Hester Marsh Restoration: Annual Report

May

2022

Elkhorn Slough National Estuarine Research Reserve

Annual report summarizing the changes in conditions at Hester marsh after implementation of a major restoration project – marsh creation via soil addition

Construction status: Construction Started
Phase I Construction start date: December 11,2017
Phase I Earth moving end date: August 8, 2018
Phase I Construction end date: March 12, 2019
Phase II Construction start date: 24 August, 2020
Phase II Earth moving end date: 29 December 2021
Phase II Construction end date: Planting still in progress

Fountain, M., Jeppesen, R., Endris, C., Woolfolk, A., Watson, E., Aiello, I., Fork, S., Haskins, J., Beheshti, K., Pausch, R., Tanner, K., Thomsen, A., Wilburn, B., Krause, J., Eby, R., Wasson, K. Hester Marsh Restoration. Annual Report 2021. Elkhorn Slough National Estuarine Research Reserve. Available from https://www.elkhornslough.org/tidal-wetland-program/

Table of Contents

EXECUTIVE SUMMARY

The Elkhorn Slough Tidal Marsh Restoration was a large-scale estuarine restoration project undertaken in Elkhorn Slough, Monterey County, central California. The project was a 147-acre (60 ha) restoration of an integrated coastal landscape, ranging from tidal creeks to salt marsh to adjacent grassland. Phase I was implemented in 2018 and included 61 acres (24 ha) of tidal marsh and 5 acres (2 ha) of coastal grassland. Phase II was implemented in the fall of 2020 and includes an additional 29 acres (12 ha) of tidal marsh and 5 acres (2 ha) of coastal grassland. Phase III includes a final 29 acres (12 ha) of tidal marsh and 3 acres (1.2 ha) of coastal grassland. The remaining 15 acres (6 ha) of borrow area will be restored as funding permits. Phase II is very near completion at the time of this report writing and Phase III is slated to start in the fall of 2022. Soil addition has increased marsh plain elevation in a formerly diked marsh that had degraded to shallow mudflat over the past half century. A high elevation target was set for most of the marsh landscape to allow for resilience to rising sea level. Monitoring revealed that construction met the elevation targets and subsequent elevation loss was limited. The project area now includes the most extensive high marsh landscape in Elkhorn Slough, Monterey, CA. Major tidal creeks were excavated at a similar density and configuration to historical conditions.

Revegetation of most of the marsh was anticipated to occur through colonization of water-borne seeds. The highest portion of the Phase I marsh, at the marsh-upland ecotone, was revegetated with 17,000 greenhouse-grown marsh plants in six blocks, with every plant part of an experimental treatment. The Phase II marsh was planted with 400 marsh plants as a part of freshwater addition and soil modification experiments. The Phase I grassland restoration includes 13 acres (5 ha) and 9 species grown from seed and greenhouse-grown plants. Phase II grassland restoration includes 3 acres (1 ha), and was planted with over 20,000 native grasses and wildflowers, and seeded with 65 lbs. of native flower and grass seed. Monitoring included many components, including elevation, water quality, marsh plant recolonization by seeds, outcomes of marsh and grassland planting, and animal use of the project area. Monitoring will continue over the next decade to track the development and maturation of habitats. (https://www.elkhornslough.org/tidal-wetland-program/hester-marsh-restoration/).

Compliance Summary

This post construction report has been prepared in compliance with State and Federal grant guidelines as well as terms and conditions listed in the following project permits:

§ U.S. Army Corps Engineers – Clean Water Act Section 404 Nationwide Permit authorization

§ Central Coast Regional Water Quality Control Board – Water Quality Certification

§ California Coastal Commission, Central Coast District - Coastal Development Permit waiver

§ California Department of Fish and Game - Lake or Streambed Alteration Agreement

§ National Marine Fisheries Service – Incidental Take Permit / Biological Opinion (ESA) and Incidental Harassment Authorization (MMPA)

§ U.S. Fish and Wildlife Service – Incidental Take Permit / Biological Opinion

We have compiled a single post-construction report to satisfy all specific permit conditions. Since several of the post-construction monitoring requirements overlap and serve multiple purposes, we thought it useful to provide all the information in a single report for wide distribution. No amphibians or marine mammals were injured during the project (See Appendix 1, p. 1, Appendix 2, p. 13, and Appendix 3, Appendix 12). No delays or extreme measures were necessary to ensure compliance. To date, no long term adverse impacts to water quality have been detected within the project area. All Best Management Practices and Mitigation Measures outlined in the above permits were implemented.

Monitoring Summary as of April 2022

The project is currently monitored using remote sensing combined with traditional field ecology methods. Remote sensing includes UAV imaging of area elevation and tidal channel formation. Traditional monitoring includes monitoring of water quality using sondes, determining plant species identity, percent cover of vegetation, canopy height, and above ground biomass along transects in the marsh, at which we also monitor sediment deposition, and below ground carbon content. Finally, we monitor landscape changes using point photography, and animal community surveys include area bird and marine mammal counts. The success criteria for the project are outlined in the monitoring plan (Appendix 4) and in the Project Objective Status below.

As of April 2022, the project area elevation at Phase I and II are currently on target, without much loss in elevation since earth-moving was completed in August 2018 and December 2021, respectively. Compaction that has occurred was in deep zones, not in the added soil, and little erosion has been documented.

In Phase I, monitoring has revealed that survival and growth of the 17,000 marsh plants placed in six blocks in the highest portion of the marsh has been good. Higher cover was achieved with widely spaced plants than clusters – competition was more important than facilitation. For some species, survival and growth increased with elevation (highest near the top of the blocks). In Phase II, initial survival of marsh plants is good.

In the unplanted marsh plain at Phase I, thousands of marsh plants have colonized, especially at high elevations and near creeks. The most common of these is the marsh dominant, *Salicornia pacifica*. *Spergularia marina* is also well-represented. Three other native marsh species (*Frankenia salina, Distichlis spicata, Cressa trexillensis*) have appeared at low abundance, as have two common non-native marsh species (*Parapholis incurva, Atriplex prostrata*). The size of all these marsh plants is still small, so bare ground still dominates the landscape at this stage, particularly at intermediate elevations where salinity stress may be highest. Overall, cover by colonizing vegetation in monitoring transects increased dramatically at first, then tapered off (0% in summer 2018, 16% in 2019, 28% in 2020 and 2021). The unplanted marsh plain in the nearly completed Phase II appears to be recruiting similar to, or better than, the first year of Phase I.

On the newly restored marsh plain, we have observed an abundance of animal tracks, from raccoon, rabbits, and sea otters, to lizards, birds, and even crabs. Sea otters are observed in the main channel, and hundreds of shorebirds are frequently observed resting near the channel edge, especially at high tides when the lower marshes elsewhere in the estuary are submerged.

We evaluated the "blue carbon" function of Hester Marsh, nearby references marshes, and marshes that were previously diked and subsided, focusing on mudflat, high marsh, and the marsh-upland ecotone. Three years after soil addition with 29% vegetated cover, our results show some carbon is being sequestered by the new marsh, but it will be many years until it reaches its full potential, since establishment of a mature marsh with high above and belowground biomass takes time. Deposition of carbon in sediment during flooding tides is very limited due to the intentionally high elevation of this climate-resilient marsh plain. Emissions of nitrous oxide and methane were greater at lower elevations, but higher elevations were typically sinks for these gases. Nitrous oxide emissions - though small and variable - appeared to offset a significant portion of the climate change mitigation function of these wetlands due to its high global warming potential. We expect that once fully vegetated these emissions will be reduced. Reducing nitrogen inputs into coastal estuaries would likely have important climate change mitigation benefits. Our results also suggest that drowned marshes may preserve their carbon sequestration function even as they convert to mudflats and bare ground, although more study is needed to confirm this finding due to the unvegetated aspect of these marshes. We will continue to study the progress of this restoration project to adaptively manage where possible to achieve targets, and to inform future restoration projects.

In the uplands native grass seeds were collected locally at grass farms and from the local watershed. Individual plants were raised in the ESNERR greenhouse and by a contracted nursery, resulting in 18,000 locally sourced grass plugs and over 100 pounds of native grass seed being planted within 5 acres (2 ha) of the Phase I upland. Survivorship and growth is good. The Phase II grassland was planted with over 20,000 native grass and wildflower plugs and seeded with 65 lbs. of native grass and wildflower seeds between December 2021 and March 2022. To date, plug survival and seed germination in the Phase II grassland look good.

PROJECT BACKGROUND INFORMATION

Problem statement

The project sought to restore a resilient coastal ecosystem, from tidal creeks to marsh plain and adjacent coastal grassland. These formerly ecologically rich habitats, which hosted a suite of native species and provided essential filtering function between the upland agricultural fields and the waters of Elkhorn Slough were in a landscape that had been degraded due to human land uses primarily the diking and draining of wetlands. Our project was designed to restore a resilient coastal ecosystem, reduce greenhouse gasses, and improve important estuarine habitat. This project, comprised of three phases - Phase I, II and III - was part of a larger plan to restore about one hundred nineteen acres (48 ha) of tidal marshes in Elkhorn Slough and an adjoining twenty-eight acres (11 ha) of existing buffer areas to perennial grassland. Phase I consisted of land acquisition, planning (for the entire project), permitting (for most of the project), obtaining soil for the overall restoration work, placing soil on 47 acres (19 ha) of degraded habitat and creating 14 new acres (5 ha) of marsh from scraping. Phase II consists of refining the design based on lessons learned from Phase I, additional permitting, and placing soil on approximately 26 acres (10 ha) of degraded habitat and creating 3 new acres (1.2 ha) from scraping. Phase III consists of placing soil on approximately 29 acres (12 ha) of degraded marsh. Eelgrass and oyster restoration components are also included in Phase II and III.

By the completion of Phase I, II, and III we will have restored about 119 acres (48 ha) of tidal salt marsh and 28 acres (11 ha) of coastal perennial grassland buffer in the southern area of Elkhorn Slough. Phase I construction was completed spring, 2019. Anticipated date of completion for Phase II is fall 2022. Anticipated start date of Phase III is fall/winter 2022.

Project location and site history

The Elkhorn Slough estuary is one of the largest estuaries in California. The slough provides important habitat for an exceptionally broad range of resident and migratory birds, fish, and other wildlife, and plays a crucial role in the local estuarine and nearshore food web. Elkhorn Slough estuary is located on the central California coast, in Monterey County (Fig. 1). The Project area is located in the south western part of the estuary (Fig. 2)

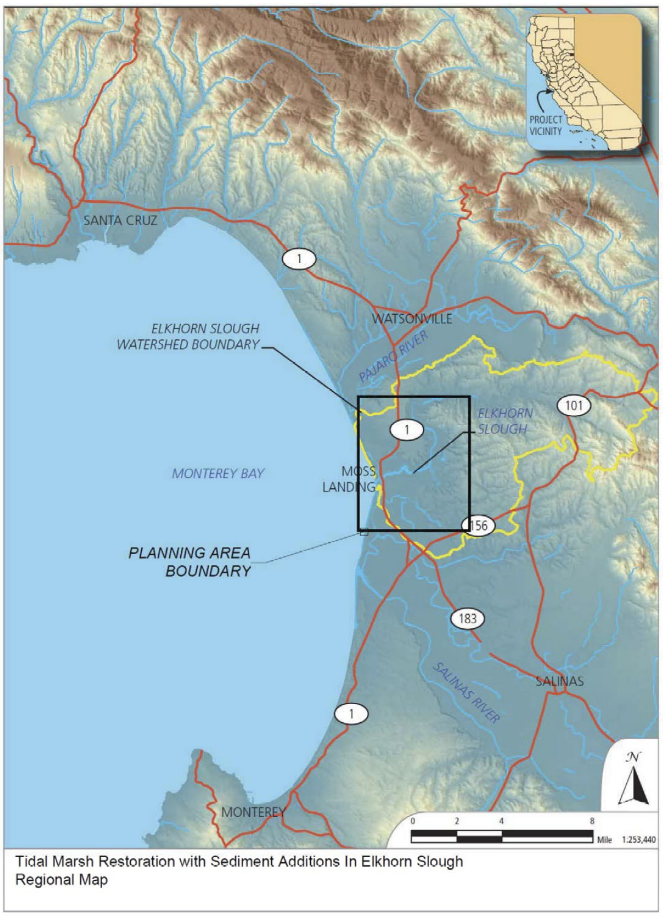


Fig. 1. Elkhorn Slough estuary in Monterey Bay, central California.

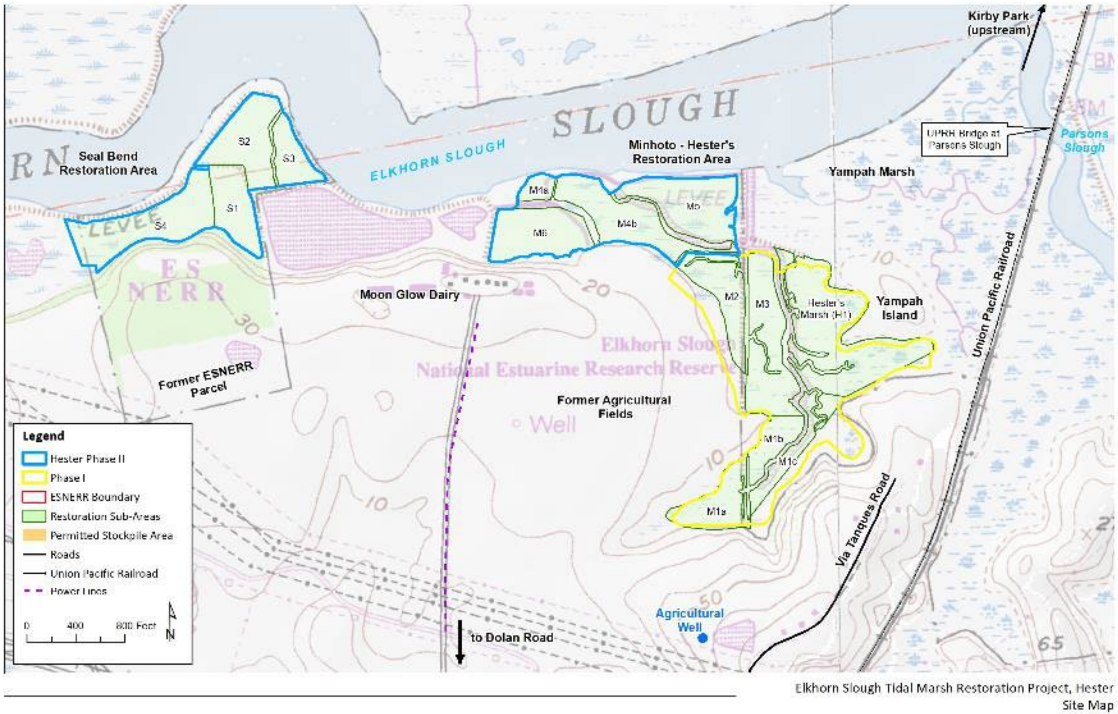


Fig. 2. Project area at restoration site, Hester marsh

The Elkhorn Slough Tidal Marsh Restoration Project will ultimately restore about 147 acres (48 ha) of salt marsh ecosystem in Monterey County. Phase I restored 47 acres (19 ha) of degraded marsh, and created 14 acres (5.7 ha) of new marsh, and 5 acres (2 ha) of upland ecotone and native grassland within the buffer area. Phase II will restore about 26 acres (10 ha) of marsh, create 3 acres (1.2 ha) of new marsh and 5 acres (1.2 ha) of perennial grassland. Phase III will restore 29 acres (12 ha) of degraded marsh, and 3 acres (1.2 ha) of perennial grassland. The remaining 15 acres (6 ha) of the borrow area will be restored to perennial grassland as funding permits.

The Elkhorn Slough watershed encompasses approximately 45,000 acres (18,211 ha). The Elkhorn Slough Ecological Reserve is owned and managed by the California Department of Fish and Wildlife (CDFW). Those lands are also designated as ESNERR with administrative and research funding provided by the National Oceanic and Atmospheric Administration (NOAA) to CDFW through the Elkhorn Slough Foundation (ESF). ESF is an accredited land trust and partner to CDFW. ESF owns nearly 3,565 acres (1,443 ha) and manages conservation easements on an additional 300 acres (121 ha) of private land in the Elkhorn Slough watershed (Contreras, pers. Comm., Elkhorn Slough Foundation, 2014). A large portion of Elkhorn Slough is designated by CDFW as the Elkhorn Slough Marine Protected Area. The boundary of this designation extends to the Mean High Water level. Therefore, some of this restoration occurred within the Marine Protected Area.

Elkhorn Slough Tidal Marsh

Elkhorn Slough has historically faced substantial tidal wetland loss related to prior diking and marsh draining, and is presently facing unprecedented rates of marsh degradation (Fig. 3). Over the past 150 years, human activities have altered the tidal, freshwater, and sediment processes which are essential to support and sustain Elkhorn Slough's estuarine habitats. Fifty percent of the tidal salt marsh in Elkhorn Slough has been lost in the past 150 years. The most extensive marsh loss in the system was due to diking and draining of marshes to "reclaim" them for agricultural uses. The act of draining wetlands led to soil compaction and land subsidence, from 1 to 6 feet (0.3-1.8 m). Decades later, the dikes began to fail, reintroducing tidal waters to some of the reclaimed wetlands. Rather than converting back to salt marsh, the areas converted to poor quality, high elevation intertidal mudflat, as the lowered landscape was inundated too frequently to support tidal marsh, and insufficient sediment supply was available in the tidal waters to rebuild elevation. In addition to marsh loss due to diking, marshes in undiked areas have also deteriorated, with loss of cover and widening of creeks over time (Van Dyke and Wasson 2005). Multiple factors are likely responsible for this marsh loss, including increased tidal energy due to construction of the Moss Landing Harbor mouth, decreased sediment and freshwater inputs due to diversion of the Salinas River, subsidence and increased salinity due to groundwater overdraft, and eutrophication-driven subsidence and bank collapse. (Watson et al. 2011, Wasson et al. 2015, 2017).

Fig. 3. Project Area with intact, degraded, and restored marsh plain over time.

In 2004, ESNERR initiated -an ecosystem-based management initiative (Tidal Wetland Project) to evaluate marsh dieback and tidal erosion at Elkhorn Slough and to develop restoration and management strategies. Experts from multiple disciplines agreed that without intervention, excessive erosion would continue widening the tidal channels and that salt marsh would continue to convert to mudflat. If left unabated, continued erosion at present rates could result in a significant loss of habitat function and decrease estuarine biodiversity. Habitat loss is expected to become more severe with accelerating sea level rise. As described more fully in the following subsections, this project's restoration approach and experimental design addressed these issues across a range of impacted tidal marshlands, including subsided marsh areas that supported substantially less emergent marsh and more mudflat than was historically present.

PROJECT OBJECTIVES

These objectives are all long-term in nature and fully accomplishing them will take multiple years. However, we provide below a short synopsis of monitoring information to date.

Objective 1 – Restore 147 acres of functioning, resilient salt marsh ecosystem in Elkhorn Slough.
Objective 2 – Reduce tidal scour in the lower main channel of Elkhorn Slough
Objective 3 – Increase resilience to climate change
Objective 4 – Protect and improve surface water quality
Objective 5 – Support communities of animals that use and/or benefit from tidal marsh ecosystems
Objective 6 – Increase understanding of salt marsh restoration
Objective 7 – Increase blue carbon function

REGULATORY CONTEXT

ESNERR contracted with Environmental Science Associates (ESA) to assist with securing the necessary federal, state and county permits for the Elkhorn Slough Tidal Marsh Restoration Project. ESA prepared the IS/MND in support of this project as well as all documents, and regulatory permit applications. The regulations relevant to the project were as outlined in Appendix 5 (MMRP), Federal and State Regulations.

PROJECT ACTIVITIES

Summary
Phase I project activities began with a planning phase of 3 years, followed by a permitting phase of 3 years. Fundraising spanned the entire 6 years. During this time a soil source was identified. The soil was tested for chemical and horticultural suitability. Twenty-five thousand cubic yards of suitable soil was transported to the site. Other than the pilot project, water management and/or turbidity control measures were constructed around the work areas prior to placing material on the marsh. Earth moving for Phase I first occurred in 2018 followed by preparation of upland scraped soils and then planting. After fill placement on the marsh, any temporary features, such as water management berms and culverts, were removed. Intensive monitoring is anticipated to

span from 2015 to 2025 to encompass pre- during- and post- construction. Phase II earthmoving occurred from 2020 to 2021 and phase III earthmoving will primarily occur in 2022-23 with a period of intensive monitoring to follow each phase.

Trainings
For all three construction Phases, all personnel engaged in construction activities were provided cultural resources and environmental training initially and six months after that (Appendix 6).

Annual Inspection (RWQCB)

Details are in the SWWP final report.

Success criteria

See objectives and status below.

Construction Sequencing

The general approach for sequencing construction was as follows:

- The construction contractor mobilized equipment and prepared the project site by mowing.
- All material was staged or onsite borrow.
- Soil was placed on the site.

Phase I:

- o The fill study area was completed as the containment berm was being constructed. The fill study area was approximately 6000 cubic yards (4600 m^3) of soil. It was used to test fill in tidal conditions and the subsidence model that would inform the final fill elevation.
- o Once initial containment was complete, haul roads were constructed across the marsh and marsh fill commenced from east to west, north to south (on the east side) and south to north (on the west side).
- o The north eastern-most quadrat was completed first.
- o In total over 230,000 cubic yards (175,850 m^3) of soil were moved.

Phase II:

- o A containment berm was constructed around the fill area.
- o Once containment was complete, haul roads were constructed across the marsh and marsh fill commenced from the northeast to southwest.
- o In total 130,000 cubic yards (100,000 m^3) of soil were moved.

- All temporary construction materials and facilities were removed, and areas temporarily disturbed were returned to pre-construction conditions.

The construction contractor operated during all tidal cycles depending on site conditions and the nature of the construction activity. In Phase I, heavy equipment work on the site was from December 2017 – July 2018, plants were planted through March 12, 2019. The construction contractors primarily worked 5 day weeks, at no more than 10 hours a day. Phase II earthmoving started in late August of 2020 and ended in December 2021, plants were planted and seeded through March 2022. The construction contractors worked 4 day weeks, at no more than 10 hours a day. Night-time construction activities did not occur.

Mitigation Measures/ Protective Measures

CEQA and NEPA mitigation measures implemented throughout the project in order to minimize impacts to water quality, air quality, biological resources, cultural resources, and hazardous material management are below. All permit mitigation/ protective measures are summarized in Appendix 5 (see individual permits for the details).

Mitigation Measure AIR-1: Implementation of a Dust Control Plan

The project's unmitigated construction air pollution emissions associated with both Phase 1 and future phases would exceed the MBUAPCD's 82 pounds per day PM10 construction emissions threshold. However, implementing Mitigation Measure Air-1 would reduce PM10 emissions for all phases to levels less than the MBUAPCD's PM10 significance thresholds. As a result, the project would have a **less than significant impact with mitigation**.

The following mitigation measure applies to activities associated with project construction. Implementation of this measure would reduce PM10 emissions from 135 to 44 pounds per day during Phase 1 and from 152 to 48 pounds per day for Phases II-III. The measures to reduce construction related PM10 emissions reflect basic dust control measures recommended in the MBUAPCD's CEQA Air Quality Guidelines.

- All active construction areas shall be watered to minimize dust
- All trucks hauling soil, sand, and other loose materials shall be covered with tarpaulins or other effective covers
- All construction haul routes shall be watered to minimize dust
- The contractor shall limit traffic speeds along the unpaved haul route to 15 miles per hour
- All grading activities during periods of high wind (over 15 mph) will be prohibited
- Haul trucks shall maintain at least 2'0" of freeboard.
- Seed disturbed upland areas as soon as possible
- Cover or seed inactive storage piles.
- Post a publicly visible sign which specifies the telephone number and person to contact regarding dust complaints. This person shall respond to complaints and take corrective action within 48 hours. The phone number of the Monterey Bay Unified

Air Pollution Control District shall be visible to ensure compliance with Rule 402 (Nuisance).

- Limit the area under construction at any one time.

Mitigation Measure BIO-1a: Seasonal Avoidance

Construction activities shall be timed to avoid the peak of the pupping season for sea otters and harbor seals, as determined by consultation with regulatory agency staff. Marine mammals in the project vicinity shall be monitored by a qualified biological monitor (see Mitigation Measure BIO-1c below); the monitor shall establish disturbance-free buffers established through agency consultation.

Mitigation Measure BIO-1b: Education Program

A qualified biologist shall conduct mandatory biological resources awareness training for construction personnel. The awareness training shall be provided to all construction personnel to brief them on the need to avoid effects on marine mammals and other special-status species. If new construction personnel are added to the project, the contractor shall ensure that the personnel receive the mandatory training before starting work.

Mitigation Measure BIO-1c: Biological Monitoring

A qualified biologist shall be present during all construction activities to ensure that impacts on marine mammals are avoided to the extent feasible. The biological monitor shall have the authority to stop project activities before any marine mammals are harassed by project activities (as defined by the Marine Mammal Protection Act). Biological monitoring shall begin ½ hour before work begins and shall continue until ½ hour after work is completed each day. Work shall commence only with approval of the biological monitor, to ensure that no marine mammals are present in the vicinity of construction activities. In addition, biological monitors will, to the extent feasible, monitor for fish, including listed species that may occur within the project site.

Mitigation Measure BIO-2a: Seasonal Avoidance of Nesting Birds

Construction should be scheduled to avoid the nesting season to the extent feasible. CDFW recognizes the period between 1 February and 31 August as nesting season in the Elkhorn Slough area. If it is not possible to schedule construction to occur between September and January, then measures **BIO-2b (Pre-Construction Surveys)** and **BIO-2c (Buffer Zones)** are applicable.

Mitigation Measure BIO-2b: Pre-construction Surveys

Prior to commencement of new activities (i.e., activities that are not currently ongoing in any given area) during the breeding season, pre-construction surveys will be conducted by a qualified ornithologist no more than 7 days prior to the initiation of new disturbance in any given area. Pre-disturbance surveys should be used to ensure that no nests of species protected by the MBTA or California Fish and Game Code will be disturbed during project implementation. During this survey, the ornithologist will inspect all potential nesting habitats (e.g., trees, shrubs, buildings, and various substrates on the ground) in the project area for nests. Surveys will be conducted within search radii corresponding to disturbance-free buffer zones described below for non-listed raptors (500 feet) and non-raptors (250 feet), including in off-site areas adjacent to the project (where such areas are accessible).

Mitigation Measure BIO-2c: Buffer Zones

If an active nest is found, a qualified biologist will determine the extent of a disturbance-free buffer zone to be established around the nest until nesting has been completed. Disturbance-free buffer zones are typically 500 feet for non-listed raptors and 250 feet for non-raptors. Nests will be considered active until surveys conducted by a qualified ornithologist confirm nesting is complete. However, construction within 100 feet of these nests may proceed if, based on monitoring of the birds' behavior, a qualified biologist determines that such activities are not likely to result in the abandonment of the nest. Per CDFW recommendations, monitoring should be conducted as follows:

- A qualified biologist should monitor activity at each nest for three days (8 hours of monitoring each day) prior to the onset of construction activities to develop a baseline of the normal behavior of the birds attending the nest. If the behavior observed at the nest is consistent on Days 1 and 2 of monitoring, Day 3 of monitoring may be skipped.

- A qualified biologist should monitor activity at each nest for 8 hours on the first day that construction occurs within the standard buffer (e.g., within 250 feet of a non-raptor nest). If the biologist determines that the birds' behavior is not adversely affected, project activities may continue. The biologist should continue to monitor the nests for 1 hour/day on any day when construction activities occur within the standard buffer around an active nest.

If at any time the biologist determines that project activities within the standard buffer is adversely affecting the behavior of the birds such that the nest is in jeopardy of failing, construction activities should retreat to honor the standard buffer until the nest is no longer active (i.e., the young have fledged).

In addition to the above-described mitigation measures, nesting deterrence can be implemented to minimize the potential for nesting birds to constrain project activities or to be impacted by those activities. The most effective nesting deterrence in non-developed areas includes vegetation removal to remove nesting substrate. Also, removal of nest-starts (incomplete nests that do not yet contain eggs or young) by qualified biologists could also be conducted. Such nest-start removal will begin early in the breeding season (e.g., February) and continue regularly until vegetation can be removed and construction commences.

Mitigation Measure CUL-1: U.S. Army Corps of Engineers Standards

The lead agency shall require the following standards during implementation of the Phase 1 restoration project:

1) Project personnel working onsite shall attend a mandatory pre-Project training led by a Secretary of the Interior-qualified archaeologist. The training would outline the general archaeological sensitivity of the area and the procedures to follow in the event an archaeological resource is unearthed or discoveries of human remains.

2) If any road improvements are needed at a later date, a lead archaeologist shall monitor that work and assess the condition of any materials. The State site record shall be updated with the resulting information.

3) Following completion of the Phase 1 restoration, the archaeologist shall inspect site CA-MNT-2432 and the general vicinity to ensure that no Project-related site disturbance occurred during implementation. The State record shall be updated.

Mitigation Measure CUL-3: Inadvertent Discovery of Paleontological Resources (CUL-2 refers to future project phases)

If paleontological resources, such as fossilized bone, teeth, shell, tracks, trails, casts, molds, or impressions are discovered during ground-disturbing activities, all ground disturbing activities within 100 feet of the find shall be halted until a qualified paleontologist can assess the significance of the find and, if necessary, develop appropriate salvage measures in conformance with Society of Vertebrate Paleontology Guidelines (SVP, 1995; SVP, 1996).

Mitigation Measure CUL-4: Inadvertent Discovery of Human Remains

If human remains are encountered during ground disturbing activities, State Health and Safety Code Section 7050.5 requires that no further disturbance shall occur until the County Coroner has made the necessary findings as to origin and disposition pursuant to PRC Section 5097.98. If the remains are determined to be of Native American descent, the coroner has 24 hours to notify the Native American Heritage Commission. The Native American Heritage Commission would then identify the person(s) thought to be the Most Likely Descendent of the deceased Native American, who shall make recommendations for the treatment of any human remains.

Mitigation Measure GEO-1: Maximum Slope Angle of Stockpiled Sediment

Unless otherwise determined for the project by a geotechnical engineer, all sediment or soils stockpiled onsite shall be sloped at an angle not steeper than one and one half horizontal to one vertical.

Mitigation Measure HAZ-1: Spill Prevention and Cleanup

In the event of a release or spill of hazardous materials, the contractor shall immediately control the source of the leak and contain the spill. The construction contractor shall make all required hazardous materials release reporting notifications to the Monterey County Health Department and CDFW Elkhorn Office when a hazardous material spill occurs. Contaminated soils shall be excavated, tested and disposed of at an appropriate, licensed disposal facility. For details of the Spill Prevention Plan, see Appendix 7.

PROJECT OBJECTIVES: OVERVIEW AND STATUS

Many of these objectives are long-term so this should be considered a living document that will be updated annually as monitoring data is compiled.

Objective 1 – Restore 147 acres of salt marsh ecosystem

Restore 147 acres (59 ha) of functioning, resilient salt marsh ecosystem in Elkhorn Slough from channel to grasslands. This includes restoring an extensive diked and drained salt marsh through soil addition, creating a broad ecotone and native-dominated grassland through scraping and planting. The primary performance measure on this objective is the restoration of the physical attributes of the ecosystem. Thus, the sub-objectives focus on the physical attributes including elevation, tidal creeks, and healthy plants.

1.1 Raising the marsh plain

Objective overview

Hester marsh experienced diking and draining between 1930 and 1970. This process caused the ground to subside. When the berms eroded and full tidal waters were returned to the Hester marsh area, the ground did not expand or re-elevate, leaving the area too low to support healthy tidal marsh. Phase I added approximately 230,000 cubic yards (175,850 m^3) of soil across 61 acres (25 ha) to raise the marsh to an elevation that should be more sustainable in the face of sea-level rise. Some of the soil used to raise the marsh plain was obtained from the Pajaro River Bench Excavation Project (http://santacruzcounty.us/PajaroRiverExcavationProjectVideo.aspx) and was beneficially reused for this restoration project; the remaining soil was scraped from adjacent fallow agricultural land. Phase II added approximately 130,000 cubic yards (100,000 m^3) of soil across 26 acres (10.5 ha). Construction guidelines ensured that the desired high marsh elevation would be met initially; long-term restoration success depends on high elevation being maintained, without much loss due to erosion or subsidence.

Rationale

The Phase I restoration target marsh plain elevation was just above Mean Higher High Water (MHHW), or 6.2 feet (1.89 m) NAVD. In general, very permeable soils were used for marsh fill so the marsh plain is approximately flat to simplify design and construction. Had less permeable soils been used, the design would have included a slightly sloped (~0.5%) marsh plain to improve drainage. The site was overfilled to 6.4 feet (1.95 m) NAVD to meet the target elevation after one year of settlement and consolidation. The marsh will continue to settle over the longer term (see Appendix 8). This target elevation should be the long-term, stable elevation of the marsh (e.g. 5 years after construction was complete and all settlement/compaction has occurred). Soil, and thus marsh plain elevation is expected to be retained over time, because we have observed deposition (and not erosion) on feldspar markers put at marsh plain elevations throughout Elkhorn Slough. We expect to observe this pattern at the project site, too. Building on Phase I, the restoration targets for Phase II and III were set a little higher at 6.4 feet (1.95 m). This was based on the subsidence observed in the first 6 months post construction of Phase I and the success of marsh vegetation in Phase I at the higher elevation. The site was overfilled to 6.6 feet (2.01 m) NAVD.

Monitoring approach

Volumetric analyses of topographic change, including construction cut/fill, soil retention, tidal creek development, and tidal scour/deposition were performed using acquisition data from terrestrial laser scanner (TLS) surveys, laser level surveys, and unmanned aerial vehicle (UAV) overflights. UAV imagery and DEMs, post-processed with the ground control points (GCPs) to ensure maximum accuracy, were the primary data sources used to calculate landscape change in Hester marsh. UAV flights occurred immediately after construction and were repeated at 1-3month intervals (in the first year) to coincide with marsh vegetation transects and/or GCP elevation surveys. DEM comparisons (i.e. subtracting one DEM from another) using ArcGIS provided a quantitative assessment of volume change for all features in the marsh such as the tidal channels and marsh plain. For monitoring fine-scale (mm accuracy) elevation changes to the surface of the marsh, we installed three surface elevation tables (SETs) coupled with feldspar marker horizons. Each SET location included a paired deep rod SET and shallow SET which allowed us to determine if subsidence and/or compaction occurred within the soil profile between the shallow and deep rod depths. At Phase II, one additional SET deep/shallow pair along with feldspar marker horizons will be placed in the marsh in Summer/Fall 2022.

Status

Approximately 230,000 cubic yards of soil were added in Phase I. The marsh plain elevation at the end of construction was 6’2” – 6’8” ft./in. (1.87-2.03 m) with an average of 6.4 ft. (1.95 m) NAVD. This is high in the current tidal frame and was based on our tolerance for a maximum of 10% upland weeds under the current sea-level scenario (Fresquez 2014). One critical component of the elevation is understanding the properties of the underlying soils and how they will respond to the weight of the new soil. Measuring this during the initial 5 months of fill gave better information on how high to initially fill the marsh and confidence in what the final elevation would be (Appendix 8). The marsh plain is anticipated to settle to 5.8 – 6.4 feet (1.77 – 1.95 m) over the long term. Analysis of the entire marsh landscape with DEMs generated by UAV revealed that most elevation loss occurred in the first month following construction, with only very slight loss in the following two years (see Appendix 4, Section 1.1 Raising the marsh plain). For example, Fig. 4 shows that average elevation loss at 310 survey points scattered across the marsh totaled 1.2 in (3.1 cm) immediately following construction, and then an additional 0.6 in (1.6 cm) by September 2020. This gives us confidence that long term consolidation will be slow and minimal. Comparison of net elevation change vs. change in protrusion of conduit pipes that had been pounded to refusal suggests the elevation loss is occurring deeper than 5-10 feet, through compaction of the underlying soil, not that which was added.

Approximately 130,000 cubic yards (100,000 m^3) of soil were added in Phase II. The marsh plain elevation at the end of construction was 6'3" – 7'6" ft./in (1.90-2.28 m) with an average of 6.6 ft. (2.0 m). Summary of elevation loss in the first months will be described in the next annual monitoring report.

Soil addition for Phase III is planned to be completed by fall 2023, and will be described in more detail in the next annual monitoring report.

1.2 Maintain primary tidal creeks and avoid major erosion over time

Objective overview

Tidal channel networks in salt marshes are critical features that transport water, nutrients, and sediments to salt marsh plants, provide drainage for the salt marsh plain (Kearney and Fagherazzi 2016) and provide nursery and foraging habitat for fish, invertebrates, and marine mammals. A restored marsh must therefore include a tidal creek network that is sized proportionally (both in width of tidal channels and network density) to the marsh plain in order to ensure proper hydrology and bank stability over time. Underestimating a properly sized creek network can result in ponded water, hypersaline conditions, and drowned marsh vegetation whereas an overestimation may promote erosion and/or inhibit sediment accretion on the marsh plain.

While initial tidal creek formation was created by construction equipment mimicking the historic tidal channel network, we expect that tidal action and run-off after heavy rainfall will continue to shape the tidal creeks in the project area. One experiment that was included in Phase I was a firm channel edge of bay mud along one side of the main channel through the project site. This was initially designed by our engineer to stop a potential mud wave created by construction equipment moving across the marsh during restoration. This did mud wave did not occur, but the method was successful in reducing erosion and was implemented for Phase II and III along the main channel.

Rationale

All existing channels at Hester marsh Phase I, with the exception of the main channel, were filled during construction and re-excavated according to layout designs established by Ducks Unlimited (DU). Final plans identified a tidal creek density of 426 ft./acre (321 m/ha) (excluding the main channel). Initial project plans developed by PWA recommended a channel density of 440 ft./ac. (331 m/ha). This is at the low range of drainage densities found in the natural salt marshes of San Francisco Bay (440 – 870 ft./ac. [331 – 655 m/ha], PWA 1995), but substantially higher than the creek density found in our nearest high elevation marshes, Old Salinas River

Channel (241 ft./ac. [182 m/ha]) and Hudsons Landing (321 ft./ac. [242 m/ha]). Historical creek densities at Yampah Marsh (circa 1937), adjacent to Hester marsh, were in the range of 206 ft./ac. (155 m/ha). At Phase II, PWA recommended a channel density of 522 ft./ac. (393 m/ha), but this was significantly reduced by ESNERR and DU in order to minimize potential erosion.

We aimed for construction of the marsh that included a tidal network that was properly sized (both in width of tidal channels and network density) to accommodate the volume of water entering and exiting Hester marsh. Although some minor erosion of loose material was expected once the area was opened to the tides, we hoped to see tidal creeks maintain their stability with no excessive widening or erosion in the future. Currently, other channels in non-diked marshes of Elkhorn Slough are experiencing channel widening at an average rate of approximately 10 cm/yr. (Brent Hughes, pers. communication). It is also possible that small channels may evolve on the marsh plain where they weren't expected. If this occurs, we will identify these in the UAV imagery and make every effort to monitor them over time.

Monitoring Approach

Upon the completion of grading we calculated the final creek density using UAV imagery and the delineation of channel lengths in ArcGIS (divided by the total marsh area). If necessary, tidal creek volume may be calculated using the UAV DEMs in order to determine proper drainage of the marsh plain in the future. We are continuing to track creek development over time using UAV imagery. A recent publication by our team highlights the uses of UAV in monitoring at Hester, including tracking of the channel and creeks at Hester (Haskins et al. 2021).

Status

The post-construction tidal creek density at Hester marsh Phase I and Phase II (including the main channel) was 401 ft./ac. (302 m/ha) and 285 ft./ac. (214 m/ha), respectively, in the range of other healthy marshes at Elkhorn Slough (Appendix 4, Fig. 5). Post-construction UAV digital elevation model (DEM) comparisons of the Phase I Hester marsh over the first 12 months' post construction, indicate moderate erosion along the creeks (Appendix 4, Table 1). Total volume loss for areas that are within 3.3 ft. (1 m) of the creek-bank edge is 281.7 cu. yd. (215.4 m^3) while mean elevation change is -0.6 in (-1.5 cm). Less erosion was observed on the firm channel edge (Appendix 4, Fig. 6).

1.3 Create marshes with a healthy plant community

Objective overview

Tidal marshes are among the most productive ecosystems on earth, and provide key services including shoreline protection, water quality improvement, provision of fish habitat (Gedan et al. 2009), and carbon sequestration (McLeod et al. 2011). Globally, marshes have been degraded by numerous human activities, including diking, river diversion, and eutrophication (Gedan et al. 2009), and in the future, accelerated sea level rise poses a large threat to marsh sustainability (Kirwan and Megonigal 2013). At Elkhorn Slough, about 50% of historic salt marshes have been lost in the past 150 years (Van Dyke and Wasson 2005), mostly due to diking. Undiked marshes in the system are also degraded, failing to track current sea level rise (Raposa et al. 2016) likely due to anthropogenically-driven conditions such sediment starvation and eutrophication. Our goal for the Hester site was thus both to restore tidal marsh lost to diking, and to create a marsh that is higher and more resilient to sea level rise than most other marshes in the estuary. Specific objectives included

- marsh habitat spanning at least 119 acres (48 ha) of the project area, an increase of 10% estuary-wide over pre-project conditions
- once established, a more stable marsh than many others in the system that are losing cover over time
- marsh productivity, community composition and function similar to healthy high marsh reference sites in the estuary

Rationale

The creation of a high plain with ample tidal creeks described in the preceding sections (1.1, 1.2) should set the stage for a healthy high marsh. For the most part, the restoration followed a "field of dreams" approach: if you build it, they'll come. Pickleweed (*Salicornia pacifica*) was expected to readily colonize the soil addition area between about Mean High Water and Mean Higher High Water through recruitment from seeds brought in on the tides (Mayer 1987). Thus, there was little planting below an elevation of 6.4 ft. (1.95 m) NAVD88, except for 1200 *Jaumea* plants installed near the main tidal creek entrance to the project site. About 4000 marsh plants were also planted into bare areas in the main marsh area in December 2019, to make use of leftover plant stock left in the greenhouse. Above 6.4 ft. (1.95 m) NAVD88 we planted high marsh species (see section 1.4 below). We conducted small-scale restoration experiments to determine whether we can enhance restoration success. We tested the use of biochar made from eucalyptus removed from elsewhere on the Reserve as a soil amendment that could improve plant colonization, growth or survival. We also tested fine granite sediment available from a local quarry to determine whether this is a viable source for future sediment addition projects. Last, we conducted a caging experiment to exclude crabs from the tidal creek banks and adjacent marsh to determine whether this decreased erosion rates and enhanced marsh health relative to controls.

Monitoring Approach

We monitor overall extent of marsh habitat using UAV imagery. We compare extent of marsh before vs. after restoration, with imagery collected and analyzed frequently in the first years following restoration, and at least every 2 years in later years. We compare marsh cover at Hester to three or more sites in the estuary. We also will compare assessments employing the California Rapid Assessment Method (CRAM) for wetlands, before vs. after restoration. CRAM is a standardized habitat assessment protocol which allows spatial and temporal comparisons of site assessment of hydrology, topography, and vegetation in the project area (CWMW 2012). In the first months after earth moving for Phase I was completed, we walked the entire site to search for surviving plants and new colonists, and created a GIS layer of results. For a more detailed assessment of marsh health and functions, we sampled along ten transects spanning entire marsh gradient in Phase I (see Fig. 1, where these transects are first described). At ten quadrats along each transect, we assessed percent cover and canopy height. At Phase II, two additional transects were established soon after construction was completed. We compare data from these twelve restoration transects to data from eight transects we monitor regularly using standard NERR vegetation monitoring protocols. Three of these eight sites have high marshes; we expect Hester transects to be similar to these. The other five regularly monitored sites are lower marshes; we expect Hester transects to have greater cover and canopy height than these. The biochar, granite fines and crab exclusion experiments are similarly monitored for cover and height.

