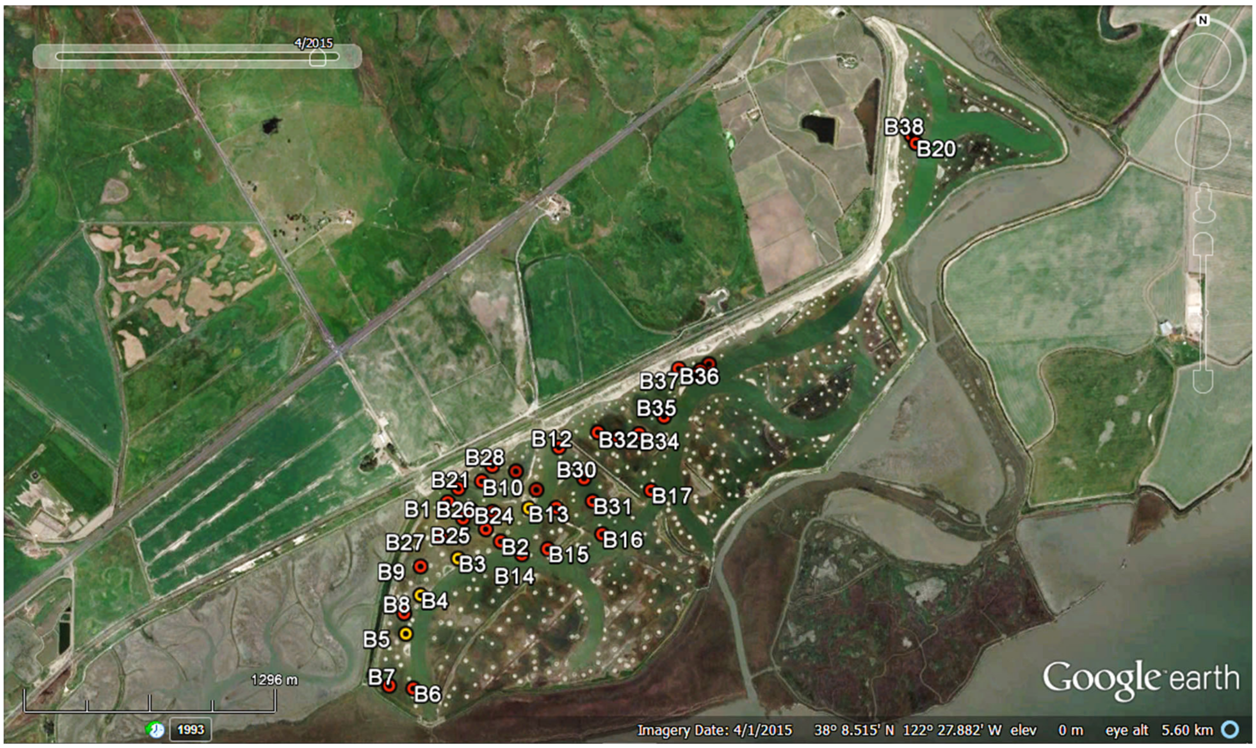


Figure 17. Location of Marsh Mounds Monitored for Erosion

Note that mounds in orange were included in early erosion measurements, but were transferred to use as experimental mounds in spring 2016. Mounds used for erosion monitoring are located on the north side of the channel due to access at the time of installation, and therefore may not represent erosional effects throughout the entire site.

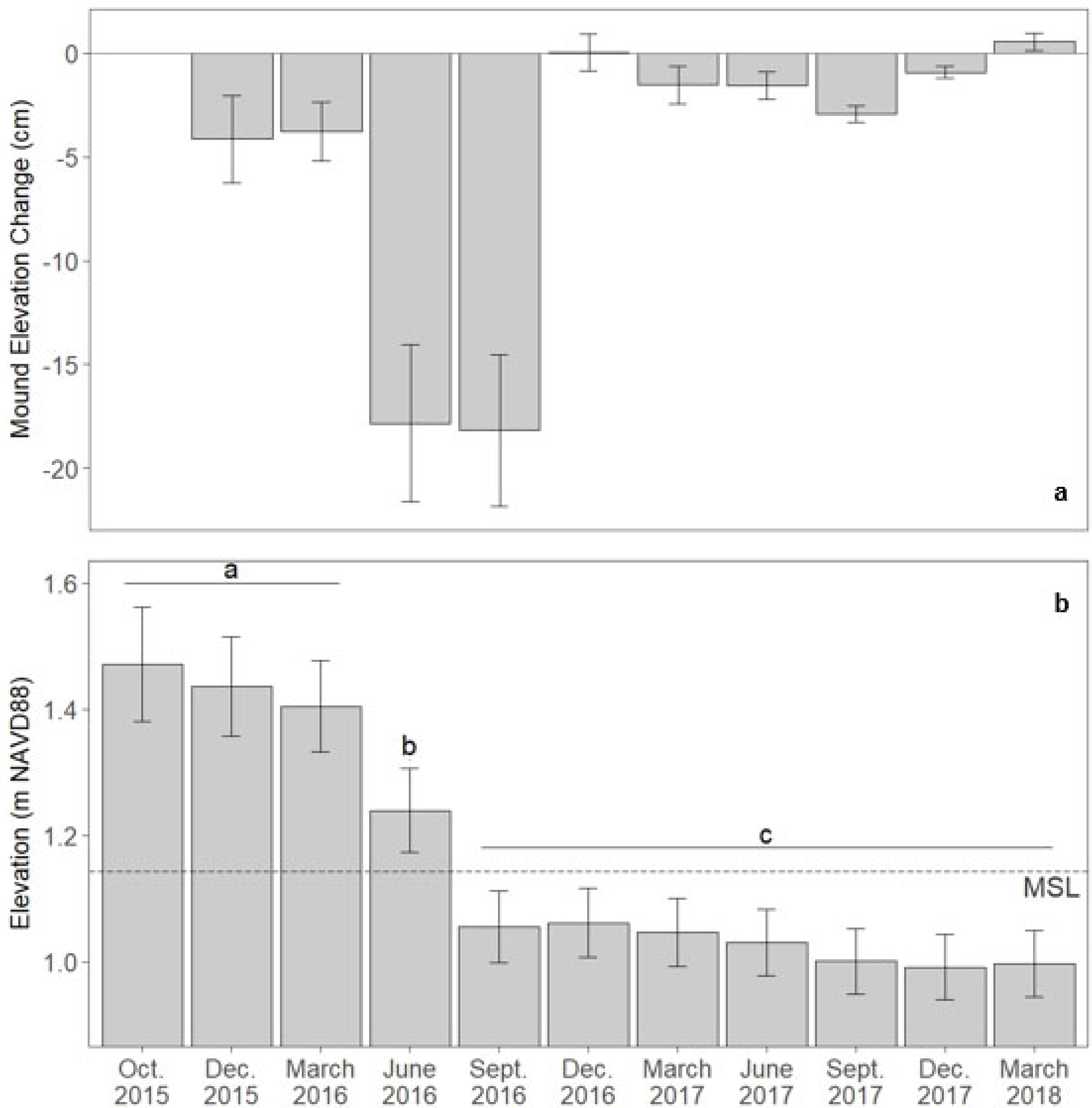


Figure 18. Marsh Mound Erosion Data, Breach to December 2016

a) Elevation change of mounds from the previous monitoring point, hereafter 'change in elevation' (e.g., December 2015 value represents change from October 2015 – December 2015); b) Elevation of mounds at each monitoring point; letters denote statistically similar elevations, "MSL" indicates mean sea level. Error bars denote 95% confidence intervals. Source: Buchbinder 2018

Preliminary data suggests that, despite the challenge of sustaining marsh mound plantings, if vegetation can be successfully established on mound surfaces there may be some reduction of mound surface erosion (Figure 19).