Status

In the unplanted marsh plain at Phase I of Hester Marsh, thousands of marsh plants have colonized in the first year following construction. The most common of these by far is the marsh dominant, *Salicornia pacifica*. *Spergularia marina* is also fairly common. Three other native marsh species (*Frankenia salina,* D*istichlis spicata, Cressa truxilensis*) have also appeared at low abundance, as have two common non-native marsh species (*Parapholis incurva*, *Atriplex prostrata*). The canopy height of all these marsh plants is still very low. Total cover of native marsh plants colonizing the transects has increased from 0% in 2018 to 16% in 2019 to 28% in 2020 and 2021. Areas that were bare in summer 2019 generally remained bare in summer 2020 and 2021. Bare areas that were planted in December 2019 with 4000 marsh plants leftover from the previous year did not yield success; virtually all of these plants died within two months. Likewise, pickleweed transplanted along the 100 quadrats at the 10 transects had the highest mortality in the bare areas. This suggest that bare areas have stressful conditions for small plants, and further research is underway to elucidate the mechanisms at play. An analysis of factors that predict cover (Thomsen 2020, Thomsen et al 2021) suggests that pickleweed colonization is greatest at the highest elevations (where salinity is low, and where king tides deposit seeds) and lowest marsh elevations along creek banks (where regular tidal inundation delivers seeds and prevents hypersalinity). At intermediate elevations, colonization appears to be higher where soils are less firmly consolidated and soil salinity is lower. We are exploring soil amendments and de-compaction methods to ameliorate stress for plants. Biochar amendments conducted at different scales at Hester Phase I have thus far not shown a significant benefit to vegetation. Along tidal creeks, exclusion of crabs from experimental plots at Hester Phase I has shown that colonizing crabs negatively impact plant species richness and plant growth for species other than *S. pacifica*. Crabs had no effect on *S. pacifica* cover, but cover did vary as a function of bank side—the sandier East bank was slow to colonize, while the muddier West bank was quick to be colonized by both crabs and marsh plants. At Phase II, new experiments are exploring whether initial freshwater addition (by sprinklers) can enhance restoration success, whether mounding or ripping soil makes conditions more favorable, and whether large greenhouse-grown plants fare better than small ones.

1.4 Create marsh-upland ecotone with diverse plant community

Objective overview

Our goal was to create an unusually extensive, wide marsh-upland ecotone on a gentle slope at the Hester restoration site to increase representation of rare ecotone specialist species and provide future avenues for marsh migration in the face of sea level rise. Our objectives for the ecotone were:

- a diverse community of native high marsh and salt-tolerant grassland plants, including representation of rarer species (i.e. an ecotone not dominated by pickleweed, which can tolerate this zone)
- high percent cover to support functions such as productivity, animal habitat, and carbon sequestration (i.e. bare ground not dominant after the first years)
- low representation of non-natives (i.e. low percent cover by marsh non-natives such as *Lepidium*, *Parapholis*, and *Atriplex*, and low percent cover by upland non-natives)

Rationale

The marsh-upland ecotone is a critical transition zone between wetland and upland habitats. In California, the marsh-upland ecotone harbors higher plant diversity than adjacent habitats, and supports animal communities and ecosystem functions such as nutrient cycling (James and Zedler 2000, Traut 2005). This transition zone spans the area from about Mean Higher High Water to the highest King Tide line. At Elkhorn Slough, this elevational zone (approximately 5.9 to 7.5 ft. [1.8 to 2.3 m] NAVD88) is typically very narrow due to steep slopes, and is often highly invaded by non-native species (Wasson and Woolfolk 2011). The ecotone is also very sensitive to water level variation (Wasson et al. 2013).

Monitoring Approach

The majority of the ecotone was not planted, just as with the main marsh at the project site. Previous studies (Mayer 1987) suggest high marsh plants will colonize within years. However, to augment this natural colonization, in January 2019 we planted about 17,000 marsh plants in six different blocks at Hester Phase I, to ensure good representation by all the common high marsh natives in the estuary as well as some rarer ones. We focused on the very highest portion of the ecotone (6.4 – 7.4 ft. [1.95-2.25 m] NAVD88), where arrival of seeds is most limited due to rarity of tidal inundation – only the highest tides flood this zone. This planting should increase diversity and abundance of high marsh species relative to other sites. We used an experimental approach to this planting, to make a number of comparisons that will inform future work:

- Planted to unplanted areas, to examine how long they differ, and to quantify recruitment by different species and the role of planted areas as a source
- Different marsh species, to compare how well they hold their own against other species and to quantify ecosystem services they perform
- Soil amended with biochar vs. controls, to determine whether biochar enhances survival or growth

- Clustered vs. uniform spacing of plantings, to investigate whether intra-specific facilitation enhances restoration success

Another 500 high marsh plants were planted to the north of the experimental plots as part of two volunteer events with high school students.

<u>Status</u>

Prior to construction, in 2017, we quantified abundance and distribution of marsh plants along 36 transects across the ecotone at Hester Phase I (both Yampah and Hester side). We also measured ecotone width. From this, we can calculate the approximate acreage of each plant species at the site prior to restoration, to compare to post restoration.

Monitoring revealed that initial survival of the 17,000 marsh plants placed in six blocks in the highest portion of the marsh at Hester Phase I was very high (ranging from 85% for *Distichlis* to 99% for *Jaumea* from January to July 2019). While herbivory can be high at some restoration sites in the area, it was low at these Hester plantings (Wasson et al. 2021). By July 2021, percent cover varied significantly among planted species and was greatest for *Frankenia* and least for *Spergularia*. For most species, survival and growth increased with elevation (highest near the top of the blocks). Comparison of clustered vs. more widely and uniformly spaced plantings revealed that the latter was more effective at generating cover. Clustering improved early survival of two species, but decreased growth of all five species (intraspecific competition proved more important than facilitation). Amendment of planting holes with biochar had no measurable effect on survival or growth.

Comparison of planted and unplanted ecotone areas revealed that planted areas have higher marsh plant richness, containing the planted five species and pickleweed which colonized naturally, while the unplanted areas almost entirely hosted a single species, pickleweed. Percent cover by native marsh species was high in both planted and unplanted ecotone areas on the Minhoto side, around 75% by July 2021.

The five planted species were assessed in terms of 30 metrics of ecosystem function, ranging from blue carbon services to productivity measures useful for traditional measures of restoration success to effects on environmental conditions and co-occurring plant and animal communities. The investigation revealed strong differences in the multi-functionality of the five planted species (and the unplanted pickleweed in adjacent areas), highlighting the importance of restoring marsh diversity as well as cover.

1.5 Restore a native species dominated perennial coastal grassland on former farmlands

Objective overview

Our goal was to restore at least 5 acres (2 ha) of native grassland species in the upland portion of the project area. Our objectives for the grassland were:

- No establishment of highly invasive plants, such as yellow starthistle, perennial pepperweed, iceplant, jubata grass, or veldt grass
- In unrestored portion of this zone, 70% cover by cover crop
- In scraped areas, in 5 acres (2 ha) or more:
    - an assemblage of native grasses and forbs plants, based on species found at our reference sites
    - at least 30% cover of native plant species
    - relatively low cover of non-native plant species

Rationale

Coastal prairie is a species-rich habitat that occurs within 62 miles (100 km) of the coast and is dominated by native grasses and forbs. It hosts not only an array of insects, amphibians, reptiles, birds, and mammals, but also a number of rare annual forbs. Approximately 99% of California native grasslands have been lost over the last 200 years, making them one of the most critically endangered ecosystems in the U.S. (Noss et al. 1995). Locally, native grassland has been lost via conversion to agricultural fields, although some has been urbanized as well. Much of the remaining prairie has been impacted by large-scale community shifts from indigenous grasses and forbs to exotic, mostly European, plants. In California, native grasslands are sometimes associated with nutrient-poor soils, such as serpentine soils, and these harsh areas are thought to be refuges for native species - places difficult for exotic plants to colonize (Harrison and Viers 2007). The scraped upland soils at the project site may provide a unique opportunity for grassland restoration: the scraped soils are presumably free of an exotic plant seedbank, and low nutrients may prevent the establishment of tall invasive species that often hamper grassland restoration projects elsewhere. A handful of previously scraped grasslands on ESNERR (scraped decades ago for levee improvements) are dominated by native grassland species, a handful of short exotic annuals, and patchy bare areas. These sites - on Yampah Island, near ESNERR's South Marsh sonde, below the big barn, and on Hummingbird Island - provide reference conditions that guided restoration efforts in the Hester grassland.

Monitoring Approach

In Winter 2019 we conducted visual surveys to determine if we had achieved 70% cover of the cover crop. At least three times a year (winter, spring, and summer), staff walk the grassland area to determine if invasive weeds are present in the project site. Invasive weeds are removed immediately. In early June 2019, late May 2020, and early June 2021 staff monitored transects through grassland restoration areas, using point intercepts to document the percent cover and species composition of target and non-target plants.

Status

The entire grassland area, including the zone described as "upper ecotone" in section 1.4, was seeded or planted between November 2018 and January 2019 to prevent erosion, invasion by exotic weeds and to start to establish restored coastal grasslands.

Eight acres (3 ha) of the grassland (including the "upper ecotone"), primarily in areas that were not scraped or only slightly scraped, were planted with a cover crop, Merced rye in January 2019. These areas are expected to retain an exotic seed bank and high nutrients that may create conditions favorable for tall invasive plants. It may be difficult to convert them to a native plant assemblage.

Five acres (2 ha) of the grassland and upper ecotone, in areas more deeply scraped, were planted or seeded with locally sourced native grassland species November-December 2018. One and a half acres (0.6 ha) were planted with native grassland plugs, including gumplant, rush, creeping wildrye, meadow barley, and salt grass for a total of 18,000 plants. Three and a half acres (1.4 ha) were seeded with native species, including California brome, needlegrass, meadow barley, gumplant, and blue wildrye for a total of over 100 pounds of seed. By May 2021, target plants in seven of ten restored plots had reached or exceeded the target of 30% cover: hand planted gumplant, rush, creeping wildrye, meadow barley, and salt grass, as well as hand seeded needlegrass and meadow barley. California brome and blue wildrye were not faring well – while greater than or close to the 30% cover target in 2019, they declined in the following years, to just 3% or less in June 2021. Seeded gumplant was not surveyed – that plot had very high cover of tall semi-woody gumplant, making it difficult to survey, but visual estimates suggest over 90% cover of seeded gumplant in June 2021. See Appendix 4 section 1.5 for details. Monitoring results are being applied to grassland restoration designs for Hester Phases II and III.

In Phase II, 3 acres (1 ha) of scraped grassland was planted or seeded with locally sourced native grassland species, December 2021–March 2022. One acre (0.4 ha) was hand seeded with 15 lbs. of gumplant. One acre (0.4 ha) was seeded with a mix of native perennial grasses and annual wildflowers, including 25 lbs. of purple needlegrass, 21 lbs. of meadow barley, 0.5 lbs. of California oat grass, 1 lb. of California poppy, and 1 lb. of sky lupine. The final acre (0.4 ha) was planted with native perennial grass plugs and wildflowers, including 7,600 meadow barley, 4,400 California oat grass, 3,100 blue eyed grass, 2,900 purple needlegrass, 1700 creeping wildrye, 130 wild licorice, 100 lomatium, and 100 yampah seedlings.

1.6 Restore oysters into tidal creeks as a part of the salt marsh ecosystem

Objective overview

Our goal is to restore an additional iconic foundation species to the Hester Marsh ecosystem, the native Olympia oyster. Specifically, we set out to deploy 5000 hatchery-raised juveniles in an initial effort (funded by GHG2), with the expectation this would yield 1000 adults two years later. More ambitiously, we planned to deploy 50,000 additional juveniles (funded by OPC), with the expectation this would yield 10,000 adults two years later. We committed to engaging the Amah Mutsun Native Stewards in this work.

Rationale

The Elkhorn Slough oyster population is at risk of local extinction, as happened at the next major estuary to the south, Morro Bay (Wasson 2010). Restoration elsewhere in the estuary has been successful (Zabin et al. 2013). Since recruitment at Elkhorn is very low relative to other sites from Mexico to Canada (Wasson et al. 2016), restoration will be supported with aquaculture. This has proven successful in the past (Wasson et al. 2020).

Monitoring Approach

Monitoring involves counting live oysters and assessing their sizes. It is difficult work, conducted in mud at very low tides, and thus done only twice a year.

Status

For the first round of aquaculture, adult broodstock were brought to Moss Landing Marine Laboratories in June 2021. Juveniles were settled on clam and abalone shells and tiles, and deployed to Hester Creek, South Marsh and Whistlestop Marsh in December 2021. Over 7000 juveniles were deployed, exceeding the target of 5000 for this round. Initial monitoring of a subset of these juveniles revealed growth of about 10 mm and about 75% survival to March 2022.

1.7 Restore eelgrass into tidal creeks as a part of the salt marsh ecosystem

Objective overview

Our goal is to restore still another vital foundation species to the Hester Marsh ecosystem, eelgrass. Specifically, we set out to transplant 800 shoots into 12 blocks in Hester Creek (Phase I-II) and Moonglow Creek (Phase III).

Rationale

Eelgrass supports numerous ecosystem functions and services, and these can be regained rapidly following restoration (Beheshti et al. 2021). Incorporating eelgrass into the new marsh creeks should enhance fish diversity, improve water quality and increase sediment retention.

Monitoring Approach

Restoration plantings will be tracked for survival and growth. The twelve planted blocks will be compared to the twelve unplanted blocks, in terms of fish diversity and abundance, and bank erosion rates.

Status

This work will be initiated in 2023.

Objective 2 – Reduce tidal scour

Objective overview

This project aimed to reduce tidal scour in Elkhorn Slough through adding soil to historically diked and drained areas. Soil addition will displace over 430,000 cubic yards (328,760 m^3) of tidal prism and accommodation space in the slough.

Rationale

Elkhorn Slough has experienced several past episodes of increased tidal prism, most notably the Moss Landing jetty opening in 1947 and the return of tidal flow to formerly diked wetlands in the 1980s, (e.g. Parsons Slough and North Marsh). The results were significantly higher tidal velocities that accelerated the rate of tidal erosion in both the main channel and smaller creeks and, in turn, created a positive feedback loop that further increased the tidal prism (Van Dyke and Wasson, 2005). Raising the marsh plain elevation in Phase I marsh effectively displaced over 230,000 cubic yards (175,850 m^3) of tidal prism, thereby decreasing current velocities and tidal scour and facilitating sedimentation in both Hester marsh and the Elkhorn Slough main channel. Both Phase 2 and 3 will add about 130,000 cubic yards (100,000 m^3) each further displacing tidal water and reducing tidal scour. In total about 460,000 cubic yards (351,700 m^3) of soil will be added across all phases.

Monitoring Approach
We used remote sensing (UAV) to quantify tidal prism in the project area.

Status
GIS analyses of pre- and post-construction DEMs suggest a significant decrease in the volume of water now entering Hester marsh Phase I and II. Excluding the main channel which remained unaltered during construction, only 8.9 acre feet of water now enters Phase I Hester tidal creeks (calculated at mean higher high water) compared with 84.5 acre feet before construction (89% reduction) when incoming tides would overtop onto the marsh plain. The amount of wetted surface area during MHHW is also significantly lower, from 44.7 acres to 6.6 acres (85% reduction) (18 ha to 2.6 ha) (Appendix 4, Figs. 35-36). Also excluding the main channel at Phase II, only 4.5 acre feet of water is entering Hester tidal creeks compared with 46 acre feet before construction (90% reduction). Wetted surface area during MHHW at Phase II also dropped from 26.1 acres (10.6 ha) to 2.9 acres (1.2 ha) (89% reduction). (Appendix 4, Figs. 37-38).

Objective 3 – Increase resilience to climate change

Objective overview
Providing resilience to climate change in estuarine ecosystems in Elkhorn Slough through increasing the extent of tidal marsh of sufficient elevation (just over MHHW) to withstand moderate sea level rise is imperative. The project has increased estuarine resilience both onsite and offsite. The elevation of the new marsh plain is higher than the average for the surrounding estuary, have a gentler slope between the marsh and the upland, and the ecotone will be highly diverse.

Rationale

3.1 Elevation Increase
This project retained a full tidal range and established a marsh plain at a high elevation suitable to reduce excessive inundation time and produce robust stands of tidal marsh vegetation. The goal was to create a marsh plain inundated less than 10% of the time, which is less than typical marshes in the estuary, that are near their lower elevation limits. This was expected to maximize soil retention and accretion (Friedrichs and Perry 2001), giving these landscapes the greatest potential to persist in the face of sea level rise. The position of the project in the estuary was close to the estuarine mouth, where most of the sediment supply originates. A nearby tidal wetland has been documented to be gaining marsh over the last decade (ESNERR, unpublished data), providing evidence that given the right elevation, marsh vegetation and location relative to the mouth of the slough, the project site will be able to thrive despite relative sea level rise. Our calculations suggest that our restored site will withstand 20 inches (50 cm) of SLR while most of the other marshes at Elkhorn Slough will drown (Fountain, et al. 2020).

While the restored acreage is anticipated to be resilient to moderate rates of sea level rise of 0.08 – 0.12 inches (2-3 mm/y), under higher rates of 0.28 inches (7 mm/y) (Rahmstorf 2007) the habitat mosaic will gradually shift landward. Therefore, it is important to allow landward migration of vegetation in addition to creating the correct elevation.

3.2 Upland slope angle

Recent modeling revealed that there is limited potential for marsh migration in much of the estuary due to steep hillsides adjacent to the marshes (Fountain et al. 2020). At the project site, excavation of over 460,000 cubic yards (351,700 m^3) and grading of the uplands adjacent to the wetlands will have created a band of gentle slope (e.g. 1:30) on the hillside, fostering creation of a wider ecotone habitat. This facilitated future marsh migration potential. This project, with its upland grading and establishment of a wide ecotone, is designed to allow the marshes to migrate into the adjacent transitional zone and native grassland.

3.3 Ecotone diversity

Planting diverse high marsh and ecotone communities, relative to what is found in other marshes increased the project area's resilience to climate change. High plant diversity provided a wider range of plant adaptations, which in turn can survive the conditions or the new level of temperature, precipitation, soil moisture or soil nutrients. Climate smart restoration guidance suggests it is good to have multiple plant species, some of which may end up being well adapted to new changed conditions of temperature, precipitation, and sea level rise.

<u>Status</u>

This project retained a full tidal range and established a marsh plain at a high elevation suitable to reduce excessive inundation time and produce robust stands of tidal marsh vegetation. The new marsh plain, due to its increased elevation, will be one of the most resilient areas to sea level rise at Elkhorn Slough estuary. The Phase I marsh plain is inundated about 1.9% of the time; in contrast, typical marshes in the estuary are inundated 16% of the time, and even the highest marshes in the system are inundated 11% of the time – the restoration site is exceptionally high in the tidal frame (see Appendix 4, section 3 for details).

Objective 4 – Protect and improve surface water quality

<u>Objective overview</u>

Establishing a healthy tidal marsh serves many purposes. First, it provides a vegetative buffer that can absorb nutrients from a eutrophic estuary. Second, it facilitates sedimentation and accretion to withstand sea level rise. Third, conversion of degraded marsh and high areas of mudflat can result in improved water quality. Instead of a large shallow lagoon of oxygen-depleted water during the night time, most tides now fill only a small proportion of the restored area, which is the deeper tidal channels, leading to less oxygen depletion. Also, the restored soils do not fuel as much microbial oxygen consumption. By restoring tidal marsh, we anticipate improved surface water quality in Elkhorn Slough. Although we expect an improvement in water quality, non-point source nutrient loads are typically very difficult to track as are the improvements in water quality.

Rationale

Surface water quality in Elkhorn Slough has been compromised for decades. Major threats to water quality are agricultural run-off from adjacent fields (Gee et al. 2010) and nutrients entering the slough from the Monterey Bay subtidal canyon and Old Salinas River, particularly on flood tides (Chapin et al. 2004) leading to increased algal growth (Hughes et al. 2011), and highly variable levels of dissolved oxygen, causing fish mortality and decrease in invertebrate growth when hypoxic (Jeppesen et al. 2018). Salt marsh plants can improve water quality by functioning as a producer of dissolved oxygen (Nidzieko et al. 2014, Santana et al. 2018) and thus increase the levels of dissolved oxygen in the water during higher high tides. Salt marsh plants can also facilitate sedimentation due to the physical structure of the plants changing the water velocity and allowing sediment in the water to settle onto the marsh, increase elevation, and decrease turbidity of the water in the estuary (Reed 1995). Last, salt marsh plants can provide a vegetative buffer, filter out nutrients and areas with restored buffer zones have shown to improve in water quality, with respect to particularly nitrate and phosphate (Gee et al. 2010).

Monitoring Approach

Water quality near the restoration site was monitored using YSI dataloggers, deployed before, during, and after restoration in accordance with the protocol of the National Estuarine Research Reserve System (NERRS SOP).

Status

Once tidal flow was restored to the Phase I project area, and construction was completed water quality improved in several ways. The lowest levels of dissolved oxygen were higher after construction than before construction and the amount of time with hypoxia in the project area was lower after construction than before, for the first three years immediately following construction (95% decrease in year 1, 50% in year 2, 85% in year 3 (Appendix 4, Table 5). The soil addition replaced water volume, hence the volume of water during hypoxic events exported from the project area to the main channel was decreased relative to pre-construction. Turbidity levels on outgoing tides were lower than on incoming tides, for 43% of the time pre-construction and 75% of the time post-construction suggesting that soil is not eroding as much for the new marsh as it was from the old marsh (See Appendix 4, Table 6).
Monitoring of water quality in Phase II will start in August of 2022, and pre-construction monitoring of water quality in Phase III started in April of 2021.

Objective 5 – Support Wildlife
Support communities of animals that use and/or benefit from tidal marsh ecosystems

Objective overview
Elkhorn Slough contains ~2,690 acres (1,089 ha) of estuarine habitat, including subtidal channels, tidal creeks, mudflats, salt and brackish marshes. These habitats provide a rich ecosystem that supports over 340 bird, 550 marine invertebrate, and 102 fish species. Sea otters, fish and birds were chosen for closer monitoring either because of their special status (otters) or the breadth of their distribution in the estuary (fish and birds). This project improves Southern sea otter habitat through increasing extent of coastal salt marsh by 9% for resting otters adjacent to an area heavily used by otters. The restored marsh and tidal channels are expected to provide increased foraging opportunities for a range of different species including fish. The goal is to maintain or improve fish communities in the project area. For shorebirds, the objective of this monitoring effort is to determine if shorebird communities in the project area change following restoration of the Hester marsh.

5.1 Improve Southern Sea otter habitat

Rationale
Southern sea otters, a federally threatened species, have in the last ten years or so, moved into the marsh at the southeast end of Elkhorn Slough called Yampah Creek (immediately adjacent to Hester marsh). New data suggest that the tidal salt marsh in Elkhorn Slough may be an important refuge and foraging habitat for mother and pup otters (Kvitek et al. 1988, Oftedal et al. 2007, Hughes et al. 2013, Eby et al. 2017). Currently the greatest density of mother and pups in their entire range is found in Elkhorn Slough. This project improves Southern sea otter habitat through increasing extent of coastal salt marsh by 9% for resting otters adjacent to an area heavily used by otters.

Monitoring Approach
The Reserve Otter Monitoring Program (ROMP), involves trained volunteers conducting consistent surveys at a dozen sites throughout the estuary during a two-hour period, typically on two consecutive Tuesdays a month. This dataset is ideal for assessing effects of restoration, because there are data for the restoration areas before vs. after restoration, and adjacent areas to track for comparison. More detail on the monitoring methods and results is in Appendix 4, section 5.1.

Status
Over the past decade, otter numbers have shown variability at most sites, but with no clear long-term trends. All three restoration areas (Phase I-III) had very low use of otters prior to restoration, since they were degraded high mudflats. Immediately after construction was completed at Hester Phase I, signs of otter activity in the project area were observed. Overall,

otter numbers in this area remain low; there have been <0.03 otters in Hester Phase I on average for the past decade, and there is no clear increase resulting from restoration yet. Overall, the high otter numbers observed in tidal creeks surrounded by dense salt marsh vegetation, such as at Yampah Creek, make it likely otters will gradually continue to increase in the restored marshes as they revegetate. In the future, after 50 cm of sea level rise, when most Elkhorn Slough marshes are gone, this restoration area will provide unique value to the otters as the only extensive area with emergent vegetation, in particular for hauling out and resting.

5.2 Maintain fish species composition consistent with other tidal channels in Elkhorn Slough

Rationale

Estuaries provide nursery habitat for a wide range of fish species (Caffrey et al. 2002) and Elkhorn Slough is no exception. The slough provides critical nursery habitat for commercially harvested fish and other species living in Monterey Bay and Elkhorn Slough including a number of federally listed and managed species. In general, fish diversity and abundance in Elkhorn Slough are on the decline and this is most likely due to anthropogenic impacts on their habitat (Hughes et. al. 2012). The restored marsh provides increased foraging opportunities (either directly or through prey species), refuge from predation, and improved water quality (See Objective 4).

Monitoring Approach

Fish surveys were conducted pre- and post-construction in the restoration area. Analyses included comparison of species richness, diversity, and individual abundances of common species, before and after restoration.

Status

During the pre-construction surveys at Phase I we captured three different fish species. The most abundant was top smelt (hundreds per seine) followed by arrow goby, and then staghorn sculpin (less than ten per seine). Six surveys have been conducted post construction, from late summer 2019 to spring 2022. The most abundant species continue to be top smelt followed by gobies, and staghorn sculpin. Additionally, a few bay pipe fish, northern anchovy, pacific herring, diamond turbot (first documented instance for the slough) and California Halibut were observed post-construction.

5.3 Provide habitat for diverse waterbird communities

Rationale

Each year, thousands of shorebirds stop to rest, eat and recover in Elkhorn Slough and other areas along the Pacific Flyway, utilizing food resources of high marshes as well as mudflats and shallow subtidal areas (Ramer et al., 1991). In this restoration project we aimed to create new salt marsh which will provide important resting and refuge habitat for shorebirds. It should be noted that potentially lower diversity and abundance is likely when shifting the habitat from high mudflat to salt marsh, although the new marsh will improve overall ecosystem health while not impacting shorebird foraging in the large areas of adjacent mudflat.

Monitoring Approach

Following a BACI design, we conducted area searches of waterbirds within pre-defined boundaries of subsections of the Phase I restoration area and unrestored (control) sites. We carried out surveys at various tidal heights and conducted at least ten surveys prior to restoration and will survey again after restoration, with the following objectives:

- Compare species composition before and after restoration.
- Compare species composition of the restored marsh site to baseline data of other marsh areas using data from quarterly surveys that have been conducted since 2003 at Elkhorn Slough Reserve.

Status

Prior to construction, the restoration area had significantly greater total waterbird abundance and species richness than the salt marsh control site. Waterfowl were also significantly more abundant at the restoration area than the salt marsh control area. An abundance of Long-billed curlews, Marbled Godwits, Willets plus small sandpipers have been observed in the new landscape in the first months following construction, perhaps using it as a high tide refuge. Formal avian surveys will not be conducted until the marsh is further established.

Objective 6 – Increase understanding of salt marsh restoration

Increase understanding of how best to restore salt marsh through conducting a well-designed and monitored project so that lessons learned can inform future salt marsh restoration projects in the estuary.

Project Management (time, scope, schedule)

Good project management is key to the success of a project on this scale and there are always lessons to be learned in this area.

Roles and responsibilities

Defining roles and responsibilities at the project start is key to ensuring all tasks are identified. This also ensures staff are committed and accountable. The role and responsibilities should be revisited periodically throughout the project when tensions arise, new staff come on board or new issues arise.

Stakeholder Engagement

Stakeholder engagement is key to the success of a project like this. Without stakeholder support the project can be misinterpreted or the context for restoration lost. Wetland fill is not usually appropriate for wetlands but having a broad stakeholder base that understands historic land use impacts and how to reverse those is key.

Funding road blocks

Another cause of project delays is insufficient funding. Often first order cost estimates are highly inaccurate. These need to be identified early and strategies developed well ahead of time to ensure fewer delays. Understanding costs can always be challenging but visiting other restoration projects and understanding their costs is important to ensuring enough funds have been raised to complete the project.

Permitting

One of the primary causes of project delays is permitting delays. These need to be identified early and strategies developed well ahead of time. Having an interagency permitting meeting to establish permit pathways, staff, and a schedule is critical. Often agency staff may not realize they are working contrary to another agency in terms of mitigation measures or timeline. Ironing these issues out ahead of time will go a long way to removing this road block.

Construction

Construction of a project at this scale has a lot of moving parts from ensuring regulatory compliance to daily decision making on unintended variables.

Geotechnical

One of the construction elements we spent the most amount of time on was how much the weight of the new soil would compact the soil below it thereby providing direction on how much the site could be filled. Ultimately, we tested the site during construction and modeled the subsidence to determine final fill elevations. This is detailed in Appendix 8.

Source Material

We extensively tested our source and site material for chemical contamination as required. We also investigated the source for invasive weeds. We had weeds treated in situ with the hopes we would receive material free of invasive weed seed. However, some material appeared to be delivered with weed seed included, requiring maintenance of the material through the winter and spring to control for invasive weeds. When then had to carefully monitor placement of this material. In terms of lessons learned, having a plan in place to deal with invasive weed for imported material would be helpful.

Monitoring/ Research
(experimental approach to tidal creeks, ecotone planting, grassland planting, amendments)

Objective overview
We anticipate many lessons learned from monitoring the restoration project over time and while the details are throughout the report the lessons learned will be summarized here.

Status
1. *Firm channel edge* – Using a firm channel edge of bay mud, reduced erosion of newly placed soils along the main channel of Phase I. This technique was employed more extensively during phase II and III due to the long reaches of vulnerable restored marsh along the main channel of Elkhorn Slough (Appendix 4, Fig. 6).
2. *Setting the marsh elevation to maximize climate resilience* - Building on Phase I, the restoration targets for Phase II and III were set a little higher at 6.4 feet (1.95 m). This was based on the subsidence observed in the first 6 months post construction of Phase I and the success of marsh vegetation in Phase I at the higher elevation. Phase II was overfilled to 6.7 feet (2.01 m) NAVD (Appendix 4, Fig. 4).
3. *Tidal channel bank slope* – Steep channel banks are a characteristic of health marshes but in Elkhorn Slough we have a large population of marine mammals that use the creek banks for resting. In phase I we have steeper banks (2:1) that did not hold shape as well so for Phase II we laid the slopes back to 3:1.
4. *Tradeoffs between short-term and long-term vegetation* – Building the marsh so high, we created stressful desert-like conditions that resulted in slower colonization than would have been the case had we built a lower, more frequently inundated marsh plain. But the one we built will be the only one remaining with 50 cm of sea-level rise. Managers should be aware of these tradeoffs.
5. *Clustering benefits are limited* – in the ecotone, we found no benefits to clustering plants; uniform plants generated higher cover. However, in the more stressful middle elevations, a modest benefit to "nurse plants" was observed.
6. *Marsh diversity enhances function* – quantification of 30 ecosystem functions of six marsh species revealed that each one performs differently; there is no single "winner" that optimizes all functions. So to enhance multi-functionality, planting diverse marsh species is recommended.
7. *Biochar amendments provide no benefit* – biochar added to greenhouse gas planting holes (for ecotone planting) did not affect plant growth or survival (five species, n=108), and biochar plots were not colonized by more wild recruitment than adjacent control plots (n=10). We used unprimed biochar made from eucalypts; it is possible that other types of biochar or combining it with compost might have benefits.
8. *Blue carbon benefits are slow to accrue* – ancient marshes store more carbon than new ones, both above and especially belowground. It is important to recognize that conservation of existing marshes is key to maintain blue carbon services, and that restored marshes will need time to perform well.

Objective 7 – Increase blue carbon function

Objective overview

The carbon sequestered in vegetated coastal ecosystems has been termed "blue carbon". Vegetated coastal ecosystems have extremely high carbon sequestration rates (Duarte et al. 2004). Elkhorn Slough, with its extensive marshes with documented high carbon sequestration rates, protected lands and restoration resources, represents the best opportunity for blue carbon conservation and enhancement in central California. The objective of Phase I of this project was therefore to significantly increase the blue carbon function of the Elkhorn Slough estuary by increasing extent of healthy salt marsh by 9%, and

- to sequester 129 Mg atmospheric CO_2 y^{-1} in marsh soils, additional to pre-restoration conditions, for at least 100 years
- to sequester 156 Mg atmospheric CO_2 in standing biomass of marsh vegetation, additional to pre-restoration conditions, for at least 100 years
- Do not significantly increase emissions of nitrous oxide or methane as a result of the project

Additional objectives for Phase II were

- to measure GHG benefit before vs. after restoration
- to compare GHG benefit at restoration site 4 years after restoration to intact marshes and great than unrestored wetlands
- to improve understanding of GHG benefit of incorporation biochar into marsh restoration project
- to improve understanding of GHG mitigation services provided by five different marsh plant species

Rationale

The carbon sequestered in vegetated coastal ecosystems has been termed "blue carbon". Although the surface area of coastal vegetation is orders of magnitude smaller than other key carbon sequestering habitat types, such as tropical forests and northern peatlands, the contribution of blue carbon to countering global warming may be more important to the global carbon budget (McLeod et al. 2011), because vegetated coastal ecosystems have extremely high carbon sequestration rates (Duarte et al. 2004). Coastal salt marshes are particularly important as carbon sinks because the carbon they capture is buried, and indefinitely sequestered. At higher salinities, coastal marshes generally have negligible emissions of nitrous oxide and methane, and thus are likely to have a net benefit for mitigating climate change (Chmura et al. 2011). One goal for the Hester restoration was to provide a net benefit for greenhouse gas reduction by sequestering carbon while not substantially affecting gas emissions.

Monitoring Approach

Since few salt marsh restoration projects have been carefully monitored, an important objective of this project was to carefully document the consequences of the project for greenhouse gases. One component of this monitoring was simply to quantify the net change in carbon storage within the restoration footprint before vs. after restoration, to determine whether the above objectives will be met. To do this we sampled representative habitat types in the project area prior to restoration (for carbon storage in aboveground plant biomass, in soil, and for greenhouse gas fluxes), and did the same after restoration. We can then calculate averaged rates by habitat type extent based on a GIS analysis. A second component of the monitoring was to determine how the restoration site compares to control sites (other degraded, formerly diked marsh sites) and to reference sites (intact high marshes in the system). To do this we compared carbon sequestration and greenhouse gas fluxes across representative habitat types at the project site, control sites, and reference sites.

Status

Initial pre-restoration monitoring was conducted in 2015. Post-restoration monitoring began at Phase I in 2018 and continued through 2021. A thorough description of monitoring methods and results, as well as interpretation of the findings, is provided in Appendix 11. Selected highlights of the lessons learned follow:

- **Restoration trajectory is slow:** In the three years following construction, Hester Marsh Phase I sequestered some carbon; carbon densities increased in this period. However, since much of the restoration footprint is still bare, and the plants that are present are tiny, carbon sequestration is still very limited. Funders and practitioners must have realistic expectations about the timeline of restoring blue carbon functions. Until the marsh plain is fully vegetated with a lush canopy, the restored site will not perform at its peak capacity, and this will likely take decades.
- **Degraded sites sequester carbon:** While previously diked sites such as Hester Marsh prior to restoration have low habitat value, with little marsh cover and high algal cover due to subsidence of the marsh plain, our results suggest that they can sequester substantial amounts of carbon at least in the short-term. Mudflats lack emergent vegetation, but due to high inundation times, accumulate sediment at the surface, and have low decomposition rates. Contrary to our expectations, our calculations suggest that carbon sequestration was maximized at Hester Marsh during the degraded period relative to the prior intact marsh or the future restored marsh. Thus this project will not increase carbon sequestration compared to having taken no action. Assuming our calculations are correct, we will never meet our ambitious original goals of increasing carbon sequestration with this project.

- **There are elevation trade-offs:** Hester Marsh was explicitly built very high, so as to be the only marsh in the estuary resilient 50 cm of SLR. Once vegetated, high elevations have peak biomass of marsh plants in California estuaries, which supports high carbon storage. However, lower elevations vegetate more quickly, and also have higher rates of surface accretion due to more frequent inundation, and lower rates of decomposition, due to soil anoxia. So it may not be possible to optimize sea-level rise resilience in the long-term and carbon sequestration rates in the short term.

- **Gas emissions can offset carbon sequestration**: Our study suggested that emissions of greenhouse gases – both nitrous oxide and methane – may significantly offset the carbon sequestration benefits of restoration. Nitrous oxide emissions accounted for a larger percentage of our observed carbon sequestration offsets than methane, due to the higher global warming potential. Emissions were lower in vegetated than bare areas at Hester, suggesting a trend towards decrease over time. Improved management of nutrient-loading to estuaries not only would improve water quality but also decrease nitrous oxide emissions and increase net carbon sequestration of estuaries.

CONCLUSION

The Elkhorn Slough Tidal Marsh Restoration Project took many years of planning, fundraising, permitting and design. It is a representation of local, state and federal partners working together on all levels from funding (see below) to permitting and planning. One of the unique aspects of the project, critical to having measurable outcomes, is the high investment in science. The system has been well studied so the baseline is strong allowing for thoughtful and in-depth scientific inquiry. This informed project design and lead to a better project with more certain and quantifiable outcomes. Nevertheless, it is still a natural and dynamic system that will likely face unforeseen challenges in the face of climate change. Monitoring over the 10-20 years will shed light on local dynamics as well as serve as a resource for tidal marsh restoration projects around the globe.

FUNDING

Six different agencies provided funding for the project (phase I and II):

- California State Coastal Conservancy
- California Department of Water Resources (through the Integrated Regional Water Management Program)
- US Fish and Wildlife National Coastal Wetlands Conservation Program
- California Department of Fish and Wildlife – Wetland Restoration for Greenhouse Gas Reduction Program (Cap and Trade Funds)
- California Wildlife Conservation Board
- California Ocean Protection Council

In addition, staff time and resources were contributed by the key partnering organizations: California Department of Fish and Wildlife, NOAA's Office for Coastal Management, and the Elkhorn Slough Foundation.

LITERATURE CITED

Beheshti, K M , Williams, S L , Boyer, K E , Endris, C, Clemons, A, Grimes, T, Wasson, K and Hughes, B B. 2021. Rapid enhancement of multiple ecosystem services following the restoration of a coastal foundation species. *Ecological Applications*. https://doi-org.oca.ucsc.edu/10.1002/eap.2466

Caffrey, J M, Brown M, Tyler W B, Silberstein M, editors. 2002. Changes in a California estuary: A profile of Elkhorn Slough. Elkhorn Slough Foundation, Moss Landing.

California Wetlands Monitoring Workgroup (CWMW). 2012. California Rapid Assessment Method (CRAM) for Wetlands and Riparian Areas, Version 6.0 pp. 95

Chapin, T P, Caffrey, J M, Jannasch, H W, Coletti, L J, Haskins, J C, Johnson, K S. 2004. Nitrate sources and sinks in Elkhorn Slough, California: results from long-term continuous in situ nitrate analyzers. *Estuaries*, *27*(5), 882-894

Chmura, G L, Kellman, L, Guntenspergen, G R. 2011. The greenhouse gas flux and potential global warming feedbacks of a northern macrotidal and microtidal salt marsh. *Environmental Research Letters*, *6*(4), 044016

Duarte, C M, Middelburg, J J, Caraco, N. 2004. Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences discussions*, *1*(1), 659-679

Eby, R, Scoles, R, Hughes, B B, Wasson, K. 2017. Serendipity in a salt marsh: detecting frequent sea otter haul outs in a marsh ecosystem. *Ecology* 98*:*2975-2977

Fountain, M., Endris, C., Woolfolk, A., & Wasson, K. (2020). *Salt marsh conservation, restoration and enhancement opportunities in and around Elkhorn Slough in the face of sea level rise. Elkhorn Slough Technical Report Series 2020:2* (Elkhorn Slough Technical Report Series No. 2). ESNERR

Fresquez, C C. 2014. The Ecological Factors Influencing The Marsh-Upland Ecotonal Plant Community And Their Use As Part Of An Effective Restoration Strategy. Dissertation. University of California, Santa Cruz, Santa Cruz, California.

Friedrichs, C T, Perry, J E. 2001. Tidal salt marsh morphodynamics: a synthesis. *Journal of Coastal Research*, 7-37

Gedan, K B, Silliman, B R, Bertness, M D. 2009. Centuries of human-driven change in salt marsh ecosystems. *Annual Review of Marine Science 9*, 117-141

Gee, A K, Wasson, K, Shaw, S L, Haskins, J. 2010. Signatures of restoration and management changes in the water quality of a central California estuary. *Estuaries and coasts*, *33*(4), 1004-1024

Harrison, S P, Viers J H. 2007. Serpentine grasslands. In M R Strongberg, J D Corbin, C M D'Antonio (Eds.), *California Grasslands* (145-155). Berkeley and Los Angeles, CA: University of California Press.

Haskins J, Endris C, Thomsen AS, Gerbl F, Fountain MC, Wasson K. 2021. UAV to Inform Restoration: A Case Study From a California Tidal Marsh. *Front Environ Sci*. 9:642906. doi:10.3389/fenvs.2021.642906

Hughes, B B, Haskins, J C, Wasson, K, Watson, E. 2011. Identifying factors that influence expression of eutrophication in a central California estuary. *Marine Ecology Progress Series*, *439*, 31-43

Hughes, B, Fountain, M, Carlisle, A, Levey, M, Gleason, M. 2012. The Impacts of nutrient loading and environmental conditions on the fish assemblage and available nursery habitat in Elkhorn Slough. Technical Report for the Nature Conservancy.

Hughes, B B, Eby, R, Van Dyke, E, Tinker, M T, Marks, C I, Johnson, K S, Wasson, K. 2013. Recovery of a top predator mediates negative eutrophic effects on seagrass. *Proceedings of the National Academy of Sciences*, *110*:15313-15318

James, M L, Zedler, J B. 2000. Dynamics of wetland and upland subshrubs at the salt marsh-coastal sage scrub ecotone. *The American Midland Naturalist*, *143*(2), 298-311

Jeppesen, R, Rodriguez, M, Rinde, J, Haskins, J, Hughes, B, Mehner, L, Wasson, K. 2018. Effects of hypoxia on fish survival and oyster growth in a highly eutrophic estuary. *Estuaries and Coasts*, *41*(1), 89-98

Kearney, W S, Fagherazzi S. 2016. Salt marsh vegetation promotes efficient tidal channel networks. Nature Communications 7, Article number: 12287

Kirwan, M L, Megonigal, J P. 2013. Tidal wetland stability in the face of human impacts and sea-level rise. *Nature*, *504*(7478), 53

Kvitek, R G, Fukayama, A K, Anderson, B S. et al. 1988. Marine Biology 98: 157. https://doi.org/10.1007/BF00391191

Mayer, M A. 1987. *Flowering plant recruitment into a newly restored salt marsh in Elkhorn Slough, California*. Master's thesis. San Jose State University.

Mcleod, E., G. L. Chmura, S. Bouillon, R. Salm, M. Björk, C. M. Duarte, C. E. Lovelock, W. H. Schlesinger, and B. R. Silliman. 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. Frontiers in Ecology and the Environment **9**:552-560.

Murphy, A.E., Kolkmeyer, R., Song, B. et al, 2019. Bioreactivity and Microbiome of Biodeposits from Filter-Feeding Bivalves. Microb Ecol 77, 343–357. https://doi.org/10.1007/s00248-018-01312-4

Nidzieko, N J, Needoba, J A, Monismith, S G, Johnson, K S. 2014. Fortnightly tidal modulations affect net community production in a mesotidal estuary. *Estuaries and coasts*, *37*(1), 91-110
NOAA National Estuarine Research Reserve System (NERRS SOP). System-wide Monitoring Program. Data accessed from the NOAA NERRS Centralized Data Management Office website: http://www.nerrsdata.org/

Noss, R F, LaRoe, E T, Scott, J M. 1995. Endangered ecosystems of the United States: A preliminary assessment of loss and degradation. 28. National Biological Service, Washington, D.C.

Oftedal O T, Ralls, K , Tinker, M T, Green, A. 2007. Nutritional constraints on the southern sea otter in the Monterey Bay National Marine Sanctuary.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science*, *315*(5810), 368-370

Ramer, B A, Page, G W, Yoklavich, M M. 1991. Seasonal abundance, habitat use, and diet of shorebirds in Elkhorn Slough, California. *Western Birds*, *22*,157-174

Raposa, K B, Wasson, K, Smith, E, Crooks, J A, Delgado, P, Fernald, S H, Ferner, M C, Helms, A, Hice, L A, Mora, J W, Puckett, B. 2016. Assessing tidal marsh resilience to sea-level rise at broad geographic scales with multi-metric indices. *Biological Conservation*, *204*, 263-275

Reed, D J. 1995. The response of coastal marshes to sea-level rise: Survival or submergence?. Earth Surf. Process. Landforms, 20: 39-48

Santana, R, Lessa, G C, Haskins, J, Wasson, K. 2018. Continuous Monitoring Reveals Drivers of Dissolved Oxygen Variability in a Small California Estuary. *Estuaries and Coasts*, *41*(1), 99-113

Shikuzawa, J. 2022. *Ecosystem Functions of Plant Diversity in Restoration: Comparisons from a Large-Scale Marsh Restoration Experiment in Central California, USA*. Master of Resource Management thesis, University of Akureyri, Iceland

Standard 2018. Standard Methods for the Examination of Water and Wastewater. method “4500-NH_3 Nitrogen (Ammonia)”). https://www.standardmethods.org/doi/abs/10.2105/SMWW.2882.087

Thomsen AS. 2020. Integrating Field Methods, Remote Sensing and Modeling to Monitor Climate-Adapted Tidal Marsh Restoration. M.S. Thesis, California State University Monterey Bay.

Thomsen, A S, Krause, J, Appiano, M, Tanner, K E, Endris, C, Haskins, J, Watson, E B, Woolfolk, A, Fountain, M C, Wasson, K. 2021. Monitoring vegetation dynamics at a tidal marsh restoration site: integrating field methods, remote sensing and modeling. *Estuaries and Coasts.* DOI: 10.1007/s12237-021-00977-4

Traut, B H. 2005. The role of coastal ecotones: a case study of the salt marsh/upland transition zone in California. *Journal of Ecology*, *93*(2), 279-290

Van Dyke, E, Wasson, K. 2005. Historical ecology of a central California estuary: 150 years of habitat change. *Estuaries*, *28*(2), 173-189

Wasson, K. 2010. Informing Olympia oyster restoration: evaluation of factors that limit populations in a California estuary. *Wetlands* 30:449-459.

Wasson, K, Woolfolk, A. 2011. Salt marsh-upland ecotones in Central California: Vulnerability to invasions and anthropogenic stressors. *Wetlands*, *31*(2), 389-402

Wasson, K, Watson, B E, Van Dyke, E, Hayes, G, Aiello, I. 2012. A novel approach combining rapid paleoecological assessments with geospatial modeling and visualization to help coastal managers design salt marsh conservation strategies in the face of environmental change. *Elkhorn Slough Technical Report 2012: 1.* http://www.elkhornslough.org/research-program/technical-report-series/

Wasson, K, Woolfolk, A, Fresquez, C. 2013. Ecotones as indicators of changing environmental conditions: rapid migration of salt marsh–upland boundaries. *Estuaries and Coasts*, *36*(3), 654-664

Wasson, K, Suarez, B, Akhavan, A, McCarthy, E, Kildow, J, Johnson, K S, Fountain, M C, Woolfolk, A, Silberstein, M, Pendleton, L, Feliz, D. 2015. Lessons learned from an ecosystem-based management approach to restoration of a California estuary. *Marine Policy* 58:60-70

Wasson, K, Hughes, B B, Berriman, J S, Chang, A L, Deck, A K, Dinnel, P A, Endris, C, Espinoza, M, Dudas, S, Ferner, M C, Grosholz, E D, Kimbro, D, Ruesink, J L, Trimble, A, Vander Schaaf, D, Zabin, C J, Zacherl, D. 2016. Coast-wide recruitment dynamics of Olympia oysters reveal limited synchrony and multiple predictors of failure. *Ecology* 97:3503-3516.

Wasson, K., Jeppesen, R., Endris, C., Perry, D.C., Woolfolk, A., Beheshti, K., Rodriguez, M., Eby, R., Watson, E.B., Rahman, F. and Haskins, J., 2017. Eutrophication decreases salt marsh resilience through proliferation of algal mats. *Biological conservation*, *212*, pp.1-11.

Wasson, K, Gossard, D J, Gardner, L, Hain, PR, Zabin, C J, Fork, S, Ridlon, A D, Bible, J M, Deck, A K, Hughes, B B. 2020. A scientific framework for conservation aquaculture: A case study of oyster restoration in central California. *Biological Conservation* 250, p.108745.

Wasson K, Tanner KE, Woofolk A, McCain S, Suraci JP. 2021. Top-down and sideways: Herbivory and cross-ecosystem connectivity shape restoration success at the salt marsh-upland ecotone. *PLoS ONE*. 16(2):e0247374. doi:10.1371/journal.pone.0247374

Watson, E B, Wasson, K, Pasternack, G B, Woolfolk, A, Van Dyke, E, Gray, A B, Pakenham, A, Wheatcroft, R A. 2011. Applications from paleoecology to environmental management and restoration in a dynamic coastal environment. Restoration Ecology 19:1-11

Zabin, C J, Wasson, K, Fork, S. 2016. Restoration of native oysters in a highly invaded estuary. *Biological Conservation* 202:78-87

APPENDIX LIST

Appendix 1
Amphibian monitoring log, approvals

Appendix 2
Marine mammal protocol and disturbance list

Appendix 3
Construction monitoring Phase I: marine mammals, amphibians, water quality

Appendix 4
Detailed monitoring protocol and results

Appendix 5
Mitigation, monitoring, and reporting program (MMRP)

Appendix 6
Environmental training pamphlet and sign-in sheet

Appendix 7
Spill prevention plan

Appendix 8
Geotechnical assessment

Appendix 9
California rapid assessment method (CRAM) report

Appendix 10
Reserve otter monitoring program (ROMP) protocol

Appendix 11
Evaluation of blue carbon function

Appendix 12
Harbor Seal Incidental Harassment Agreement Report Phase II

Appendix 1

Amphibian monitoring log, approvals

Table 1. Monitoring for amphibians at Minhoto saltwater marsh restoration project, ESNERR, Dec 2017 – Mar 2018.

Date	Survey Type	Person	Time	Notes
12-1-17	Pre-disturbance survey	DCB	1000-1230	Surveyed entire stockpile 5 days prior to initial disturbance
12-7-17	Local	DCB, MF	1015-1310	Mobilization of equipment
12-11-18	Pre-disturbance of stockpile area #1	DCB	0830-1000	No burrows or any man-made pipes of any kind that could provide shelter to amphibs
12-15-17	Pre-disturbance of stockpile area #2	BMM	0700-0830	Focus on ground squirrel burrows, approx. 70 GS burrows over 2 acres; no animals observed
12-18-17	Re-check stockpile area #2	DCB	1000-1100	No animals observed
12-19-17	Re-check stockpile area #2	MF	0700-0800	Overnight rain <0.1”; No animals observed; also checked near old barns (next to equipment staging area) and found raccoon scat
12-22-17 thru 1-9-18	No work at site			
1-11-18	Pre-disturbance of stockpile area #3	BMM	0800-1000	Approximately 60 ground squirrel burrows observed in the wide swath between the two excavation pits; gopher burrows were also abundant. No amphibians were observed. One burrow appeared to be a fox den, based on canid sign. Called Monique to pass on the info; she showed up ~0940 to view the potential canid den site. Apparently, Monique previously camera-monitored the den for a week and found no use by mammals. However, the camera did record a single burrowing owl. Monique later met with Warren
1-11-18	Disturbance of Stockpile #3	MF	1100-1200	Watched ground disturbance of Stockpile #3.
1-19-18	Surveyed road and all disturbed areas	MF	0630-0800	Overnight rain <0.1”; No animals observed.
1-22-18 thru 1-26-18	No work at site			
3-1-18 through 3-1-18	No work at site	MF		Overnight rain >0.1”; Even though there was no work since I was out there I went ahead and surveyed. No animals observed.

USFWS approval of amphibian biological monitors (e-mail)

From: Martin, Jacob <jacob_martin@fws.gov>
Sent: Monday, November 13, 2017 10:03 AM
To: Monique Fountain
Cc: Brown, Gregory G SPN
Subject: Re: Elkhorn Slough TMR Amphibian Relocation Plan: file# 2014-00395S

Hi Monique,

We have sufficient information on Bryan and Dana's qualifications on file and they are hereby approved to implement the minimization measures required in biological opinion number 2016-F-0226.

thanks,

Jacob M. (Jake) Martin
Senior Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Ventura Fish and Wildlife Office-Santa Cruz Sub-office
1100 Fiesta Way
Watsonville, CA 95076
(805) 677-3327
jacob_martin@fws.gov

On Thu, Nov 9, 2017 at 2:41 PM, Monique Fountain <monique@elkhornslough.org> wrote:

Hi Jake,

It turns out that Corey, Valentine and Antonia are not available to monitor this project. I am requesting that you approve two local independent amphibian biologists that have worked in the area for years and have their own state and federal permits. Would you approve Dana Bland and Bryan Mori to implement the minimization measures required in the biological opinion number 2016-F-0226?

Monique

From: Martin, Jacob [mailto:jacob_martin@fws.gov]

Sent: Friday, October 27, 2017 12:14 PM

To: Monique Fountain

Cc: Brown, Gregory G SPN

Subject: Re: Elkhorn Slough TMR Amphibian Relocation Plan: file# 2014-00395S

Hello Monique,

You submitted a California Red Legged Frog (Rana draytonii) and California Tiger Salamander (Ambystoma californiense) Relocation Plan, which included a request to approve project biologists (Corey Hamza, Valentine Hemingway, and Antonia Akhavan), to implement minimization measures required in biological opinion number 2016-F-0226. I have reviewed the plan and its associated biologist approvals and have determined that they are consistent with the biological opinion. They are hereby approved. Thank you for your coordination on this matter. Please contact me if you have any questions.

Thanks,

Jacob M. (Jake) Martin
Senior Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Ventura Fish and Wildlife Office-Santa Cruz Sub-office
1100 Fiesta Way
Watsonville, CA 95076
(805) 677-3327
jacob_martin@fws.gov

On Wed, Oct 25, 2017 at 10:53 AM, Monique Fountain <monique@elkhornslough.org> wrote:

Jake and Greg,

Attached is the California Red Legged Frog and California Tiger Salamander Relocation plan required by the USFW Biological Opinion - conservation measure #2.

Please let me know if you have any questions,

Monique

____

Monique Fountain
Tidal Wetland Program Director
Elkhorn Slough National Estuarine Research Reserve
1700 Elkhorn Road,
Watsonville, CA 95076
phone: 831.728.5939 x242
fax: 831.728.1056

California Red Legged Frog (*Rana draytonii*) and California Tiger Salamander (*Ambystoma californiense*) Relocation Plan

In the event that a California Red Legged Frog (CRLF) or California Tiger Salamander (CTS) is found during construction activities, the following efforts will be undertaken to relocate the animals to a safe suitable habitat location. All handling of animals will be conducted by the USFW approved and permitted project biologist (permit attached). In the event the approved biologist is unavailable, one of several other backup permitted biologists will be called upon to carry out the necessary relocation activities.

California Tiger Salamander

In the event an animal is unearthed as a result of construction activities, the animal will be measured, age estimated, photographed and sexed if possible and taken to a nearby burrow that is outside of the construction area (ex. California ground squirrel) and released in the entrance of the burrow. In the event an animal is encountered above ground during winter and spring migration, the animal will be measured, age estimated, photographed, and sexed if possible. A best estimate will be made as to the direction the animal was traveling and the animal will be taken in that direction until outside of the construction area and released under a moistened cover board or organic material.

California Red Legged Frog

California Red Legged Frogs could be encountered in one of two ways: unearthing an animal in an underground burrow, or encountering a migrating animal above ground or just underneath surface cover. Under both circumstances, the animal will be taken to the nearest freshwater wetland and released in close proximity to the water. If the nearest suitable freshwater wetlands at the time of encountering the animal are on adjacent properties, efforts will be made to contact the land owner and ask permission to release the animal on their property. The nearest suitable freshwater wetland will likely be one of those identified in the assessment below that was provided for the Biological Opinion.

AMPHIBIAN ASSESSMENT
FOR
ELKHORN SLOUGH TIDAL MARSH RESTORATION PROJECT

Introduction

The Elkhorn Slough National Estuarine Research Reserve (ESNERR) proposes to restore approximately 145 acres of tidal salt marsh, salt marsh–upland ecotone habitat, and perennial grasslands in the Elkhorn Slough Estuary. For a detailed description of the tidal marsh restoration project, please refer to the Draft Initial Study prepared by ESA in 2014.

The focus of this report is to assess the potential habitat suitability of the sediment stockpile and vegetated buffer areas adjacent to the tidal marsh for three special status amphibian species: California tiger salamander (CTS) (*Ambystoma californiense*), Santa Cruz long-toed salamander (SCLTS) (*Ambystoma macrodactylum croceum*), and California red-legged frog (CRLF) (*Rana draytonii*). The CTS is both state and federally listed as a threatened species. The SCLTS is both state and federally listed as an endangered species. And the CRLF is federally listed as a threatened species and is a state species of special concern.

Methods

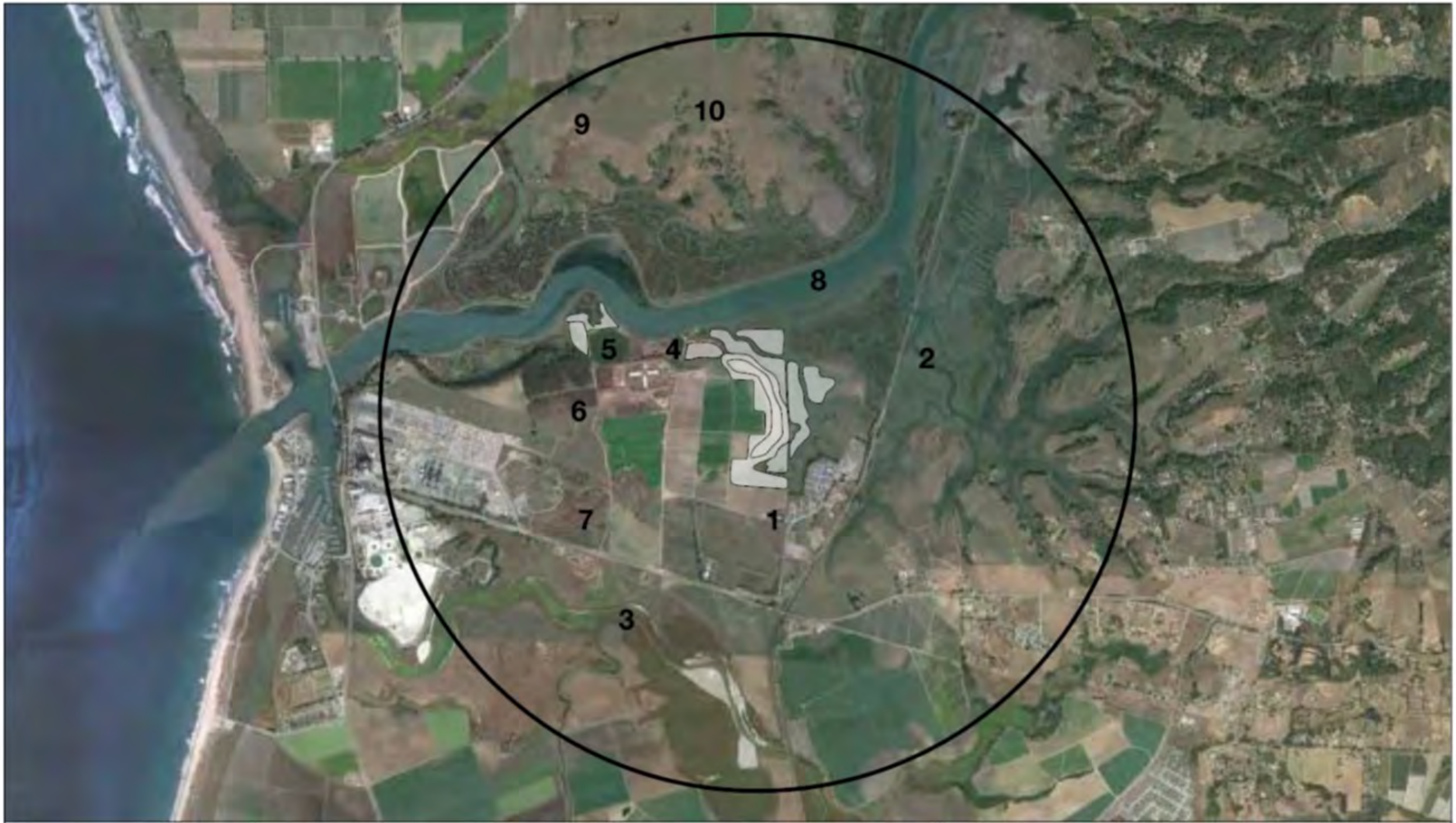
Dana Bland, Wildlife Biologist, conducted a reconnaissance survey of the project site on November 17, 2014, with ESNERR Project Coordinator, Monique Fountain, and Stewardship Coordinator, Andrea Woolfolk. Dana walked the area of potential amphibian habitat, and the ESNERR staff members showed Dana marsh areas slated for restoration, the freshwater habitats within 2 km of the project site, and explained the general history of the land uses in the vicinity.

This assessment used the guidelines provided by the USFWS and CDFW (2003, 2005, and 2012).

Google Earth 2013 aerial photo was used to prepare Figure 1 showing habitats within 2 km (1.2 mi) of the project area. The occurrences of CTS, SCLTS and CRLF were mapped within 2 km (Figure 2) of the project area and 5 km (Figure 3) using data from the California Natural Diversity Data Base (CNDDB), and information from other studies in the vicinity (Coastal Conservation and Research Inc. (CCR) 2008, BRG and Dana Bland & Assoc. 2000, 2002), and survey records from ESNERR (Nina D'Amore, pers. Comm.). Andrea Woolfolk provided the mapping of the CNDDB data.

Project Area Description

Soil for the tidal marsh restoration will be obtained from a stockpile adjacent to the marsh (Figure 1). Approximately 20 acres of the 40-acre stockpile and perennial grassland restoration area will be impacted; 7 acres will become tidal marsh, approximately 7 acres will be excavated and used for marsh restoration, and approximately 26 acres will be restored as upland perennial grassland.



Base Map Source: Google Earth

N

SCALE: 1" = .55'

0 .55' 1.1'

LEGEND

1-10 Aquatic Habitats

2 km (1.2 miles)

Sediment Stockpile

Vegetated Buffer

Salt Marsh Restoration Area

Dana Bland & Associates
Consulting Biologists

Elkorn Slough Tidal Marsh Restoration Project
Habitats within 2 km of Project Site

Figure 1
11/14

From at least 1930, as per historic aerials on Google Earth, to 2009, the Minhoto property was farmed in various row crops that extended up to the edge of the tidal marsh. When California Department of Fish and Wildlife (CDFW) acquired the Minhoto property in 2009, a buffer of 200 to 500 feet was established along the edge of the tidal marsh where no farming was allowed. This is the area currently designated as the soil stockpile and vegetated buffer in Figure 1. It is disked and planted in cover crops annually to reduce weeds. In July of 2013, approximately 50,000 cy of sediment from the Pajaro River was placed on the buffer area.

As of November 17, 2014, the soil stockpile had not been disked. Ground squirrel burrows were observed along the fence at the southern Minhoto property boundary, near the large pump structure that feeds the farm pond at the southwestern property edge (#1 on Figure 1), in openings in the vegetation along the dirt road west of the project site, and at the northern end of the stockpile. There are a few scattered ground squirrel burrows in open areas in the stockpile also.

Figure 1 shows the project site and the habitats with 2 km (1.2 mi) of the project site. The aquatic habitats within 1.2 km of the project site are numbered 1-10 on Figure 1 and explained below in Table 1. The area immediately to the west of the project site is row crop agriculture, and a little further west is Moonglow Dairy. At the western edge of the 2km radius is industrial uses, including a power plant, currently run by Dynergy. To the south of Dolan Road is rural residential and mixed use including agriculture and ranching. To the northeast is the ESNERR. To the east is residential, a school, and more rural residential and agriculture. To the north is the main stem of the Elkhorn Slough and north of that is the private ranch, and on the northwestern edge of 2km radius, a portion of the State owned wildlife reserve (former salt ponds).

Table 1. List of aquatic habitats with 2km (1.2 mi) of the soil stockpile for the Elkhorn Slough Tidal Marsh Restoration Project, Moss Landing, CA, Dec 2014. Refer to Figure 1.

No.	Fresh/Salt	Type	Vegetation	Perennial?	Notes
1	Fresh	Man-made	Bulrush, dense	Usually	Filled by well, 0.5 ppt salinity
2	Saline	Natural	Salt marsh	Yes	Trib to main stem of slough
3	Brackish to fresh	Natural	Mixture	Yes	Lower Moro Cojo Slough; salinity depends on if tide gates leak; amphibs found in upper slough in fresh water
4	Fresh	Man-made	Bulrush	Yes	Fed by runoff from dairy ops; sampled for amphibs by N. D’Amore but none found
5	Fresh	Man-made	Bulrush	Yes	Fed by runoff from dairy ops
6	Fresh	Man-made	None	No	A depression in a cattle pen – highly disturbed, sometimes filled with straw

7	Fresh to Alkaline	Man altered	Bulrush to alkaline	No	A natural channel altered by dike on north side, but undergoing restoration in upstream portions; CRLF and CTS found here
8	Saline	Natural	Salt marsh	Yes	Main stem Elkhorn Slough
9	Fresh	Man-made	Fresh water marsh	Unknown	Stock ponds. CRLF observed here.
10	Fresh	Man-made	Fresh water marsh	Unknown	Stock ponds. CRLF observed here.

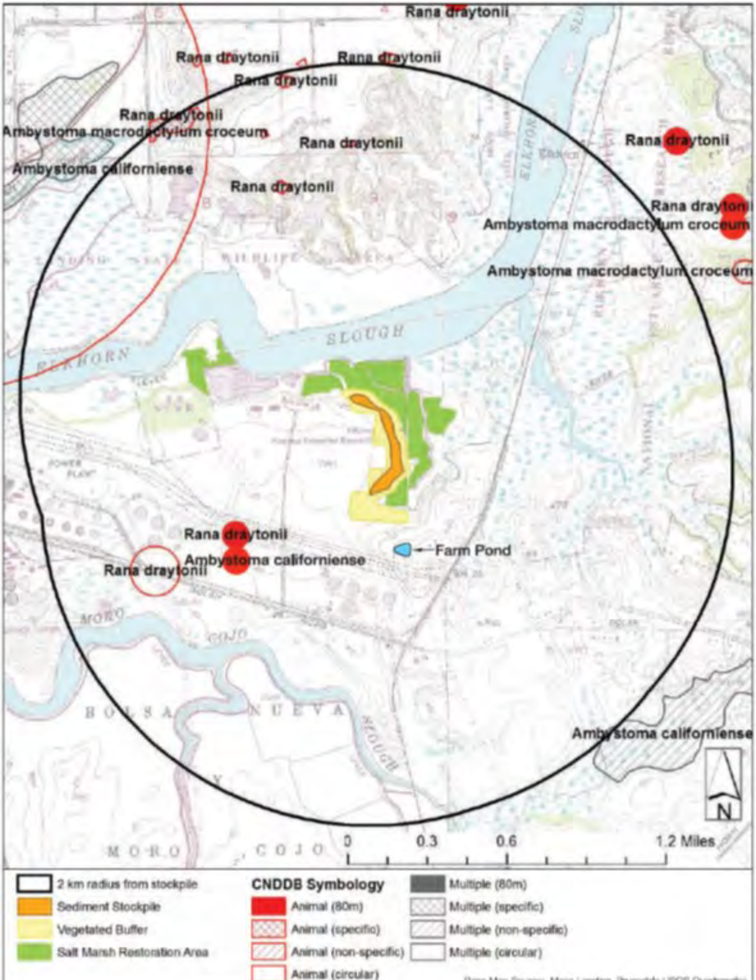
Figure 2 shows the known locations of the three amphibian species of concern within 2 km of the project site, and Figure 3 shows the amphibian locations within 5 km of the project site. There are two known occurrences of CRLF within 2 km: one in the swale adjacent to the dike/levee on the north/west edge (location #7 in Table 1, Figure 1), and one in a culvert pool under the railroad tracks next to Dolan Road, which is the drainage fed by the swale mentioned above (not shown separately on Figure 1). There is also known occurrences of CTS in the same swale (location #7) which were found by Dana Bland during two separate years of pitfall trapping (winter 1999-2000 and 2000-2001). However, no larvae were found during dip netting of the swale. The swale has fresh water marsh to alkaline marsh vegetation; however, the water alkalinity/salinity was not tested during the early 2000 study. The CCR may have collected more information since that time; the property was donated to them and their group has been restoring the area for the last decade.

Location #4 is a large freshwater pond with levees on the slough sides, and dense bulrush. Nina D'Amore seined the pond once for amphibian larvae, but none of the special status species were observed (A. Woolfolk, pers. Comm.). This pond is fed by runoff from the dairy.

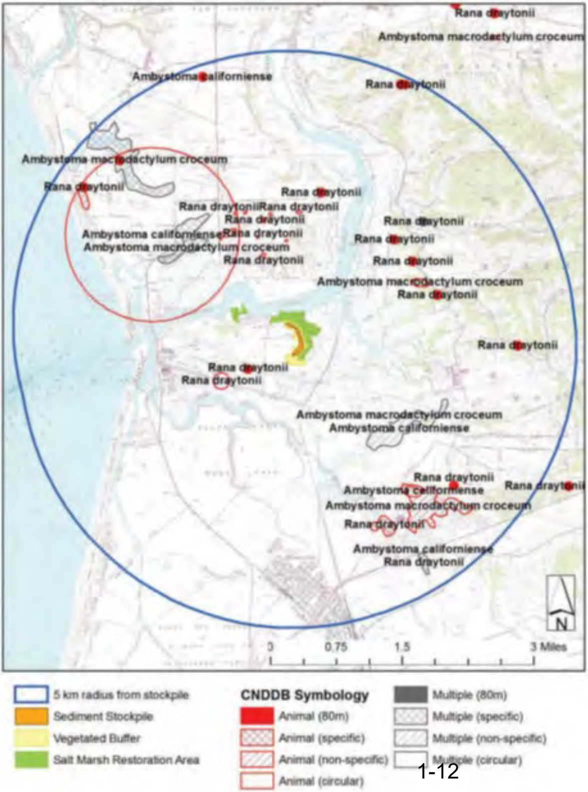
Farm pond (location #1, Figure 1), is the closest freshwater aquatic habitat to the project site. It is shown in the photo in Figure 4. It is currently densely overgrown with bulrush. The pond is filled with water from an adjacent well, with 0.5ppt salinity (A. Woolfolk, pers. Comm.), and used by the farm operations as needed. The pond usually has water into late summer/fall, as shown on Google Earth aerials. There are no known records of anyone surveying this farm pond for amphibian larvae.

There are no other known records of CTS, SCLTS or CRLF within 2km of the project site on the south side of Elkhorn Slough. The Slough is a significant barrier to movement by these three amphibians from known occurrences on the north.

The topography of the area is generally flat. There is a slope from the top of the stockpile area to the edge of the marsh, an elevation decline of approximately 20 feet (information provided by A. Woolfolk, ESNERR). After the material is removed from the stockpile for the marsh restoration, the slope will be recontoured to a stable slope and planted with perennial grasses.



Dana Bland & Associates Consulting Biologists	Elkorn Slough Tidal Marsh Restoration Project California tiger salamander, Santa Cruz long-toed salamander, and California red-legged frog occurrences within 2 km (1.2 miles) of Project Stockpile Area. Data source: see text	Figure 2 11/14



Source: CNDDB October 2014

Figure 4. Farm pond on Minhoto property, location #1 in Table 1 and Figure 1.

Figure 5. Pump that fills pond shown in Figure 4. In middle background is marsh to be restored, and on left above green marsh area is the sto[illegible] area.

Summary

CTS

The soil stockpile for the Elkhorn Slough Tidal Marsh Restoration Project contains ground squirrel burrows that may provide potential upland habitat for CTS, and adult CTS have been observed approximately 0.5 mile to the west in a seasonal swale (Location #7 on Figure 1) (Dana Bland & Assoc. 2000, 2001).

CRLF

CRLF have also been observed in the same seasonal swale as the CTS (Location #7 on Figure 1), 0.5 mi to the west of the soil stockpile, but they may only occur in the burrows in the soil stockpile when taking short term cover while dispersing between other aquatic or riparian habitats. The soil stockpile contains no riparian or freshwater marsh habitat suitable for CRLF. Other freshwater habitats within 2 km of the project site (e.g., Locations #4 and 5 on Figure 1) may provide suitable habitat for CRLF, but are part of the dairy and are not expected to be impacted by this project.

SCLTS

SCLTS are not expected to occur in the soil stockpile. The closest known location of this species is the Lower Cattail Pond on the ENSERR, which is 1.5 miles to the NE (greater than 2 km, shown on Figure 3). Individuals would have to cross saline portions of the slough tributaries in order to arrive at the project site, which is so unlikely that the possibility is negligible. The SCLTS population in the Upper Moro Cojo Slough is approximately 1.7 miles southeast of the project site, as shown in Figure 3. There are several busy roads, such as Dolan Road, Castroville Boulevard, and Shaffi Road, that would present partial barriers to salamander travel to get from the slough to the stockpile. And also the stockpile is usually bare, tilled soil, not the type of moist vegetated habitat that SCLTS seek for habitat. In summary, the soil stockpile does not have upland habitat suitable for SCLTS, either as temporary dispersal because of the distance from breeding sources, or as upland because it has no moist cover vegetation that this species needs for upland habitat.

References

California Department of Fish and Wildlife. 2014. California Natural Diversity Data Base. Rarefind5 Program, Natural Heritage Division, Sacramento, CA.

Biotic Resources Group and Dana Bland & Assoc. 2000. Dolan Road Wetland Mitigation Site, year 1 (2000) Monitoring Report. 2000. Report prepared for Graniterock Company, Dec. 2000.

Biotic Resources Group and Dana Bland & Assoc. 2002. Dolan Road Wetland Mitigation Site, year 2 (2002) Monitoring Report. 2002. Report prepared for Graniterock Company, Dec. 2002.

U. S. Fish and Wildlife Service. 2003. Interim guidance on site assessment and field surveys for determining presence or a negative finding of the California tiger salamander, October 2003.

U. S. Fish and Wildlife Service. 2005. Revised guidance on site assessments and field surveys for the California red-legged frog, August 2005.

U. S. Fish and Wildlife Service and California Department of Fish and Wildlife. 2012. Guidance on site assessment and field studies to determine presence or report negative finding of the Santa Cruz long-toed salamander. Unpub. Report, Ventura and Sacramento, CA. Dated Dec 2012.

NATIVE ENDANGERED & THREATENED SP. RECOVERY
ENDANGERED & THREATENED WILDLIFE

Permit Number: TE082546-6

Effective: 01/05/2017 Expires: 01/04/2022

Issuing Office:

Department of the Interior
U.S. FISH & WILDLIFE SERVICE
Endangered Species Permit Office
2800 Cottage Way, Suite W-2606
Sacramento, CA 95825-1846
permitsR8ES@fws.gov

ENDANGERED SPECIES DIVISION CHIEF

Permittee:

ELKHORN SLOUGH NATIONAL ESTUARINE RESEARCH RESERVE
1700 ELKHORN ROAD
WATSONVILLE, CA 95076
U.S.A.

Name and Title of Principal Officer:
KERSTIN WASSON - RESEARCH COORDINATOR

Authority: Statutes and Regulations: 16 USC 1539(a), 16 USC 1533(d); 50 CFR 17.22, 50 CFR 17.32, 50 CFR 13.

Location where authorized activity may be conducted:
ON LANDS SPECIFIED WITHIN THE ATTACHED SPECIAL TERMS AND CONDITIONS

Reporting requirements:
ANNUAL REPORT DUE: 1/31
See permit conditions for further reporting requirements.

Conditions and Authorizations:

A. General conditions set out in Subpart B of 50 CFR 13, and specific conditions contained in Federal regulations cited above, are hereby made a part of this permit. All activities authorized herein must be carried out in accord with and for the purposes described in the application submitted. Continued validity, or renewal of this permit is subject to complete and timely compliance with all applicable conditions, including the filing of all required information and reports.

B. The validity of this permit is also conditioned upon strict observance of all applicable foreign, state, local tribal, or other federal law.

C. Valid for use by permittee named above.

SPECIAL TERMS AND CONDITIONS
Elkhorn Slough National Estuarine Research Reserve

1. This permit was previously issued on November 6, 2008. The terms and conditions set forth in that permit are hereby superseded by this amendment.

2. Acceptance of this permit serves as evidence that the permittee understands and agrees to abide by the "General Permit Procedures and Permit Regulations for Native Endangered and Threatened Wildlife Species Permits," 50 CFR Part 13, 50 CFR 17.21 and 17.22 (endangered wildlife) and/or 50 CFR 17.31 and 17.32 (threatened wildlife), as applicable found at: http://www.fws.gov/carlsbad/r8permits/permitprocedures-regulations.htm

3. The permittee must have all other applicable State and Federal permits prior to the commencement of activities authorized by this permit. In addition, this permit does not authorize access to Federal, Tribal, State, local government, or private lands as it is the responsibility of the permittee to obtain land owner permission prior to commencing permitted activities on such lands.

4. The permittee is authorized to take (harass by survey, capture, collect tissue samples, conduct pathology tests, collect dead and moribund individuals, mark, release, and restore habitat for) the California red-legged frog (*Rana draytonii*), and take (harass by survey, capture, collect tissue samples, release, and restore habitat for) the Santa Cruz long-toed salamander (*Ambystoma macrodactylum croceum*) and the California tiger salamander (*Ambystoma californiense*, Central DPS), in conjunction with research and monitoring activities for the purpose of enhancing their survival, as specified in the permittee's February 5, 2016, permit renewal request, in accordance with the conditions stated below.

5. Permitted activities are restricted to the following geographic area in California:

   Monterey and Santa Cruz Counties.

   Notifications to conduct activities at the above authorized locations pursuant to this permit shall be submitted in writing to the Recovery Permit Coordinator at the appropriate Fish and Wildlife Office (FWO) of the U.S. Fish and Wildlife Service (Service) at least 15 days prior to conducting such activities. The appropriate FWO is determined as follows:

   Ventura Fish and Wildlife Office (VFWO):
   For areas from Los Angeles County north and west of the Santa Monica pier, west of the 405 freeway, north of the San Gabriel Mountains, and west of the San Andreas Rift Zone; Ventura County; Santa Barbara County; areas in San Luis Obispo County west of the Carrizo Plain; and Monterey, San Benito, and Santa Cruz Counties in their entirety, contact the Ventura Fish and Wildlife Office, 2493 Portola Road, Suite B, Ventura, California 93003 (telephone: 805-644-1766).

For guidance regarding field office jurisdiction please reference:
http://www.fws.gov/carlsbad/r8permits/R8JurisdictionalMaps.html
If still in doubt in determining the jurisdictional boundary lines within any jurisdictional field office, contact the Recovery Permit Coordinator of the applicable FWO to ensure your activities are conducted and reported within the correct jurisdiction.

Notifications shall include, as appropriate: (a) an explanation of the purpose of the study and a clear description of methods, including the names of field personnel and the number and dates of surveys; (b) the number of individuals proposed to be captured and/or collected; (c) a map (at a minimum, a 1:24,000 scale U.S. Geological Survey (USGS) topographical map) depicting the location of the survey site(s); (d) the assessor's parcel number (APN) for the site (if possible); and (e) geographic information system (GIS) data depicting the survey site or global positioning system (GPS) coordinates (if possible). Information may be submitted electronically if pre-arranged with the Recovery Permit Coordinator.

After 15 days of the Service's receipt of the notification, the permittee may commence activities authorized by this permit unless authorization is denied by the Service. If the permittee is denied authorization to conduct the proposed activities or activities at the requested location(s), including previously authorized sites, a request for reconsideration may be submitted to the Endangered Species Division Chief at the Service's Regional Office for the Pacific Southwest Region (Region 8), 2800 Cottage Way, Room W-2606, Sacramento, California 95825-1846, as provided in 50 CFR 13.29. The procedures specified in 50 CFR 13.29(b) must be followed.

6. Authorized individuals:

Only individuals on the attached List of Authorized Individuals (List) are authorized to conduct activities pursuant to this permit. The List, printed on Service letterhead, may identify special conditions or circumstances under which individuals are authorized to conduct permitted activities and must be retained with these Special Terms and Conditions. Each named individual will be responsible for compliance with the terms and conditions of this permit.

To request changes to the List, the permittee must submit written requests to the Recovery Permit Coordinator at the VFWO at least 30 days prior to the requested effective date. The request must be signed and dated by the permittee and include:

a. The permit number.

b. The name of each individual to be appended to the List.

c. The resume/qualifications statement of each person to be appended to the List, detailing their experience with each species and type of activity for which authorization is requested.

d. The names, phone numbers and email addresses of a minimum of two references including letters of reference. Letters of reference should address the individual's qualifications for the specific activities to be conducted.

e. The names of the individuals to be deleted from the List.

Note: This procedure is for personnel changes only. For requests to renew/amend this permit, a complete application must be submitted to the Endangered Species Division Chief at the Region 8 office.

7. Taking of the California red-legged frog (frog, CRLF):

The permittee is authorized to harass by survey, capture, handle, collect tissue samples, conduct pathology tests, collect dead and moribund individuals, mark, release, and restore habitat for the frog within the geographic boundaries specified above and the time limitation specified in the permit, provided that:

a. All surveys shall follow methodology described in the most current survey protocol for the frog.
   i. If water conditions are such that visual surveys are feasible and adequate, only visual survey methods shall be employed. Snorkeling and walking through shallow water may be used during visual sampling.
   ii. For presence/absence surveys only, if positive identification of the California red-legged frog is made at a site, no capture and handling shall be done.
   iii. If captured frogs are handled for identification, measurement, and photographs before being released, all measurements shall be obtained in an expedient manner.
   iv. No egg masses may be harassed in any manner for any activity authorized in this permit.
   v. Larval frogs shall not be handled out of the water for longer than 30 seconds unless rewetted, and shall not be retained for longer than 5 minutes for processing.
   vi. Unless otherwise specified in a study plan previously approved in writing by the Service, all frogs shall be released at the point of capture.
   vii. Frogs will not be removed from the wild and held in captivity for any reason unless prior written approval is acquired by the appropriate FWO, unless the severity of an injury to the frog obviates immediate care. Animals shall be transported according to accepted methods, in moist cloth bags or in terrarium with moisture gel or non-cellulose sponge to minimize desiccation.

b. Capture methods shall follow commonly accepted techniques for amphibian field sampling, including: (i) capture by hand (wet hands only); and (ii) dip-netting.

c. The hands and arms of all workers handling frogs shall be free of lotions, creams, sunscreen, oils, ointment, insect repellent, or any other material that may harm frogs. Handling of frogs shall be done with wet hands.

d. Amplexing pairs of frogs shall not be captured, handled, or disturbed.

e. Information on new localities for the frog shall be reported immediately, and this notification shall be followed up in writing to the appropriate FWO and the California Natural Diversity Database within 3 working days of their discovery. Information may be submitted electronically if pre-arranged with the Recovery Permit Coordinator.

f. In an effort to minimize the spread of pathogens that may be transferred as result of permitted activities, surveyors shall follow the guidance outlined below for disinfecting equipment and clothing after entering a pond and before entering a new pond, unless the wetlands are hydrologically connected to one another.

    i. All organic matter shall be removed from nets, traps, boots, vehicle tires and all other surfaces that have come into contact with water or potentially contaminated sediments. Cleaned items shall be rinsed with clean water before leaving each study site.
    ii. Boots, nets, traps, hands, etc., shall be scrubbed with a bleach solution (0.5 to 1.0 cup per 1.0 gallon of water), Quat-128 (1 to 60), or a 3 to 6 percent sodium hypochlorite solution. Equipment shall be rinsed clean with water between study sites. Cleaning equipment in the immediate vicinity of a pond or wetland shall be avoided (e.g., clean in an area at least 100 feet from aquatic features). Care shall be taken so that all traces of the disinfectant are removed before entering the next aquatic habitat.
    iii. When working at sites with known or suspected disease problems, disposable gloves shall be worn and changed between handling each animal. Gloves shall be wetted with water from the site or distilled water prior to handling any amphibians. Gloves shall be removed by turning inside out with hands cleaned using a hand cleaner and water rinse to minimize cross-contamination.
    iv. Used cleaning materials (liquids, etc.) shall be disposed of safely, and if necessary, taken back to the lab for proper disposal. Used disposable gloves shall be retained for safe disposal in sealed bags.

g. When working in potential frog habitats, such as freshwater streams, vernal pools, agricultural canals, and stock ponds, the permittee shall be aware of all areas known to support co-occurring endangered and threatened species, including: tidewater gobies (*Eucyclogobius newberryi*). The permittee shall take suitable precautions to avoid injuries and mortalities to these species, up to and including avoidance of the area.

h. Tissue samples (tail or toe clips and associated blood) may be collected for genetic, disease, and/or contaminants testing. Collection will generally follow the

UC Davis Tissue Collection Protocol for Genetic Research (Leyse et al 2003), but whole live individuals shall not be sacrificed.

i. When swabbing to test for the presence of chytrid fungus, the UC Berkeley Briggs NIH Group Swab Protocol (2004-2007), or other appropriate protocols, as approved by the VFWO, must be followed.

j. When testing for chytrid fungus or other disease, a new glove shall be used for each individual frog when capturing by hand, and when handling each individual frog and tadpole.

k. Healthy voucher specimens shall not be collected. Dead specimens may be collected at any time. Diseased or injured specimens not expected to survive (moribund) may be collected. Malformed and possibly diseased individuals may be collected and submitted to a laboratory for testing. No more than 20 malformed and possibly diseased individuals shall be taken from any subpopulation/locality sampled.

l. Frogs may be marked with PIT tags. Frogs less than 50 millimeters in length (snout to urostyle) may only be PIT-tagged using tags weighing 0.07 grams or less (Biomark model TXP148511B or similar). PIT-tags larger than 12-gauge must not be used on frogs of any size. Frogs must not be anesthetized at any time.

m. Habitat restoration may be conducted in accordance with a plan approved by the VFWO. Appropriate activities may include removing sediment, managing vegetation, removing invasive species, or other activities as agreed to by the permit holder and the VFWO.

8. Taking of the Santa Cruz long-toed salamander (long-toed salamander):

The permittee is authorized to harass by survey, capture, handle, collect tissue samples, and release larvae, juveniles and adults, and restore habitat for the long-toed salamander within the geographic boundaries specified above and the time limitations specified in this permit, provided that:

a. The permittee has submitted a proposal to survey at a given site and has received written approval from the VFWO to proceed. The permittee's request to conduct surveys activities shall include a description of the study site, maps or aerial photos of the site, and if appropriate, a diagram of the layout of the traps and drift fences in relation to property boundaries, topographic features, etc. Requests to conduct surveys or research activities shall be submitted at least 15 days prior to the desired commencement of activities. Information may be submitted electronically if pre-arranged with the Recovery Permit Coordinator.

b. When applicable, the permittee shall follow the Service's Guidance on Site Assessment and Field Surveys to Detect Presence or Report a Negative Finding of the Santa Cruz Long-toed Salamander, issued in 2012 or the most recent version.

c. All handling of long-toed salamanders must adhere to the following measures:
   i. Handling shall be done in an expedient manner with minimal harm to the individuals being handled. The hands and arms of all workers handling long-toed salamanders shall be free of lotions, creams, sunscreen, oils, ointment, insect repellent, or any other material that may harm tiger salamanders. Handling of long-toed salamanders shall be done with wet hands.
   ii. If captured long-toed salamanders exhibit signs of distress (e.g., lack of response to stimuli or erratic behavior), they shall be immediately released at the point of capture.
   iii. All captured long-toed salamanders shall be released at the point of capture unless that location puts them in imminent danger, in which case they shall be placed in a nearby refugium sufficient to protect them.
   iv. Larval long-toed salamanders shall not be handled out of the water for longer than 30 seconds unless rewetted, and shall not be retained for longer than 5 minutes for processing.

d. Capture of larval long-toed salamanders in ponds is achieved via dip-netting with standard aquatic nets, cast nets, seines, and umbrella seines in the following manner:
   i. Capture of larval long-toed salamanders in ponds shall occur after April 15 to avoid disturbing eggs. Earlier start dates must be justified in writing by the permittee and approved by the VFWO.

e. In an effort to minimize the spread of pathogens that may be transferred as result of these surveys, surveyors shall follow the guidance outlined below for disinfecting equipment, clothing and hands after surveying a pond and before entering a new pond, unless the wetlands are hydrologically connected to one another:
   i. All organic matter shall be removed from nets, traps, boots, vehicle tires, and all other surfaces that have come into contact with water or potentially contaminated sediments. Cleaned items shall be rinsed with clean water before leaving each study site.
   ii. Boots, nets, traps, hands, etc., shall be scrubbed with a 70 percent ethanol solution, a bleach solution (0.5 to 1.0 cup per 1.0 gallon of water), Quat-128 (1 to 60), or a 3 to 6 percent sodium hypochlorite solution and rinsed clean with water between study sites. Cleaning equipment in the immediate vicinity of a pond or wetland shall be avoided (e.g., clean in an area at least 100 feet from aquatic features). Care shall be taken so that all traces of the disinfectant are removed before entering the next aquatic habitat.
   iii. When working at sites with known or suspected disease problems, disposable gloves shall be worn and changed after handling each animal.