Based on visual observation of the mounds from shore, as the mounds are eroding, sediments are being deposited in the matrix between the mounds and adjacent to the side-cast ridges. Mound sediments contain coarse grained materials not likely to be transported as suspended sediments. These sediments are accumulating adjacent to the mounds and suspended sediments brought in by the tides are depositing rapidly. It appears that some of these coarse sediments have been pushed by wind waves to towards the T-zone and are being deposited in the intertidal zone that otherwise has received considerable wave scour.

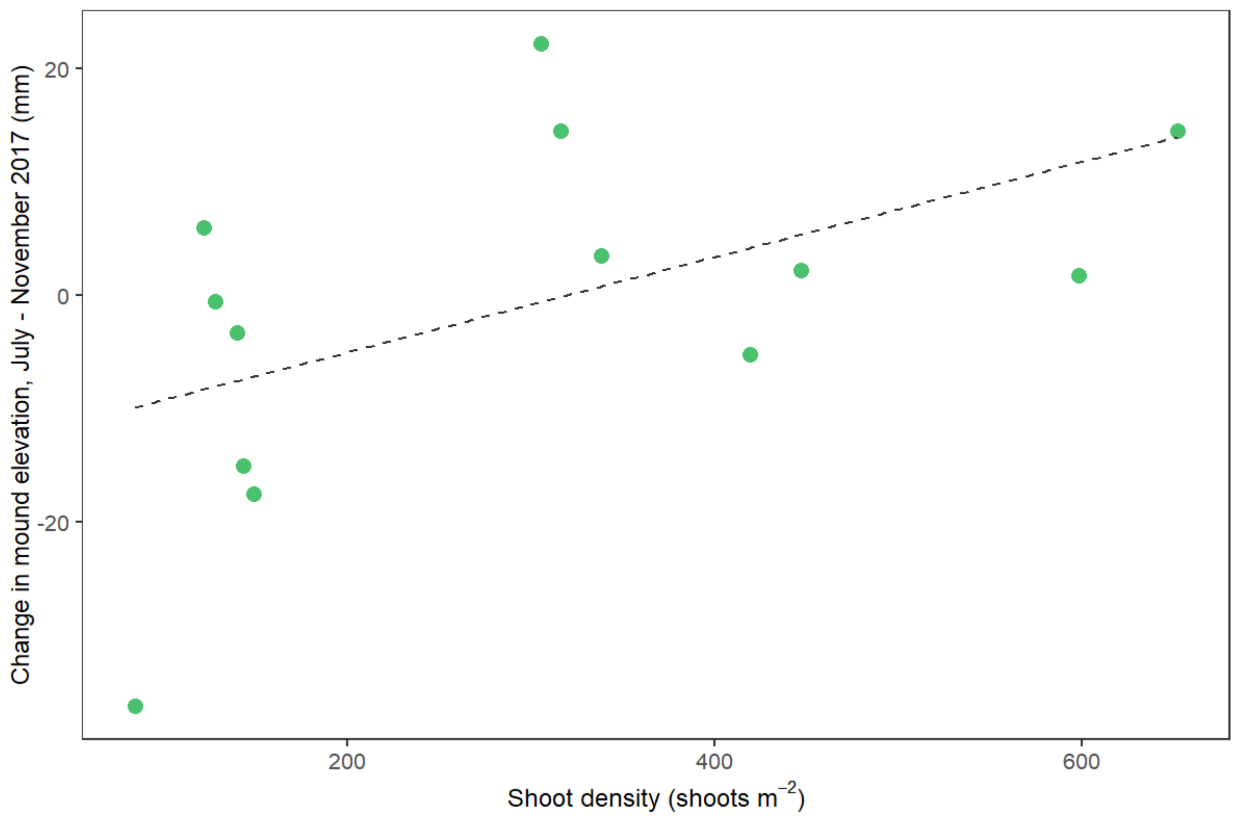


Figure 19. Linear Regression of Mound Spartina Planting and Reduced Mound Erosion Effect
(R^2 = 0.2009, p = 0.07)

5.7.2 Marsh Mound Erosion from Remotely Sensed Monitoring

The second approach to assessing marsh mound erosion is through comparison of mound elevations across the four DEMs. This method provides a site-wide assessment and allowance for splitting mounds by those that were revegetated as part of the SFSU graduate student research and continued later by the Invasive Spartina Project, and those mounds that were not revegetated. It also allows for separating mounds within the main basin more subject to wind-wave erosion and the northeastern “fish tail” basin that has been subject to less wind-wave erosion. Figure 6 shows which mounds were planted in which years by the ISP. Figure 20 plots the average elevations of the tops of the mounds from construction to 2020, separating the mounds by basin and revegetation status.

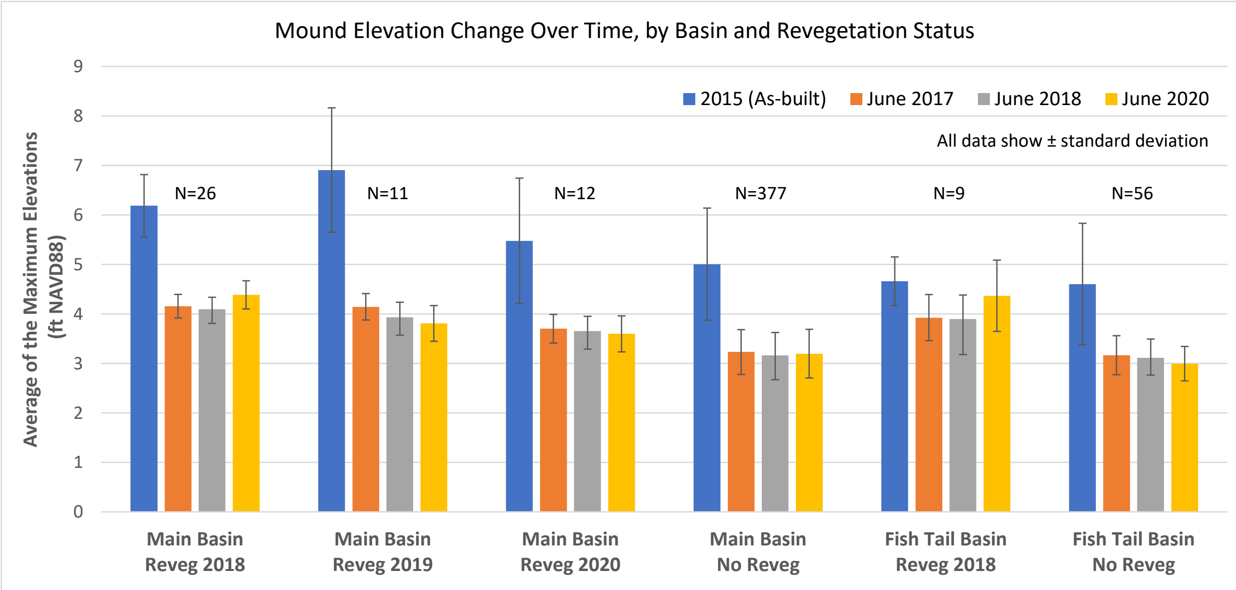


Figure 20. Mound Erosion from DEMs by Revegetation Status and Basin

The mound erosion data generates several considerations:

- The planting of mounds in 2018 in both basins had a significant positive effect on retaining and possibly rebuilding mound elevations by 2020.
- The later revegetation efforts, in 2019 and 2020, did not show a significant effect by 2020. New data in future years may show the influence of that revegetation effort.
- Mounds in the main basin lost more elevation than those in the fish tail basin, regardless of revegetation status. This aligns with the north levee shoreline not experiencing the erosion like that observed in the main basin, and is likely due to the area being more sheltered from wind waves and having a shorter wind fetch.

5.8 Levee Erosion

Erosion of varying degrees has taken place along much of the northern tidal flood control levee, from its west terminus heading east to where the site narrows, and the western levee separating the project from the adjacent Sonoma Baylands restoration project in the reach north of where dredged sediment had been placed during construction (Figure 21). Appendix E presents the levee erosion quantitative data (DU topographic transects and LiDAR-derived scarp locations): Ducks Unlimited surveyed levee transects in May 2017 and October 2018 to assess the extent of erosion along the western “separator” and northern levees, SF Bay NERR extracted erosion scarps from slope data derived from the June 2018 LiDAR topographic data.

Data sources: Air photo (PAS, 2019; NAIP, 2012); project extent/boundaries (GillenH2O, 2021-2022);

1:24,000 (1" = 2,000' at letter size)

0 1,000 2,000 Ft

0 300 600 M

SONOMA LAND TRUST

SIEGEL ENVIRONMENTAL

Sears Point Levee Adaptive Management

Figure 21

Reaches of Levee Erosion

The Project committed major resources to timely restoration of tidal marsh with a costly wide, dissipative terrestrial ecotone (transition zone) to provide specific long-term wildlife habitat functions and biodiversity conservation functions. The progressive erosion of a concave to planar wave-cut bench profile in the wide “habitat levee” (generally 20:1 to 10:1 slope) would create an unintended, adverse abrupt, discontinuous notch or break between terrestrial and tidal marsh vegetation (Figure 22). This abrupt habitat discontinuity would degrade the evolution of the tidal marsh-terrestrial transition zone. Rapid intervention is needed to minimize further development of a steepened, notched (scarped, wave-cut) profile, and establish the original vegetation objectives and shoreline processes as much and as soon as possible. The longer the wave-reflective scarped erosional profile and processes remain in place, the longer the erosion phase is likely to persist, and delay marsh restoration objectives.

Figure 22. Levee Comparisons, Before and After Erosion

Wind-wave erosion of levee benches steepens the initially wide, gently sloping constructed transition zone platform to an enlarging, abrupt, notched (scarped) profile separating high tidal marsh and terrestrial grassland in early stages of primary succession. A-A’: western levee, north end, view to northeast; profile 2015 (pre-breach)-2019 evolution shows the change from a smooth ramp profile to a near-vertical retreating scarp and scour zone above a narrow belt of fringing salt marsh. B-B’, northern levee, central, view to east; barren intertidal profile 2016-2018 shows ongoing erosion and profile steeping to a wave-cut scarp and bench. Periodic wind-wave erosion during the growing season removes pioneer salt marsh plants maintains the barren profile. (Photos and descriptions by Peter Baye)

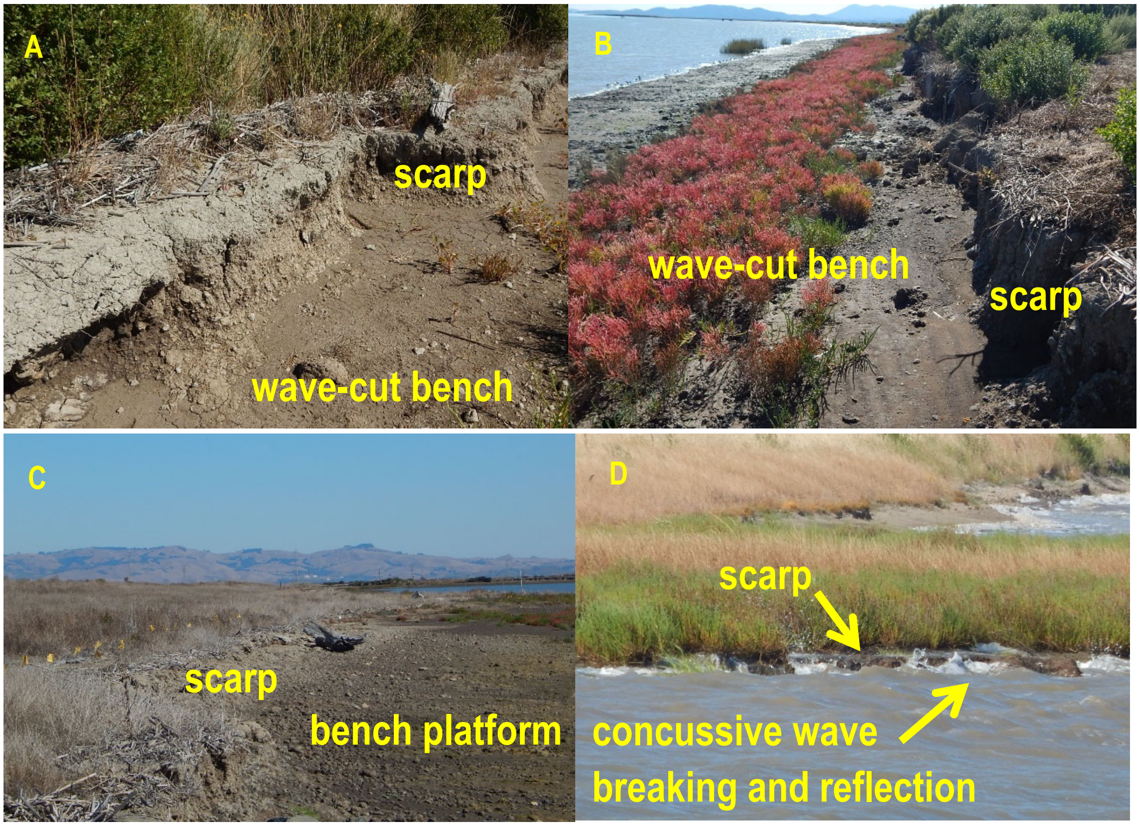


Figure 23. Examples of Scarp Development Around the Site

Actively retreating vertical wave-cut scarps about 0.5-2 ft high form in the northern segment of the western levee (A), and along most reaches of the northern levee at and between constructed pan berms (B, C). Once this steep cliffed profile develops, erosional wave energy concentrates at the scarp and its toe (scour zone) at high tides, when concussive wave breaking and reflection occurs (D). (Photos and descriptions by Peter Baye)

Initiation of wave-attenuating fringing marsh above Mean Sea Level is interrupted by cycles of wind-wave erosion during the growing season as well as in the winter storm season. To establish, seedling and juvenile plant growth and development to critical size (root anchoring and spread) must outpace the rate of surface erosion or undermining by waves by the end of the growing season (Figure 24). Otherwise, persistent eroded barrens develop, and compacted levee foundation substrate (relatively more resistant to root penetration) becomes exposed, and increases vulnerability of pioneer plants. Modification of short-term surface erosion rates within seedling colonies, to enable them to reach critical, resilient individual and patch size, is therefore a potential limiting shoreline stabilization process to integrate with other measures.