Gloves shall be wetted with water from the site or distilled water prior to handling any amphibians. Gloves shall be removed by turning inside out to minimize cross-contamination.

iv. Used cleaning materials (liquids, etc.) shall be disposed of safely, and if necessary taken back to the lab for proper disposal. Used disposable gloves shall be retained for safe disposal in sealed bags.

f. Capture of adults and juveniles in terrestrial habitats may be achieved through placement and checking of cover boards or through visual surveys of surface refugia. The permittee must lift cover boards and natural cover objects (logs, debris, etc.) carefully to prevent injury to any long-toed salamanders and must replace them to their original positions.

g. Tissue samples (tail or toe clips) may be collected for genetic analysis in the course of research activities. Collection will generally follow the UC Davis Tissue Collection Protocol for Genetic Research (Leyse et al 2003), but whole live individuals shall not be sacrificed. Samples must be sent with a copy of the permit under which they were collected to Dr. Bradley Shaffer, University of California Los Angeles, Los Angeles, California (or other depository as authorized by the VFWO).

h. Habitat restoration activities may be conducted in accordance with a plan approved by the VFWO. Appropriate activities may include removing sediment, managing vegetation, removing invasive species, or other activities as agreed to by the permit holder and the VFWO.

i. Information on new localities for the long-toed salamander shall be reported verbally and followed up in writing to the VFWO and the California Natural Diversity Database within 3 working days of their discovery. Information may be submitted electronically if pre-arranged with the Recovery Permit Coordinator.

j. Injured long-toed salamanders shall be taken for veterinary care to the University of California, Davis, if appropriate, and held in captivity until they are deemed releasable. The disposition of such animals shall be disclosed to the Service within 3 days of the incident. The appropriate FWO may make further recommendations regarding the treatment of such individuals.

9. Taking of the California tiger salamander (tiger salamander):

The permittee is authorized to harass by survey, capture, handle, collect tissue samples, release, and restore habitat for the tiger salamander within the geographic boundaries specified above and the time limitations specified in this permit, provided that:

a. The permittee has submitted a proposal to survey at a given site and has received written approval from the appropriate FWO to proceed. The permittee’s request to conduct surveys activities shall include a description of the study site, maps or aerial photos of the site, and if appropriate, a diagram of the layout of the traps and drift fences in relation to property boundaries, topographic features, etc. Requests to conduct surveys or research activities shall be submitted at least 15 days prior to the desired commencement of activities. Information may be submitted electronically if pre-arranged with the Recovery Permit Coordinator.

b. All handling of tiger salamanders must adhere to the following measures:
   i. Handling shall be done in an expedient manner with minimal harm to the individuals being handled. The hands and arms of all workers handling tiger salamanders shall be free of lotions, creams, sunscreen, oils, ointment, insect repellent, or any other material that may harm tiger salamanders. Handling of tiger salamanders shall be done with wet hands.
   ii. If captured tiger salamanders exhibit signs of distress (e.g., lack of response to stimuli or erratic behavior), they shall be immediately released at the point of capture.
   iii. All captured tiger salamanders shall be released at the point of capture unless that location puts them in imminent danger, in which case they shall be placed in a nearby refugium sufficient to protect them.
   iv. Larval salamanders shall not be handled out of the water for longer than 30 seconds unless rewetted, and shall not be retained for longer than 5 minutes for processing.

c. Capture of larval tiger salamanders in ponds is achieved via dip-netting with standard aquatic nets, minnow traps, cast nets, seines, and umbrella seines in the following manner:
   i. Capture of larval tiger salamanders in ponds shall be done in a manner to avoid disturbing tiger salamander eggs.
   ii. The permittee must receive approval from the appropriate FWO prior to using minnow traps. Minnow traps shall be deployed overnight and checked frequently enough to ensure that larvae are not killed or injured, and do not exhibit signs of physiological stress due to low oxygen levels. The frequency of trap inspections shall be determined empirically for each site, but shall not exceed 24 hours between inspections. Minnow trap deployment shall be avoided when daytime high temperatures reach or exceed 80 degrees Fahrenheit, or when water temperatures reach or exceed 70 degrees Fahrenheit.

d. In an effort to minimize the spread of pathogens that may be transferred as result of these surveys, surveyors shall follow the guidance outlined below for disinfecting equipment and clothing after surveying a pond and before entering a new pond, unless the wetlands are hydrologically connected to one another.
   i. All organic matter shall be removed from nets, traps, boots, vehicle tires, and all other surfaces that have come into contact with water or potentially contaminated sediments. Cleaned items shall be rinsed with clean water before leaving each study site.
   ii. Boots, nets, traps, hands, etc., shall be scrubbed with a 70 percent ethanol solution, a bleach solution (0.5 to 1.0 cup per 1.0 gallon of water), Quat-128 (1 to 60), or a 3 to 6 percent sodium hypochlorite solution and rinsed

clean with water between study sites. Cleaning equipment in the immediate vicinity of a pond or wetland shall be avoided (e.g., clean in an area at least 100 feet from aquatic features). Care shall be taken so that all traces of the disinfectant are removed before entering the next aquatic habitat.

iii. When working at sites with known or suspected disease problems, disposable gloves shall be worn and changed after handling each animal. Gloves shall be wetted with water from the site or distilled water prior to handling any amphibians. Gloves shall be removed by turning inside out to minimize cross-contamination.

iv. Used cleaning materials (liquids, etc.) shall be disposed of safely, and if necessary taken back to the lab for proper disposal. Used disposable gloves shall be retained for safe disposal in sealed bags.

e. Capture of adults and juveniles in terrestrial habitats may be achieved through placement and checking of cover boards or through visual surveys of surface refugia. The permittee must lift cover boards and natural cover objects (logs, debris, etc.) carefully to prevent injury to any tiger salamanders and must replace them to their original positions.

f. Tissue samples (tail or toe clips) may be collected for genetic analysis in the course of research activities. Collection will generally follow the UC Davis Tissue Collection Protocol for Genetic Research (Leyse et al 2003), but whole live individuals shall not be sacrificed. Samples must be sent with a copy of the permit under which they were collected to Dr. Bradley Shaffer, University of California Los Angeles, Los Angeles, California (or other depository as authorized by the VFWO).

g. Habitat restoration may be conducted in accordance with a plan approved by the VFWO. Appropriate activities may include removing sediment, managing vegetation, removing invasive species, or other activities as agreed to by the permit holder and the VFWO.

h. Information on new localities for the tiger salamander shall be reported verbally and followed up in writing to the appropriate FWO and the California Natural Diversity Database within 3 working days of their discovery. Information may be submitted electronically if pre-arranged with the Recovery Permit Coordinator.

10. Minor deviation from the stipulated terms and conditions may be authorized on a case-by-case basis when approved by the applicable FWO unless an amendment to this permit would be required.

11. This permit does not cover any activities authorized pursuant to a biological opinion or habitat conservation plan (HCP). All such activities must be authorized by the office that wrote the biological opinion, issued the section 10(a)(1)(B) incidental take permit based on an HCP, or is the lead field office implementing the HCP. Note also that this permit is not to be construed as meaning that the permittee or other authorized individuals are

qualified to conduct activities pursuant to a biological opinion or HCP except insofar as the activities are similar to those authorized in this permit. Their qualifications for activities to be done pursuant to the biological opinion are subject to review and written approval for the specific activities by the office that wrote the biological opinion, issued the section 10(a)(1)(B) incidental take permit based on an HCP, or is the lead field office implementing the HCP.

12. This permit does not authorize take of federally listed species that are not specifically authorized pursuant to this permit. However, the Service acknowledges that incidental take of a co-occurring federally listed species could potentially occur while conducting certain permitted activities. When applicable, the following conditions now apply to all federally listed animals that the permittee is not authorized to take pursuant to this permit, but which may be incidentally sighted, encountered, captured, injured, or killed:

    a. Each individual authorized pursuant to this permit shall be knowledgeable about potentially co-occurring listed species that may occur throughout the habitats in which permitted activities are conducted and must be observant and cautious to the extent that “take” of a co-occurring listed species is minimized to the maximum extent practicable.

    b. Any federally listed animal that the permittee is not authorized to take pursuant to this permit, but is incidentally captured during the course of conducting authorized activities, shall be released immediately at the point of capture.

    c. During the course of your permitted activities, if an incidental injury or mortality occurs to a federally listed species not authorized in this permit, the permittee shall follow instructions specified in condition 13 below.

    d. Any incidental capture, injury or mortality of a federally listed species not authorized in this permit shall be recorded and reported in the annual report submitted pursuant to this permit.

    e. We request that all incidental encounters and/or sightings of other federally listed species not authorized under this permit be recorded and reported in the annual report submitted pursuant to this permit and also reported to the California Natural Diversity Database (CNDDB) as specified in condition number 16 below.

13. The number of individuals allowed to be incidentally injured or killed during permitted activities is as follows:

	Adult	Metamorph	Larvae
Long-toed salamander	0	1	2
Tiger salamander	0	1	2
Red-legged frog	0	1	2

    a. Any incidental injury or killing must be reported within 3 working days to the Regional Recovery Permit Coordinator (telephone: 760-431-9440) and the

Recovery Permit Coordinator at the appropriate FWO.

b. In the event that the number of individuals allowed to be incidentally injured or killed is exceeded during the performance of permitted activities, the permittee must:

i. Immediately notify the Regional Recovery Permit Coordinator and the Recovery Permit Coordinator at the appropriate FWO. Within 3 working days, the permittee shall follow-up such verbal notification in writing to each office.

ii. With the written notification, the permittee is to provide a report of the circumstances that led to the injury or mortality. A description of the changes in protocols that will be implemented to reduce the likelihood of such injury or mortality from happening again should be included, if appropriate. A copy of this report shall also be sent to the California Department of Fish and Wildlife (CDFW), Attention: Permitting Biologist, Wildlife Branch, 1812 Ninth Street, Sacramento, California 95811 (telephone: 916-445-3764).

c. Dead specimens and/or appropriate parts of dead specimens that are incidentally taken pursuant to this section shall be preserved in accordance with standard museum practices. Within 120 days, the preserved specimen(s) shall be properly labeled and deposited with one of the designated repositories specified below. Specimens must be accessioned with complete collecting data. The permittee shall supply the repository with a copy of this permit to validate that the specimens supplied to the museum were taken pursuant to a permit. Collection data (e.g., dates and location) and deposition of carcasses by the permittee must be reported in the subsequent annual report.

14. The permittee is authorized to salvage all authorized species' carcasses and provide them to one of the designated repositories within 120 days by following condition number 13.c above. Any specimens salvaged will be documented and specified in the annual report submitted to the appropriate field office.

15. Designated repositories:

The Museum of Vertebrate Zoology, University of California, Berkeley, California; the California Academy of Sciences, Golden Gate Park, San Francisco, California; the Museum of Natural History, University of California, Santa Cruz, California; or as otherwise authorized by the VFWO.

16. California Natural Diversity Database forms shall be completed, as appropriate, for each listed species addressed herein and submitted to the Biogeographic Data Branch, CDFW, 1416 9th Street, Suite 1266, Sacramento, California 95814 (also accessible online at: http://www.dfg.ca.gov/biogeodata/cnddb). Copies of the form can be obtained from the CDFW at the above address (telephone: 916-322-2493). The appropriate field office

will be notified via email when the forms are submitted. This can consist of a one sentence email simply stating the forms were submitted.

17. All reports or other documents that include information gathered under the authority of this permit (e.g., reports prepared by consulting firms for their clients, theses, or scientific journal articles) shall reference this permit number. Copies of such documents shall include a transmittal letter and be provided to the Recovery Permit Coordinator at the appropriate FWO upon their completion. Draft documents, raw/field data, and other information resulting from work conducted under the authority of this permit shall be submitted to the Service upon request.

18. Annual reports:

    In order to track, document, and assess all project-specific activities conducted pursuant to this permit, we are requiring an annual summary report be submitted to the Recovery Permit Coordinator of each FWO specified in condition number 5 above by January 31, following each year this permit is in effect, that summarizes all of the activities conducted during the previous calendar year. Activities that are continuous (i.e., overlapping in two or more calendar years), must be reported each year the activity is in effect. These reports may be submitted electronically if pre-arranged with the Recovery Permit Coordinator. The annual summary report will include but not be limited to the following:

    a. Permittee name and permit number with date of expiration.

    b. A section listing all authorized activities conducted for each permitted species during the previous calendar year. This information can be in tabular format and should provide a summary of each activity for each species authorized in this permit. This section will include but not be limited to:

        i. The name and title of each permitted activity conducted during the previous calendar year.

        ii. The version of each activity report (draft or final) and the report date. If a draft report was submitted, indicate the reason (ongoing activities, processing or analysis of data, final report in review, final report in progress, etc.) and the anticipated final report finish date.

        iii. The specific location of the project site, including the County.

        iv. The common and scientific names of the listed species for which the permitted activity was conducted.

        v. Indicate whether or not the species was observed.

        vi. Indicate whether or not GIS or GPS data was submitted.

vii. The date and name of the FWO where each individual report(s) have been or will be submitted.

c. The number of individuals incidentally injured and/or killed, including dates, locations, circumstances of take, and repository receiving the preserved specimen(s). If no injuries or mortalities occurred, please state this in writing in your annual summary report.

d. Other pertinent observations made regarding the status or ecology of the species.

e. Planned future activities, if authorized under this permit.

f. If no activities were conducted with any or all species authorized under this permit, please state this in writing in the annual report to the applicable FWO.

19. Failure to comply with reporting requirements may result in non-renewal or suspension/revocation of this permit.

____

Endangered Species Division Chief

United States Department of the Interior
FISH AND WILDLIFE SERVICE
Pacific Southwest Region
2800 Cottage Way, Suite W-2606
Sacramento, California 95825-1846

LIST OF AUTHORIZED INDIVIDUALS
TE-082546-6

1. Individuals authorized to independently conduct all activities pursuant to this permit:

   Antonia Akhavan and Valentine Hemingway.

2. Individual authorized to independently conduct the following activities with the California red-legged frog pursuant to this permit — harass by survey, capture, handle, release, and restore habitat for:

   Corey Hamza.

3. Individual authorized to independently conduct the following activities with the Santa Cruz long-toed salamander pursuant to this permit — harass by survey, capture, handle, release, and restore habitat for:

   Corey Hamza.

4. Individual authorized to independently conduct the following activities with the California tiger salamander pursuant to this permit — harass by survey, capture, handle, release, and restore habitat for:

   Corey Hamza.

   Other individuals may conduct activities pursuant to this permit only under the direct, on-site supervision of an independently authorized individual specified above. "On-site supervision" is defined as an unauthorized person conducting activities within 3 meters (9.8 feet) of an authorized individual.

____
Endangered Species Division Chief

This List is only valid if it is dated on or after the permit issuance date.

From: Martin, Jacob <jacob_martin@fws.gov>
Sent: Friday, October 27, 2017 12:14 PM
To: Monique Fountain
Cc: Brown, Gregory G SPN
Subject: Re: Elkhorn Slough TMR Amphibian Relocation Plan: file# 2014-00395S

Hello Monique,

You submitted a California Red Legged Frog (Rana draytonii) and California Tiger Salamander (Ambystoma californiense) Relocation Plan, which included a request to approve project biologists (Corey Hamza, Valentine Hemingway, and Antonia Akhavan), to implement minimization measures required in biological opinion number 2016-F-0226. I have reviewed the plan and its associated biologist approvals and have determined that they are consistent with the biological opinion. They are hereby approved. Thank you for your coordination on this matter. Please contact me if you have any questions.

Thanks,

Jacob M. (Jake) Martin
Senior Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Ventura Fish and Wildlife Office-Santa Cruz Sub-office
1100 Fiesta Way
Watsonville, CA 95076
(805) 677-3327
jacob_martin@fws.gov

On Wed, Oct 25, 2017 at 10:53 AM, Monique Fountain <monique@elkhornslough.org> wrote:

Jake and Greg,

Attached is the California Red Legged Frog and California Tiger Salamander Relocation plan required by the USFW Biological Opinion - conservation measure #2.

Please let me know if you have any questions,

Monique

____

Monique Fountain
Tidal Wetland Program Director
Elkhorn Slough National Estuarine Research Reserve
1700 Elkhorn Road,
Watsonville, CA 95076
phone: 831.728.5939 x242
fax: 831.728.1056

Appendix 2

Marine mammal protocol and disturbance list

Elkhorn Slough Tidal Marsh Restoration
Marine Mammal Monitoring Protocol

Goals

1. Ensure that marine mammals are not subject to injury under the Marine Mammal Protection Act and the Federal Endangered Species Act.
2. Record marine mammal disturbances, due to construction activity
3. Collect field data about the movement and activity of marine mammals during construction monitoring, which will inform NMFS and USFWS on marine mammal sensitivity to disturbance and provide reference for future construction projects.

Objectives

1. Ensure that construction activity is halted when there is a reasonable possibility that marine mammals will enter the exclusion zone (within 15 m of construction activity) in order to avoid any potential for physical injury.
2. Ensure that presence, distribution, movement and behavior of harbor seals and sea otters within the project area and surrounding vicinity is recorded when there is a reasonable possibility that marine mammals will experience behavioral harassment.

Observation location (Figure 1)

Monitoring during construction will occur from one observation area at Yampah Island. It is accessed by foot and provides a vantage point of the entire construction area, main channel of Elkhorn slough, Yampah marsh and Parsons. This includes the entire area within which harbor seals and sea otters present might reasonably be expected to experience disturbance due to construction activities.

Monitoring protocol

A US Fish and Wildlife Service- and NMFS- approved biological monitor will monitor for marine mammal disturbance. Monitoring will occur at all times when work is occurring: 1) in water, 2) north of a line starting at 36˚ 48'38.91 N 121˚ 45'08.03 W and ending 36˚ 48'38.91 N 121˚ 45'27.11 W, or 3) within 100 feet of tidal waters. When work is occurring in other areas, monitoring will be implemented for at least the first 3 days of construction. Monitoring will continue until there are 3 successive days of no observed disturbance, at which point monitoring may be suspended. Monitoring will resume when there is a significant change in activities or location of activities within the project area or if there is a gap in construction activities of more than one week. In these cases, monitoring will again be implemented for at least the first 3 days of construction and will not be suspended until there are 3 successive days of no observed disturbance.

The biological monitor will have the authority to stop project activities if marine mammals approach or enter the exclusion zone. Biological monitoring will begin 0.5-hour before work begins and will continue until 0.5-hour after work is completed each day. Work will commence only with approval of the biological monitor to ensure that no marine mammals are present in the exclusion zone. In addition, biological monitors will, to the extent feasible, monitor for fish, including listed species that may occur within the project site.

Pre and post construction daily censuses - A census of marine mammals in the project area and the area surrounding the project will be conducted 30 minutes prior to the beginning of construction on monitoring days, and again 30 minutes after the completion of construction activities.

Data collected during censuses will include:

- Environmental conditions (weather condition, tidal conditions, visibility, cloud cover, air temperature and wind speed), recorded during pre- and post-construction daily census counts
- Numbers of each species spotted
- Location of each species spotted
- Status (in water or hauled out)
- Behavior

Hourly counts - Conduct hourly counts of animals hauled out and in the water.

- Data collected will include:
    - Numbers of individuals of each species
    - Location, including zone and whether hauled out or in the water
    - Time
    - Tidal conditions
    - Primary construction activities occurring during the past hour
    - Number of mom/pup pairs and neonates observed
    - Notable behaviors, including foraging, grooming, resting, aggression, mating activity, and others
    - Tag color and tag location (and tag number if possible)—for sea otters, note right or left flipper and location between digits (digits 1 and 2 are inside; digits 4 and 5 are outside)
- Notes may include any of the following information to the extent it is feasible to record:
    - Age-class
    - Sex
    - Unusual activity or signs of stress
    - Any other information worth noting

Construction related reactions- Record reaction observed in relation to construction activities including:

- Time of reaction
- Concurrent construction activity
- Location of animal during initial reaction and distance from the noted disturbance.
- Activity before and after disturbance
- Status (in water or hauled out) before and after disturbance

Code reactions:

Level	Type of response	Definition
1	Alert	Head orientation or brief movement in response to disturbance, which may include turning head towards the disturbance, craning head and neck or (in the case of seals) craning head and neck while holding the body rigid in a u-shaped position, changing from a lying to a sitting position, or brief movement of less than twice the animal's body length. Alerts would be recorded, but not counted as a 'take'.
2	Movement	Movements away from the source of disturbance, ranging from short withdrawals at least twice the animal's body length to longer retreats, or if already moving a change of direction of greater than 90 degrees. These movements would be recorded and counted as a 'take'.
3	Flush	All retreats (flushes) to the water. Flushing into the water would be recorded and counted as a 'take'. For sea otters, any change from in-water resting to diving/swimming would also be considered a flush and counted as a 'take.'

Construction shutdown - if applicable

Steps for shutting down and resuming construction

1. Alert construction foreman of animal using the red flag and/or phone call or text message (use 1 blow from air horn if needed)
2. Record the construction activity and the time of shutdown
3. Record the reaction and location of the animal
4. Give clearance signal (green flag) and text message or phone call for construction activities when animal is seen outside of 10-meter zone and traveling away from the construction area, or when the animal is not spotted for 15 minutes
5. Record the time construction resumes

Figure 1. Observation post and observation area. Note: Some areas around the railroad tracks and within the healthy marsh just north of the post cannot be seen at low tides.

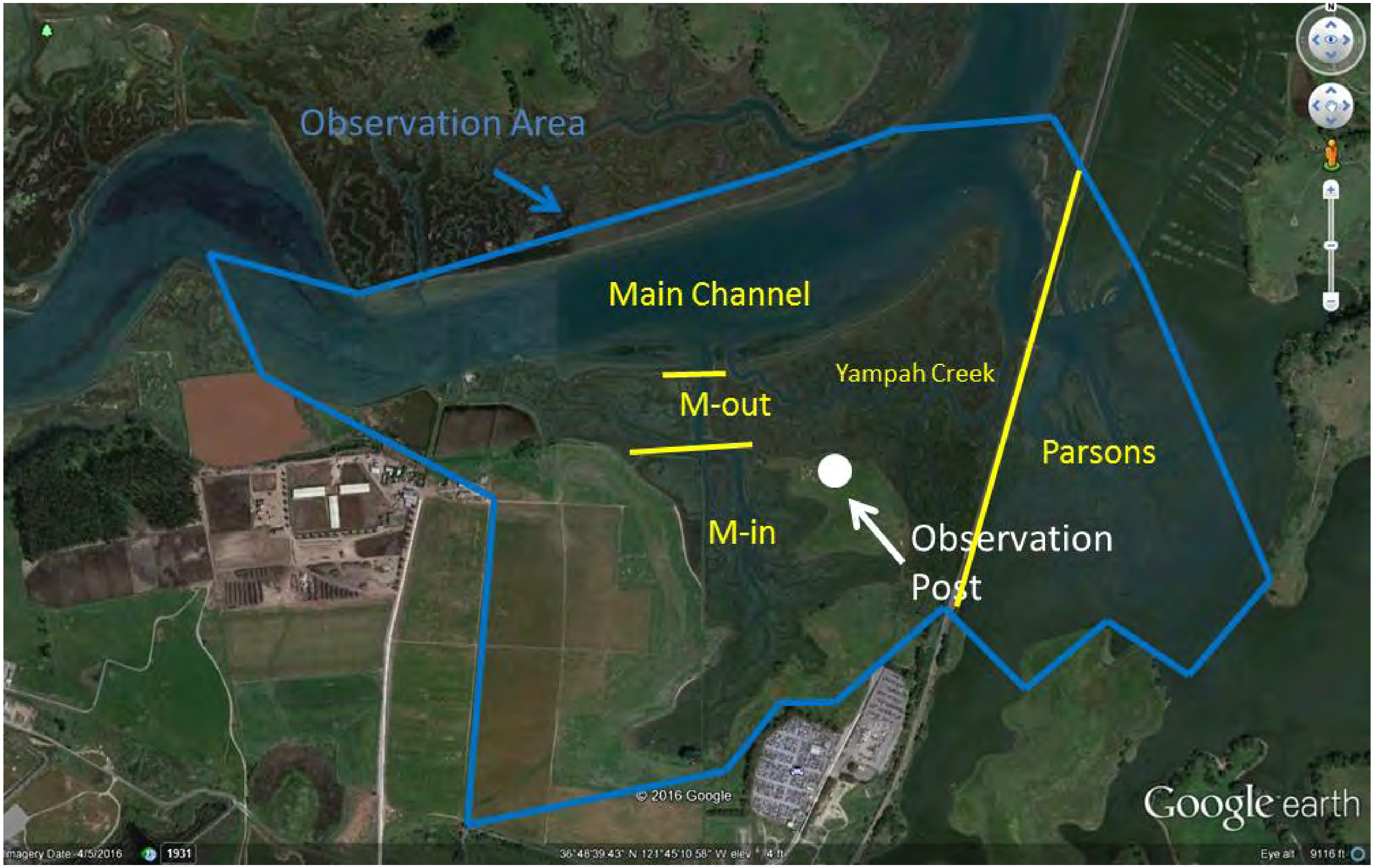


Figure 2. Observation zones

CONSTRUCTION SHUT DOWN

1. Put up red flag
2. Call Warren 209-481-6213
3. IF you can’t reach Warren and construction continues, blow the air horn
4. Look in binder for general protocol and next steps.
5. If in doubt call Monique, Rikke, or Ron

Monique xxx-xxx-xxxx
Rikke xxx-xxx-xxxx
Ron xxx-xxx-xxxx

Daily Protocol

AM shift

1. Arrive at ESNERR about 45 minutes before on-site shift starts

2. Pick up the iPad and check that you have the equipment you need in the field [equipment list]

3. Download the most recent HanDBase data bases from drop box [iPad sync instructions]

   - there are two different databases, the mmData.PDB for hourly counts and the incident log named disturbance.PDB

4. Go to field site

5. By the green gate, please wipe your feet on the brush to remove any seeds from your footwear

6. If the gate is locked, the combo is 2367, this is also the combo for the porta-potty

When you get to the field site and have arrived at the green box:

7. Put on a high visibility vest

8. Put up red flag

9. Note the time and conduct the pre count

10. Text Warren 209-481-6213 that construction is OK to start (7:30am)

11. Put up the green flag

12. Get your scope or binoculars ready for the first hourly observation

For the hourly observations:

13. Count all areas from near the green box on top of the hill unless you must be elsewhere

14. Record data on iPad

15. Rinse and repeat ☺

For incidents/disturbances:

16. From your hourly count, you'll know which animals are where. When construction begins in the morning, or resumes after lunch, or after a break, watch the animals to see if they are disturbed by the change in construction equipment activity (disturbance = head lift, flush, etc. see Key for definitions)

17. Leave site when PM shift arrives but first

   - Hand off iPad to next observer

   - give brief report of anything next observer should know

18. If the afternoon person doesn't show up, call Monique xxx-xxx-xxxx or Rikke xxx-xxx-xxxx

PM shift

1. Arrive at field site about 10-15 minutes before shift starts

2. Get iPad and equipment from AM observer

3. Be ready to collect marine mammal data according to protocol at shift start time

4. Follow marine mammal protocol for monitoring

5. Text Warren 30 mins before sunset, if equipment is still moving, and ask them to please stop construction.

6. Put up the red flag at this time

7. Conduct your post count 0.5 hrs after construction ended

8. Put the flags, tripod, scope, chair etc. in the green box

9. Take the iPad(s) with you and

10. Lock the green gate behind you

8. Go to ESNERR

9. Synchronize HanDBase TWO databases with Drop Box [iPad sync instructions]

10. Plug in iPad(s) for charging

Important passwords, lock combos Green gate at field site: 23xx
Porta potty: 23xx
Elkhornwifi2: 831728xxxx
ESF Mudroom wifi: OttersRxxxx

Morning routine

1. Put on a high visibility vest

2. Put up red flag

3. Note the time and conduct the pre-count

4. Text Warren 209-481-6213 that construction is OK to start (7:30am)

5. Put up the green flag

6. Get your scope or binoculars ready for the first hourly observation

Afternoon power down

1. 30 mins before sunset:
   text Warren and ask them to STOP construction, if equipment is still moving

2. Put up red flag

3. Note the time and conduct the post-count 30 mins after construction stopped

4. Put up the flags next to the green box

5. Put tripod, scope, chair, etc. in the green box and lock it

6. Take the iPad with you and go to the reserve to upload today's files

USFWS approval of Biological Monitors of Marine Mammals

From: Carswell, Lilian [mailto:lilian_carswell@fws.gov]
Sent: Thursday, June 15, 2017 10:19 AM
To: Monique Fountain
Cc: Stephanie Egger - NOAA Federal; Leilani Takano
Subject: Re: Approval Needed: Qualified Protected Species Observers/Biological Monitors

Hi Monique,

I have reviewed the attached CVs, and they all meet or exceed the minimum requirements for biological monitors that we agreed to in the monitoring plan. This email serves as our official approval of the monitors whose CVs are attached.

Please let me know if you have any questions.

Best,

Lilian

~~~~~~~~~~~~~~~~~~~~~~~~~~

Lilian Carswell
Southern Sea Otter Recovery
& Marine Conservation Coordinator
US Fish and Wildlife Service
UC Santa Cruz--Long Marine Laboratory
115 McAllister Way
Santa Cruz, CA 95060-5730

Telephone: (805) 677-3325
Email: Lilian_Carswell@fws.gov
~~~~~~~~~~~~~~~~~~~~~~~~~~

NMFS approval of Biological Monitors of Marine Mammals

From: Stephanie Egger - NOAA Federal <stephanie.egger@noaa.gov>
Sent: Monday, July 17, 2017 2:05 PM
To: Carswell, Lilian
Cc: Monique Fountain; Leilani Takano
Subject: Re: Approval Needed: Qualified Protected Species Observers/Biological Monitors

I concur with Lilian.

Thank you,

Stephanie

On Mon, Jul 17, 2017 at 4:42 PM, Carswell, Lilian <lilian_carswell@fws.gov> wrote:

Hi Monique,

Thanks. I've reviewed Marjorie Bowles' CV, and she appears to be qualified to serve as a

biological monitor for the project.

Best,

Lilian

~~~~~~~~~~~~~~~~~~~~~~~~

Lilian Carswell
Southern Sea Otter Recovery
& Marine Conservation Coordinator
US Fish and Wildlife Service
UC Santa Cruz--Long Marine Laboratory
115 McAllister Way
Santa Cruz, CA 95060-5730

Telephone: (805) 677-3325
Email: Lilian_Carswell@fws.gov

On Mon, Jul 17, 2017 at 1:25 PM, Monique Fountain <monique@elkhornslough.org> wrote:

Hi Stephanie and Lilian,

Two of our current observers have limited availability so attached is another cv for your approval.

Thanks,

Monique
~~~~~~~~~~~~~~~~~~~~~~~~

Incident #	Time	Constr. Activity	Visual/Sound	# reacted se	# reacte	# reac	# react	Zone	Distance (m)	Reaction coc	Shutd	time shutdo	time restart	Disturbance Notes	Total Seals	Total Otters	Date	Observer	Do you thi	reaction trigger	animal
1	09:58	excavating and filling	Sound	7				Minhoto - out	175	1 - Alert	No				15		12/13/2017	MF	Yes	Construction	seal
2	10:03	excavating and filling	Sound	3				Minhoto - out	175	1 - Alert	No				15		12/13/2017	MF	Yes	Construction	seal
3	10:12	excavating and filling		1				Minhoto - out	360	1 - Alert	No				15		12/13/2017	MF	Yes	Construction	seal
4	12:25	people only		2				Minhoto - out	300	1 - Alert	No				12		12/13/2017	RGE	Yes	Construction	seal
5	12:35	equipment moving cl	Visual AND Sound	12				Minhoto - out	300	3 - Flush	No				12		12/13/2017	RGE	Yes	Construction	seal
6	07:51	equipment moving cl	Visual AND Sound	3				Main Channel	300	1 - Alert	No				3		12/14/2017	MB	Yes	Construction	seal
7	12:45	equipment moving cl	Visual AND Sound	10				Main Channel	300	2 - Moveme	No				12		12/14/2017	MB	Yes	Construction	seal
8	12:53 PM	tractors starting	Sound	0	1	0	0	Minhoto - in	150	1 - Alert	No			Construction stopped for 1hr broken excavator. Loud dozer started up.	0	1	12/19/2017	DG	Yes	Construction	otter
9	7:42 AM	excavating and filling	Sound	0	0	0	1	Minhoto - in	350	1 - Alert	No			Loitering where Minhoto out channel enters Minhoto in	0	1	12/20/2017	DG	Yes	Construction	otter
10	7:45 AM	people only	Visual	0	1	0	0	Minhoto - in	25	3 - Flush	No			Occurred at 6:50 when I (Don Glasco) approached Minhoto channel.. HO otter jumped into water and proceeded into. Minhoto in	0	1	12/20/2017	DG	No	Observer	otter
11	12:39 PM	tractors starting	Sound	2	0	0	0	Minhoto - out	1000	1 - Alert	No			One other seal further out raised head later, not sure related. Second seal raised its head a little later, n	16	0	12/20/2017	RGE	Yes	Construction	seal
12	8:31 AM	excavating and filling	Visual AND Sound	1	0	0	0	Minhoto - out	150	1 - Alert	No			Just one seal raising head and watching trucks move	5	0	1/10/2018	RGE	Yes	Construction	seal
13	7:30 AM	tractors starting	Sound	2	0	0	0	Minhoto - out	500	2 - Moveme	No			Unsure if seals were reacting to the equipment, or if the seals were reacting to the observer, probably the latter	5	0	1/17/2018	MB	No	Observer	seal
14	1:43 PM	excavating and filling	Visual AND Sound	5	0	0	0	Minhoto - out	500	1 - Alert	No			Several seals along Minhoto out raised heads, but this was as Elkhorn Safari boat passed by.	0	0	1/17/2018	SH	No	Other	seal
15	2:40 PM	excavating and filling	Visual AND Sound	6	0	0	0	Minhoto - out	500	1 - Alert	No			Seals became alert, but likely due to large group of people walking thru construction site. (At 2:27pm)	12	0	1/17/2018	SH	No	Other	seal
16	7:34 AM	equipment moving cl	Visual AND Sound	2	0	0	0	Minhoto - out	300	2 - Moveme	No			Two seals in Minhoto Out. One turned to look, second that had just hhauled out left area slowly into M In checked area out, then left.	2	0	1/29/2018	RGE	Yes	Construction	seal
17	7:37 AM	equipment moving cl	Visual AND Sound	1	0	0	0	Minhoto - in	200	1 - Alert	No			Seal was hauled out in Minhoto in, raised its head when vehicles were turned on.	1	0	1/30/2018	RGE	Yes	Construction	seal
18	7:53 AM	equipment moving cl	Visual AND Sound	1	0	0	0	Minhoto - in	200	2 - Moveme	No			Seal entered water as people passed construction site	1	0	1/30/2018	RGE	Yes	Construction	seal
19	6:58 AM	people only	Visual AND Sound	0	1	0	0	Minhoto - in	25	3 - Flush	No			Was walking levee to check interior, otter hauled out on far side of island, didn't see till it flushed. Swam 20 meters, then groom.	0	1	2/6/2018	SH	No	Observer	otter
20	7:11 AM	people only	Visual AND Sound	0	0	0	1	Minhoto - out	25	2 - Moveme	No			While walking levy for preconstruction survey otter in water had head up watching and kept swimming	0	1	3/5/2018	JP	No	Observer	otter
21	12:31 PM	no activity	Visual	2	0	0	0	Minhoto - out	70	1 - Alert	No			12:24. 3 seals on West Bank of Minhoto out. Lunch break so no vehicular noise. I was inspecting Minhoto out from construction levy. Two seals raised heads in alert and watched me. Resumed normal resting position once I moved away. Don Glasco	3	0	3/5/2018	DG	No	Observer	seal
22	7:03 AM	people only	Visual	0	0	0	1	Minhoto - out	0	2 - Moveme	No			Sea otter resting/floating near levee. Slowly swam out as I approached doing pre construction survey from levee	0	1	3/6/2018	JP	No	Observer	otter
23	6:48 AM	no activity	Visual	0	0	0	1	Minhoto - in	50	2 - Moveme	No			6:35 As I approached Minhoto channel, 'Sleepy' (male otter) moved from base of Hester Marsh northern dike into center of Minhoto Out channel where he stopped and resumed relaxed resting. Don Glasco	0	1	3/8/2018	DG	No	Observer	otter
24	9:06 AM	people only	Visual	6	0	0	0	Minhoto - out	100	3 - Flush	No			From me walking out on the berm to count. 8 of 18 were pups. All with mom.	18	0	4/11/2018	MF	No	Observer	seal
25	9:27 AM	people only	Sound	2	0	0	0	Minhoto - out	100	3 - Flush	No			Cutting pvc pipe for dewatering. All moms and pups.	12	0	4/11/2018	MF	Yes	Construction	seal
26	3:04 PM	excavating	Sound	1	0	0	0	Minhoto - out	100	1 - Alert	No			Excavation of a geotechnical hole. Noise of long reach excavator.	10	0	4/11/2018	MF	Yes	Construction	seal
27	3:08 PM	excavating	Sound	2	0	0	0	Minhoto - out	100	3 - Flush	No			Mom and pup	10	0	4/11/2018	MF		Construction	seal
28	3:21 PM	excavating	Sound	2	0	0	0	Minhoto - out	100	3 - Flush	No			2x Mom and pup came in and another mom and pup flushed.	10	0	4/11/2018	MF		Construction	seal
29	4:22 PM	other	Sound	1	0	0	0	Minhoto - out	100	2 - Moveme	No			Installing a pump for dewatering.	11	0	4/11/2018	MF	Yes	Construction	seal
30	7:37 AM	tractors starting	Visual AND Sound	2	0	0	0	Minhoto - out	100	1 - Alert	No			Mother and pup	17	1	4/12/2018	MF		Construction	seal
31	7:17 AM	excavating and filling	Visual	2	0	1	0	Minhoto - out	100	3 - Flush	No			Construction had been underway for at least 15-20 minutes. Disturbed mom and pup seal into water when I was doing pre-check on levy. Mom alerted me to their presence by huffing. As I left area she and pup went into water.	3	0	5/1/2018	DG	No	Observer	seal
32	5:26 PM	no activity	Visual	0	1	0	0	Minhoto - in	20	3 - Flush	No			Otter was hauled out and I couldn't see it until I walked down. Stayed in area, just not comfortable hauled out while I was close.	0	1	5/29/2018	RGE	No	Observer	otter
33	9:40 AM	excavating and filling	Visual	0	1	1	0	Main Channel	3	3 - Flush	No			Disturbance caused by kayaker, not construction. Just outside M Out.	2	1	6/4/2018	RGE	No	Other	seal
34	12:51 PM	excavating and filling	Visual AND Sound	3	0	0	0	Minhoto - out	50	2 - Moveme	No			First truckload of dirt deposited after lunch break caused seals to react	3	0	6/4/2018	SH	Yes	Construction	seal
35	7:37 AM	equipment moving cl	Visual AND Sound	4	0	0	0	Minhoto - out	100	2 - Moveme	No			Bulldozer first approaching Minhoto Out site	7	0	6/5/2018	SH	Yes	Construction	seal
36	2:35 PM	equipment moving cl	Sound	1	0	0	0	Minhoto - out	100	1 - Alert	No			Lone seal separated from others, calm head raise in direction of noise from catapillar.	8	0	6/5/2018	RGE	Yes	Construction	seal
37	2:56 PM	equipment moving cl	Sound	2	0	0	0	Minhoto - out	125	1 - Alert	No			Dump trucks back after gone for an hour	10	0	6/5/2018	RGE	Yes	Construction	seal
38	7:20 AM	tractors starting	Visual AND Sound	2	0	0	0	Minhoto - out	100	3 - Flush	No			First truckload of dirt dumped in Minhoto Out.	4	0	6/7/2018	SH	Yes	Construction	seal
39	3:14 PM	excavating and filling	Visual AND Sound	25	0	0	0	Minhoto - out	3	3 - Flush	No			Not related to construction. Two inflatables came all the way in to M In, one got stuck, no hull number. Very macho, f... you every other word. Said we needed bigger signs, bragged about how many other seals they had flushed. Time of incident was about 1410,	25	0	6/12/2018	RGE	No	Other	seal
40	4:37 PM	equipment moving cl	Visual AND Sound	6	0	0	0	Minhoto - out	20	2 - Moveme	No			Between counts seals moved closer to the main channel. No noticeable flushing en mass.	8	0	6/26/2018	MB	Yes	Construction	seal
41	6:40 AM	people only	Sound	2	0	0	0	Minhoto - out	40	3 - Flush	No			Birds flushed before I could even see seals. Seals never saw me, but left area.	2	0	7/9/2018	RGE	No	Other	seal
42	8:40 AM	excavating and filling	Sound	1	0	0	0	Minhoto - out	150	1 - Alert	No			Seal alerted as cat started pushing dirt in. Watched but no nervous reaction.	1	0	7/9/2018	RGE	Yes	Construction	seal
43	6:53 AM	no activity	Visual	0	0	0	1	Minhoto - out	15	2 - Moveme	No			Otter didn't notice me at first, when it did it scurried about 15 meters away, then back to sleep.	0	1	7/11/2018	RGE	No	Observer	otter
44	9:15 AM	excavating and filling	Visual	2	0	2	0	Minhoto - out	20	3 - Flush	No			2 seals that had recently hauled out flushed as I stood up for count. Moving.back from edge to avoid further disturbances. They flushed at 9:00. came back at 9:15	5	0	7/11/2018	RGE	No	Observer	seal
45	9:32 AM	other	Visual	8	0	0	0	Minhoto - out	15	3 - Flush	No			Kat came into Minhoto Out by boat to collect traps set yesterday	8	0	8/22/2018	RGE	No	other	seal

Appendix 3

Construction monitoring Phase I: marine mammals, amphibians, water quality

-APPENDIX 3-

Construction monitoring results

Marine Mammals
Southern sea otters and harbor seals were monitored in accordance with the requirement of National Marine Fisheries Service and U.S. Fish and wildlife service. Monitoring details can be found in Appendix 2 and requirements in Appendix 4 (State and Federal regulations). Raw data are linked here. The monitoring areas included the project area and adjacent marshes within view (Fig. 1).

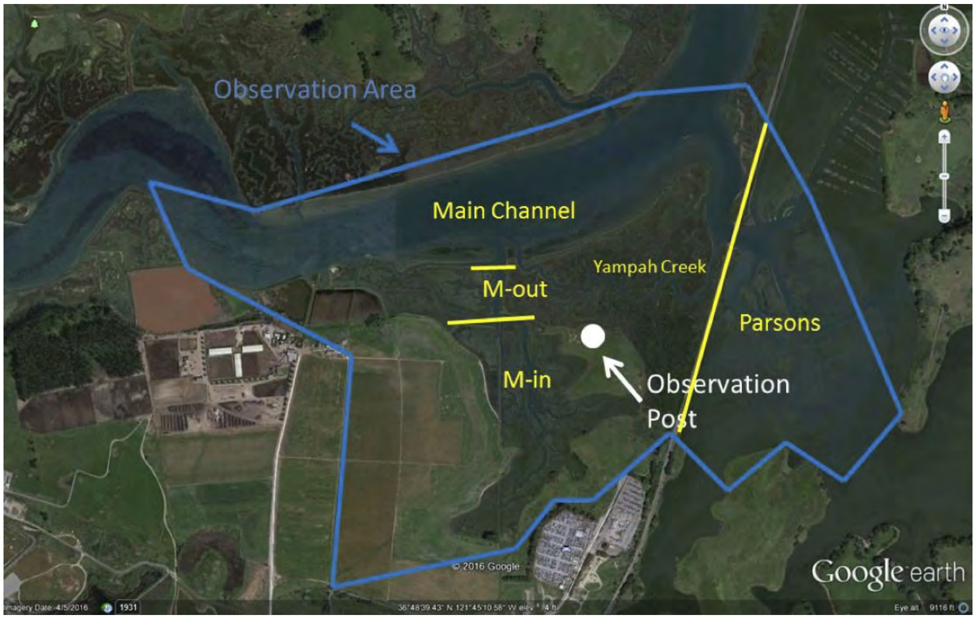


Fig. 1 Monitoring zones and observer location at the projecct site at Hester

Harbor Seals, counts

Harbor seal counts during the daytime (6AM - 6PM) ranged from 0 to 16 individuals in M-in, 0 to 56 in M-out, and 0 to 257 individuals in the entire observation area. The average number of seals per hourly count in the same three areas were 0.19 seals/hr, 8.25 seals/hr, 55.94 seals/hr. The lowest average and max number of seals were observed in the mornings during the pre-construction counts, and the hourly and post-construction counts were very similar.

Sea Otters, counts

Sea otter counts during the daytime (6AM - 6PM) ranged from 0 to 2 individuals in M-in, 0 to 14 in M-out, and 0 to 53 individuals in the entire observation area. The average number of otters per hourly count in the same three areas were 0.04 otters/hr, 0.14 otters/hr, 12.67 otters/hr. The lowest average and max number of otters were observed in the evenings during the post-construction counts, in the M-in and M-out areas, and the during-construction hourly counts were the highest for average and max number of otters/hr.

****NO HARBOR SEALS OR SOUTHERN SEA OTTERS WERE INJURED DURING CONSTRUCTION****

Disturbances

Over almost a thousand hourly counts (976) we observed 45 disturbance events, most likely caused by construction or construction monitoring activity. 9 of the 45 incidents were otter disturbances, and 36 of the 45 incidents were harbor seal disturbances.

Otters were mostly disturbed by marine mammal observes less than 50 meters from the animal (red symbols, Fig. 2). Only in two instances (blue circles) was an otter alert due to construction (Fig. 2).