Figure 24. Impact to Pioneer Vegetation Establishment
Root systems of pioneer salt marsh plants (A - pickleweed, B - cordgrass) are exposed by rates of erosion that uproot them during the growing season, before plants can establish, anchor themselves, and spread. Uprooted plants wash up on shore (C), leaving exposed, scoured compacted levee foundations that resist root penetration (D) and promote vulnerable, shallow seedling root systems. Summer 2018. (Photos and descriptions by Peter Baye)

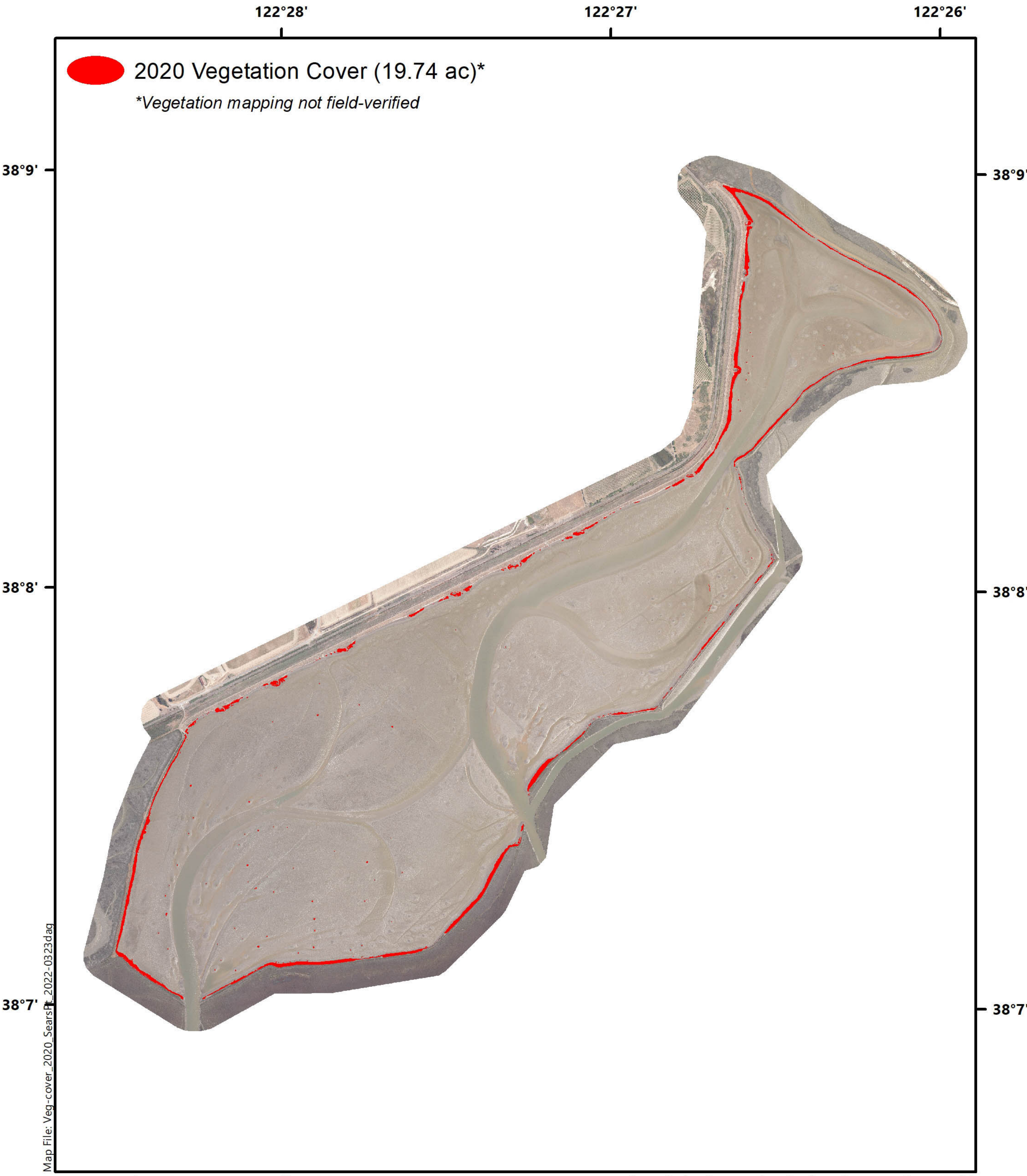
We compiled these data to understand relationships between levee slope, outboard wind-wave buffering features, and erosion extent to adjacent features such as marsh mounds, water depth, and past wind data. Data collection consisted of topographic transects of the levee where erosion has been observed, topographic transects of the winter 2017 debris wrack line deposited on the levee slopes by the extreme high tides and wind waves, wind direction and intensity data from publicly available nearby weather stations, levee aspect from maps, water depth from the baseline topographic data, proximity of wind-wave buffering features (mounds, sidecast ridges), computed fetch distances, construction methods and compaction data, and vegetation presence.

5.9 Vegetation

5.9.1 Intertidal Vegetation – Regulatory Compliance

Regulatory compliance established a performance metric of 30 acres of intertidal vegetation by year 5. Figure 25 shows the extent of this vegetation in 2020, just under 20 acres, meaning that this regulatory performance criterion has not been met.

Figure 25 shows that the vegetation is restricted almost entirely to the margins of the site, along the levees. The Invasive Spartina Project planted 57 of the 490 mounds between 2018 and 2020 (Figure 6), making up a very small proportion of the vegetation by 2020. Figure 25 also shows that the shoreline of the north levee in the "fishtail basin" is fairly continuous and of modest width. This area has not experienced the extensive erosion that occurred in the main basin and caused repeated loss of establishing marsh vegetation, effectively retarding establishment of persistent vegetation communities. This problem triggered the construction of a large adaptive management project in fall 2021 for the purpose of restoring the lower ecotone levee slopes and halting ongoing erosion by installing nature-based shoreline erosion protection features (see Section 5.8).



Map File: Veg-cover_2020_SearsPt_2022-0323dag

Data Sources: Photo (QS, 2020); Veg cover (GillenH2O, 2022)

Sears Point Restoration Project, Sonoma County, CA

June 2020 Vegetation Cover
Intertidal Restoration Area

1:24,000 (1" = 2,000' at letter size)

0 1,000 2,000 Feet

0 300 600 Meters

Sonoma Land Trust
Gillenwater GillenH2O Consulting
Siegel Environmental

Figure 25

5.9.2 Intertidal Vegetation – Western Shoreline

The western levee provided an experiment for assessing the role of shoreline protection in promoting vegetation establishment. The southern half of this levee had dredged material placed in containment cells extending about 300-425 ft out from the levee, to approximate mid-tide elevations (Figure 3 and Figure 12A). This sediment originated from dredging the connector channel between the western breach and deeper waters of San Pablo Bay and the Petaluma River entrance channel. The northern half of the levee had no dredged material placed. The experiment thus allowed comparison of a protected versus unprotected shoreline on erosion and vegetation recruitment.

This “natural” experiment created the opportunity to generate a field study in collaboration with Dr. Kathy Boyer of San Francisco State University. The key questions were: does the shoreline protected by the elevated sediment buffer 1) result in vegetation extending farther out into the bay than the unprotected shoreline; 2) differ in species composition; and 3) is the levee erosion scarp greater in the unprotected shoreline than the protected shoreline. SFSU students and the NERR collected field data on September 25 and October 4, 2019.

The results of this study are quite consistent with our general observations concerning intertidal wetland plant recruitment between 2016 and 2020 in various other shoreline habitats at Sears Point. Scarp height along the protected shore averaged 10 cm (± 7.5 cm standard deviation) whereas along the unprotected shore it averaged 48 cm (± 16 cm standard deviation), a significant difference. The average vegetation transect length for the protected shore was 9.8 m (± 2.1 m) while the average transect length for the unprotected shore was 5.3 m (± 1.7 m) (Figure 26). This meant that there were more plots in the protected shoreline transects (87) versus unprotected (47). In these more constricted zones of vegetation, the unprotected sites had about three times as much annual pickleweed (*Sarcocornia depressa*), much reduced cordgrass and alkali bulrush, and about half the salt grass. This suggests that increased elevation of off-shore sediments is likely to reduce onshore wave energy through lower tide stages and provide a better opportunity for intertidal wetland vegetation recruitment. This, in turn, is likely to create additional buffers to shoreline erosion once the intertidal vegetation becomes well established. See Appendix K for further details.

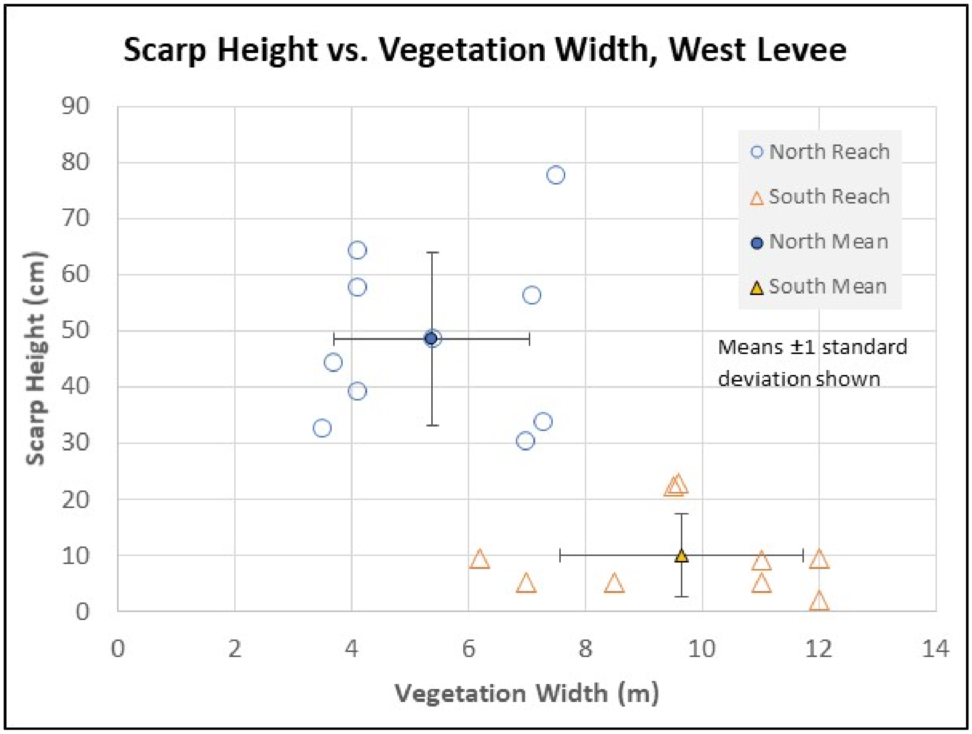


Figure 26. Scatter Plot of Scarp Height to Vegetation Width, West Levee, Fall 2019
Source: Mike Vasey, unpublished (see Appendix K)

5.9.3 Intertidal Vegetation – Observed Patterns Over Time

Though the target of 30 acres total of tidal wetland vegetation within five years of restoration was not reached, tidal wetland vegetation has established where conditions permitted on all intertidal shorelines and the target is likely to be reached within a few years more. In those sites that are subject to heavy wave energy and erosion, intertidal vegetation has not successfully recruited and been sustained. However, each year, particularly as sediment accretion has raised the mudflat elevation of much of Sears Point, there has been an increase of intertidal vegetation especially in the sheltered areas of the site (Figure 25).

Further, along certain key shoreline segments, there are good prospects for tidal marsh expansion into the accreting mudflat (Figure 25). This is particularly true along the southern reach of the west levee associated with the dredged-soil placement cell, the western reaches of the outboard levee between the two breaches and just to the east of the east breach, the northern levee within the fishtail basin, and to a lesser extent the outboard levees in the fishtail basin.

Although wave erosion has denuded some features at Sears Point, such as the mounds, artificial pond shorelines, and vulnerable stretches of unprotected shoreline, these erosion events have generated substantial coarse-grained sediments that have been widely distributed around the shoreline, particularly in wave-protected areas such as the lee side of the artificial pools, and these deposits have proven to provide good recruitment sites for intertidal wetland vegetation. We have observed that during winter storms and harsh conditions, intertidal vegetation declines in abundance. However, each year, it seems to bounce back and increase in cover. Certain special "pioneer" species such as ELPA and SADE appear to be well adapted to boom and bust cycles and generally contribute to the persistence of dominant vegetation such as SAPA and SPFO. These early succession species may well help to stabilize shorelines and provide suitable conditions for the expansion of perennial, rhizomatous species such as SAPA and SPFO. These observations were incorporated into the design and construction of the north and west levee nature-based erosion adaptive management actions. In short, it appears that several places are recruiting and sustaining intertidal wetland vegetation and these are likely to continue to expand, especially as mudflats adjacent shorelines continue to accrete and gain elevation.

5.9.4 Transition Zone Vegetation, Spring 2017

During a survey of T-zone vegetation on April 28, 2017, the following observations were made. From the top of the levee to the high tide wrack line, there is practically one hundred percent cover. Thus, there is presumably a good root mass in the soil and little evidence of erosion along this upper T-zone. The top meter near the levee road was not planted. This zone is primarily dominated by *Festuca perennis* and *Spergula arvensis* along with approximately twelve other species (mostly non-native) contributing to this grassland. There is a relatively broad middle zone (3-4 m) that was ploughed and sown with oat hay, an agricultural crop species widely planted around the north bay shoreline. About half the number of non-native species are found in this zone. At the base of the T-zone levee, there is another area about one meter wide between the cultivated middle zone and the upper wrack line. Dominant species in this zone include *F. perennis* and *Cotula coronopifolia.* This band has some interesting recruits. Several young shrubs of *Baccharis pilularis* have established, particularly in the region of the boat ramp. Occasional occurrences of two unusual wetland species, *Ranunculus muricata* and a native species, *Plagiobothrys bracteatus*, were found in this zone. These species are more typical of inland vernal pools and may reflect the fresher conditions at the high tide line during the wet 2017 winter.

In the intertidal zone between high tides and low tides, there are some interesting recruitment patterns. Where large logs have been stranded, there are patches of *Sarcocornia pacifica* in wind protected areas east of these features. Similarly, the eastern areas in the wind shadow of the artificial pannes are generally heavily vegetated with *S. pacifica* as well as *Atriplex prostrata* and in fine clays in the lower zone, *Spartina foliosa.* Within one of these *S. pacifica* patches, there also was a single occurrence of *Sesuvium verrucosum*, more typical of inland pools. Lower in the intertidal zone some patches of *Spartina foliosa* have established.

Interestingly, the marsh panne features seem to break up the wind wave energy. Wetland vegetation has established very nicely on these features (Figure 25). North and eastern outer zones of the pools are dominated by *F. perennis* and dense stands of *Cotula coronopifolia. Sarcocornia pacifica* and *Spergula arvensis* form mat like vegetation around the south and western outer boundaries. *C. coronopifolia, Jaumea carnosa* and *S. pacifica* dominate the middle and deeper inner zones of the pools. The unusual native annual *Plagiobothrys bracteosa* was found on the low turf like growth on the south outer zone at one of the ponds. It appears that wind wave energy is primarily spent on the south and western boundaries of these features while wave wash then deposits wrack and sediment on the northern and eastern boundary. Again, vegetation in the lower T-zone and intertidal area to the east of these pannes appears to provide protection for vegetation recruitment and establishment.