For harbor seals, construction was the most frequent ultimate source of disturbance (24 of 36 instances), observers caused 5 of 36 disturbances, and other causes accounted for 7 of 36 disturbances. All construction related disturbances were when seals were within 400 meters of the disturbance source (Fig. 3), and most of the seals flushes (11 of 12) were when the distance between the disturbance source and the flushed animals was 100 meters or less. When seals flushed, the cause was often “other” such as a kayaker, a bird, or in one instance, a mom-pup pair arrived at the haul out spot, and another mom-pup pair flushed.

Proportionally, number of disturbance incidents were low relative to how many otters and seals were observed in or near the project area. Mostly seals were disturbed by construction and mostly when both visual and auditory cues were present. Sound alone seemed to disturb seals more than visual cues alone.

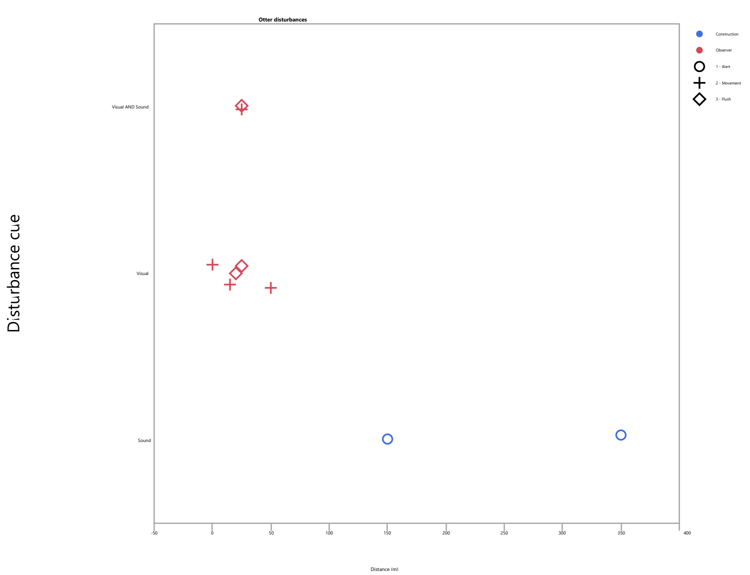


Fig. 2 Otter disturbances at the project site December 2017 to August 2018. Reaction of a disturbed animal is indicated by the shape of the symbol and the ultimate cause of disturbance is indicated by the color (blue = construction; red = observer). The proximate causes of disturbance (visual cue, auditory

cue or both visual and auditory at once) are separated on the y-axis, and the x-axis indicates the distance between the source of disturbance and the disturbed animal. One symbol in the figure represents one disturbance event, on a given day.

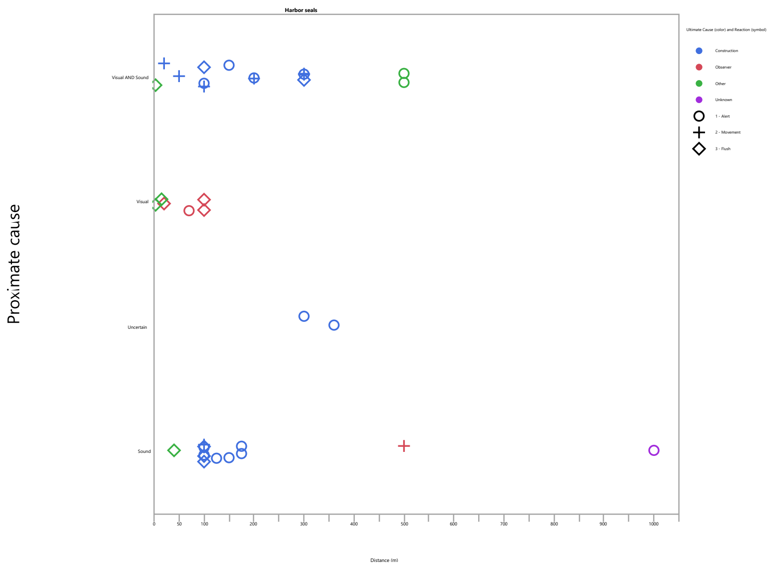


Fig. 3 Seal disturbances at the project site. Reaction of the disturbed animal is indicated by the shape of the symbol and the ultimate cause of disturbance is indicated by the color (blue = construction; red = observer; green = other; purple = unknown). The proximate causes of disturbance (visual cue, auditory cue or both visual and auditory at once) are separated on the y-axis, and the x-axis indicates the distance between the source of disturbance and the disturbed animal. One symbol in the figure represents one disturbance event, on a given day.

Amphibians

During pre-, during-, and post-construction monitoring, we did not observe any amphibians at the site of the project area. For details of the monitoring log, see Appendix 1, Table 1.

****NO AMPHIBIANS WERE INJURED DURING CONSTRUCTION****

Water Quality

Water quality was monitored continuously with a YSI sonde throughout construction, except for the months of June and July, where the instrument was at risk of damage due to equipment activity in the project arear.

Generally, turbidity adjacent to the project area did not appear unusually high during or immediately after construction (Fig. 4). After tidal flow was restored to the project area, we did observe some brief turbidity spikes near the construction area (Fig. 4). Although it is unknown what the true cause of the peaks were, we do not believe that construction caused any widespread turbidity plumes in the estuary, for the following reasons:

Peak 1, observed from 9/9/18 lasted from 7pm to 10:30 pm, and occurred on an incoming tide. Hence, the peaks was brief and not likely to be caused by waters from the project area, as the tide was coming in from the main channel.

Peak 2, observed from 9/10/18 lasted from 11:45am to 9/11/18 at 3pm. While the initial high turbidity was on an outgoing tide, the turbidity remained high on the incoming tide as well. While turbidities in the hundreds were observed adjacent to the project area, no such elevated turbidities were observed at the nearest permanent water quality stations at Vierra or at South Marsh (Fig. 5, Fig. 6)

Peak 3, observed from 9/13/18 from 4am to 3pm occurred near the end of an outgoing tide, but no turbidity spikes were observered at the nearest permanent water quality stations at Vierra or at South Marsh (Fig. 5, Fig. 6)

Peak 4, observed from 9/19 at 2am to 4am occurred on an incoming tide and is thus not likely to be caused by waters from the project area, as the tide was coming in from the main channel.

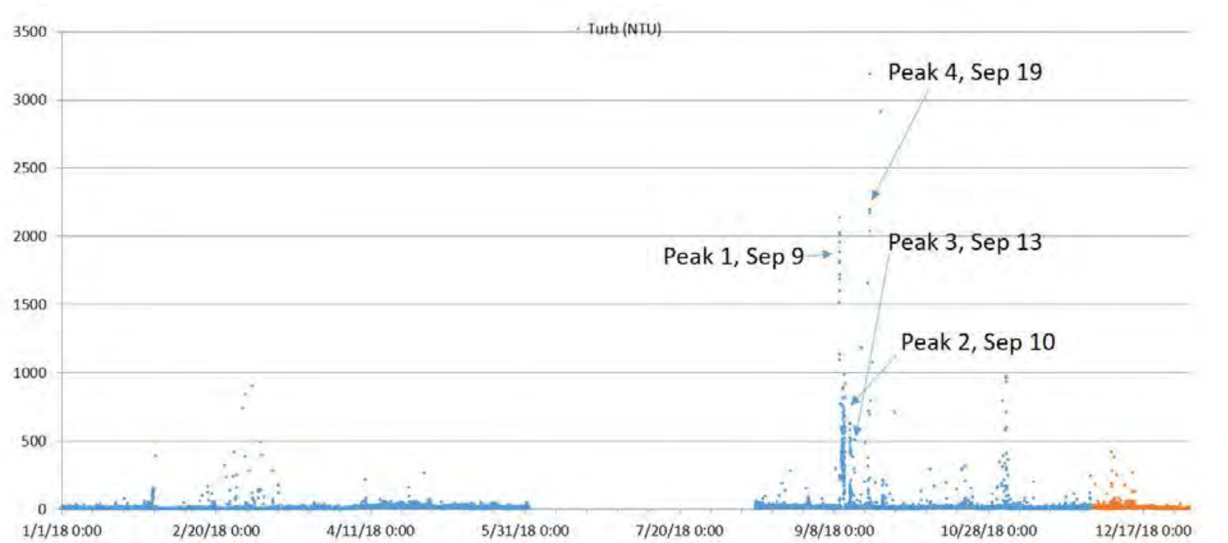


Fig. 4 Hester water quality 2018 - turbidity

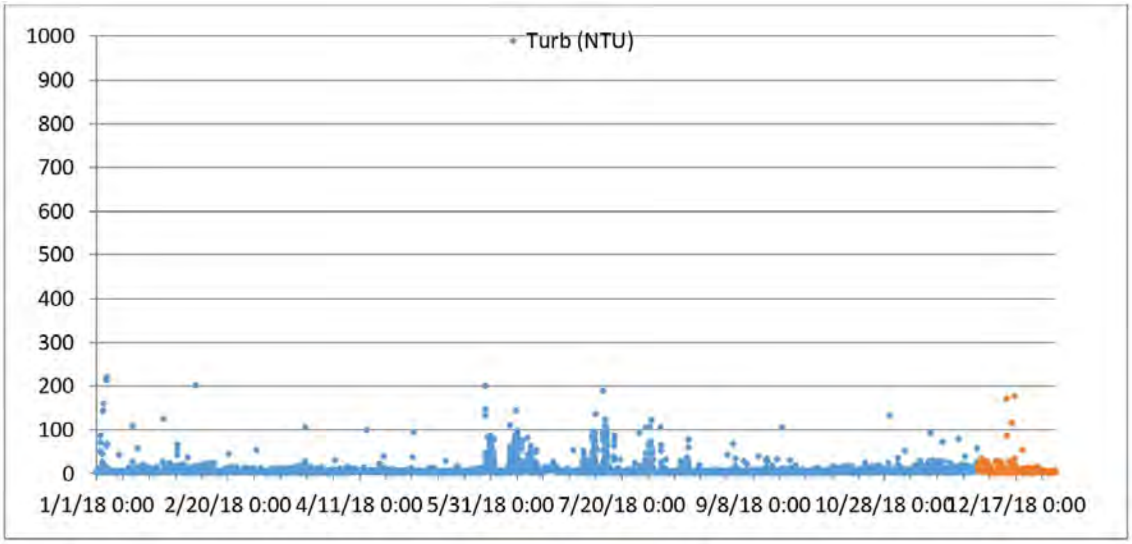


Fig. 5 Vierra water quality 2018 - turbidity

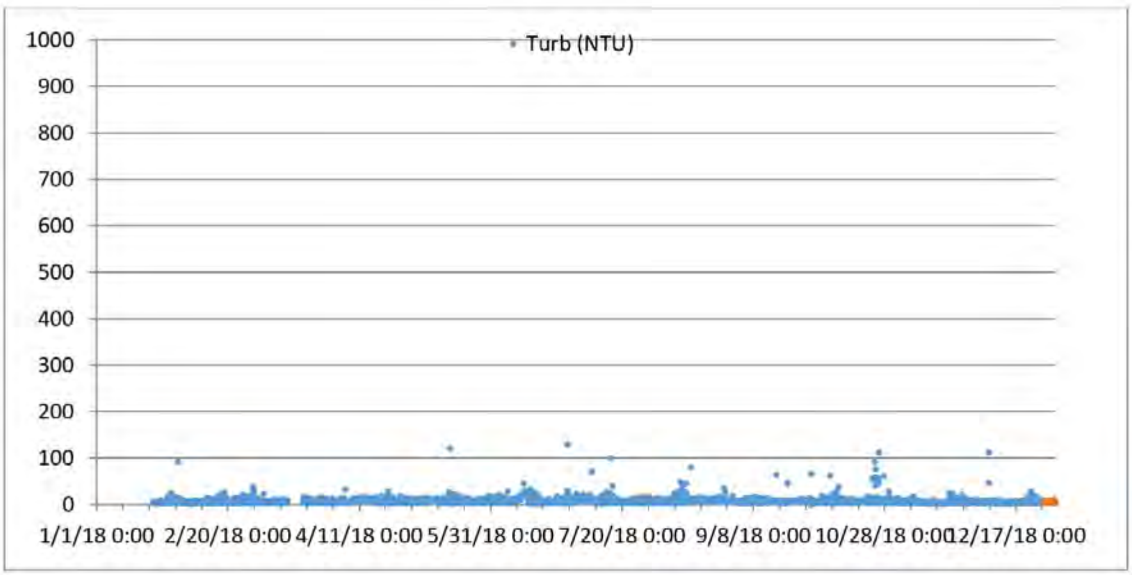


Fig. 6 South Marsh water quality 2018 - turbidity

Appendix 4

Detailed monitoring protocol and results

APPENDIX 4 –
DETAILED MONITORING METHODS AND RESULTS

Contents

All sections of the methods and results will refer to locations of sample collection and transects within the project area (Fig. 1) unless a section has an additional map.

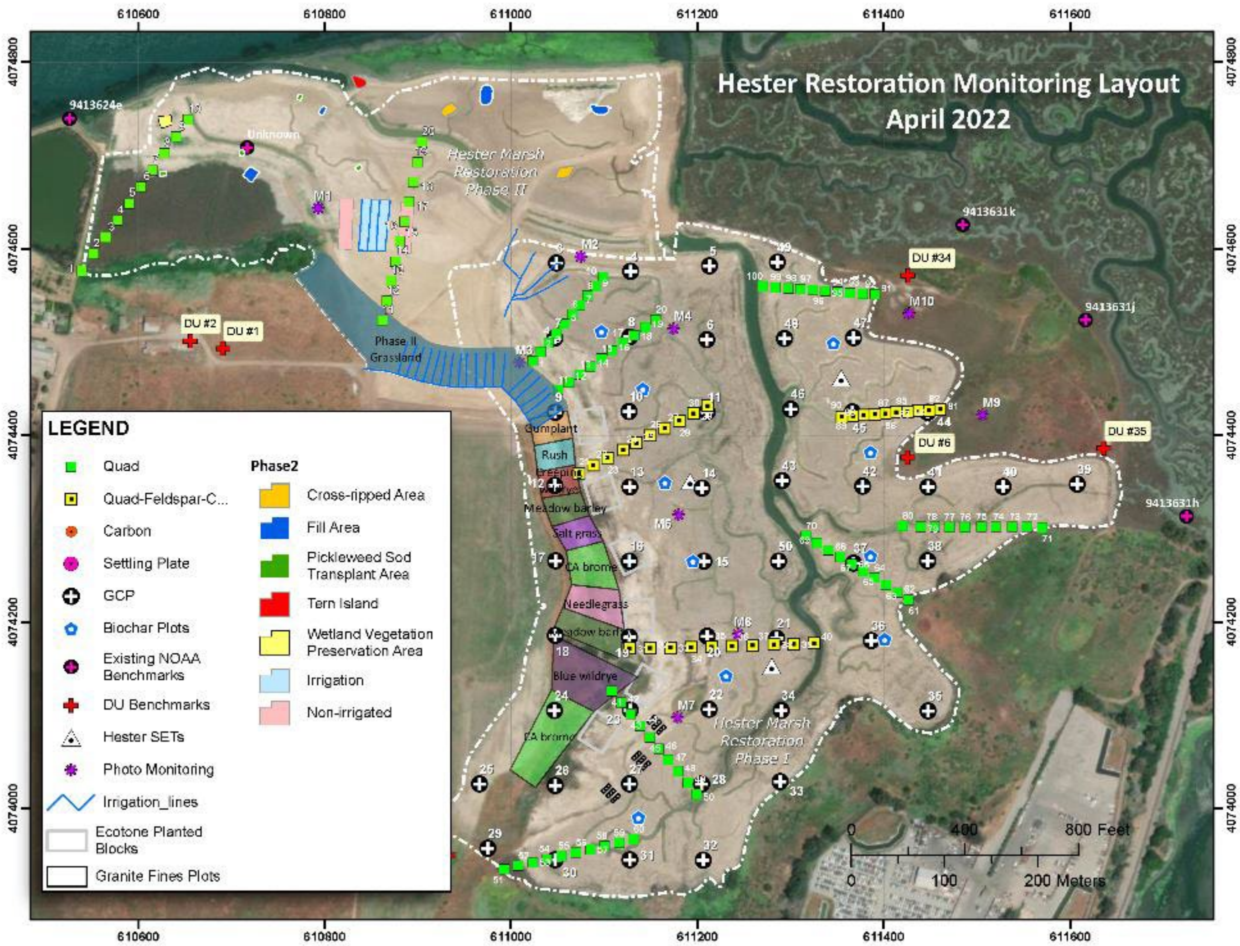


Fig. 1. Monitoring and transect map of project area.

OBJECTIVE 1 – RESTORE 66 ACRES OF SALT MARSH ECOSYSTEM

Restore 66 acres of functioning, resilient salt marsh ecosystem in Elkhorn Slough from channel to grasslands.

1.1 Raising the marsh plain

1.1.a Sediment added to create marsh (implementation objective)

More background on target elevation

The restoration target of 6.2 feet (1.89 m) NAVD for Phase I was in accordance with the recommendations made by the salt marsh working group, which recommended target elevations between 5.8 – 6.4 feet (1.77 – 1.95 m). Initially there was great uncertainty about construction tolerance and settlement/consolidation rates (e.g. anywhere between 0.1 and 0.7 feet (30.1 – 21.3

cm) over the first years). The selected contractor agreed to a variance of 0.25 feet (7.6 cm) around the mean, yielding a flat marsh initially ranging from 6.15 to 6.65 feet (1.87 – 2.03 m) for phase I, allowing us to stay within the minimum and maximum acceptable elevations.

> Maximum: The highest acceptable elevation was 6.6 feet (2.01 m) NAVD88 to ensure acceptable inundation and subsequent recruitment of marsh plants. This elevation was temporarily exceeded during construction, but was within the range of the target elevation immediately following construction. Carla Fresquez (2014) found the lowest upland plants at about 6.3 feet (1.92 m), and upland plants reached 10% cover at about 6.7 feet (2.04 m). Thus, having the maximum elevation around 6.6 feet (2.01 m) precluded weed infestations. Field surveys by ESNERR staff confirmed that invasive plant cover does not become substantial until about 7 feet (2.13 m) or above.
>
> Minimum: The lowest elevation acceptable for the sediment addition area of the main Hester marsh restoration project was 5.0 feet (1.52 m) NAVD88. Elevation should, at no point in time, be lower than this in the main marsh plain (except for the minor sloping immediately adjacent to creeks). This minimum elevation would be represented by a small portion of the total marsh area. The choice of 5.0 feet (1.52 m) as the minimum acceptable elevation was based on a variety of sources. This elevation represents approximately Mean Higher High Water, which is known to be at the lower end of the *Salicornia* distribution. On a berm at Hester, where we estimated marsh elevation was about 4.6 feet (1.40 m), we converted marsh to mudflat accidentally through trampling, suggesting this marsh was close to its lower tolerance. Marsh/crab surveys conducted in summer 2013 revealed variation of marshes at elevations from 4.4-5.1 feet (1.34 – 1.55 m), with some marshes showing stress and others not.

Building on Phase I, the restoration targets for Phase II and III were set a little higher at 6.4 feet. This was based on the subsidence observed in the first 6 months post construction of Phase I and the success of marsh vegetation in Phase I at the higher elevation. The selected contractor was able to meet the same variance of 0.25 feet (7.6 cm) around the mean, yielding a flat marsh initially ranging from and 6.35 to 6.85 feet (1.94 – 2.09 m) for phases II and III.

Methods

Overview of tasks

Volumetric analysis of topographic change was performed using acquisition data from both terrestrial laser scanner (TLS) surveys and unmanned aerial vehicle (UAV) overflights. 1 centimeter-scale accuracy can be achieved with a TLS while 3 – 5 cm scale accuracy can be achieved with UAV orthomosaic imagery and digital elevation models (DEMs). In order to create DEMs with the highest accuracy possible it was necessary to incorporate ground control points into the post-processing. For this purpose, all UAV and

TLS methods are described below and will serve as a reference for other sections in this document.

Additionally, three surface elevation tables (SETs) at Phase I coupled with feldspar marker horizons were installed for monitoring fine-scale (mm accuracy) elevation changes to the surface of the marsh. Each SET location included a paired deep rod SET and shallow SET which allowed us to determine if subsidence and/or compaction was occurring within the soil profile between the shallow and deep rod depths. The deep SETs were also utilized as TLS elevation controls for monitoring elevations throughout the marsh. Previously, no deep rod benchmarks existed inside Hester Marsh. Four feldspar marker horizons were placed at the corners of each SET location for monitoring sediment accretion over time. At Phase II, one additional SET deep/shallow pair along with feldspar marker horizons will be placed in the marsh in Summer/Fall 2022.

Materials

Terrestrial Laser Scanner (TLS) from MLML, controller, batteries, targets, tripod
Unmanned Aerial Vehicle (UAV) DJI Phantom 4 Pro, controller, batteries, landing pad
Ground control points (GCPs) consisting of 12” round bucket lids (50),
12” garden staples (2 per GCP)
½” x 10’ EMT conduit pipe (TLS foresights)
½” x 24” PVC pipe (80)
Flags
Deep-rod and shallow SETs (3)
Feldspar (initially used for accretion); tiles (later used for accretion)
Gas-powered jackhammer

Frequency

Once immediately following construction

Detailed Monitoring methods: Data collection

Establishing transects/GCPs for TLS data collection:

Ten vegetation monitoring transects were established in the Phase I restoration marsh, and two at the Phase II marsh (Fig. 1), each stretching from the ecotone to the main channel. The most landward quadrat was located at an elevation of 2.2-2.3 m NAVD88, to match the location of the ecotone boundary at other marsh transects around the estuary. The most seaward quadrat was located near a creek or channel edge. The other eight quadrats were spaced uniformly along the transect line in between these. Two or three GCPs per transect were set approximately 2-5 meters away from the transect line. Quadrat locations were marked with ½” x 24” PVC pipe or conduit pipe (transects 3, 4, 9) hammered into the ground to mark the landward left corner (when looking down and facing the water end of the transect line) of the quadrat site.

We used RTK GPS (EOS Arrow 200 with ArcGIS Collector) immediately following construction in order to establish a baseline dataset of positions and elevations of transect quadrat corners and GCPs (bucket lid centers). Although we encountered accuracy issues due to discrepancies between the RTK receiver and GPS base-station, we were able to correct the data by registering coincident positions with established benchmarks. Subsequent surveys at Phase I (October 2018 and January 2019) were completed using a combination of TLS and laser leveling (using a Sprinter 150). We found that laser leveling achieved the best results for collecting elevations (Z) whereas TLS provided accurate horizontal positions (X and Y). A comparison of the elevation data from August 2018 (RTK) to January 2019 (laser level) reveals an RMSE of 0.035 m. The RMSE can be considered our detection limit (i.e. error) for any change analyses relative to our first RTK survey. This value is slightly higher than the 1 cm or less detection limit that TLS/laser leveling is capable of for identifying change. Thus, in the future we aim to consistently use TLS/laser leveling for field surveys. Similarly, at Phase II, we established quadrat positions using a Spectra SP20 RTK GPS. Elevations at each quadrat corner were then surveyed with a Sprinter 250 laser level, using an existing deep-rod benchmark in the marsh as the reference point. Additionally, ten 10' rebar posts were hammered into the marsh soil to depths of 6.7' near the western edge of Phase II for the purpose of monitoring deep subsidence. We affixed rebar caps with reflector stickers on the tops of the rebar posts in order to monitor their elevations with TLS. The first baseline survey was performed on 12/21/2021. Post-processed TLS/laser level data were converted to GIS layers that can be used to track vertical changes over time and also imported into the UAV post-processing methodology. At the ten quadrats along three of the transects (3,4, 9) at Phase I, conduit pipe was pounded to refusal in August 2018 and the length of these pipes was measured repeatedly over time to detect compaction or erosion. Feldspar marker horizons were poured in August 2018 to track accretion; these were later replaced in 2020 with buried tiles. At Phase II, we did not use conduit pipe or feldspar maker horizons. Instead, we used PVC as the quadrat marker and buried 6" x 6" white ceramic tiles approximately 5 cm under the soil surface at a distance of 60 cm to the right of the PVC pin (looking towards the slough). Initial measurements of the tiles to determine baseline depth will be taken in spring 2022 after the winter high tides will have settled the disturbed material.
To calculate inundation time, we used water level data from the NERR system-wide monitoring database to calculate percent of time different elevations are inundated.

We compared inundation frequencies of the restoration site vs. other marshes in the estuary.

UAV Data Collection:
We used a DJI Phantom 4 Pro with a built-in 20-megapixel camera and an additional Sentera Multispectral Double 4k sensor. GCPs, consisting of white 12” round 5-gallon bucket lids, were installed at specified locations on the ground and anchored with two ¼” x 16” rebar posts. GCP positions were surveyed using RTK prior to the first post-construction flight (see above). Since August 2018, UAV flights have been conducted on a frequent basis (once or twice per month) in order to document any monitoring developments (e.g. ecotone experiments, grassland planting, etc.) or identify any vegetation growth on the marsh. Additionally, a second GCP/UAV survey was completed in January and mid-October of 2019 in order to conduct surface change analyses. Drone Deploy was used for flight planning and processing orthomosaics and DEMs, while Agisoft and FieldAgent Platform were used for processing multispectral orthomosaics and GCP position information.

SET / Feldspar Marker Horizon:
Three surface elevation tables (SETs) were installed at Hester marsh Phase I according to the protocols established by the National Park Service (Lynch et al., 2015). Exact locations of the SETs were determined from field and map observations immediately following construction. Installation of the deep rods required a gas-powered jackhammer. At Phase II, one additional SET deep/shallow pair along with feldspar marker horizons will be installed in the marsh in Summer/Fall 2022.

Establishing X, Y, and Z coordinates for deep-rod SET benchmarks:
Elevation controls were established at one existing benchmark (DU #34) on Yampah Hill using long-term static GPS observations (Trimble 5800 receiver) in August 2018. Eventually, TLS or laser leveling will be used to transfer GPS observations to other SETs or benchmarks in the local area. Differential leveling between benchmarks may be used to quickly and accurately assess any vertical changes to benchmarks over time. Similar techniques will be used at Phase 2 to establish elevation controls at the deep-rod benchmarks, including the existing NOAA benchmark.

Detailed Monitoring methods: Data analysis

- Post-processed UAV datasets include geo-rectified multispectral orthomosaic imagery (red, green, blue, near-infrared [NIR] and red edge) and DEMs.
- UAV datasets were analyzed using ArcGIS Desktop Advanced v10.5. The ArcGIS Spatial Analyst extension was used to compare DEMs and calculate volumetric and/or elevation change between successive flights.

- Reclassified the post-construction UAV DEM to show tidal datums based on Eric Van Dyke's 2012 Technical Report.
- Calculated the total surface areas for each tidal datum for both pre and post-construction DEMs and create table for comparison.
- Compile all SET and feldspar marker observations and report in a pre-formatted spreadsheet.

Results

At Hester Phase I, approximately 230,000 cubic yards (175,850 m^3) of sediment were added to an average elevation of 6.4 feet (1.95 m) NAVD. At Phase II, approximately 130,000 cubic yards (100,000 m^3) of sediment were added to an average elevation of 6.6 feet (2.0 m) NAVD. Fig. 2 and Fig. 3 below show the area (acres) of tidal datums (within the construction zone only) at Hester Marsh change from before construction, relative to after construction. Nearly 50 acres (20 ha) of elevation that should support new high marsh (i.e. includes above MHHW and ecotone) was created at Phase I and another 30 acres was created at Phase II.

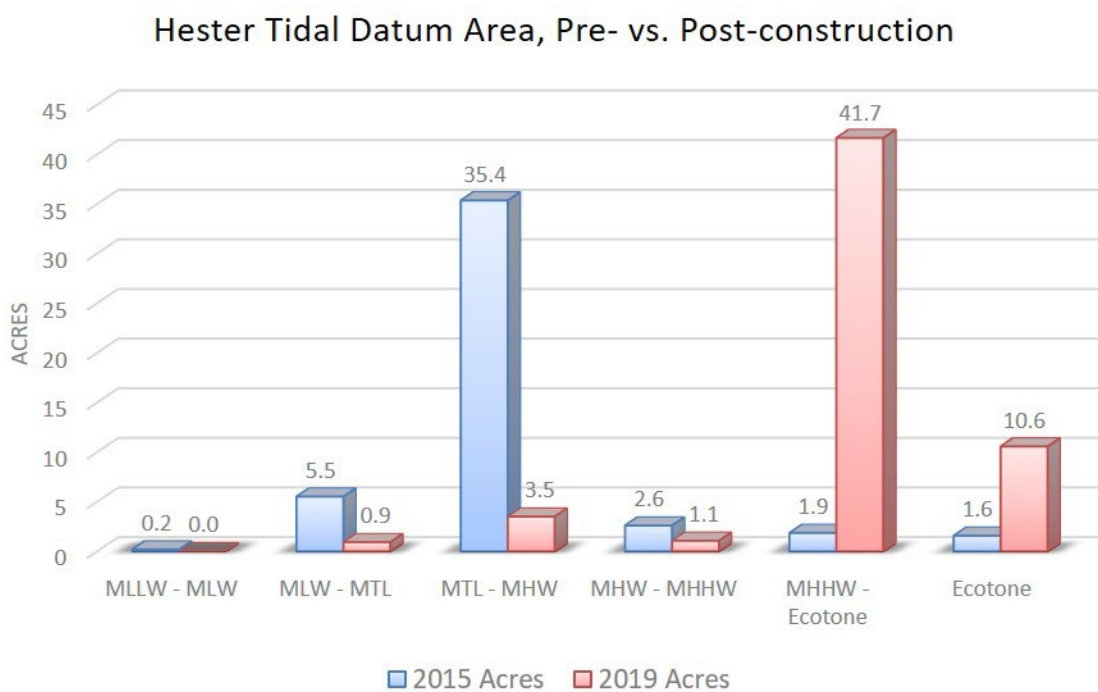


Fig. 2. Acreage of elevations before and after construction/restoration at Hester Phase I

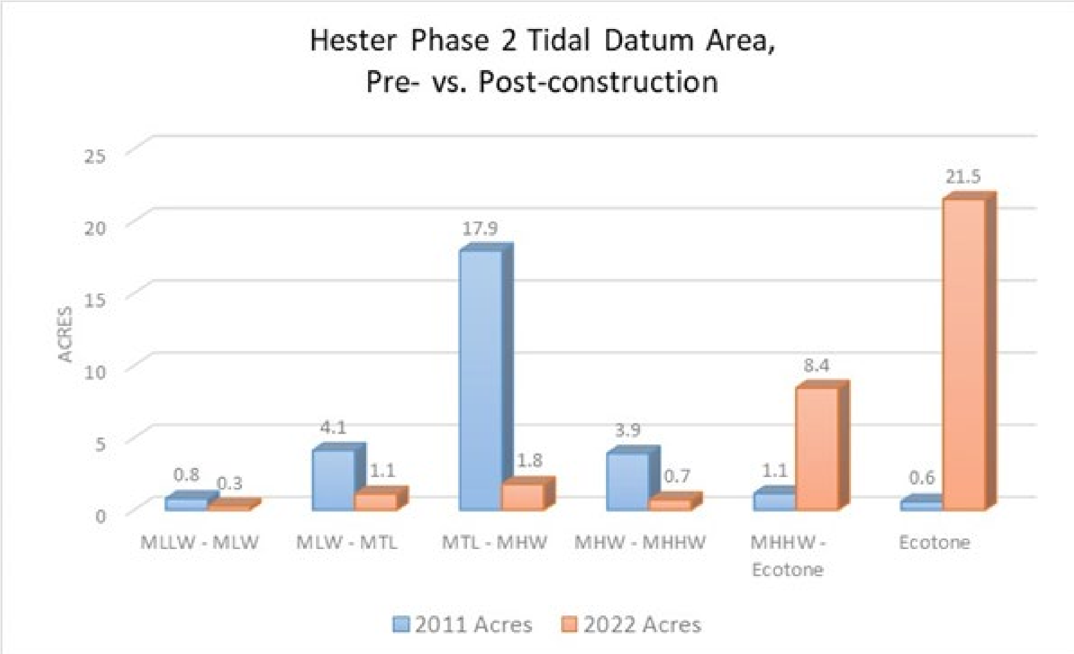


Fig. 3. Acreage of elevations before and after construction/restoration at Hester Phase II.

Key personnel
Monique Fountain, Charlie Endris, John Haskins

1.1.b Sediment retained over time

Background on test area, "the pad"
During construction at Phase I, an initial area within the project area was constructed to the desired marsh plain elevation, before the entire project area was isolated from tidal flow. The area was referred to as "the pad". The pad was briefly subject to tidal inundation, from the beginning of January 2018 to February 2018, when the project area was diked off. During the initial month after pad construction, we did not observe considerable sediment loss, and we expect sediment to be retained in the entire area over time, now that tidal flow has been restored at the end of construction.

Methods

<u>Overview of tasks</u>
Calculate sediment retention over time by comparing DEMs and/or TLS data points.

<u>Materials</u>
Refer to 1.1a

Frequency

Years 1 - 2: once every 6 months, coinciding with the TLS vegetation transects and/or GCP elevation surveys.

Years 3 - 5: once per year

Detailed Monitoring Methods

- Refer to 1.1a for DEM comparisons for each successive UAV flight.
- Additionally, before and after TLS measurements will help to confirm the UAV results by providing an additional level of accuracy (1 cm accuracy).

Results

Analysis of UAV-generated DEMs at Phase I revealed some immediate loss of elevation, followed by a very gradual decline (Fig. 4). We compared over 300 points taken from an RTK immediately following construction with DEMs generated at five different time intervals following construction. In the marsh plain overall, there was a decrease of 1.7 inches (4.7 cm) between August 2018 to September 2020. Likewise repeat elevation surveys of the 100 quadrats along the 10 transects revealed only minor loss of elevation, about 1 inch between August 2018 and September 2020 on average. Length of the conduit pipe/erosion pins along the three focal transects changed much less than that, suggesting compaction occurred deeper than the 5-10 feet these pipes had been pounded into the marsh. Feldspar marker horizons along these three transects mostly disappeared; this appeared to be due to wind blowing the feldspar and not erosion. Where marker horizons were refound, a tiny layer of accretion had occurred. In 2020 we buried tiles to track accretion rates, replacing feldspar.

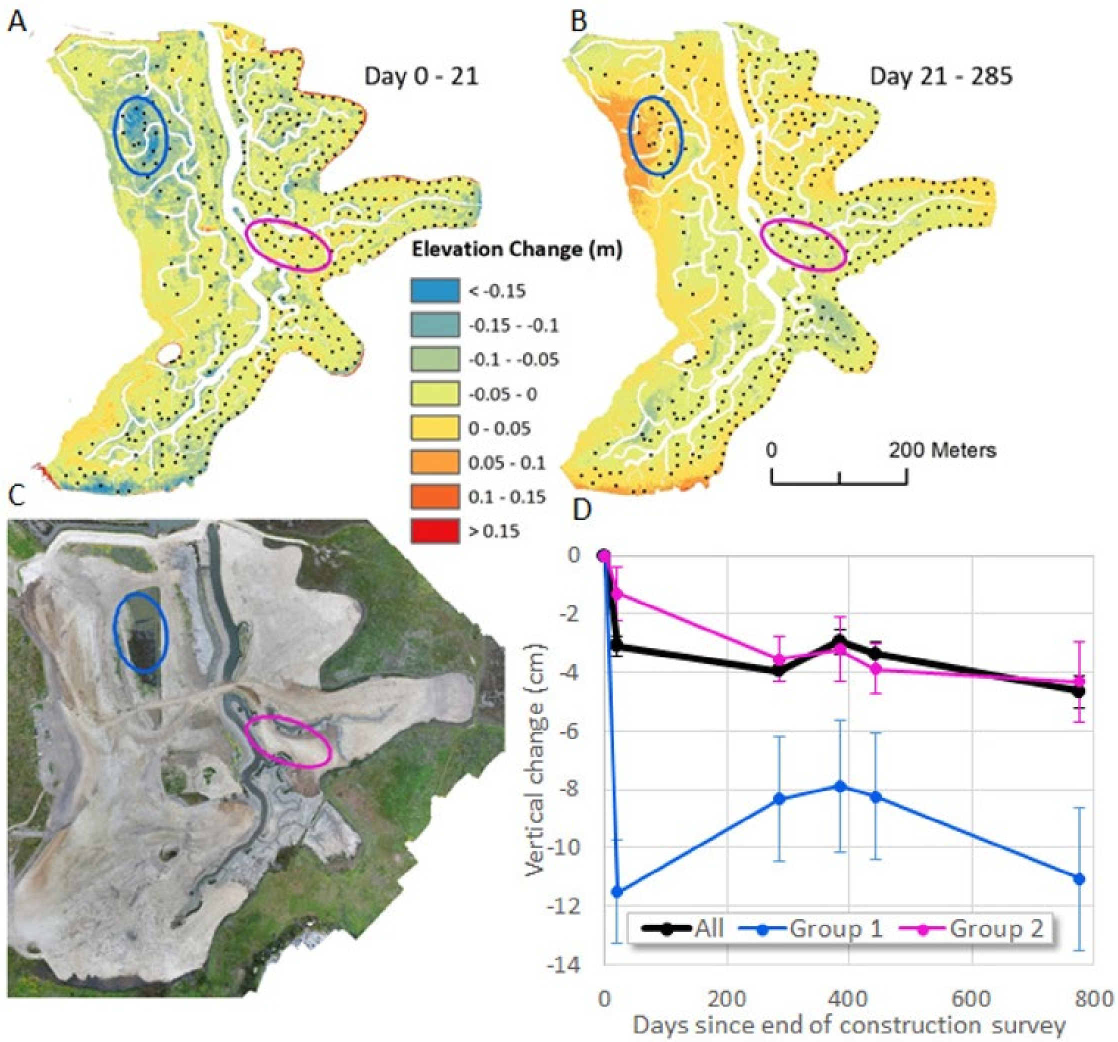


Fig. 4. Spatial and temporal patterns of elevation change at Hester Marsh. (A) DEM difference showing elevation change in the first 21 days following construction, assuming a consistent Day 0 elevation of 1.95 m. Black points show locations of the RTK survey completed at the end of construction in 2018. (B) Elevation change between Day 21 and Day 285. (C) UAV orthomosaic captured in May 2018 showing an area where excess water was contained during construction (blue oval) and where soil was compacted early on as part of a construction vehicle route (fuchsia oval). (D) Mean difference in original RTK-surveyed elevations and elevation values extracted from four post-construction DEMs at those surveyed positions. The black line represents elevation change at allRTK-surveyed positions, blue line represents the subset of locations within the blue oval in all maps, and fuchsia line represents the subset of locations within the fuchsia oval in all maps.

Key personnel
Monique Fountain, Charlie Endris, John Haskins

1.2 Maintain major tidal creeks parameters and change over time

1.2.a Tidal creek formation (implementation objective)

Methods

Overview of tasks

Calculate the final creek density using UAV imagery and the delineation of channel lengths in ArcGIS (divided by the total marsh area). If necessary, tidal creek volume may be calculated using the UAV DEMs in order to determine proper drainage of the marsh plain.

Materials

Refer to 1.1a.

Frequency

Once immediately following construction.

Tasks

- Post process UAV imagery and incorporate GCPs, if possible.
- Identify all “new” tertiary channels and delineate the thalwegs using ArcGIS.
- Sum channel lengths and divide by the total surface area of the marsh plain (referenced to MHHW) to calculate channel density.

Detailed Monitoring Methods

Refer to 1.1a

Results

The post-construction creek density at Hester Marsh Phase I and II (including the main channel) is 401 ft./ac. (302 m/ha) and 285 ft./ac. (214 m/ha), respectively, in the range of other healthy marshes at Elkhorn Slough (Fig. 5)

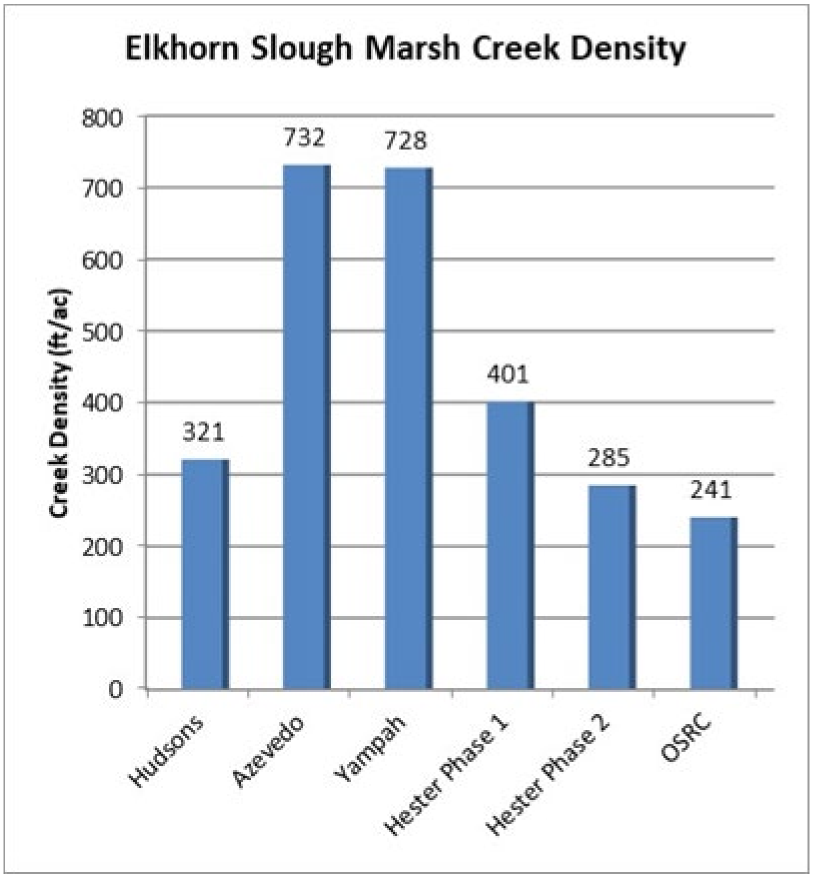


Fig. 5. Comparison of different creek densities in Elkhorn Slough marshes.

Key personnel
Monique Fountain, Charlie Endris

1.2.b Development over time (ecological function)

Methods

<u>Overview of tasks</u>
Calculate creek bank erosion by comparing successive UAV DEMs and reporting volume change. Include comparative analyses along the main channel where the western bank was reinforced with former wetland mud and the eastern bank was not reinforced.

<u>Materials</u>
See section 1.1a.

<u>Frequency</u>
Year 1 - 2: once every 6 months, coinciding with the TLS vegetation transects and/or GCP elevation surveys.
Year 3 - 5: once per year

Tasks

- See 1.1a for overall UAV/TLS methods.
- Create polygon mask that encompasses all tidal creeks with 2 m buffers
- Run DEM comparisons using ArcGIS Spatial Analyst tools
- Compare vertical profiles along the main channel bank edges

Detailed Monitoring Methods

For monitoring tidal creek development, we created a polygon mask to cover all the tidal creeks (including a 1m buffer on the edges of the creeks) and used the mask to extract volume change calculations separate from the marsh plain itself. Volume is calculated by summing all the grid cells that represent vertical change within each zone (e.g. marsh plain, tidal creeks, creek edge), and then multiplying the sum by the area of a single grid cell. We will provide a map displaying the evolution of the tidal creek morphology over time with a table of volume change relative to the first post-construction UAV survey. For comparing reinforced vs. non-reinforced bank edges along the main channel, we subtracted the August 2018 DEM from the October 2019 DEM and also created paired vertical profiles using the 3D Analyst Interpolate Line function.

Results

The creek bank edge is possibly the most dynamic feature on the newly restored marsh landscape, experiencing both erosion and deposition with every tidal cycle. Attempting to quantify the change, however, is complicated by the fact that any erosion of material from above may be re-deposited on the bank below. Nonetheless, our UAV DEM comparisons are useful in identifying specific examples of changes in creek morphology. Post-construction UAV DEM comparisons of Hester Marsh Phase I between August 29, 2018 to October 25, 2019 and to September 23, 2020 indicate moderate erosion along the creek bank edge, approximately 215.4 m^3 (281.7 cu yd) in the first year and 193.7 m^3 (253.35 cu yd) in the second year. A summary of volume, minimum, maximum, and mean elevation change for areas that fall within 1 m of the original creek bank edge are shown in Table 1.

Fig. 6 below shows an example of topographic change along the east and west banks of a portion of Hester Creek in Phase I. The west bank, reinforced with former wetland mud during construction, did not appear to experience as much erosion as the non-reinforced east bank. Additionally, the wetland mud may have helped facilitate the growth of pickleweed along the bank, as clearly evident in the DEM and the imagery.

Table 1. Volume, minimum, maximum, and mean elevation change along tidal creek banks.