In the northeastern fishtail basin that is more protected from currents and wind-wave action, there is extensive establishment of *Sarcocornia pacifica, Atriplex prostrate,* and *C. coronopifolia*, with occasional shrubs of *Grindelia stricta* var. *angustifolia,* and recruiting *Frankenia salina* and seedlings of *Jaumea carnosa*. These are classic high marsh species and their presence in this region is very encouraging.

In summary, while efforts to plant the T-zone with rhizomatous grasses was apparently disrupted by the scouring effects of unusually high tides and wind-wave energy during winter and early spring, the upper T-zone from the top of the levee to the upper tide line is densely covered with non-native annual grassland. Where the oat hay is not planted, *F. perennis* (Italian ryegrass) is a dominant and would likely be the dominant grass on the levee if it were not cultivated with oat hay. Some tidal wetland vegetation is establishing in the lower portion of this area where sediments are beginning to accumulate on top of the hard clay substrate that is a residual of the wind wave scouring events. The panne features are developing vegetation rapidly through natural recruitment. The most successful species in this dynamic environment appears to be brass buttons (*C. coronopifolia*), a non-native plant whose impact on native ecosystems has been categorized as “limited” by the Calweed mapper. Another non-native grass (Italian ryegrass or *Festuca* [formerly *Lolium*] *perennis*) appears tolerant of these conditions. If necessary, these two non-native species might be considered for erosion control services. On the mounds, alkali bulrush (*Bolboschoenus maritimus*) is a native species that might be considered for erosion control services.

5.10 Birds

One intended outcome of this project is invigoration of wildlife habitat of Sears Point, which is part of the greater San Pablo Bay National Wildlife Refuge. SLT began monitoring bird populations at Sears Point Restoration Area (SPRA) after tidal influence was reintroduced to the site in October 2015, as one indicator of marshland ecological condition.

The SPRA Monitoring Report (Appendix H) summarizes findings of field surveys to monitor waterbird populations within the site. Teams of biological consultants and citizen scientists conducted seasonal fixed-radius point counts along the SPRA shoreline from 2016 to 2021. Point count data were summarized using population metrics including abundance, density, and species richness. Survey results indicate patterns of increased avian richness and abundance—suggesting that as the site matures, the diversified habitat types within the site can sustain both over-wintering and breeding avian populations.

The SPRA provides important habitat for migratory and over-wintering bird shorebird species. Shorebirds were abundant during the fall and winter months in all years of surveying, with especially large numbers of Least Sandpiper, Dunlin, Willet, Western Sandpiper (a species thought to be declining throughout the Bay), American Avocet, Marbled Godwit, Black-bellied Plover, and Long-billed Dowitcher. The newly created mudflat and shallow water have successfully attracted diverse shorebird members in need of roosting and foraging habitat during the non-breeding season.

The expanses of open water within SPRA attracted numerous duck species during the spring, fall and winter surveys. There were greater numbers of diving than dabbling ducks overall, specifically Canvasback, Ruddy Duck, Greater Scaup, and Bufflehead. Future monitoring could help elucidate whether the site can sustain diving duck populations as the site fills with sediment and transitions from deep water to shallow mudflat habitat. The diverse over-wintering bird species present at SPRA suggest that it serves as a localized refugium in the face of ongoing development and challenging drought conditions throughout the Bay. In addition, Ruddy Duck, Gadwall, and Mallard were present during the spring and summer months, indicating SPRA provides breeding territory for these species. Breeding waterfowl population numbers will likely increase as high marsh habitat develops via sediment accretion and plant colonization.

SPRA is still in the early stages of its evolution as a tidal marsh. Though survey data represent an array of feeding guilds indicative of a healthy ecosystem, this is only a short-term diagnosis reflecting this early stage of evolution. There is much to learn about the avian community onsite as the landscape evolves and is affected by the changing climate. Ongoing surveying at the SPRA will contribute important data about the processes and implications of tidal marsh restoration and can raise public awareness via participation of the monitors serving as citizen scientists.

5.11 Fish

Appendix I presents the results of the 2017-2018 fish monitoring. Below is the executive summary from that appendix.

The Sears Point Wetland Restoration Project (Project) is one of the largest tidal marsh restoration projects along the Pacific Coast and has resulted in a 940-acre tidal marsh basin that, until recently, was diked off from San Francisco Bay (Bay) for over 140 years. Project partners (Sonoma Land Trust, National Oceanic and Atmospheric Administration [NOAA], National Marine Fisheries Service [NMFS], United States Fish and Wildlife Service [USFWS], and Ducks Unlimited [DU]) incorporated several novel design features (e.g., marsh mounds, sidecast ridges, rootwads, flooded remnant terrestrial vegetation) to decrease restoration time (via sediment accretion) and provide habitat complexity for a broad range of wetland organisms. The Project partners also incorporated a strong scientific basis into the design and restoration of the Project, emphasizing monitoring to evaluate restoration success and address uncertainties. This document describes results of fish monitoring activities conducted in 2017 with the overall goal of determining the relative abundance, habitat use, and species assemblage of the fish community in the recently restored subtidal habitat. To address this goal, several objectives were identified, which included:

- Use ARIS technology to determine relative abundance of fish in various subtidal habitats throughout the Project;
- Use traditional fish sampling methods to identify and describe fish species present and their relative abundance for comparison to ARIS results; and
- Interpret fish survey data from the current Project and compare with other restored wetland habitat restoration projects in the Bay.

Dual methodology sampling was conducted using an Adaptive Resolution Imaging Sonar (ARIS) camera as well as traditional sampling (seine and trawl) methods in the spring (May) and fall (October) of 2017. Sampling was designed to encompass five subtidal habitat types: sidecast ridge, marsh mound, levee transition slope, flooded remnant terrestrial vegetation, and rootwads. Monitoring consisted of both stationary (nine sites) and transect survey (eight transects) methods; each site and transect consisted of sampling initially with the ARIS, immediately followed by the deployment of traditional sampling gear (i.e., beach seine or otter trawl). In both cases, the ARIS continued to operate throughout the traditional sampling efforts to characterize fish avoidance behavior and relative capture efficiency. Water quality measurements were recorded at each sampling location and included water temperature, dissolved oxygen, salinity, pH, and turbidity.

During ARIS monitoring, a total of 14,358 fish was observed over the course of two sampling events at the Project. Substantially higher fish abundance was observed in fall (n = 12,766) compared to spring (n = 1,592). Over both sampling events, more fish were observed during stationary surveys (n = 10,062) than during transect surveys (n = 4,296), which was in part due to the longer duration of stationary surveys. However, despite the longer duration, more fish were observed per minute during stationary surveys (14.0 fish per minute) than during transect surveys (9.0 fish per minute).

A total of 1,568 fish (18 fish species) was collected by beach seine and otter trawl over the course of two seasonal sampling events; more fish were collected during beach seine surveys (n = 1,342) than during otter trawl surveys (n = 226). Three crustacean species were also collected (n = 2,831). Fish were more abundant during the fall sampling event (n = 977) compared to the spring sampling event (n = 591). While the beach seine catch in fall (n = 901) was nearly double the spring catch (n = 441), the otter trawl catch in fall (n = 76) was about half that of the spring catch (n = 150).

Eighteen fish species and three crustacean species were collected during the beach seine and otter trawl monitoring program. The fish community in spring was dominated by native Bay Goby, Starry Flounder, Topsmelt, and Pacific Staghorn Sculpin. Non-native gobies (Chameleon, Shimofuri, Shokihaze, and Yellowfin) and Striped Bass were also abundant. In fall, the native Topsmelt and Pacific Herring accounted for about 88 percent of the entire fish catch. Striped Bass was the most abundant non-native fish, followed by Chameleon and Yellowfin gobies. Two additional fish species, White Sturgeon (Green

Sturgeon not likely) and Bat Ray, were visually observed by field crews but were never collected. Native fish species were most abundant in the beach seine catch (89.1 percent and 95.2 percent of all individuals in the spring and fall, respectively) as compared with the otter trawl catch, with only 31.3 percent and 39.5 percent of all individuals in the spring and fall, respectively. The differences depended upon the habitat where the species were observed (shallow, channel margin habitat vs. deep water habitat).

The results of this study indicate that the Project is already providing valuable aquatic habitat for a variety of native and non-native species. Fish were observed using multiple sampling gear types in a variety of different habitats throughout the Project area. Substantially higher fish abundance was observed during the fall sampling event compared to the spring sampling event for both ARIS and traditional sampling methods.

Sidecast ridges and levee transition slope sites appeared to provide the best habitat for fish as observed by both the ARIS and traditional sampling gear. Overall, fish presence at all habitat types during early phases of habitat restoration signifies the benefits of habitat complexity. This is consistent with findings at other restored areas in the Bay such as the Tolay Creek Restoration Project and the Napa Plant Site Restoration Project.

As the Project area continues the trajectory of accumulating sediments, more plants, invertebrates and other aquatic organisms will begin to occupy the Project area and complex habitats will mature, all of which will provide improved conditions for the fish community. It is expected that nursery habitats (i.e., juvenile rearing) will continue to improve for fishes such as Starry Flounder, California Halibut, Pacific Herring, gobies, Topsmelt, and crangonid shrimp, all species that depend upon this currently limited habitat for increased production. Many of these species, such as Topsmelt, gobies, and crangonid shrimp, provide important forage for larger, mobile fishes such as Striped Bass, Green Sturgeon, White Sturgeon, and Chinook Salmon which will likely increase utilization of the Project in years to come.

The dual sampling methodology described in this document is a novel approach to sampling in the San Francisco Bay and Delta. This methodology allowed for an in-depth examination of the fish fauna throughout the variety of subtidal habitats. For example, greater abundance of fish (especially larger individuals) was observed with the ARIS camera than with traditional sampling techniques, which is at least partially illustrative of the differences in capture (or detection) efficiency between the two sampling methods. Additionally, the ARIS was able to detect species in habitats (i.e., flooded remnant vegetation) that was difficult to sample with traditional sampling gear. Conversely, the traditional sampling gear was more effective in collecting data on smaller fish species that were much more abundant in shallow water and channel margin habitat. Furthermore, traditional sampling was necessary for identifying species and examining native vs non-native species assemblages.

6 Key Findings, Conclusions and Lessons Learned

Table 10. Key Findings, Conclusions, Lessons Learned

Key Finding	Conclusions	Lessons Learned
Insufficient shoreline erosion protection measures at time of breach resulted in significant levee and marsh mound erosion, compromising restoration goals	Establishment of tidal marsh and ecotone vegetation communities impaired by episodic and repeated erosion events of shoreline and marsh mounds. Tidal flood protection functions were not compromised by the time adaptive management measures implemented in Fall 2021.	Establish sufficient shoreline erosion protection measures, especially nature-based, prior to restoring tidal action to subsided baylands sites. Examples include pre-vegetation and use of fill materials to create berm bayward of shoreline.
High deposition rates promoted rapid accretion toward marsh elevations	Restoration predictions were correct and were based on prior findings from nearby restoration projects	In locations with high available natural sediment supply, focus design on promoting accretion and protecting at-risk elements such as levees
Targeted use of dredged materials proved very effective at promoting restoration objectives. Containment ponds (250-400 ft wide with sediment placed to about +3 ft or mid tide level).	Dredged material placement promoted shoreline tidal vegetation recruitment and together these two features sheltered the southern west levee from wind waves erosion	Strategic on-site reuse of locally dredged materials can effectively promote early tidal marsh establishment and to protect constructed habitat levee slopes. Had the dredge spoils ponds been located at the north of the west separator levee dedicated to public access uses, erosion of this required levee section may not have occurred and thus would not have required fixing as part of the adaptive management project in fall 2021.
Dredging the outboard connecting channel to deep	Providing full tidal exchange at the outset greatly sped accretion rates by allowing maximum sediment influx. It	Designing in full tidal exchange at project breach is essential to promoting rapid progress

Key Finding	Conclusions	Lessons Learned
water allowed full tidal exchange at the outset	also made the site fully accessible to aquatic organisms from day 1.	toward restoration objectives. Resulting rapid accretion greatly enhances the ability to be resilient to sea level rise.
Tidal flood protection levee remains intact	The engineering design and construction of the core tidal flood protection levee met design requirements	Geotechnical design of tidal flood control levees is effective. Important to provide erosion protection for overlaying habitat levee to minimize risk of encroachment into the core flood protection levee
Mounds eroded rapidly	Unvegetated, unconsolidated soils easily eroded in high wind-wave setting. Mounds eroded 1-2 feet within first year.	Vegetate two or more seasons before breach using managed water levels to encourage brackish marsh vegetation establishment, as designed
Northern and western levee eroded rapidly	Absence of erosion protection measures leaves levee at risk. Core flood protection levee intact, habitat levee impaired	• Complete erosion protection measures before breach – vegetated mounds and levee • Cannot assess design efficacy
Northeast basin self-connecting to Upper Tolay Lagoon restoration	Narrow levee surrounded by tidal open water basins on both sides subject to erosion	• Work with nature (breach in original design not constructed due to concern of increased volume of water at Highway 37 that might exacerbate flooding)
Wind waves hamper vegetation establishment	There has been some success with *Spartina foliosa* plantings on the marsh mound surfaces but establishment has been difficult. Nonetheless, over time, survival on some of the mounds is likely to lead to long term clonal spread and these mounds may ultimately serve as reservoirs of *S. foliosa* rhizomes and seeds that will help to spread this species to other mounds and suitable habitat around the site perimeter. Wind wave scouring along the upper transition zone has apparently caused unexpected	Inclusion of erosion protection features are an essential feature to promote the ecological development of the restored shoreline and mounds as well promote the integrity of the constructed habitat levee. Absence of erosion protection features results in periodic erosion events that scour away establishing vegetation, repeatedly setting back the ecological development.