Post-construction Year	Area Surveyed (m^2)	Volume Change (m^3)	Min (m)	Max (m)	MEAN (m)
1	14,239.86	-215.4	-0.73	0.43	-0.02
2	14,239.86	-193.7	-0.33	1.13	-0.01

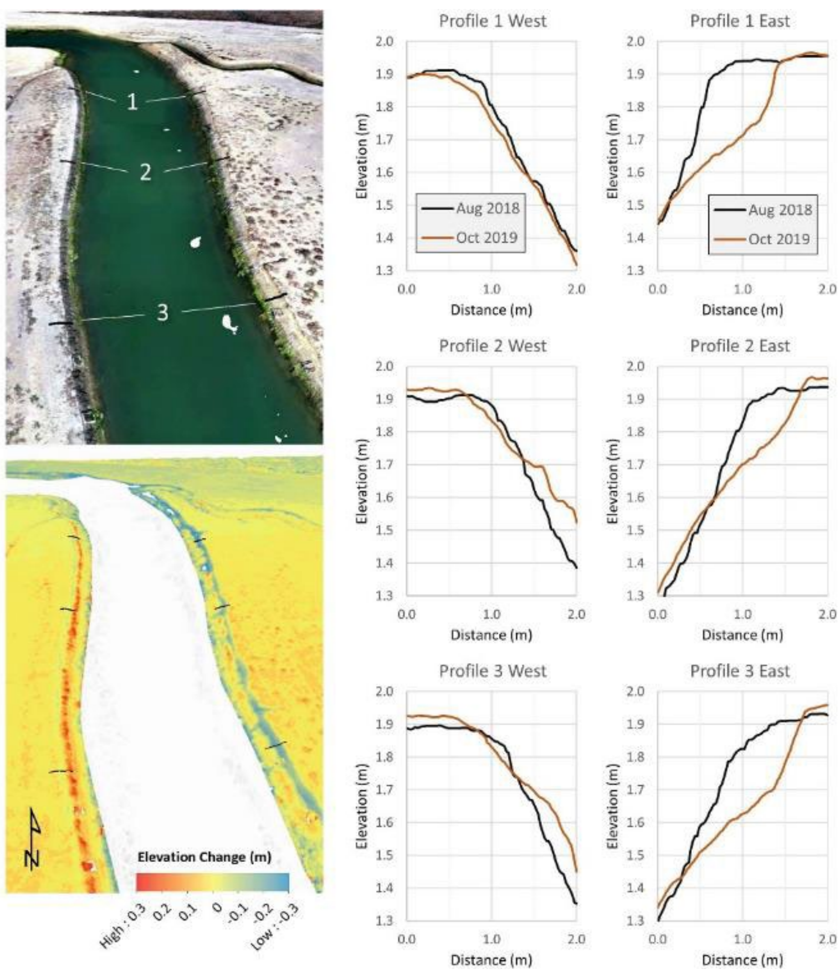


Fig. 6. A portion of Hester Creek shown in (A) an October 2019 orthomosaic, and (B) a DEM difference between August 2018 and October 2019. The west bank of the channel was reinforced with mud excavated from the former wetland; the east bank had no reinforcement. (C) Vertical profiles extracted from UAV DEMs were used to evaluate erosion of the main channel banks between August 2018 and October 2019.

Key personnel
Monique Fountain, Charlie Endris

1.3 Create marshes with a healthy plant community

1.3a Remote sensing of marsh vegetation

Methods

Overview of tasks

Quantify acres of marsh habitat using remote sensing. Conduct analysis of physical factors that may influence vegetation presence/absence using remotely sensed imagery and other spatial layers.

Materials

Quadcopter, batteries, software.

Frequency

Marsh habitat extent was quantified 6 months prior to construction. It was quantified at 3, 6, 9, and 12 months, post-construction, then will be surveyed annually for several years, then biannually. Reference marshes will be assessed at least every other year to compare long-term trajectories at Hester vs. reference marshes. Analysis of factors influencing vegetation presence and absence will focus on imagery from the end of the first growing season (October 2019, 14 months after construction ended).

Tasks

Fly UAV at project site. Conduct image classification and spatial analysis.

Detailed Monitoring Methods

We monitored overall extent of marsh habitat using UAV 4-band imagery. Normalized difference vegetation index (NDVI) layers were created from the imagery and may be used to calculate total vegetated area for each flight. We will compare extent of marsh before vs. after restoration, with imagery collected and analyzed frequently in the first years following restoration, and at least every 2 years in later years. We will conduct similar overflights of at least three other marshes in the system, one with average elevations (e.g. Yampah) and 2 others with higher than average elevations (e.g. Hudsons and OSRC) Since Hester will be our highest elevation marsh in Elkhorn Slough, we expect vegetative cover to be more stable over time than the three other comparative marshes.

Results

Vegetation has colonized Phase I. Most frequently encountered species are pickleweed and *Spergularia* sp. (Fig. 7)

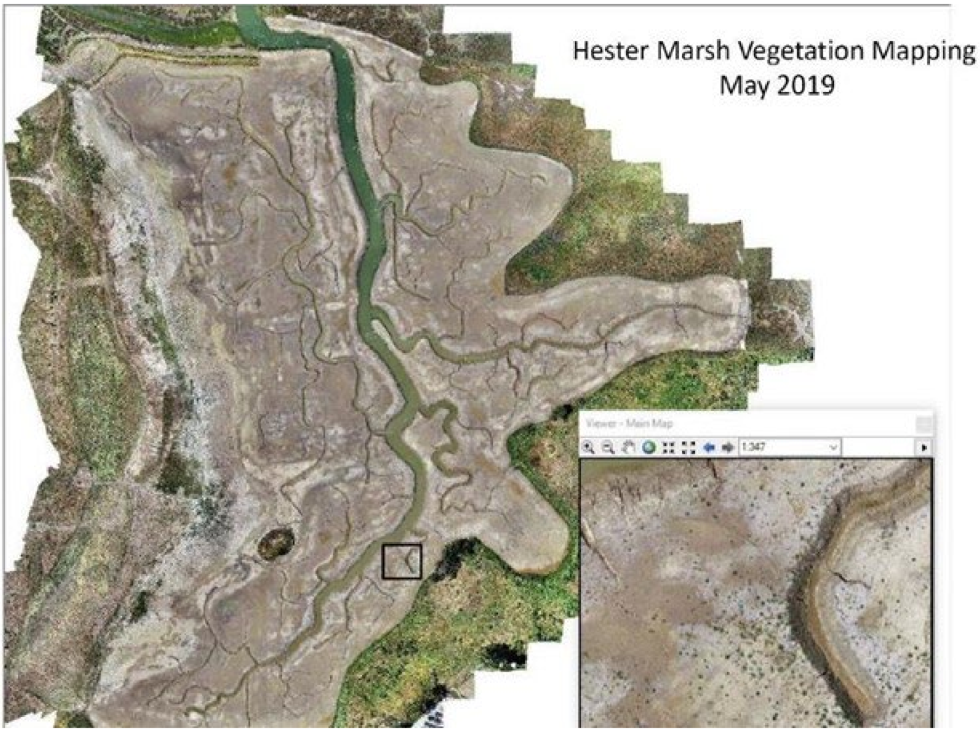


Fig. 7. Green dots in insert are primarily pickleweed and *spergularia* sp.

Preliminary image classification has been completed in ArcGIS Pro version 2.4.2 (ESRI 2018) using a supervised, pixel-based approach and maximum likelihood classifier (Fig. 8; overall accuracy approximately 94%) (Thomsen et al., 2021). The classified image is used to evaluate factors associated with vegetation colonization. For example, we performed image classifications on imagery from both October 2019 and September 2020 and compared the results within a DEM reclassified to 5 cm bins between 1.65 and 2.00 m NAVD88. The results show most vegetation expansion has occurred within the 1.75 - 1.80 m range (Fig. 9). Overall, 7.6% of the marsh (3.59 ac) had recolonized by October 2019, increasing to 15.5% (7.25 ac) by September 2020 (Haskins et al., 2021). Results of the classification for August 2021 did not show a significant increase from 2020, but was also compromised by UAV imagery that was more challenging to accurately classify. Overall, the classification results represent a conservative estimate of total marsh vegetation and may in fact be slightly lower than actual vegetation coverage. The vegetation coverage measured in the marsh transects was approximately two times higher than the vegetation coverage from the classification. For details on transect vegetation coverages, see section 1.3d Marsh transects. Similar techniques used by Thomsen et al. (2021) and Haskins et al. (2021), as described above, will be performed at Phase II once vegetation colonization can be detected in the UAV imagery.

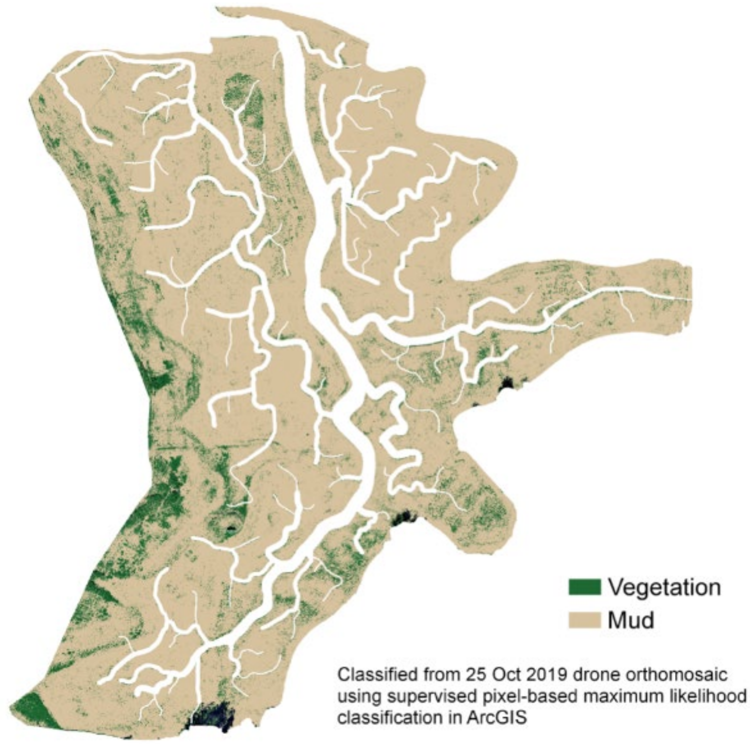


Fig. 8. Classified image of Phase I based on remotely sensed imagery collected 25 October 2019.

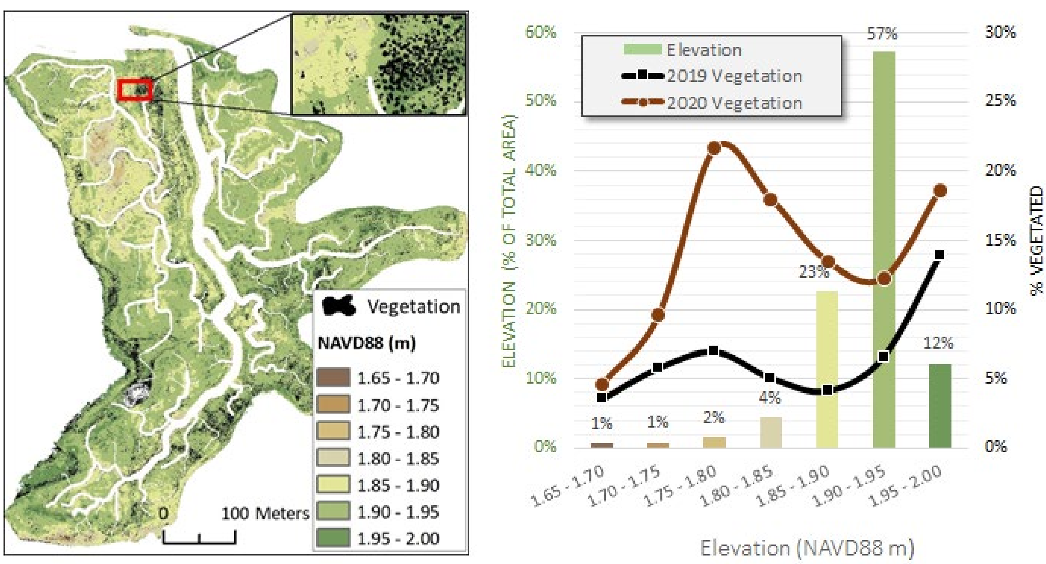


Fig. 9. Map of classified vegetation on top of an August 2018 DEM showing elevation in 5 cm increments (left). Percent of total area (histogram) and percent vegetated area (line) in each elevation bin (right). Percent vegetated area is the area of classified vegetation in an elevation bin out of the total area in that bin.

Key personnel

John Haskins, Charlie Endris, Alexandra Thomsen, Alex Lapides, Fuller Gerbl, Monique Fountain

1.3b Area searches for marsh vegetation in Phase I

Methods

Overview of tasks

Characterize survival of existing plants, initial colonization, and rare species by area searches.

Materials

Trimble GPS.
Flags.
Datasheet.

Frequency

3 months after sediment moving was complete – full survey.
Additional targeted surveys as needed later.

Detailed Monitoring Methods

We monitored survival of existing plants and initial colonization by new plants by walking the entire marsh plain and noting identity, number, and GPS coordinates of any plants present. Further surveys were conducted later to search for particular rare species of interest that did not appear in transects.

Results

In October 2018, very few live plants were found on the marsh plain at Phase I. With the exception of a few upland grasses and weeds, the only plants found were marsh species that had survived scraping on a high berm, or had burial due to the limited amount of sediment added. By May 2019, pickleweed and *Spergularia* sp. were the most common marsh plants in the project area.

Key personnel

Alexandra Thomsen, Kerstin Wasson

1.3c California Rapid Assessment Method (CRAM)

Methods

Overview of tasks

Conduct habitat assessment in accordance with standardized methods of the CRAM protocol (CWMW 2012) at the Hester site and at two control sites.

Materials

For specific protocol, see https://www.cramwetlands.org/

Frequency

The first survey was conducted about 2 years prior to construction.
The second survey will be conducted about 5 years after construction.

Detailed Monitoring Methods

In addition to monitoring methods described here, wetland habitat assessment is conducted using the California Rapid Assessment Method (CRAM) (Appendix 7). See https://www.cramwetlands.org/ for CRAM protocol.

Results

Pre-construction CRAM scores in three subareas of the project area were in the range of 56-71. See Appendix 7 for further details.
Post-construction results have not yet been collected.

Key personnel

Cara Clark, Kevin O'Connor, Rikke Jeppesen

1.3d Marsh transects

Methods

Overview of tasks

Collect vegetation data at 120 long-term monitoring plots (10 quadrats on 12 transects) at Phase I-II. Assess physical variables correlated with vegetation cover and height and conduct additional experiments as needed.

Materials

Transect tape.
Quadrat with intercepts.
Yardstick.
Intercept rod.

Frequency

- We conducted transect monitoring at eight control sites in 2016 and 2021 and plan to repeat every five years.
- We conduct transect monitoring at Hester approximately quarterly for the first year, then annually for the first five years following construction, then every 5 years for the indefinite future.
- Annual monitoring is conducted near the peak or end of the growing season (August-October).

Detailed Monitoring Methods

Location of transects at Hester: See text above on elevation monitoring and Fig. 1. There are 10 transects in Phase I, each with 10 evenly spaced quadrats from upland boundary to creek/channel boundary. There are two transects, similarly designed, in Phase II.

Reference sites: We chose eight sites representing a range of conditions and locations across the Elkhorn Slough estuary, including high, healthy marshes and lower, degrading ones (Fig. 10). We did not sample the most degraded marshes in the system, which have already largely converted to mudflat, so our sampling provides a more positive assessment of marsh health than would have been obtained from random site locations taken across the entire historic marsh footprint. We sampled mostly in areas that have never been diked, because our primary interest is in understanding marsh loss that has occurred in undiked regions of the Slough. Most marshes on the Reserve were diked and drained and converted to agricultural uses. When tidal flow was returned following establishment of the Reserve, these areas were too low to support marshes and now are shallow mudflats. Yampah Marsh, which was never diked or drained, is the only one of our sites that is on the Reserve. The marshes we sampled are listed below, approximately in order from healthiest to most degraded, with a brief description. We expect Hester Marsh to be broadly similar to the first three sites, and to have greater percent cover, canopy height and marsh community diversity than the remaining sites.

- Hudsons: a very high marsh with tall pickleweed, near the head of the estuary
- Old Salinas River Channel: a marsh that has expanded over the past century after diversion of the Salinas River, high and healthy
- Azevedo: a high marsh near a surface elevation table monitored by ESNERR
- Lavender Ridge: a marsh that includes a high ridge harboring sea lavender that is rare elsewhere in the estuary
- Bennett Southwest: a marsh that was diked, but not drained, with limited tidal flow apparently controlled by various water control structures over many decades; here marsh has been expanding; a surface elevation table will soon be installed by ESNERR nearby
- Yampah: a low marsh on ESNERR property that has shown signs of degradation recently; a surface elevation table will soon be installed by ESNERR nearby
- Round Hill: a low marsh that has shown signs of degradation recently; near a surface elevation table monitored by ESNERR
- Big Creek: a low marsh that has shown signs of degradation recently; near a surface elevation table monitored by ESNERR

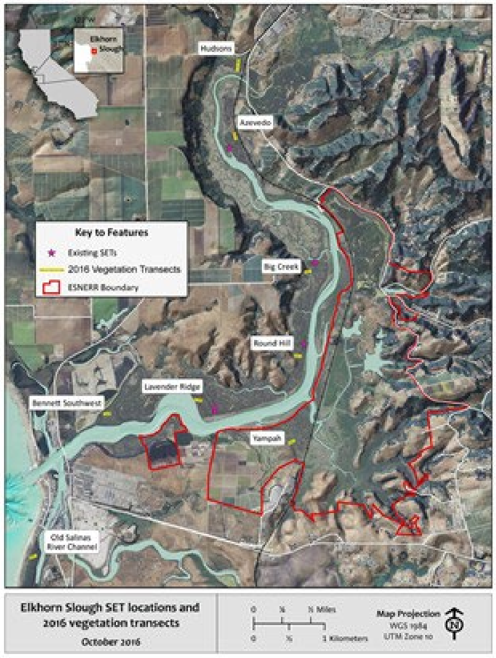


Fig. 10. Reference sites

<u>X, Y and Z coordinates</u>: Refer to 1.1a

<u>Quadrat size</u>: We used a 50 cm x 50 cm PVC quadrat (with 50 cm "legs" to prevent crushing of the marsh vegetation). This is smaller than the typical size used by researchers following the example of Charles Roman and by most NERR sites, but is perfectly adequate to capture patterns in our extremely low diversity marsh, where most plots had only a single species. We chose the smaller size because it is easier to lean over and see into from a single location, which minimizes trampling of the marsh and sampling time.

<u>Percent cover</u>: Our quadrat had strings running across it in both directions, such that there were 16 string intercepts. We dropped a steel rod 1 m in length, 2 mm in diameter, against the corner of each intercept and noted all vegetation species touching the rod. If no living plant was touching the rod, we recorded this intercept as "bare". Percent cover was calculated as (# intercepts/16) x 100. This method resulted in some plots having greater than 100% cover of all vegetation species combined, because multiple species touched the rod at a single intercept. This is ecologically accurate because the species occupy different canopy layers. Percent cover is the only vegetation metric collected at the 180 short-term quadrats.

Percent succulent cover of pickleweed: we separately tracked intercepts of woody vs. succulent pickleweed, because the latter appears to be a more sensitive indicator of marsh health.

Marsh health indicator: we multiply percent cover of succulent pickleweed by canopy height of pickleweed to get a proxy for biomass. We have found this to be a reliable indicator in previous work.

Canopy height: We marked three intercepts of our quadrat with cable ties, and searched for the tallest pickled stem within a 10 cm radius of each. The height of this stem from the marsh floor was measured with a narrow folding yardstick, without tugging on it or straightening it. These three measurements were averaged to obtain an estimate of maximum canopy height of pickleweed. We did not measure canopy height of other species because they occurred far too rarely in the transects to allow for statistical analyses.

Crab burrows: present/absent based on quick visual search of plot; the only species that makes burrows in our marshes is *Pachygrapsus crassipes*

Ground firmness: we used an index of 1-3 to assess how firm vs. unconsolidated the marsh plain was

Marsh boundaries: we assess location of the most landward marsh plant relative to the top quadrat marker to monitor change in location of the marsh-upland boundary, comparable to measurements taken at eight other sites around the estuary. We also assess location of the most seaward marsh plant relative to the bottom quadrat marker in each transect, to track changes due to channel erosion.

Salinity: soil conductivity and salinity have been monitored twice yearly along vegetation transects (April/October 2019; February 2020). Measures were made using a Geonics portable conductivity meter (EM38 MK2) to track spatial and temporal patterns in salinity, and to relate plant recruitment to salinity patterns.

Results

Hester Phase I transects were sampled in August and October 2018, April and August 2019, September 2020 and August 2021. At both periods in 2018, no live vegetation was present in any of the quadrats in the sediment addition area. Germination of newly colonized plants, mostly pickleweed, occurred in Spring 2019. By summer 2019, there was 16% cover of colonizing marsh plants in the transects; by fall 2020, this had increased to 28% (Fig. 11). A year later, cover was still 28%. Pickleweed height remained low, around 2.75 inches (7 cm) in summer

2019, 3.5 inches (9 cm) in September 2020, 4.7 inches (12 cm) in August 2021; in comparison, mature pickleweed in our reference transects is typical about 14 inches (36 cm) high. Colonization appears to be positively correlated with high elevation: quadrats with highest cover were located on the western part of the site, where sediment was scraped and elevation is highest, and in the relatively higher-elevation portions of the marsh plain on the eastern side (Fig. 12).

Despite the increase in cover from 2019 to 2020 (from 16 to 28% in the transects), it appeared little new colonization had occurred. The quadrats that had been bare in 2019 largely remained bare in 2020 and 2021. To determine whether this was due to recruitment limitation, we planted three pickleweed seedlings adjacent to each of the 100 quadrats in Spring 2020. Survival was low in general, but by far the lowest adjacent to the quadrats that had the least colonization (Fig. 13), which occurred in the middle of transects at middling elevations. We thus infer that the lack of colonization is due to stressful abiotic conditions, not lack of seeds.

Understanding the nature of the stressful conditions that prevent marsh colonization in these bare areas is an on-going area of research. We have taken penetrometer readings that suggest soil compaction may be greater in these areas, and sediment measurements that suggest salinity is higher and sediment grain size lower. Our working hypothesis is that areas with finer sediments and a high percentage of clay were more compacted and are poorly drained, making establishment by roots challenging. We are exploring soil amendment, soil decompaction, and planting of larger plants to ameliorate these stressful conditions and will provide findings in a future report.

Of the observed native cover, 99% was *Salicornia pacifica*, the marsh dominant. *Spergularia marina*, *Frankenia salina* and *Cressa truxillensis* comprised the remainder of the colonizing native cover. Average cover of non-native species along transects was very low - 1% for marsh non-natives and 1% for upland non-natives. Marsh non-natives surveyed in August 2019 were 67% *Atriplex prostrata* and 33% *Parapholis incurva*, while upland non-natives were primarily *Pseudognaphalium* sp. and unidentifiable grasses, dead at the time of survey. Average cover of *Erigeron* spp. was also nearly 1% in August 2019, but is not included in upland non-native cover calculations because native *E. canadensis* could not be distinguished from non-native *E. bonariensis* during field surveys. Non-native cover of both marsh and upland non-natives was concentrated on the western portion of the site, where sediment was scraped and elevation is highest (Fig. 14).

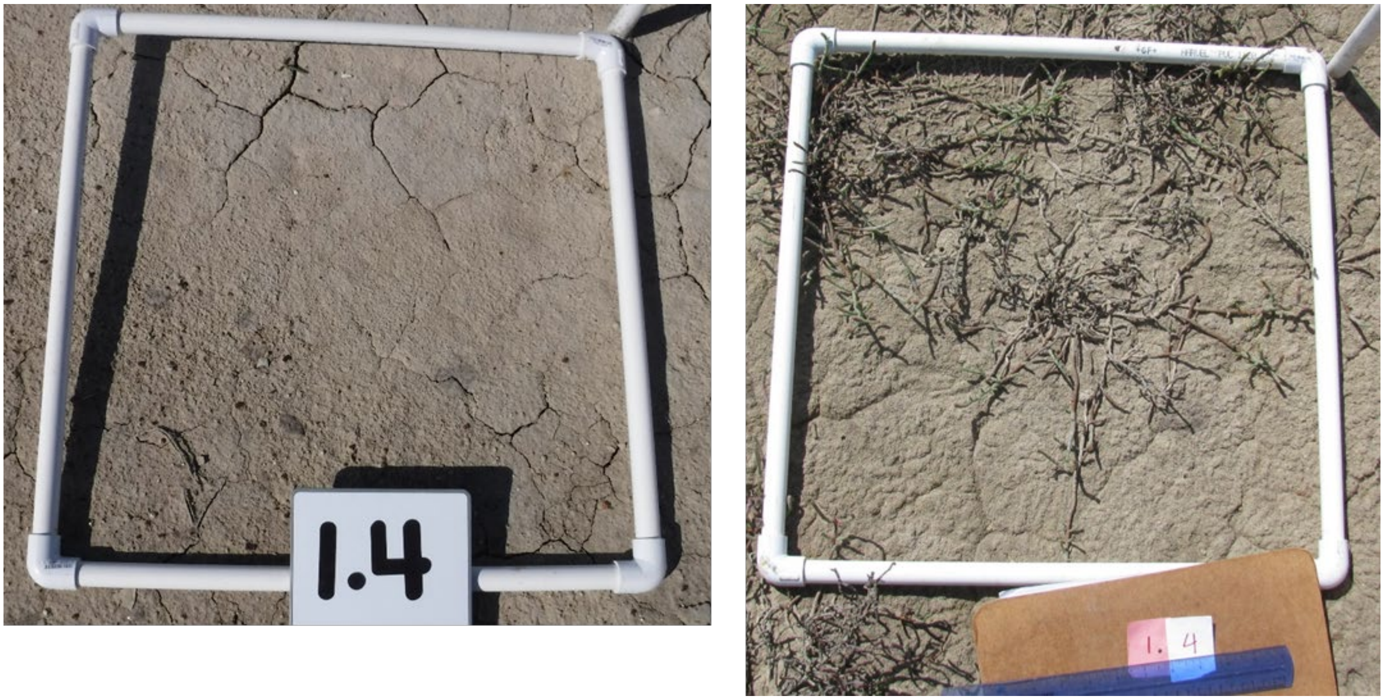


Fig. 11. Pickleweed growth between summer 2019 (left) and summer 2020 (right) at a representative quadrat on a monitoring transect.

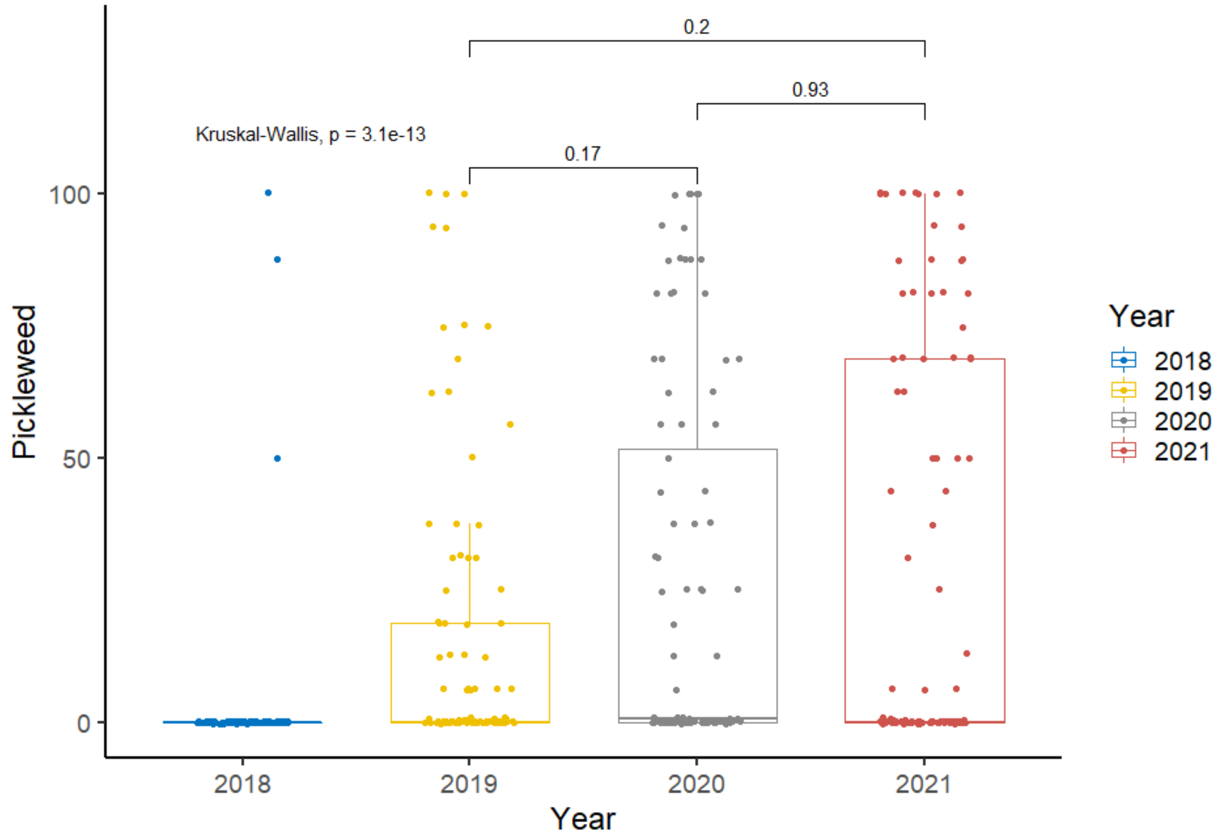


Fig. 12. Percent cover by pickleweed in the marsh transects in Phase I over time.

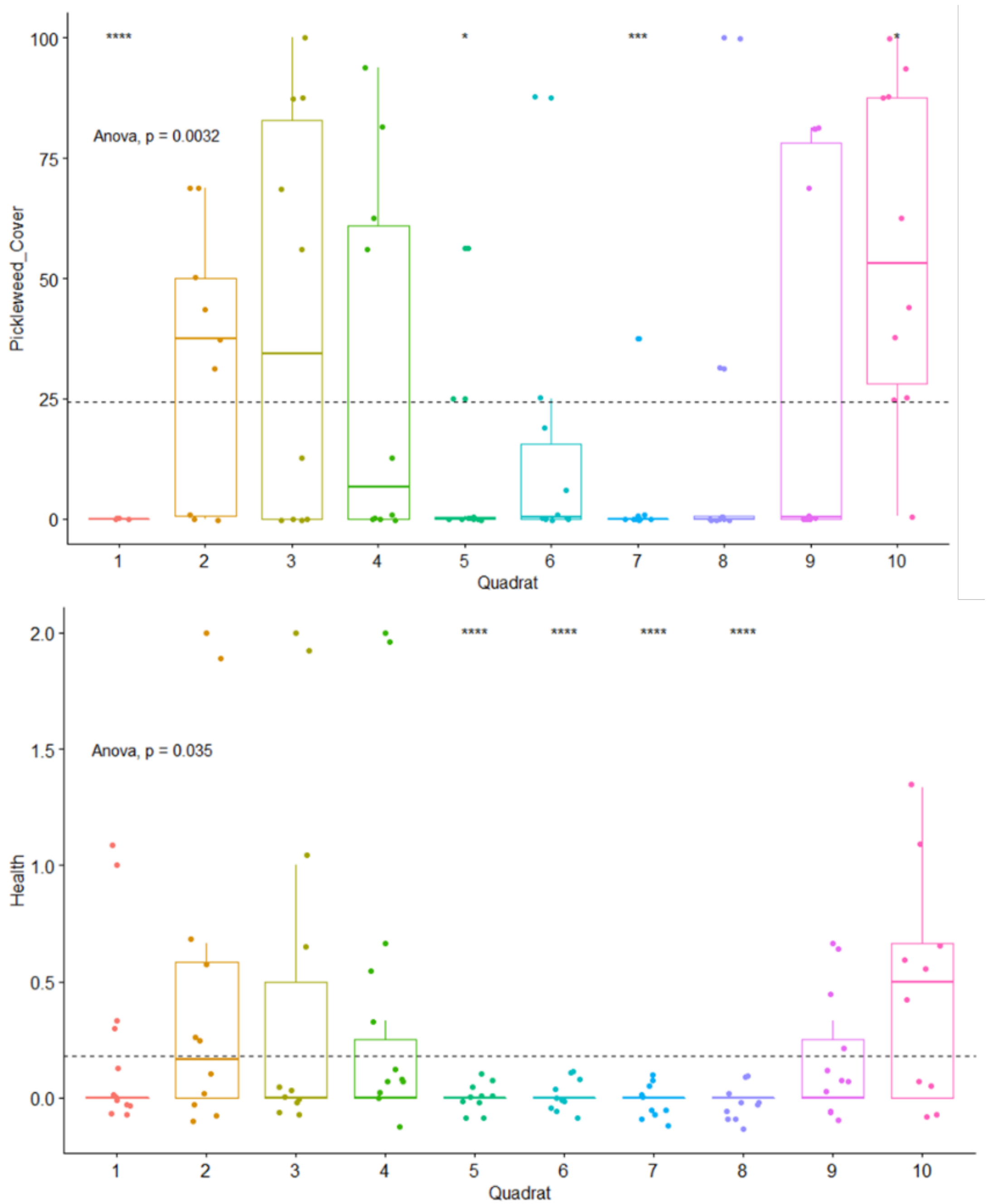


Fig. 13. Top: Percent cover of colonizing pickleweed averaged for each quadrat along the 10 quadrats in September 2020; quadrat 1 is at the upland boundary, and quadrat 10 is at the creek/channel boundary. Bottom: Average health of pickleweed transplanted to each of the same quadrats in Spring 2020. In both cases, quadrats 5-8 in the lowest elevations at the middle of the transects appear to have most stressful conditions, limiting colonization and health of transplants.

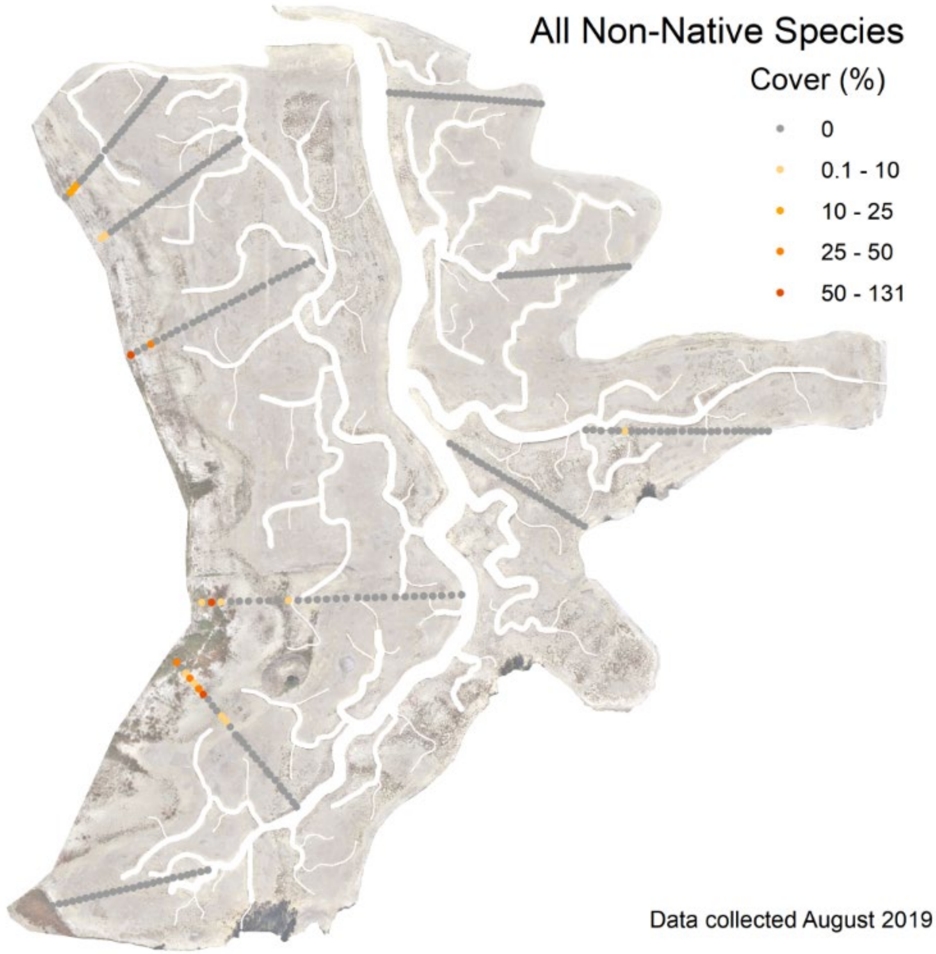


Fig. 14. Spatial variation in non-native species cover in August 2019 (marsh and upland non-natives combined). Non-natives are almost exclusively restricted to the western side of the site, where sediment was scraped and elevation is highest. Cover over 100 percent was observed at some quadrats due to canopy layering (see Percent Cover description under Detailed Monitoring Methods). Quadrats with existing vegetation are excluded.

Field measurements of apparent bulk conductivity using a portable conductivity meter (EM38 MK2) were related to soil salinity by generating calibration curves, for two sampling campaigns at the start and end of the summer dry season. To aid spatial modelling of soil salinity, a UAV survey was conducted, and the resulting multispectral imagery was used to derive elevation, vegetation, and soil moisture information. Additional spatial data relating to elevation change and distance to tidal channels were included in a partial least squares regression model (R2 = 0.86, RMSE = 5 ppt). Model predictions of salinity increase with proximity to tidal channels and at low elevations, while lower predicted salinity corresponds to previously high elevation sites where sediment was removed for restoration (Fig. 15). For a given elevation, soil salinity was lower at the start of the dry season (April) compared to the end of the dry season (September).

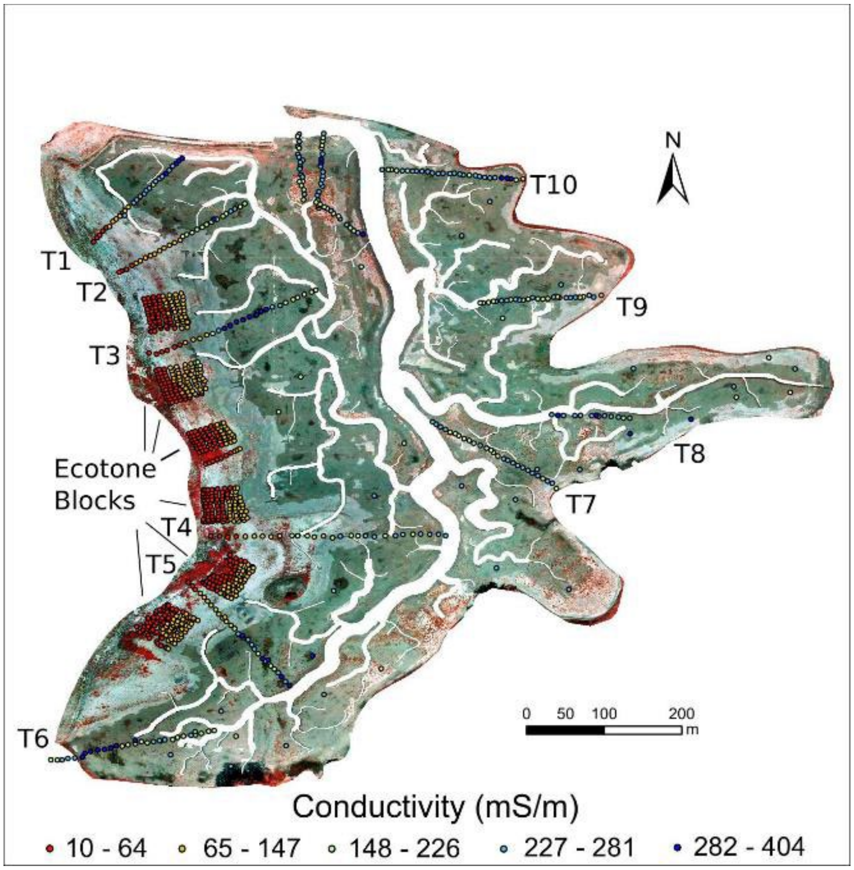


Fig. 15. Field sampling locations for apparent conductivity in September 2019 over a false-color representation of the UAV-derived multispectral orthomosaic of Hester Marsh.

Key personnel

Alexandra Thomsen, Rachel Pausch, Karen Tanner, Kerstin Wasson, Johannes Krause, Charlie Endris, Andrea Woolfolk, Monique Fountain

1.3e Biochar experiment: large plots with granite fines

Methods

<u>Overview of tasks</u>

Add biochar to experimental plots 10% by volume (Fig. 16), and monitoring plants in plots over time, to determine if biochar enhances plant growth. Conduct soil analysis to determine carbon sequestration rate immediate after construction and over time. Measure gas emissions from restored marsh, in biochar plots. Monitor plant cover and canopy height in plots with granite fines and biochar.

<u>Materials</u>

Biochar made from Reserve eucalypts.

PVC markers for plot boundaries.

Transect tapes, quadrats, yardsticks for monitoring.

Granite fines.
On-site soil.
Quadrats.
Ruler.

Frequency
Set up experiment soon after construction is completed.
Collect soil samples immediately after setup, and once cover is at 70%.
Monitor plots at least annually; more often in first year if possible.

Tasks
Add biochar to experimental plots and similarly disturb control plots.
Monitor plant cover over time.
Send soil samples to E. Watson, Drexel University, for carbon sequestration rate analysis.
Measure gas emissions when Picarro instrument is available (E. Watson and C. Weigandt).

Detailed Monitoring methods
Plot size and replication: plots 12 x 12 ft in size (3.66 x 3.66 m).
Biochar concentration: 10% by volume (aim to mix into top 4-8 inches [10-20] cm of sediment, so there will be some variation in estimate).
Methods of mixing biochar into sediment: tractor.
Use quadrats or point intercept transects depending on plot size to monitor plant percent cover and canopy height. Use Picarro gas analyzer to measure gas emissions.

Granite fines concentration: Row 1 had granite fines only, with no soil cap. Row 2 had granite fines only, capped with 6” of on-site soil. Row 3 had a 50:50 mixture of granite fines and on-site soil.

Sediment samples were collected from auger holes in August 2018 in the 9 biochar plots, about 1.5 m seaward and 1.5 to the right when facing the water of the landward, leftmost plot marker. These areas will be resampled when cores are taken from the marsh transects, to compare changes in carbon content in the biochar plots vs. rest of marsh.

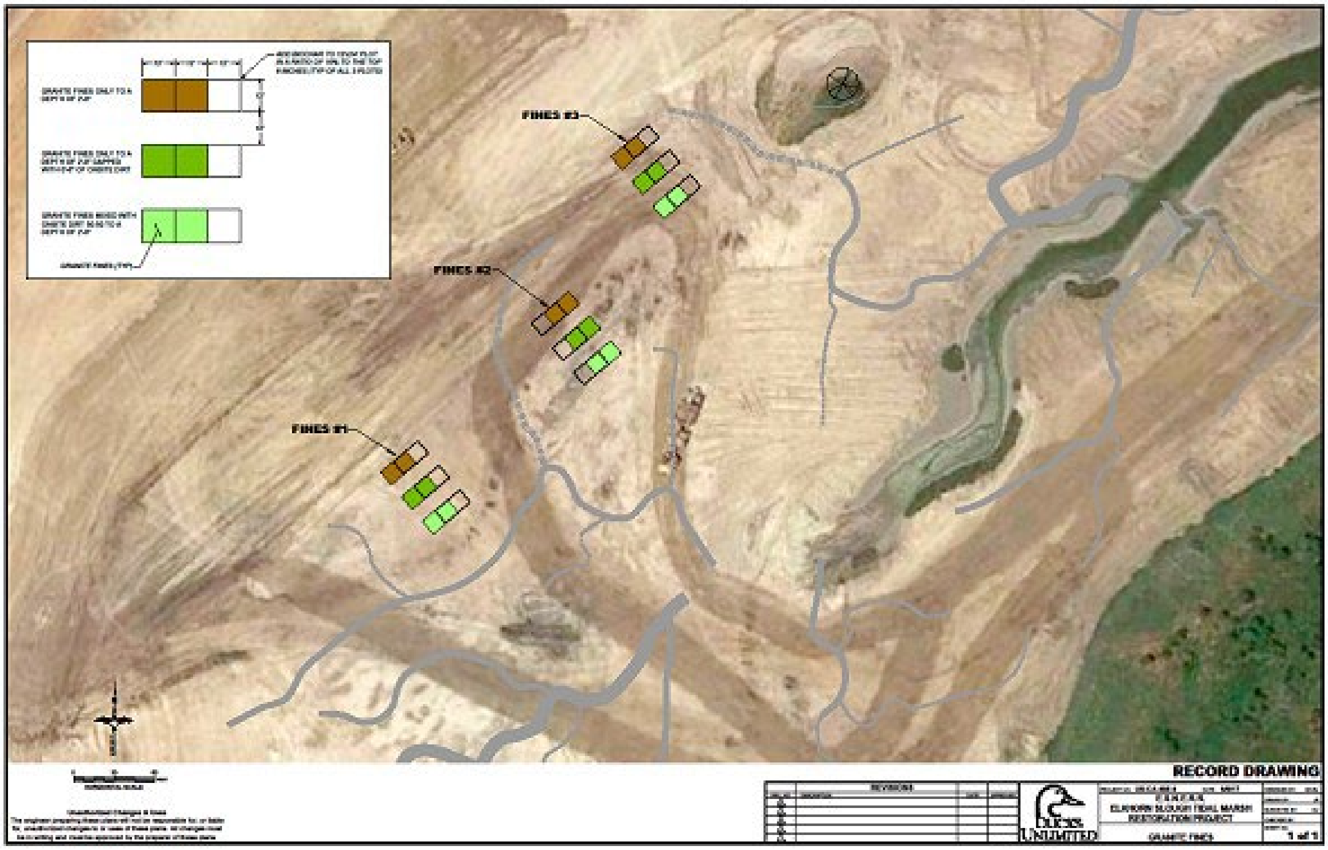


Fig. 16. Experimental design of granite fines and biochar use for restoration. Each replicate consists of three elevations each with three 12 x 12 ft squares at each elevation. One square was biochar only, one square was granite fines, and one square was both biochar and granite fines.