Key Finding	Conclusions	Lessons Learned
	impacts to the planted *Leymus triticoides* and *Distichlis spicata* rhizomes. The middle intertidal area of the T-zone is attracting recruitment by *Sarcocornia pacifica, Atriplex prostrate,* and other salt marsh species, especially where coarse sediments have been deposited (or fine sediment scoured away leaving coarser materials behind) and are protected by wave buffers (such as drift logs and, particularly, on the lee side of the artificial panne projections). *S. foliosa* is establishing sporadically in fine sediments deposited along the lower intertidal portion of the T-zone.	
High marsh and transitional vegetation repeatedly disturbed along eroding northern and western levee	Establishment of ecotone vegetation community repeatedly impaired, precluding achievement of ecological objectives	Erosion protection for habitat levee necessary to avoid prolonged state of disturbance and curtailing development of target ecological functions
Outboard levee has experienced significant erosion	Old levee not providing significant physical or ecological functions so erosion not of concern	Ok to allow old features to fall to forces of nature
Vegetation self-establishing around site margins where elevations suitable and erosion protection shelters the substrate	Natural colonization processes effective in locations where wind wave disturbance minimized	Areas protected from wind waves effective at promoting vegetation establishment
Sheltered northeast portion of site (“fish tail”) developing perimeter vegetation rapidly	The northeastern portion of the habitat levee appears more protected from wind-wave scour than the long western area. The intertidal area of this levee reach is vegetating well with *S. pacifica, Jaumea carnosa, Grindelia stricta* var. *angustifolia,* and other salt marsh species. This area will serve to contrast vegetation colonization in the main basin reaches of the north levee. Similarly, mounds in the fish tail basin will serve to	Areas protected from wind waves effective at promoting vegetation establishment

Key Finding	Conclusions	Lessons Learned
	contrast vegetation establishment in the main basin mounds.	
Noxious weeds control appears most effective through competitive exclusion vs. herbicide use.	Herbicide treatment to control Dittrichia causes chronic disturbance and ongoing cycle of invasion. In contrast, establishment of dense mats of native mat-forming vegetation (e.g., *Leymus triticoides*) has effectively precluded significant noxious weed establishment. More recent invasion by Alligatorweed (*Alternanthera philoxeroides*) is establishing on the north levee. Method to prevent spread currently being assessed.	Utilize perennial mat-forming grasses for competitive exclusion of *Dittrichia* and other weeds in place of herbicide treatments alone, and monitor efficacy.
Fish and wildlife use has been extensive and reflects the evolving stages of elevation and mudflat, marsh and ecotone formation.	Sears Point has been very effective at providing tidal aquatic and mudflat ecological functions from the outset, with these functions adjusting over time as accretion changed the timing and characteristics of substrate inundation and exposure.	“Build it and they will come” applies here – creating the geomorphic, tidal connectivity, substrate, and rapid site evolution conditions is very effective at promoting fish and wildlife use.
The ecological benefits provided by Sears Point within a landscape mosaic of restored and natural wetlands greatly benefits fish and wildlife populations.	Sears Point functions as a component of a larger regional landscape complex of restored and natural marshes. With each site having different starting elevations, rates of evolution, and connectivity the bay, they collectively provide a complex landscape mosaic that provides significant ecological benefits to a variety of fish and wildlife species, thereby promoting their resilience and recovery.	Restoring a variety of sites within a broad landscape mosaic with each providing complementary habitats Fish and wildlife benefit the most from a varied suite of habitat types within a larger landscape context.
High marsh pans had mixed results ecologically, their design intention being to provide seasonal shallow aquatic habitats	Early vegetation included some vernal pool species, indicative of the targeted habitat types. Over time, though, most became dominated by pickleweed. Some pannes experienced perimeter erosion.	More attention to pan substrate conditions (compaction, sandy alluvium over clay) and geomorphology (gentle gradients without abrupt berms) would improve ability to achieve targeted outcomes

References

Buchbinder, M.V. 2018. Facilitating ecological recovery of a salt marsh restoration site through active revegetation. Master's thesis, San Francisco State University

CLE Engineering. 2017. Sears Point Wetland Restoration Condition Bathymetric Survey Field Data Collection Procedures. Prepared for Siegel Environmental. February.

Ducks Unlimited. 2016a. Record Drawings, Phase II Construction. Prepared for the Sonoma Land Trust.

______. 2016b. Record Drawings, Phase III Construction. Prepared for the Sonoma Land Trust.

______. 2020a. Sears Point Spartina Planting, Phase 2 Project Summary Report. Prepared for the Sonoma Land Trust. September 24.

______. 2020b. Sears Point Restoration Area Spartina Monitoring Memo. Prepared for the Sonoma Land Trust. August 3.

______ and D. Edelstein. 2022. Sears Point Restoration Area 2016-2021 Avian Monitoring Report. Prepared for the Sonoma Land Trust. February 22.

Freeman, K. 2019a. Sears Point Levee Planting Project Memo. Prepared for Sonoma Land Trust. August 21.

______. 2019b. Sears Point Restoration Area Spartina Monitoring Memo. Prepared for the Sonoma Land Trust. November 8

HELIX Environmental Planning and FISHBIO. 2018. Sears Point Restoration Project Fisheries Monitoring. Prepared for Ducks Unlimited. February.

Pacific Watershed Associates. 2018. Final memo report of work for the Creeping Wild Rye (Elymus triticoides) Levee Planting Project as part of Sears Point Wetlands and Watershed Restoration Project, 2100 Highway 37, Sonoma County, California. Prepared for the Sonoma Land Trust. March 23.

______. 2019. Final memo report of work for the Creeping Wild Rye (Elymus triticoides) Levee Planting Project, Phase 2 as part of Sears Point Wetlands and Watershed Restoration Project, 2100 Highway 37, Sonoma County, California. Prepared for the Sonoma Land Trust. January 21.

Quantum Spatial. 2017. Sears Point, California LiDAR Technical Data Report. Prepared for the Sonoma Land Trust. August 30.

______. 2018. Sears Point 2018, California Topobathymetric LiDAR and Orthoimagery Technical Data Report. Prepared for the Sonoma Land Trust. August 20.

______. 2020. Sears Point, California LiDAR and Imagery Technical Data Report. Prepared for the Sonoma Land Trust. August 6.

Regional Water Quality Control Board. 2013. Order No. R2-2013-0027. Issued to the Sonoma Land Trust. May 13.

Salas, L., M. Fitzgibbon, T. Fonseca, M. Herzog, G. Ballard, D. Moody and N. Nur. 2010. The Analyst: Data analysis tool for the California Avian Data Center. [web application]. Petaluma, California. http://data.prbo.org/apps/analysts/ (Accessed: 4 October 2019).

San Francisco Bay Conservation and Development Commission. 2013. Permit No. M2012.022.00. Issued to the Sonoma Land Trust. December 6.

Shelterbelt. 2017. Sears Point Tidal Marsh Levee Weed Management 2016 Summary Report. Prepared for the Sonoma Land Trust. April.

Siegel Environmental. 2020. Sears Point Levee Adaptive Management Project Description for Regulatory Authorization Request. Prepared for the Sonoma Land Trust. February.

_____. 2022. As-Built Report, Sears Point Levee Adaptive Management Project Plan. Prepared for the Sonoma Land Trust. March.

Spye General Engineering. 2020. Sears Point Creeping Wildrye Levee Planting Project, Phase III. Prepared for the Sonoma Land Trust. January 17.

_____. 2021. Project Completion Report, Cordgrass and Bulrush Plantings within Sears Point Wetlands. Prepared for the Sonoma Land Trust.

_____. No date. Rapid, Large-scale Rhizomatous Grass Plantings in San Francisco Bay Tidal Wetlands. Presentation.

The State of the Estuary 2015, San Francisco Estuary Partnership. https://www.sfestuary.org/wp-content/uploads/2015/10/SOTER_2.pdf

U.S. Army Corps of Engineers. 2013. Permit No. 2011-00152N. Issued to the Sonoma Land Trust. September 4.

U.S. Army Corps of Engineers. 2015. Baseline topographic survey notes and data. Transmitted via email.

Wetlands and Water Resources, Inc., Farwest Restoration Engineering, Vollmar Consulting, P. Baye, and H. Spautz. 2007. Sears Point Wetlands and Watershed Restoration Project Final Preliminary Plan. Prepared for the Sonoma Land Trust. February.