Results

Colonization of plots was estimated using UAV overflights (Fig. 17), so a thorough comparison of treatments has not yet been undertaken.

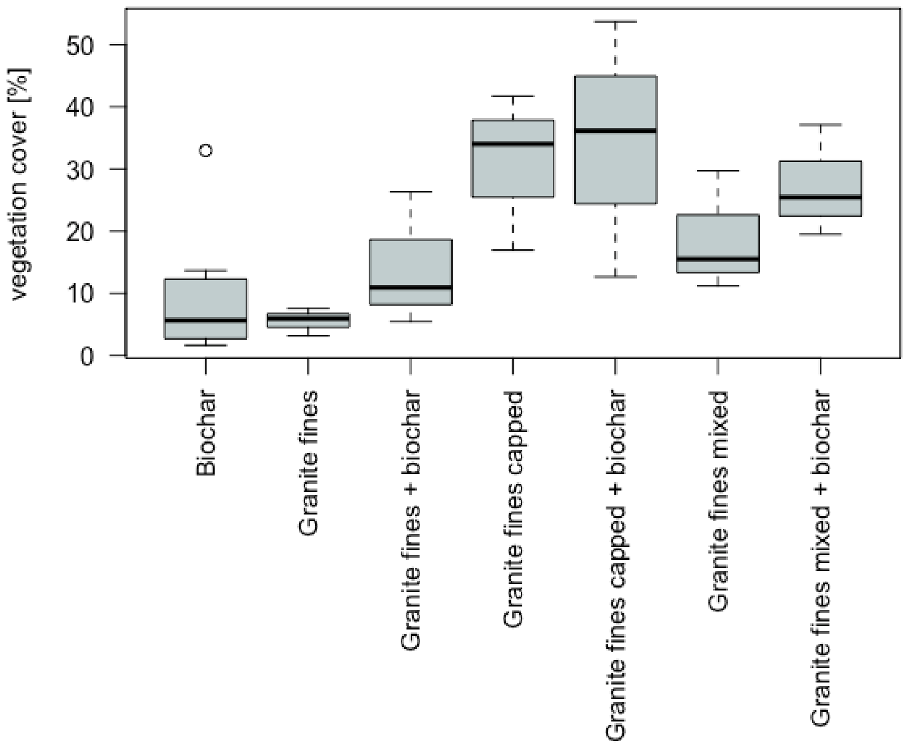


Fig. 17. Colonization estimates from UAV flights

1.3f Biochar experiment: small plots

Methods

Overview of tasks

Add biochar to experimental plots 10% by volume and monitor plants in plots over time to determine if biochar enhances plant growth, nitrogen cycling, salt stress reduction, and carbon sequestration.

Materials

Biochar made form Reserve eucalypts.
PVC markers and flags for plot boundaries
Transect tapes, quadrats, yardsticks for monitoring
Salinity mapper
LI-COR portable CO_2 gas analyzer
Soil sampling tools (sample bags/stainless steel canisters; small stainless steel corer/spoon; gloves)

Frequency

Experiment was set up in August 2019
Distichlis spicata (x3) was planted into plots in February 2020 (both control and biochar plots)
Monitoring began August 2019 (gas emissions) and is ongoing

Tasks

Add biochar to experimental plots and similarly disturb control plots
Monitor plant cover over time using drone classification and on-the-ground estimates (Braun-Blanquet)
Send soil samples and biochar samples to E. Watson, Drexel University, for denitrification potential analysis
Measure gas emissions when LI-COR instrument is available (E. Watson and C. Wigand)
Measure ground salinity when salinity mapper is available (E. Watson and C. Wigand)

Plot size and replication: plots 3.3 x 3.3 feet in size (1 x1 m); 10 locations interspersed in mid-marsh plain between long-term monitoring transect; at each location, paired control (dug and refilled with same sediment) and biochar (dug and filled with 10% by plot volume of biochar); plots are 3.9 inches (10 cm) deep, and plots with biochar have biochar mixed within bottom ~2 inches and capped with untreated sediment to prevent loss of biochar during tidal flooding.

Detailed Monitoring Methods

To determine if Reserve eucalyptus biochar enhances plant growth and supportive soil conditions, parameters including plant cover, CO_2 emissions, and salinity will be monitored in small plots treated with 10% additions by volume of biochar and compared to paired untreated plots. Additionally, sediment samples will be taken from paired plots to examine the nitrogen cycling in healthy marsh and restoration sediments.

CO_2 emissions

Plots will be measured annually to determine a rate of biochar degradation over time. Emissions have previously been measured in August 2019 immediately after plot construction to obtain a baseline emissions rate and again in February 2020. Emissions are measured using a LI-COR gas analyzer with a black-out gas chamber placed directly on bare soil for three minutes during mid-day and low-tide conditions. This measurement is intended to specifically measure the emissions released by soil biota.

Plant Growth

Distichlis spicata plants were planted in plots in February 2020 to determine if biochar may be beneficial for plant growth. Three plants were placed in the center of each plot (treated and untreated) using a dibble stick in a clustered pattern. A combination of drone flyovers and on-the-ground plant cover measurements (Braun-Blanquet method) will be conducted annually to determine the change in plant cover/survival over time. Measurement of any non-planted species will additionally be analyzed to determine the rate of recolonization.

Salt Stress

Plots will be measured for ground electrical conductivity using a non-destructive salinity mapper when available. Measurements will take place at each plot (with and without biochar) by holding the instrument 3.3 ft. (1 m) above the ground surface after calibration in non-hydric soils. Measurements will be taken during low-tide conditions.

Nitrogen Cycling

Soil samples will be taken from a subset of plots (both treated and untreated) to be analyzed for denitrification potential. Samples will be compared to samples taken from fresh eucalyptus biochar, large-scale biochar plots (Section 1.3e), and Old Salinas River Channel (Fig. 10). Samples will undergo an incubation experiment following methods similar to Murphy et al. (2019) and resulting headspace gases will be analyzed using a membrane inlet mass spectrometer (MIMS) in collaboration with Dr. Ashley Smyth of the University of Florida. Denitrification potential will be compared between samples to determine if the age of biochar has an effect, as well as to determine if denitrification potential differs between restored vs. healthy marsh soils.

Soil samples will additionally be used to determine the overall ammonium concentration of healthy marsh soils and restoration soils with and without biochar. Ammonium concentrations will be measured using a spectrophotometer on KCl-extracted sediment water (according to *Standard Methods for the Examination of Water and Wastewater*, method "4500-NH_3 Nitrogen (Ammonia)") (Standard 2018). This will elucidate if restoration or biochar has an effect on necessary soil nutrient levels for plant growth.

Results

None to date. Colonization of these plots was still limited in 2021, so full analyses have not yet been completed. There is not enough data available for CO_2 emissions monitoring to determine a trend. Salt stress and nitrogen cycling measurements have not yet been completed.

Key Personnel: Brittany Wilburn, Elizabeth Watson

1.3g Crab exclusion experiment

Methods

Overview of tasks

We monitored crab and marsh colonization algal cover, and burrow densities of Hester Phase I marsh bank faces.

We installed cages that prevent crabs from colonizing the marsh edge, plus a half cage and uncaged control.

The native grapsid shore crab, *Pachygrapsus crassipes* is a burrowing crab that has demonstrated the ability to alter the marsh landscape. Crab burrowing networks can blanket the marsh plain within a narrow elevation range. Crab feeding trials in the lab have also demonstrated that *P. crassipes* preferentially graze on belowground plant material. This may have cascading effects on the stability of the marsh plain. Root material anchors sediment and contributes to the resilience of marsh systems to erosion and subsidence. Thus, tracking the colonization of crabs into the restored Hester marsh is a unique opportunity to understand the influence of crabs on virgin sediment.

Materials

Fencing materials: Galvanized hardware cloth and wood stake design as used for past marsh-edge experiment. Pilot study using different caging designs and material showed that hardware cloth and wood were most durable and easiest to install, maintain and clean.

Monitoring materials: quadrat, meter stick, feldspar, pit-fall traps, camera.

Frequency

Conduct pilot before construction ended.
Monitor crab colonization (pitfall trapping and burrow counts) in first year.
Install cages after crabs begin to colonize (June 2019).
Maintain and monitor for 2+ years until there has been at least one marsh growing season with ample crabs in the controls.
Maintain treatments by routinely removing crabs from crab exclusions.
Survey marsh and crabs every other month for duration of study.
Transplant 3 *Jaumea carnosa* individuals into all experimental plots.

Detailed Monitoring Methods

Monitoring

This experiment began in June 2019, and data will be collected bi-seasonally. We will collect data to track the rate at which marsh plants colonize the experimental plots and control plots. We will track which species colonize and in what order and collect metrics for plant growth and success (i.e. percent cover, canopy height, biomass). We will be monitoring macro and micro-algal cover. Simultaneously we will be tracking data on crab colonization, activity (burrowing and herbivory) and population structure using CPUE data from pit-fall traps. In late Spring 2020 we transplanted plugs of *Jaumea carnosa* and have tracked their survival and growth over time. Lastly, we will characterize sediment properties across treatments using feldspar for measuring accretion rates, litterbags for quantifying decomposition rates, conducting repeat measures of distance to bank edges to measure bank erosion rates and utilizing laser level techniques to measure elevation.

Experimental Treatments

See Fig. 18 for experimental design.

1. Crab Exclusion/Full Cage: cages will extend 4 inches (10 cm) deep into the sediment; crabs will be excluded from the experimental plot area using pit-fall traps and cages. One meter of the cage will be exposed above the ground, 10cm will be placed below the sediment surface in a narrow trench.

2. Crab Treatment/Cage Control: cages will be two-sided half cages to allow for crabs to move in and out of the experimental plot area while maintaining the artifact of the cage structure. Initially we planned to do a lifted cage control. The crab treatment design we ultimately adopted ensures that algal flow in and out of the plot area and drift algae washing down from the marsh would more closely mimic the Crab Exclusion plots compared to a lifted cage

design. In this treatment we will track the colonization of crabs into the plot area and their impact on the virgin marsh and the colonization, germination and establishment of marsh plants. Cages will be the same height above the ground as the crab exclusions.

3. Control: uncaged plots will be demarcated by four wooden posts indicating the perimeter of the plot area. Control plots will be the same size as experimental plots (listed above as 1 and 2). A narrow trench will be made around the plot perimeter.

The crab exclusion cages may affect pickleweed colonization into the virgin restored marsh. In order to detect possible cage effects, we will be closely monitoring the colonization of all marsh plants. We will be simultaneously tracking the colonization of *P. crassipes* into the restored marsh plots by deploying pit-fall traps for 24hr increments seasonally. If differences in vegetative cover are detected and may be attributed to the cages, pickleweed plugs will be transplanted into the experimental plot areas to assess how the presence or absence of crabs affect marsh plants.

Exclusion cage design and placement

Fences on the edges of the tidal creeks can only be placed on a gradually sloping bank edge. The front edge of the plots (water side; parallel to the bank) has to be higher than the back (marsh edge) so the tops of the cages are at the same elevation and level. For steep banks, a different cage design is necessary to minimize disturbance (Fig. 18).

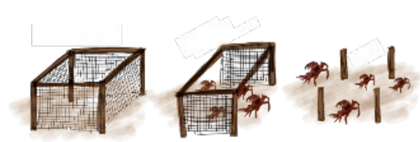


Fig. 18. Crab experimental design. We had five replicate blocks on the east and west banks of the main tidal creek channel at Hester. Each block had a full cage/crab exclusion (left), cage control/ crab treatment (center) and a no cage plot (right).

Results

Overall, marsh cover (Fig. 19) and crab abundance (Fig. 20) have been steadily increasing since we began surveying in June 2019. We have observed slight differences in crab abundance and algal cover when comparing the East and West bank faces, and although this was not one of our initial research questions, it appears that bank side has a strong effect on crab and marsh colonization. Crabs are still at relatively low densities compared to natural existing salt marsh habitats in the estuary. We expect treatment effects to emerge as crab densities increase over time.

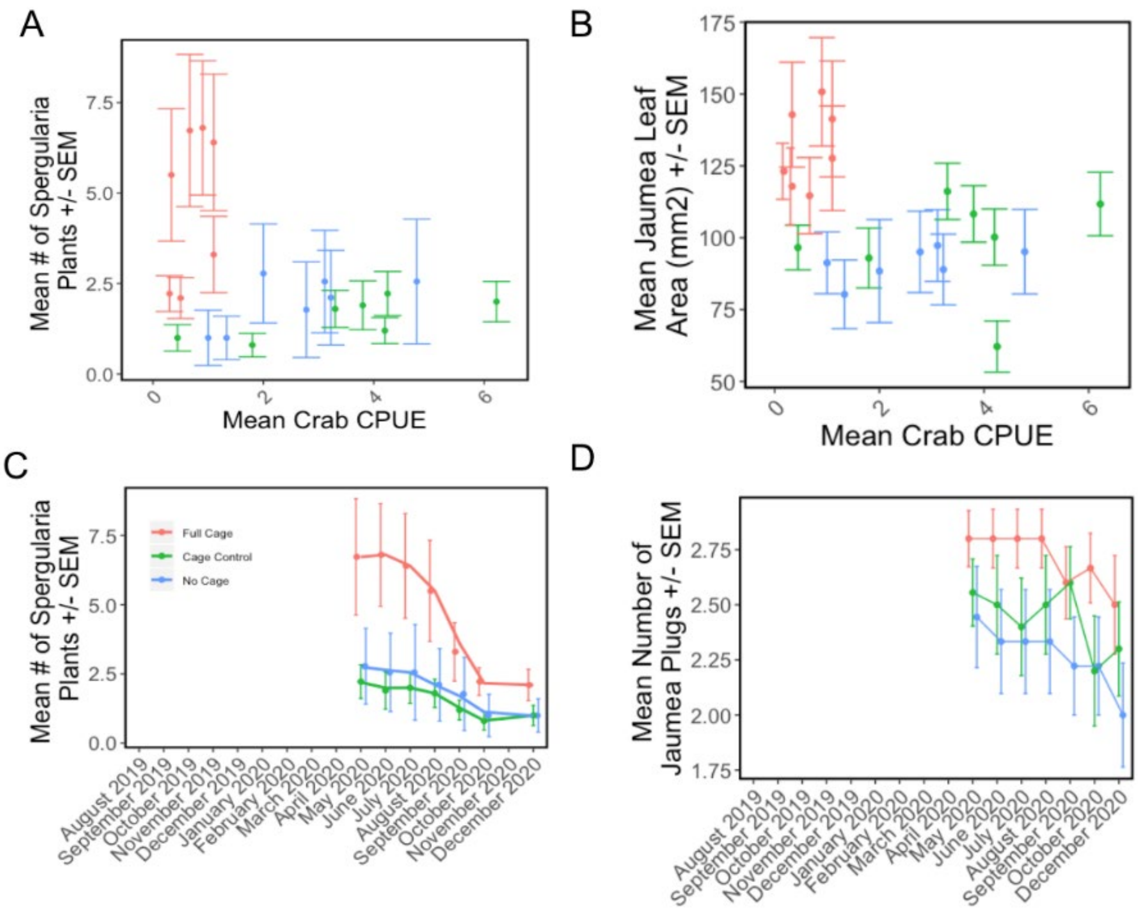


Fig. 19. A) The number of Spergularia plants and B) Jaumea leaf area decreased with increasing crab CPUE. Color coded by treatment, it is clear that full cage plots had fewer crabs and more Spergularia and larger Jaumea transplants. This is further supported by the number of C) Spergularia plants and D) Jaumea plugs in the experimental treatments over time.

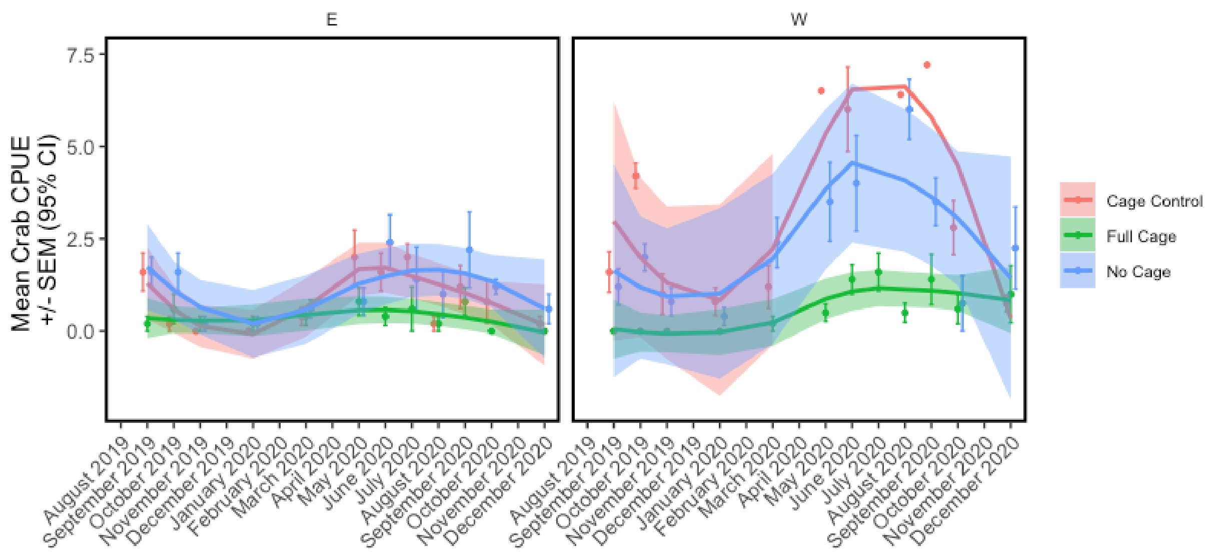


Fig. 20. Crab Catch Per Unit Effort, CPUE by treatment and bank side (left = East, right = West), CPUE in the full cage (green) plots has been kept low due to continual crab trapping. Overall CPUE is higher on the west v. east bank.

Key Personnel
Kat Beheshti, Natalie Rossi

1.3h Pickleweed outplanting to marsh areas with less cover

Methods

Overview of tasks

- Outplanted salvaged pickleweed from Phase II into bare (i.e., little vegetation) areas of Phase I
- Outplanting configurations tested hypotheses around plant size, clustering, and watering

Materials

- Pickleweed (gallon containers and 10 cm cone-tainers) salvaged from construction area in Phase II and grown in containers in greenhouse through winter
- Rulers/meter sticks/quadrats for monitoring

Frequency

Pilot experiments occurred in 2020; this experiment lasted from March 2021-March 2022. Monitoring occurred once a week during the spring and summer of 2021.

Tasks

- Harvest pickleweed from area planned for sediment addition
- Grow pickleweed to different size classes in greenhouse with and without salt-hardening (i.e., watering with salt water)
- Transplant pickleweed to bare areas of Phase I with different clustering and watering regimes
- Water plants 1-2x a week during dry periods with no rain or tide overtopping (targeted irrigation with watering can)
- Monitor once a week during dry season for condition, signs of herbivory and reproduction; monitor every six weeks for changes in plant size and ground cover

Detailed Monitoring Methods

See Pausch et al. (in prep; likely 2022) for full methods

Results

See Pausch et al. (in prep; likely 2022) for full findings. Key takeaways included:

- Irrigation was crucial for plants planted into bare areas. Plants without irrigation had 100% mortality within three months of planting (Fig. 21). Day 0 was in March 2021). Plants put into wet areas survived longer but were eventually smothered by algal wrack or drowned by standing water.
- Large plants (gallon pots) grew more and survived better than small (cone-tainers) and clustering had a relatively small effect.
- There were major site differences in plant performance that correlated with differences in sediment properties. This highlights the importance of pilot studies and site-specific observations when planning for major outplanting efforts

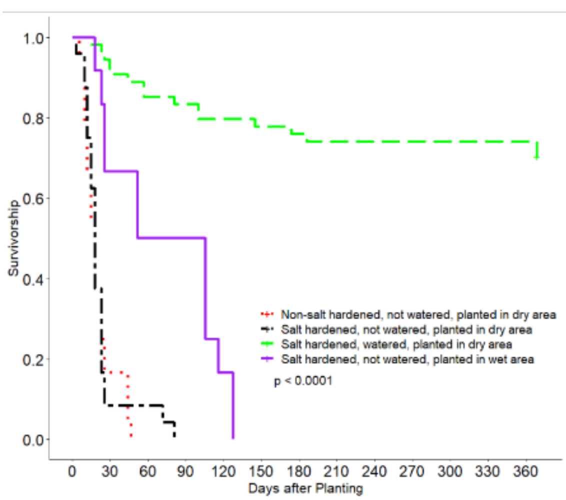


Fig. 21. Transplant survivorship across treatments. Only watered plants survived long-term. Non-watered transplants into wet areas survived longer than transplants into dry areas but after about four months, all non-watered transplants were dead.

Key Personnel: Rachel Pausch

1.3i Freshwater addition experiment

Methods

Overview of tasks

Add freshwater to tidal marsh plain for 6-9 months to see this increases transplant survival and growth, seed germination and growth, and wild recruitment

Materials

- Large-scale agriculture sprinkler system run from well and small-scale garden sprinkler system with tank.
- Greenhouse-grown marsh plants
- Pickleweed seeds

Frequency

This experiment was implemented in 2021.

Tasks

Experiment designed to compare restoration success in

- Freshwater addition (sprinkled plots) vs. controls
- Large plants vs. small
- Phase I (saltier because older) vs. Phase II
- Compacted vs. disked sediments
- Sediment removal vs. sediment addition areas
- Amended vs. non-amended soils

Detailed Monitoring Methods

Restoration success monitored in terms of

- Growth and survival of marsh plant species (transplanted in)
- Growth and survival of pickleweed seeds added to plots
- Wild recruitment of marsh plants

Results

Experiment begun in January 2021. Initial monitoring has shown strong effects of plant size, phase, and sediment condition, but no effect of sprinklers.

Key Personnel: M. Fountain, K. Wasson, J. Romero, S. Robinson

1.4a Create marsh-upland ecotone with diverse plant community

Methods

Overview of tasks

- Plant seven high marsh species into five planted areas in Phase I, in design that will allow various hypotheses to be tested
- Amend soil with biochar at subset of planting holes
- Monitor plant communities over time in planted and unplanted areas

Materials

For planting

- Greenhouse-grown plants
  - *Distichlis spicata*
  - *Frankenia salina*
  - *Jaumea carnosa*
  - *Spergularia macrotheca*
  - *Extriplex californica*
  - *Limonium californicum*
  - *Triglochin* sp.
- Markers, flags and/or PVC to lay out planting design for crews and monitoring
- Dibblers, gloves for planting day

For soil amendment

- Biochar created from eucalpts removed from Reserve
- Place into bottom of planting hole for 5% of planted plants, marked with flags

For monitoring

- Flags
- Transect tapes
- Quadrats
- Datasheets, clipboard

Frequency

- Planting occurred at Phase I in January 2019 under very muddy conditions due to rains and king tides
- Monitoring for early survival was conducted from February 2019 to July 2019.
- Annual monitoring for percent cover will occur yearly for the indefinite future, or as long as the marking flags can be maintained and identified.

Detailed Monitoring Methods

We will compare Hester ecotone transects to long-term monitoring transects at 7 control sites that we have monitored since the early 2000s to determine whether we achieved goal of greater diversity of ecotone plants at Hester (control/impact design). We also will compare richness and cover at Hester prior to restoration (from which we can estimate acreage of different ecotone species, because we know ecotone width) vs. after restoration (before/after design). Spatial plan for planted blocks (Fig. 22)

- 6 planted blocks (shown as orange boxes below), 30 m from landward to seaward edge (spanning approx. 6'4" to 7'4" [1.95-2.25 m] NAVD88 in elevation range), 116 ft. (35.5 m) in width
- We estimate bottom will be inundated 1.6% of time, top 0.05% of time, so this is quite an environmental gradient
- Unplanted area between them is around 100-130 ft. (30-40 m)

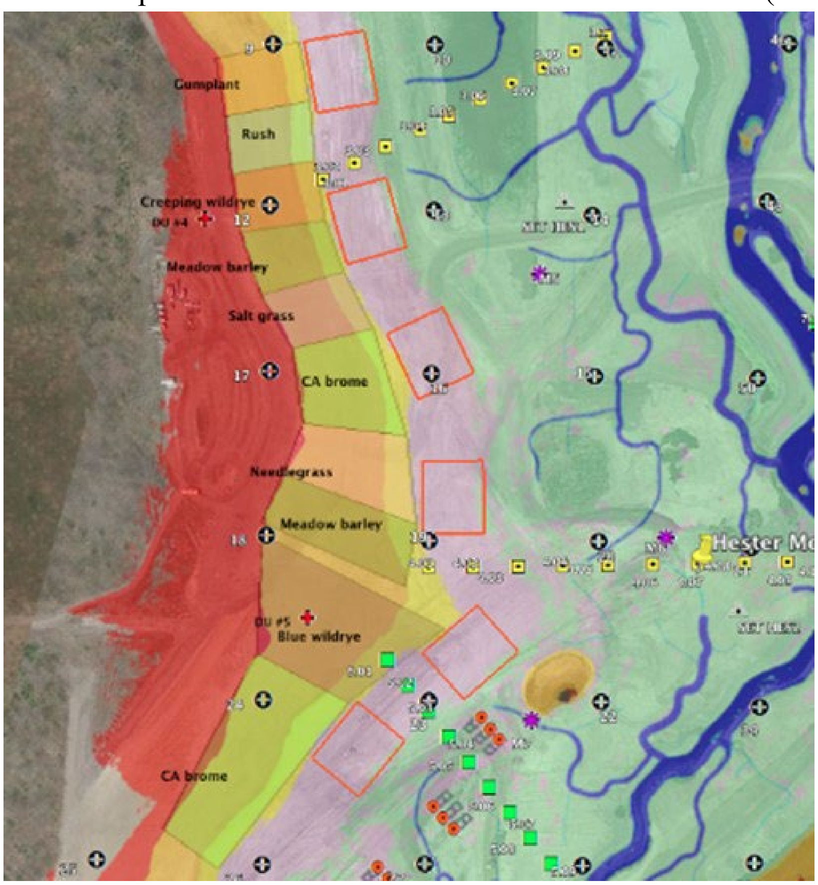


Fig. 22. Planted blocks map at Hester Phase I

Layout inside planted blocks (Fig. 23)

- Each block contains 10 planted columns that are 3m wide each, with a 0.5 buffer/walkway on either side. Within the planted column, the first and last plants are 50cm from the edge of the planted column; there plants span a ~ 2m width

- There are two consecutive columns per species, for each of the 5 focal spp.: one planted in the Uniform pattern and one in the Clustered pattern (order randomly determined, varies by block)
- Regardless of the planting pattern used, each planted column contains 270 plants (so 270 per column x 2 columns per species x 6 reps = 3240 plants per specie x 5 main species = 16,200 plants)
- In the Uniform planting, plants are spaced ~50cm from each other, and rows alternate between having 5 plants and having 4 plants.
- In the Clustered pattern, we have clusters of 9 plants (3 x 3 array) spaced ~10 cm from each other
- The walkways between columns are designated to walk on for staging planting, monitoring, etc. They are shown in gray in Fig. 23.

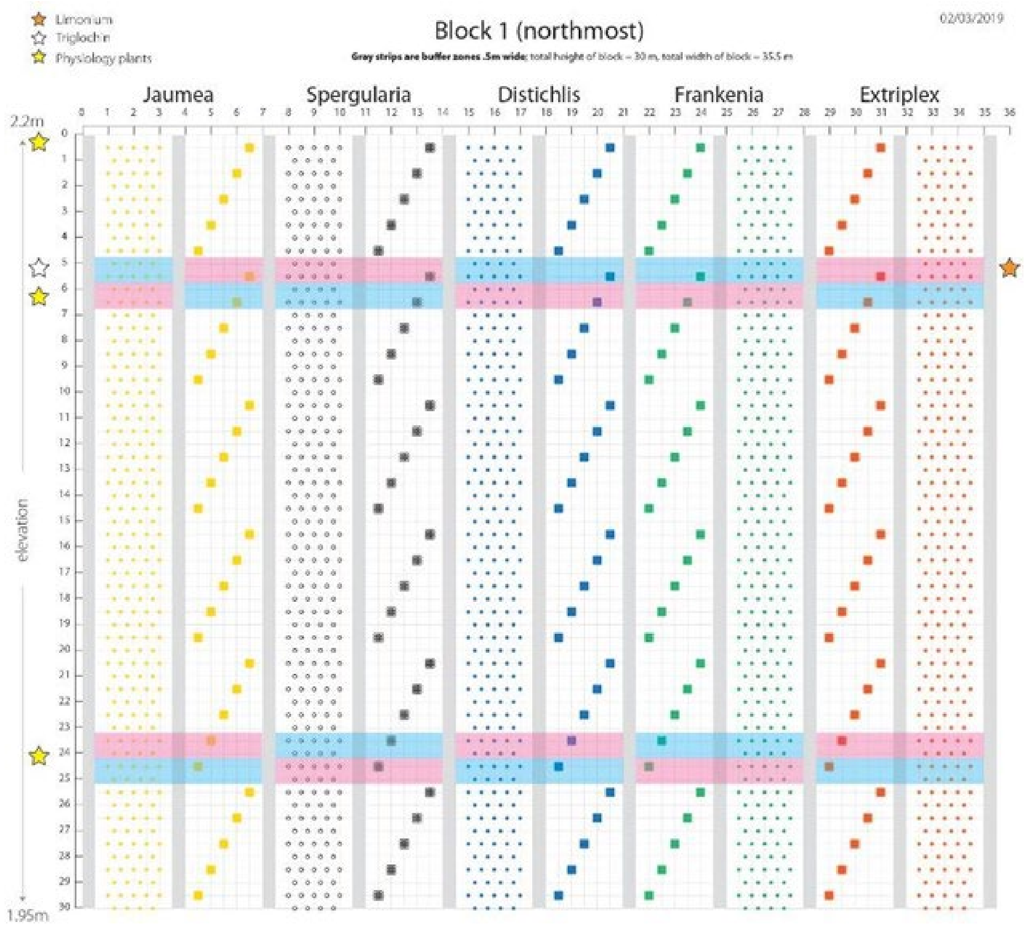


Fig. 23. Layout of plant patterns inside planted blocks.

Biochar treatment in planted blocks

- A high zone located from 18 – 25 ft. (5.5-7.5 m) below the landward boundary and a low zone 18 – 25 ft. (5.5-7.5 m) from the seaward plot boundary were used for biochar experiment
- Three feet (one meter) in each of these zones was randomly assigned to biochar treatment (blue flags and blue in Fig. 23), the other to control (magenta). Thus 9 Uniform plants and 9 Cluster plants (one cluster) in the high and one in the low received each treatment, for a total of 1080 plants in each treatment: 9 plants x 2 treatments (cluster/uniform) x 2 elevations (high/low) x 5 species x 6 blocks = 1080
- Biochar was produced from eucalyptus. It was sieved through two baskets, one made of ½" hardware cloth, the next made of ¼" hardware cloth. We had to process 3 garbage bags of unprocessed biochar to get about 6 gallons (22.7 l).
- 1 Tablespoon of biochar (Fig. 24) was added to the dibble hole (using funnel and container with bottom cut out to apply neatly). Stubby containers have 107 ml volume; one tablespoon is 14.7 ml, so we filled about 14% of the volume of the dibble hole with biochar.

Fig. 24. Biochar for planted biochar block treatment

Artisanal species

Two other species were grown in much smaller numbers due to being finicky. One of these (sea lavender) is found very high up in the ecotone. So we decided to add a single row of one of these species to the upper biochar/control zone of the blocks, on either end, like wings extending out another 3.5 m from the blocks. Each has 9 uniformly spaced plants and 9 clustered. There are three of these for *Triglochin* (white stars in diagram, 18 x 3 = 54 plants total) and nine of these for *Limonium* (orange stars in diagram, 18 x 9 = 162). Locations of the species were randomly assigned.

Field Monitoring Activity

- Prior to restoration, we took 36 transects across the ecotone along the perimeter of the restoration site (Hester (formerly Minhoto) and Yampah areas) to provide characterization of total species richness, average species richness and abundance, and ecotone width.
- Following restoration, we monitored the plantings of 17,000 nursery-raised plants. To monitor survival, we tracked all the plants that were flagged in the high and low biochar and control zone (blue and magenta bands above), 72 plants per species per block, or a total of 72 plants x 5 species x 6 blocks = 2160 plants.
- We measured plant diameter in May 2019 to characterize differences in size across the high and low biochar rows in the clustered versus uniform planting. We measured the maximum diameter of the cluster present in the high and low elevation row for each block, species, and biochar treatment combination; we divided this measurement by the number of plants alive in the cluster to generate an average diameter per plant. We measured the maximum diameter of 3 individuals in the uniform planting for each block, species, and biochar treatment combination and averaged these measurements to generate a single value we could compare to cluster measurements.
- We took photos of a few plants of each species in the same locations over time to generate a time series of representative growth changes; time points captured were March, July, and October 2019.
- To monitor percent cover, we ran ten transects through each of the main portions of each planted block to capture each of the five main species in clustered vs. uniform pattern. Surveys were conducted each summer; in June 2019 and July 2020, points at 20 cm intervals were assessed along each transect.
- We established three transects, approximately evenly spaced, through each of the five intervening unplanted areas, sampled with the same methods as the transects through planted blocks.
- We will may augment transect sampling with area searches in the unplanted area (for rare species).
- The 10 permanent transects spanning the entire restoration site will also provide a characterization of cover over time in the lower ecotone.
- Ecosystem services of different plant species will also be monitored in 2021.
- We also will compare how abundance and distribution of high marsh species has changed at Hester before vs. after restoration.

Results

<u>Pre-restoration surveys at restoration site</u>

In 2017, we conducted 36 transects across the ecotone at Hester (both Yampah and Minhoto side) to quantify abundance and distribution of marsh plants. We also measured ecotone width. From this, we can calculate the approximate acreage of each plant species at the site prior to restoration, to compare to post restoration. We also compiled a species list (Table 2) as a baseline. Initial monitoring of the planted blocks shows good survival of the plants.

Table 2. Plant species list from 2017 ecotone survey at Hester Marsh Phase I

Category & Scientific name	*Common name*	*Family*	*Abbreviation used*	*Minhoto*	*Yampah*
Salt Marsh Natives				5	7
Salicornia pacifica	pickleweed	Chenopodiaceae	p	x	x
Marsh-upland ecotone specialists					
Cressa truxillensis	alkali plant	Convolvulaceae	ct		x
Cuscuta salina	marsh dodder	Convolvulaceae	c		x
Distichlis spicata	salt grass	Poaceae (Festuceae)	d	x	x
Frankenia salina	alkali heath	Frankeniaceae	f	x	x
Jaumea carnosa	fleshy jaumea	Asteraceae	j	x	x
Spergularia marina	salt marsh sand spurry	Caryophyllaceae	s	x	x
Salt Marsh Non-natives				3	2
Atriplex prostrata	spearscale	Chenopodiaceae	ap	x	x
Cotula coronopifolia	brass buttons	Asteraceae	bb	x	
Parapholis incurva	sickle grass	Poaceae (Hordeae)	sg	x	x
Upland Natives				2	3
Baccharis pilularis	coyote brush	Asteraceae	cb		x
Epilobium sp.	willow weed	Onagraceae	ww	x	
Grindelia latifolia	coastal gum plant	Asteraceae	gp	x	x
Juncus sp.	unidentified rush	Juncaceae	ju		x
Upland Non-natives				20	14
Anagallis arvensis	scarlet pimpernel	Primulaceae	sp	x	x
Avena barbata/fatua	wild oat	Poaceae (Aveneae)	og	x	x
Brassica nigra/rapa	black/field mustard	Brassicaceae	m	x	
Brisa minor	little quaking grass	Poaceae	bm		x
Bromus diandrus (and similar spp.)	ripgut grass	Poaceae (Festuceae)	bg	x	x
Bromus hordeaceus	soft chess	Poaceae (Festuceae)	sc	x	x
Carduus pycnocephalus	Italian thistle	Asteraceae	it	x	
Conium maculatum	poison hemlock	Apiaceae	h	x	
Conyza canadensis	horseweed	Asteraceae	hr	x	x
Festuca perenne	Italian ryegrass	Poaceae (Hordeae)	irg	x	x
Geranium dissectum	cut-leaved geranium	Geraniaceae	g	x	
Hordeum marinum/sp.	foxtail, Mediterranean barley	Poaceae (Hordeae)	fg	x	x
Lepidium draba	hoary cress	Brassicaceae	hc	x	
Lotus sp.	unidentified lotus	Fabaceae	lt	x	
Picris echioides	bristly oxtongue	Asteraceae	bot	x	x
Plantago coronopus	cut-leaved plantain	Plantaginaceae	clp	x	
Plantago lanceolata	English plantain	Plantaginaceae	ep	x	x
Polypogon monspeliensis	rabbitfoot grass	Poaceae (Agrostideae)	rb	x	x
Raphanus raphanistrum/sativus	jointed charlock/wild radish	Brassicaceae	r	x	x
Rumex crispus	curly dock	Polygonaceae	cd	x	x
xxx	unidentified annual grass	Poaceae	ug	x	x

Post-restoration surveys of ecotone plantings at restoration site

At the Hester Phase I planted blocks initial survival from February to July 2019 was high overall, ranging from 85% for *Distichlis* to 99% for *Jaumea* (we calculated survival as the proportion of plants remaining in each 9-plant unit, with one uniform and one clustered unit in the high and low biochar rows for each species). We found no strong effects of either planting pattern (clustered vs. uniform) on plant survival, but initial survival was higher for clustered plantings for *Extriplex*, and marginally higher for *Distichlis* (Fig. 25). Biochar had no effect on plant survival. Elevation affected survival of most plants; lower portions appeared to be more stressful, with lower survival. The small numbers of artisanal species planted at high elevation also survived well, with 92% of *Triglochin* individuals and 96% of *Limonium* individuals surviving to July 2019.

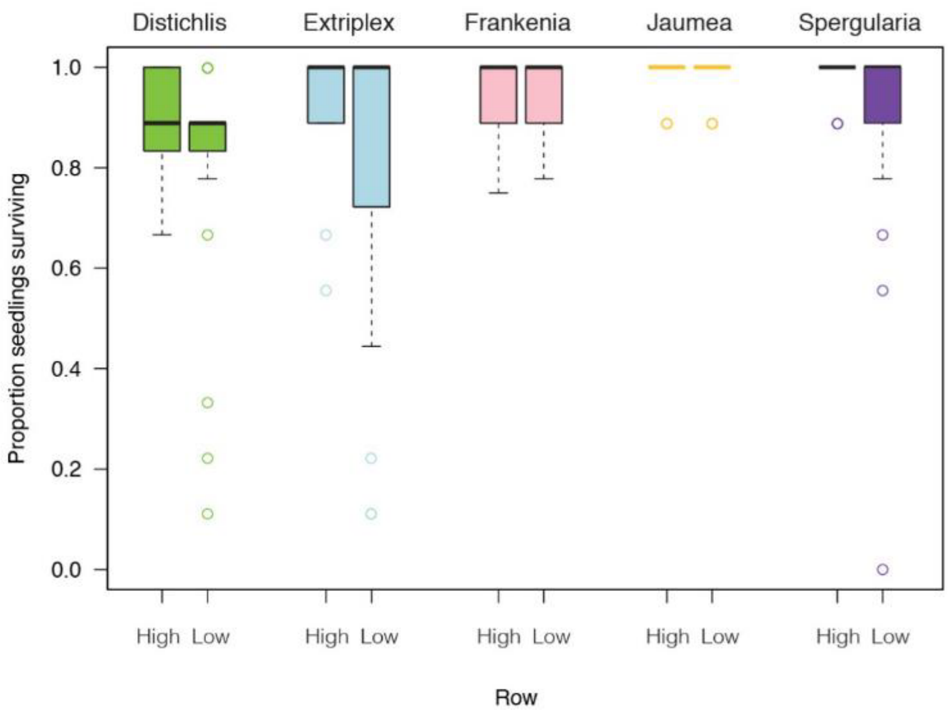


Fig. 25. Proportion of plants surviving to July 2019 for each species across the high and low elevation rows.

Fig. 26. (a) *Distichlis* in March 2019 (left) and October 2019 (right); (b) *Extriplex* in March (left) and October (right); (c) *Frankenia* in March (left) and October (right); (d) *Jaumea* in March (left) and October (right); (e) *Spergularia* in March (left) and October (right).

Fig. 27. (Left) initial conditions in the planting area showing bare landscape in January 2019; (Right) same area in July 2020 during percent cover point intercept surveys.

Repeat photography between March and October 2019 showed that all species grew substantially (Fig. 26). By July 2020, substantial growth of the plantings resulted in high cover of the species (Fig. 27). Native marsh cover was high, around 65%, in both planted and adjacent unplanted areas by July 2020 (Fig. 28). In the planted blocks, the dominant cover was by the planted species; in the unplanted, by pickleweed. There were strong species differences in cover, with *Frankenia* offering highest, and *Spergularia* lowest cover (Fig. 28). Cover by the focal species suppressed cover by other species; *Frankenia* plots had the least cover by pickleweed and by non-native weeds. Non-native marsh cover was around 15% on average in the planted and unplanted ecotone plots.

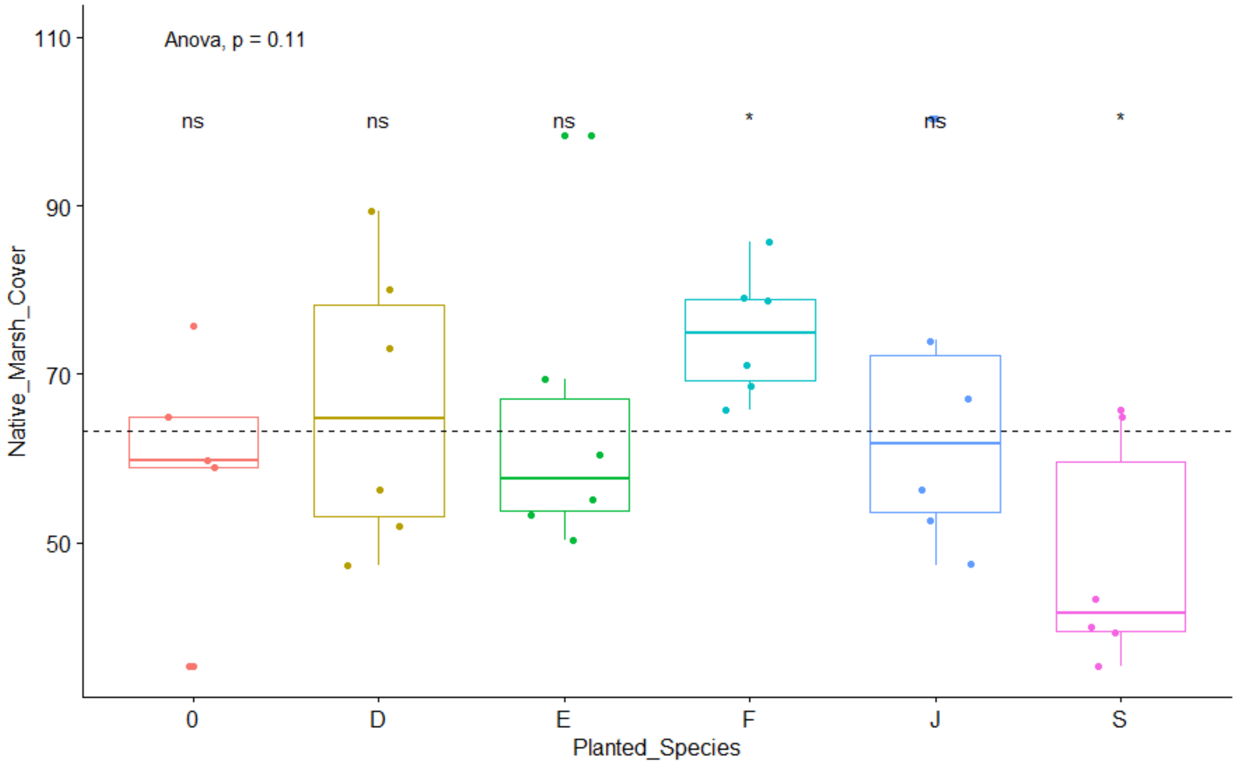


Fig. 28. Native marsh percent cover in July 2020 in blocks that were unplanted (0) or planted with *Distichlis* (D), *Extriplex* (E), *Frankenia* (F), *Jaumea* (J) or *Spergularia* (S).

Planting pattern (uniform versus clustered) had a strong effect on plant growth. Horizontal expansion (plant diameter) was much greater in uniform plantings, where plants had room to expand, but height was greater in clustered plantings. Overall, biomass as estimated by diameter x height was greater in uniform plantings. Most important as a currency for landscape restoration success, cover was higher in uniform plantings (Fig. 29). Biochar amendments to the planting hole had no measurable effect on plant growth (diameter or height). For most species, growth was positively correlated with elevation (greater in higher parts of the plots).

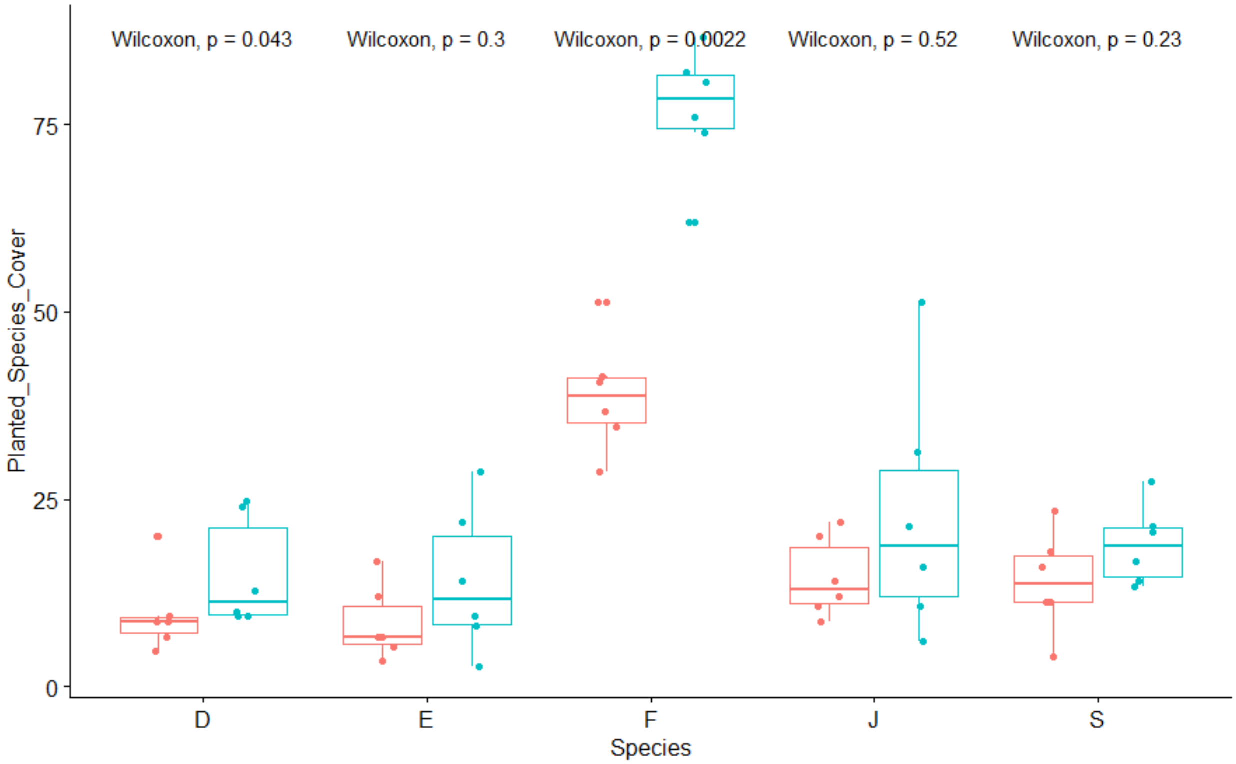


Fig. 29. Effect of planting pattern on percent cover of planted species. Clusters (red) had lower cover in all cases than more widely and uniformly spaced plants (blue) for all species (abbreviations as in Fig. 28), though this difference was only statistically significant for two species.

Key Personnel

Karen Tanner, Kerstin Wasson, Alexandra Thomsen, Andrea Woolfolk, Monique Fountain

1.4b Assess ecosystem function of marsh diversity

Methods

Overview of tasks

Compare the five species planted in the high marsh ecotone, and the unplanted pickleweed that recruited to adjacent areas.

Materials

- Various supplies and equipment, detailed in Shikuzawa 2022.

Frequency

Evaluation of ecosystem functions occurred in 2021.

Tasks

We assessed 30 metrics of ecosystem function, in four categories

- Blue carbon – related to carbon sequestration and climate change mitigation
- Productivity – metrics of importance to restoration practitioners, such as cover and recruitment to new areas
- Environmental effects – changes to soil and other conditions that affect surrounding plant and animal community
- Community interactions – effects on plant invasions and arthropod community

Detailed Monitoring Methods

See Shikuzawa 2022.

Results

Our results highlight key contrasts in ecosystem functioning among the five planted and dominant marsh species, as well as effects of tidal elevation on some of these functions. Our study reveals that though the dominant, *Salicornia pacifica*, scored high on certain metrics, such as recruitment and canopy height, the planted species outperformed *Salicornia pacifica* on others. Of the planted species, *Frankenia salina* achieved greatest cover and plant litter accumulation, and we recommend it as a species for high marsh restoration sites, due to its tolerance of highly saline and low moisture conditions. However, other planted species scored higher for metrics such as photosynthesis and arthropod species richness (Table 3). Our study illustrates the importance of biodiversity for increasing multi-functionality in salt marsh ecosystems and, specifically, in marsh restoration projects. See Shikuzawa 2022 for more details.

Table 3. Relative performance of plant species across metrics. White indicates target levels and color get darker as values get farther away from 100%. The average value for each species for each metric was converted to the percent of the highest average value for any of the six species. The highest average value is thus 100% and is shown as white; values from 50-99.9% of this are shown in light blue, and values below 50% in dark blue. Since soil redox contained negative values, dark blue indicates values above 150.1%. This color coding conveys performance for most metrics, where high values are desirable from a conservation or management perspective. However, for six metrics (*), lower values are desirable. For these, values 101-150% of the lowest average value are colored light blue, and values above this are dark blue. For two of these metrics (NEE CO_2 and CH_4), there were negative values so dark blue indicates any value below 50%.

	Metric	*Distichlis*	*Extriplex*	*Frankenia*	*Jaumea*	*Spergularia*	*Salicornia*
Blue Carbon	Aboveground plant carbon content	23	32	100	19	15	42
	Aboveground plant percent carbon	100	90	97	84	94	80
	Soil percent carbon	53	53	66	63	100	85
	Decomposition rate of green tea	95	97	100	99.9	97	94
	Decomposition rate of rooibos tea	81	100	73	88	79	52
	*Gas flux-NEE CO_2	100	1	42	20	11	23
	*Gas flux-CH_4	-239	-189	-169	100	-107	16
	*Gas flux-N_2O	100	1358	143	1160	2264	182
Productivity	Belowground plant biomass production	47	54	100	41	19	67
	Plant cover	30	15	100	34	18	69
	Plant recruitment	0.0	0.0	0.4	0.1	2	100
	Reproduction	25	100	100	92	100	42
	Canopy height	74	52	100	25	34	89
	Plant-based net photosynthesis	100	30	81	46	61	24
	Habitat-based net photosynthesis	100	21	62	39	27	54
	Aboveground plant percent nitrogen	71	64	70	100	83	67
Environmental Effects	Plant litter accumulation	26	30	100	40	43	21
	*Soil salinity	208	180	100	174	165	158
	Soil moisture content	70	81	100	94	84	84
	Soil ammonium	97	100	73	97	98	70
	Soil pH	98	100	97	96	99	97
	Soil redox potential	180	225	100	243	149	149
Community Interactions	Invasion resistance	94	93	100	95	89	99.8
	Arthropod species richness	68	83	87	100	80	67
	Arthropod total abundance	81	42	75	100	60	58
	Collembola abundance	73	8	8	100	46	56
	Coleoptera abundance	49	100	24	83	62	82
	Hymenoptera abundance	39	55	77	100	68	68
	*Argentine ant abundance	427	109	1061	367	221	100
	Number of metrics with 100% score	***5***	***5***	***11***	***6***	***2***	***2***

Key Personnel: J. Shikuzawa, B. Watson, K. Wasson

1.5 Restore a native species dominated perennial coastal grassland on former farmlands

Methods

Overview of tasks

Establish a cover crop (Merced rye) in uplands that were not scraped below topsoil level, primarily in elevations above 5.18 m NAVD88

Restore at least 1.2 ha (3 acres) of native grassland on soils scraped to a horizon below topsoil

Monitor over time for successful establishment of cover crop and native plant assemblages.

Plant Materials

Cover crop: Merced rye, seeded at a rate of approximately 112 kg/ha (100 lbs./acre)

Grassland restoration:

- Plugs
  - 1650 stub cells, gumplant (*Grindelia* sp.)
  - 1750 large cones, rush (*Juncus* sp.)
  - 1750 large cones, creeping wildrye (*Elymus triticoides*)
  - 6600 small plugs, meadow barley (*Hordeum brachyantherum*)
  - 6000 stub cells, saltgrass (*Distichlis spicata*)
- Seeds
  - 47 lbs. (21 kg) of California brome (*Bromus carinatus*)
  - 7.5 lbs. (3.3 kg) of needlegrass (*Stipa* sp.)
  - 16 lbs. (7.2 kg) of meadow barley (*Hordeum brachyantherum*)
  - 3.4 lbs. (1.5 kg) of gumplant (*Grindelia* sp.)
  - 19 lbs. (8.6 kg) blue wildrye (*Elymus glaucus*)

Frequency

Native plugs were planted over 1.5 acres (0.6 ha) between November 26 and December 19, 2018

Native seeds (California brome (11 lbs. 14 oz. of the total 46 lbs. 4 oz. available) [5.4 kg of the total 21 kg available], needlegrass, meadow barley, and gumplant) were hand broadcast over 1.5 acres (0.6 ha) on November 26, 2018

Native seeds (35 lbs. [16 kg] of California brome, 19 lbs. [8.6] kg of blue wildrye) were broadcast over 2 acres (0.8 ha) using a tractor-pulled broadcaster on December 15, 2018.

Merced rye seeds were seeded over 8 acres (3.2 ha) using a tractor-pulled broadcaster on January 4, 2019.

Detailed Monitoring Methods

Planting

The cover crop was established primarily at elevations above 5.18 m NAVD88, but included a lower, scraped section expected to be disturbed during construction of Phase 2, and the southern-most section, due to limited plant and seed supplies. Seeding was done at a rate of approximately 112 kg/ha (100 lbs./acre).

Native grassland species were planted as a series of monocultures, based on nearby reference sites, where grasslands are often a mosaic of several different species growing in single-species patches (Fig. 30 and Fig. 31)

Planting and seeding of native species occurred on scraped soils in elevations between 2.25 and 5.18 m NAVD88

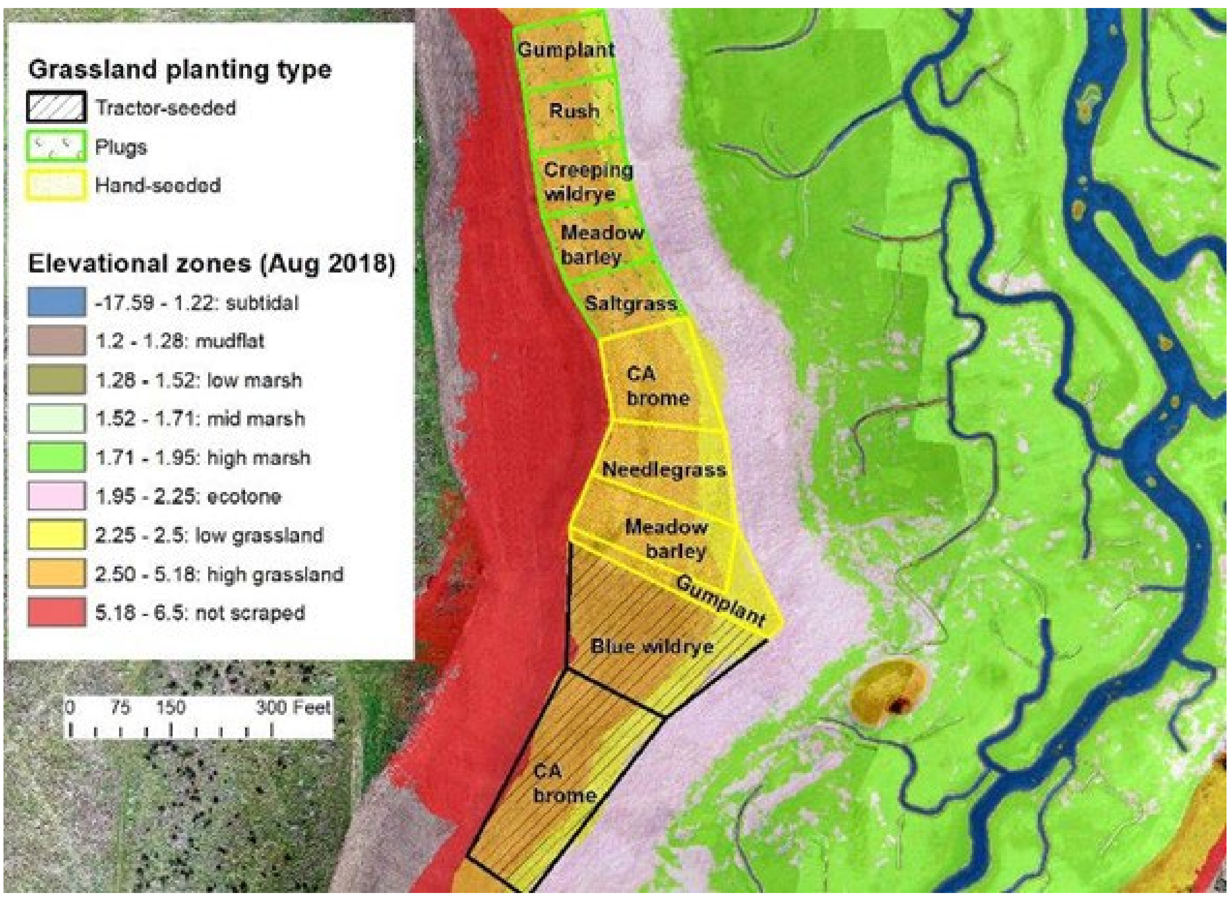


Fig. 30. Plant species distribution map

- Plug plantings
    - Meadow barley and salt grass were planted on 45 cm (1.5 foot) centers, each in their own 0.12 ha (0.3 acre) plots
    - Gumplant, rush and creeping wildrye were planted on 91 cm (3 foot) centers, each in their own 0.12 ha (0.3 acre) plots
- Hand broadcasted seed
    - 5.4 kg (12 lbs.) of California brome seed was broadcasted over 0.2 ha (0.5 ac)
    - Approximately 3.4 kg (7.5 lbs.) of needlegrass seed was broadcasted over 0.2 ha (0.5 ac)
    - 7.2 kg (16 lbs.) meadow barley seed was broadcasted over 0.2 ha (0.5 ac)
    - Approximately 1.5 kg (3.4 lbs.) of gumplant seed over 0.12 ha (0.3 ac)
    - Tractor broadcasted seed:
    - 8.6 kg (19 lbs.) of blue wildrye seed was broadcasted over 0.4 ha (1 ac)
    - 15.9 kg (35 lbs.) of California brome seed was broadcasted over 0.4 ha (1 ac)

<u>Monitoring</u>

In Winter 2019 we conducted visual surveys to determine if we had achieved 70% cover of the cover crop.

At least three times a year (winter, spring, and summer), staff walk the grassland area to determine if invasive weeds are present in the project site. Invasive weeds are removed immediately.

In summer annually for at least 3 years, staff will monitor transects through grassland restoration areas, using point intercepts to document the percent cover and species composition of target and non-target plants. Results will be compared to transect data collected at reference sites.

Results

The cover crop met or exceeded 70% cover in February 2019.

Staff have walked the grassland area regularly, removing the largest exotic plants (jubata grass, mustard, radish, curly dock and thistles) when found in native grassland restoration plots.

Staff and volunteers monitored the native grassland restoration plots in early June 2019, late May 2020 and early June 2021, using 3 randomly placed transects per plot. Transects ran from the top of the grassland plots to the bottom, at the edge of the ecotone, and each transect was 41 m long.

In 2019 percent cover of plants were recorded using a point intercept every 1 m. In 2020 and 2021 plants were recorded using a point intercept every 2 m. Data were averaged per plot.

Seeded gumplant was so tall and thick that monitors were not able to collect transect data in the plot (Fig. 31 d). In the other plots, seven of the ten restoration plots had reached or exceeded the 30% cover target by May 2021 (Fig. 32; targets could exceed 100% if a target species from another plot – like gumplant – colonized another nearby plot – like meadow barley). Hand planted gumplant, rush, creeping wildrye and salt grass all increased each year, from 2019 to 2021. Hand planted meadow barley and seeded needlegrass and meadow barley declined in 2021, possibly due to extreme drought conditions in the region, but all maintained cover above 40%. Seeded California brome and blue wildrye declined in both 2020 and 2021, and by 2021 had very low cover (< 5%). We are not sure what is drove the decline in those plots, whether it was due to the seeding method, the species, or the underlying soils which, unlike most of the other plots, were graded with topsoil after marsh construction was completed.

Fig. 31. (a) Seeding native grass seeds, (b) hand planted rush, spring 2021, (c) volunteers planting plugs, (d) seeded gumplant planted, July 2020.

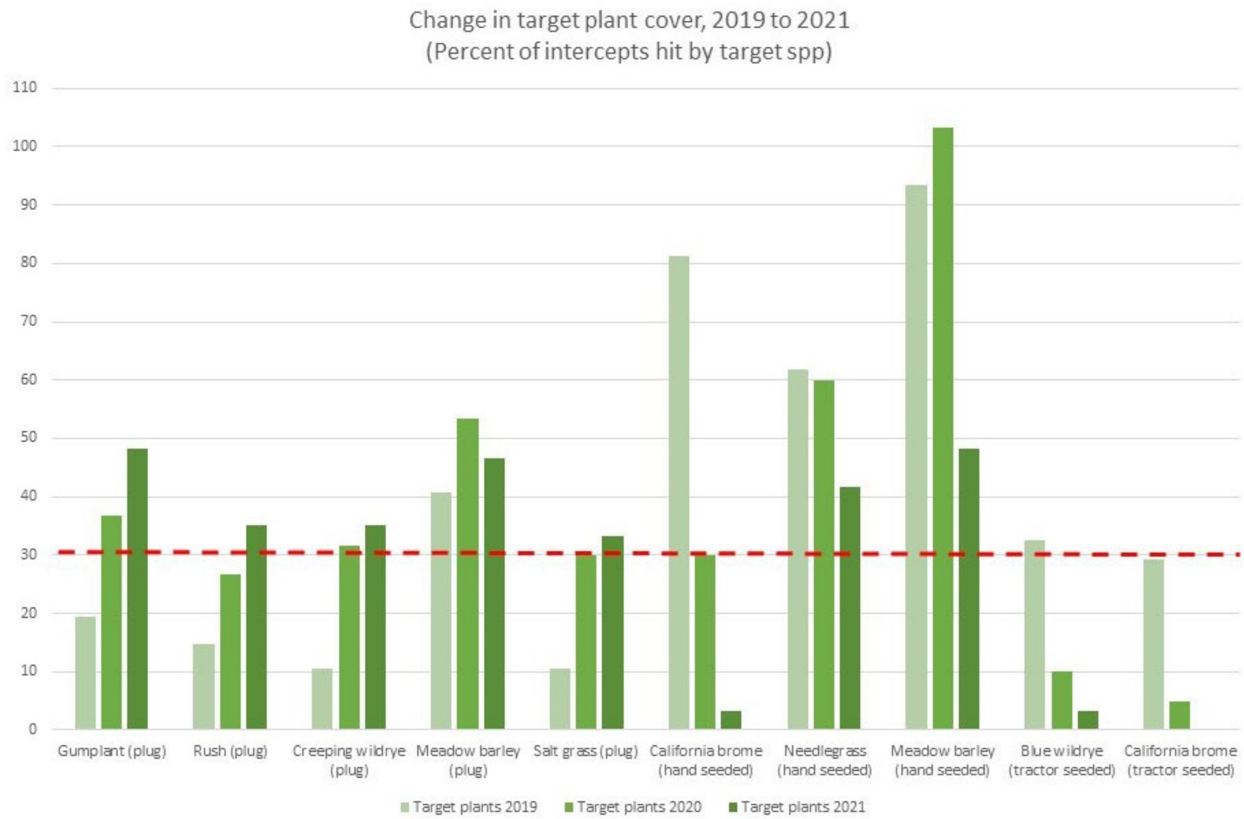


Fig. 32. Percent cover of target native plants in planted and seeded grassland plots, 2019 - 2021. Red dotted line marks the target cover of 30%.

When transect data were stratified by location on the hillside (Fig. 33), patterns were evident for a few species. Gumplant plugs, creeping wildrye, meadow barley plugs, and salt grass all reached higher percent cover at the bottom of the slope.

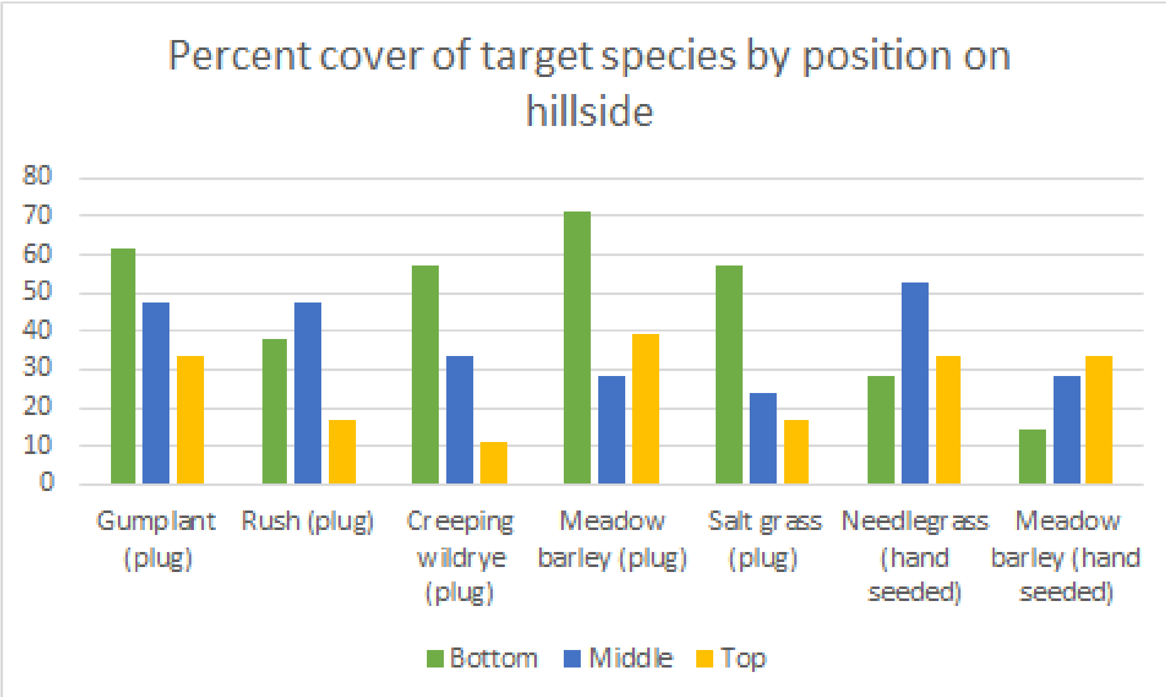


Fig. 33. Percent cover of target plants by planting area and location on slope (bottom of hillside, middle, and top of slope), June 2021. Plots with <5% cover of target plants were excluded.

Results from this monitoring are being applied to grassland restoration plans for Hester Phases II and III.

Key Personnel
Andrea Woolfolk

1.6 Restore oysters into tidal creeks as a part of the salt marsh ecosystem

Methods

Overview of tasks

Deploy hatchery-raised oysters to Hester and Moonglow Creeks.

Materials

- Oysters
- Standard aquaculture equipment and supplies
- Tiles, clam shells, PVC for deployment
- Calipers, iPads for monitoring

Frequency

Oysters to be deployed in 2021, 2022, and 2023.

Tasks

- Collect adult broodstock
- Feed and spawn at Moss Landing Marine Laboratories
- Deploy juveniles to Hester and Moonglow Creeks
- Conduct experiments to compare restoration success at different tidal elevations, on different substrates, with different ages of juveniles, and at different sites
- Monitor twice a year for the first years

Detailed Monitoring Methods

See Wasson et al. 2021.

Results

About 7000 juveniles were deployed in December 2021. Initial monitoring in March 2022 revealed excellent survival and growth. Both were higher in deeper water (Fig. 34).

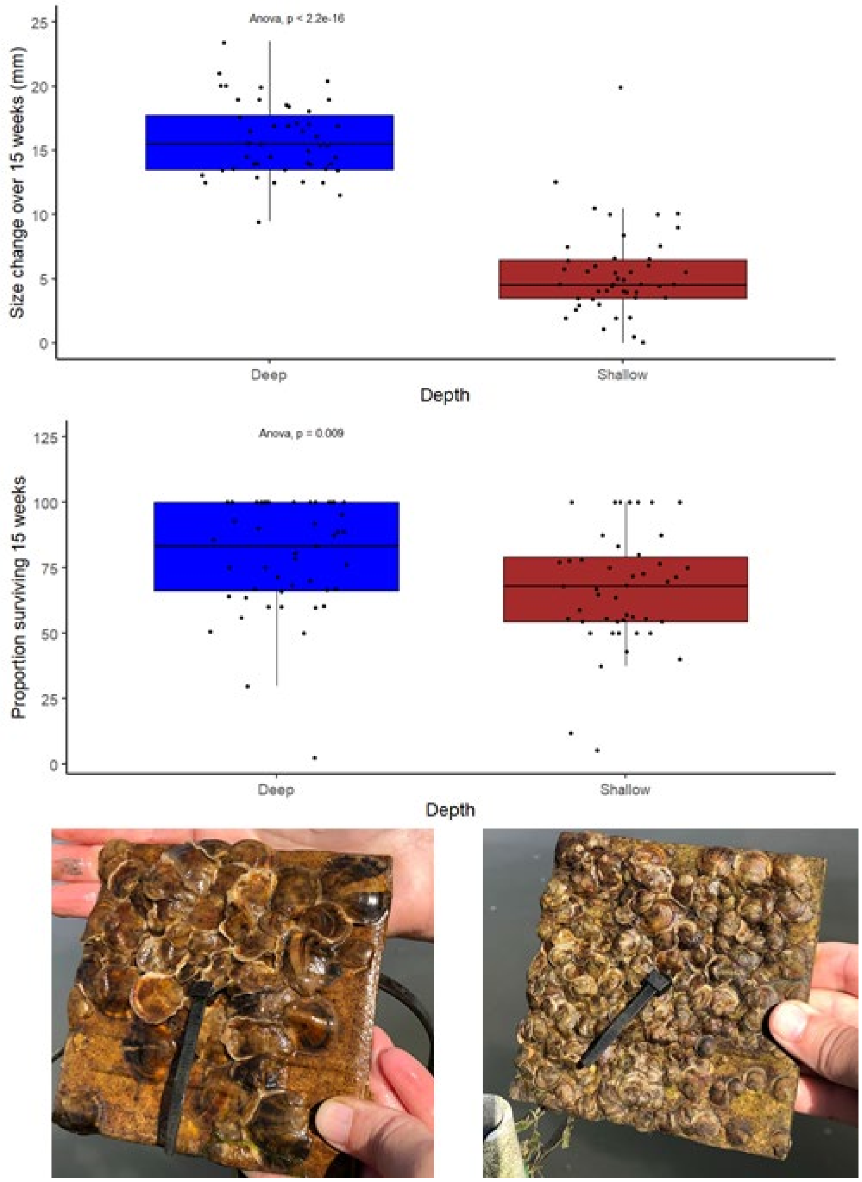


Fig. 34. Growth rate (top graph) and survival (bottom graph) of hatchery-raised oysters restored in December 2021, as monitored 15 weeks later. Deep = approximately MLLW, Shallow = approximately 1.5 ft. above MLLW. Photos at bottom show size difference of oysters in deep (left) vs. shallow (right) water.

Key Personnel: K. Wasson, J. Harris, L. Gardner

1.7 Restore eelgrass into tidal creeks as a part of the salt marsh ecosystem

Methods

Overview of tasks

TBD

Materials

TBD

Frequency

TBD

Tasks

- TBD

Detailed Monitoring Methods

TBD

Results

TBD

Key Personnel: K. Beheshti

OBJECTIVE 2 – REDUCE TIDAL SCOUR

2.1 Tidal scour reduction

Methods

Overview of tasks

Similar to 1.1a, we will calculate the volume of sediment added to the marsh plain by comparing before and after DEMs collected with the UAV. The net increase in volume will be equivalent to the volume displacement of tidal water.

Materials

See section 1.1a

Frequency

Once immediately after construction

Tasks

See section 1.1a

Detailed Monitoring Methods

See section 1.1a and 1.2. for calculating volume change based on UAV analyses

Results

GIS analyses of pre- and post-construction DEMs suggest a significant decrease in the volume of water now entering Hester Marsh Phase I. Excluding the main channel which remained unaltered during construction (Fig. 35) shows that at the level of mean higher high water (5.8'), only 8.9 acre feet of water is entering Hester tidal creeks compared with 84.5 acre feet before construction (89% reduction). At king tide levels (approximately 7.0'), water volume is reduced by 64% (Fig. 35). The amount of wetted surface area during MHHW (Fig. 36) is also significantly lower, from 44.7 acres to 6.6 acres (85% reduction). But at king tide levels, wetted surface area is now 22% greater than before construction, likely due to the expansion of the marsh on the western edge.

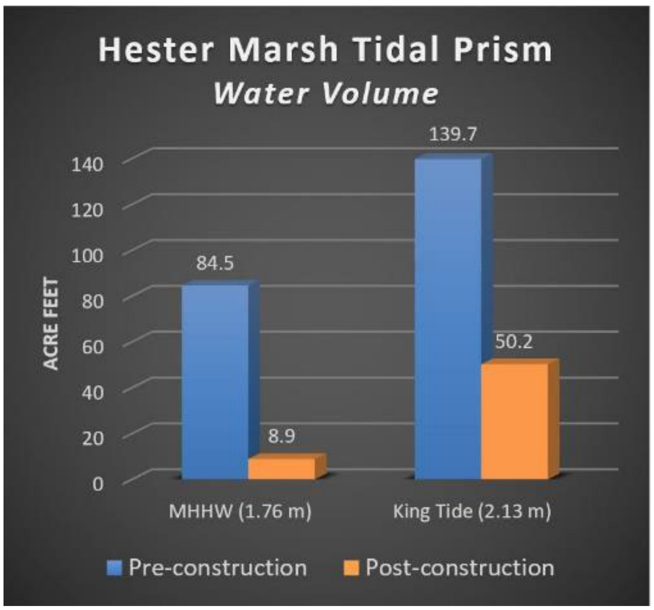


Fig. 35. Water entering Phase I tidal creeks before and after construction

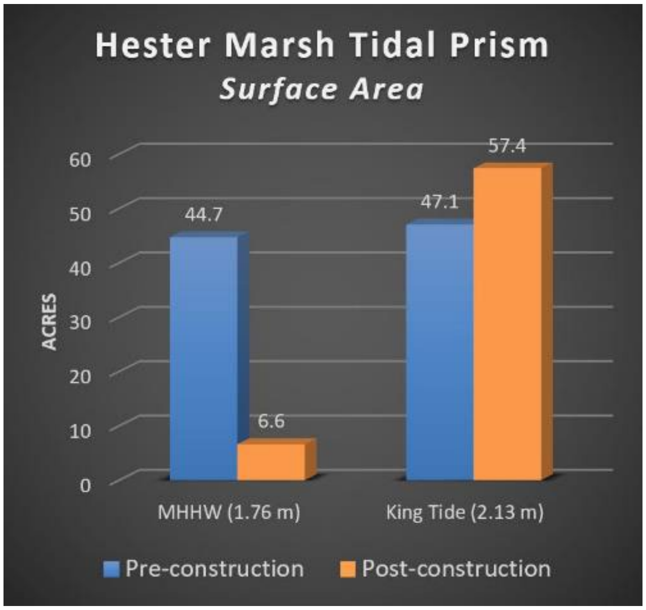


Fig. 36. The amount of wetted surface area during MHHW and king tide in the Phase I project area

Similarly, GIS results show a significant decrease in the volume of water now entering Hester Marsh Phase II. Fig. 37 shows that at the level of mean higher high water (5.8') and excluding the main channel, only 4.5 acre feet of water is entering Hester tidal creeks compared with 46 acre feet before construction (90% reduction). At king tide levels (approximately 7.0'), water volume is reduced by 71% (Fig. 37). The amount of wetted surface area during MHHW (Fig. 38) is also significantly lower, from 26.1 acres to 2.9 acres (89% reduction). But at king tide levels, wetted surface area is now 19% greater than before construction.

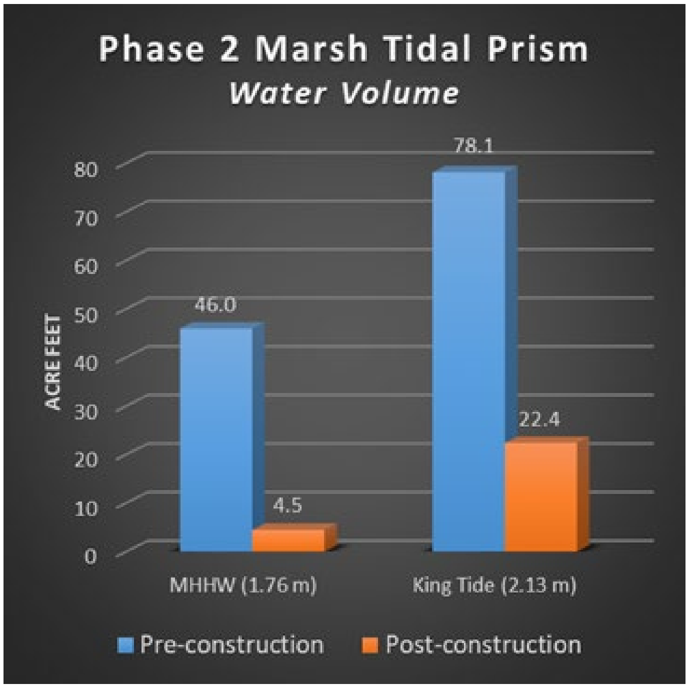


Fig. 37. Water entering Phase II tidal creeks before and after construction

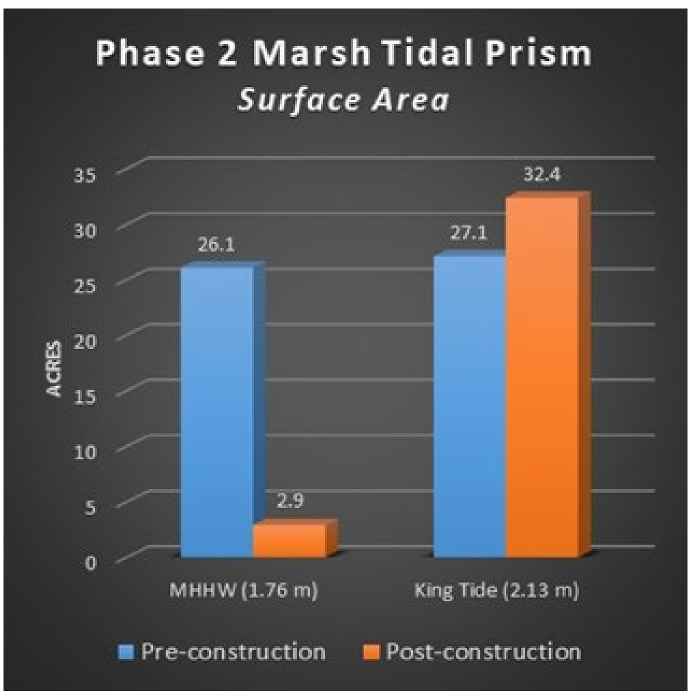


Fig. 38. The amount of wetted surface area during MHHW and king tide in the Phase II project area

Key Personnel
Charlie Endris, Monique Fountain

OBJECTIVE 3 – INCREASE RESILIENCE TO CLIMATE CHANGE

Methods

Overview of tasks

To evaluate success at creating a marsh plain that is inundated less frequently than typical marshes, yet still often enough to avoid encroachment of upland weeds, we used elevation and water level data.

Detailed Monitoring Methods

We used the same transects as described above in section 1.3 to evaluate inundation at eight unrestored natural marshes shown in Fig. 10. Four of these are low marshes typical for Elkhorn Slough (Big Creek, Round Hill, Yampah, Bennett Southwest), while four are the highest marshes in the system (Hudson, Azevedo, Lavender Ridge, Old Salinas River Channel), which serve as references of healthy marshes, at least at the upper ends of the transects. There are 10 quadrats per transect evenly spaced from the landward to seaward boundary of the marsh. Elevations were measured for each quadrat in 2016. We assessed elevation at the ten transects (each with 10 quadrats) at Hester Phase I as described above in section 1.3

We used ESNERR water level data that has been corrected to ensure that Mean Lower Low Water corresponds approximately to 0 m NAVD88, since the two are very close throughout this estuary (Van Dyke 2012). A spreadsheet with calculations of percentage of time each elevation was inundated in a representative period (2008-2013) was used to associate inundation times with each elevation from the transects.

Van Dyke E. *Water Levels, Wetland Elevations, and Marsh Loss. Elkhorn Slough Technical Report Series 2012:2*.; 2012. http://library.elkhornslough.org/attachments/VanDyke_2012_Water_Levels_Wetland_Elevations.pdf

Results

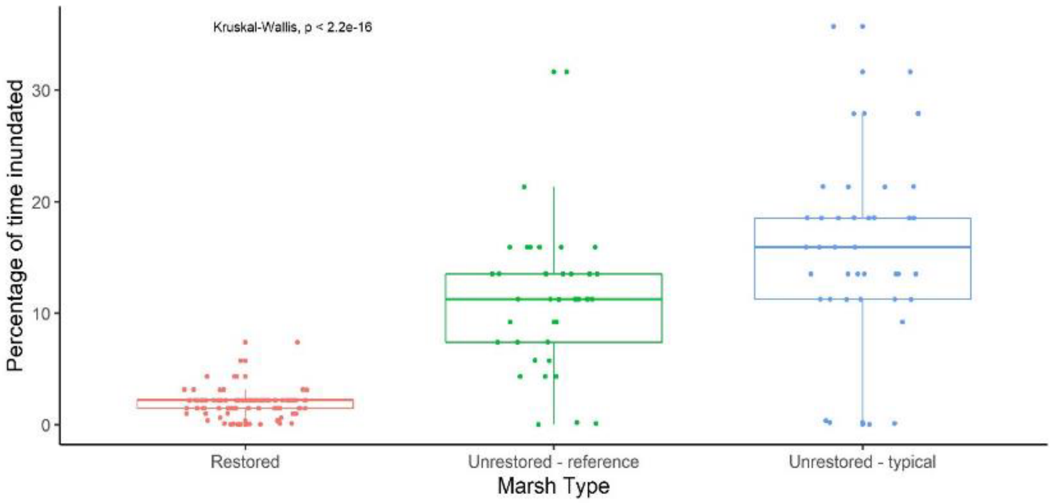
Inundation time of the new marsh plain at Hester Phase I is about 1.9% of the time, which is significantly lower than unrestored marshes in the system. Typical marshes are inundated 16% of the time (which is known to be excessive for marsh health); the best “reference” marshes in the system are inundated about 11% of the time (Table 4). The landward boundary of all marshes is at a similar elevation and is almost never inundated, but the seaward portion is much more frequently inundated at the unrestored marshes (Table 4, Fig. 39). Despite substantial variability across unrestored marshes, Hester marsh inundation is significantly lower than both reference and typical marshes (Fig. 39 top).

While elevation and inundation time are correlated, the relationship is non-linear, and inundation times decrease much more substantially below MHHW. Examination of the frequency of inundation times at Hester thus reveals a much narrower range of inundation times, all clustered very close to 2%, with a maximum of only 7.4%, while inundation times increase dramatically with declining elevation at unrestored marshes, and are above 30%, which is considerably higher than the 10-20% inundation generally considered to be the maximum for long-term salt marsh persistence.

Clearly, unrestored natural marshes in this system have very low resilience to sea level rise, as they are already near their lower elevational limit. In contrast, the newly created marsh plain at Hester is near the top of the elevational limit of marsh, and will be much more resilient to climate change.

Table 4. Inundation time of the restored marsh plain at Hester vs. unrestored natural marshes in Elkhorn Slough.

	Percent time marsh plain is inundated		
Marsh type	**Average**	**Mininum (highest quadrat)**	**Maximum (lowest quadrat)**
Restored - Hester P I	**1.9**	**0.02**	**7.4**
Unrestored - reference	**11.1**	**0.02**	**31.6**
Unrestored - typical	**16.0**	**0.02**	**35.7**



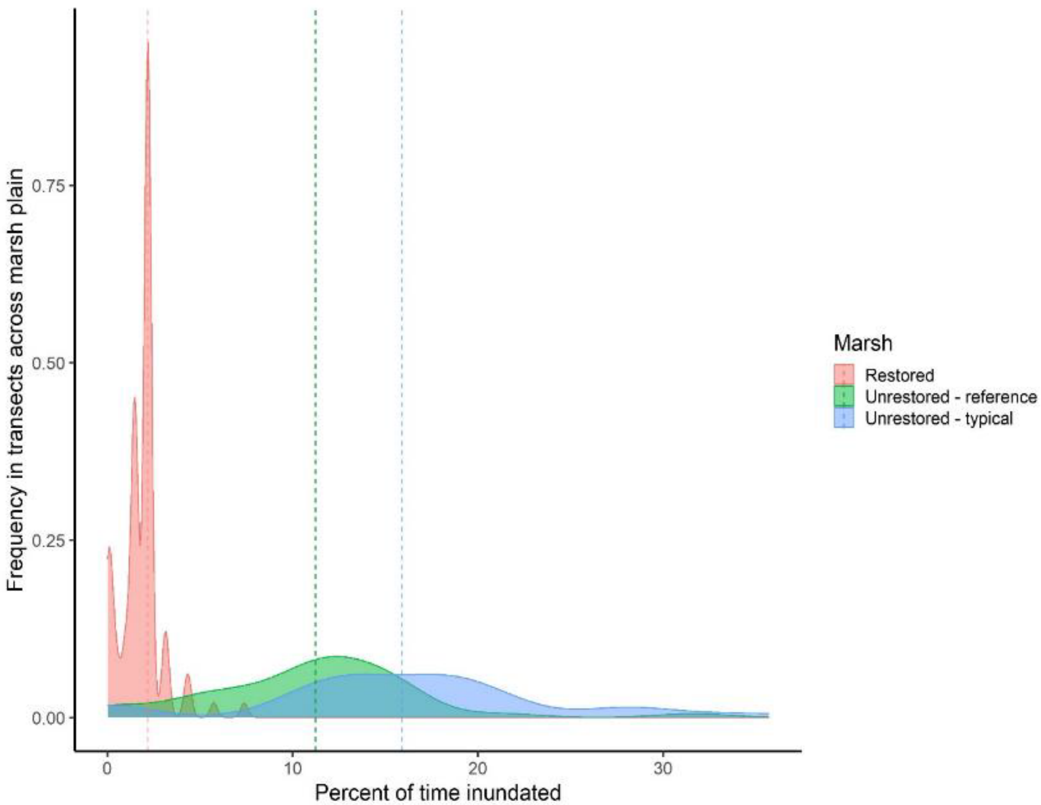


Fig. 39. Inundation of the marsh plain at Hester (100 quadrats), unrestored high reference marshes (40 quadrats), and unrestored typical low marshes (40 quadrats). Both figures are visualizations of the same data; the top panel compares mean and variance and provides a statistical analysis. The bottom panel shows the frequency of different inundation times across the marsh plain at the three types of marshes. It is clear that all of Hester marsh plain is inundated only infrequently, while unrestored marshes are inundated much more often, beyond the limit of what is considered healthy for the marsh dominant, *Salicornia pacifica.*

Key Personnel

Monique Fountain, Charlie Endris, Kerstin Wasson

OBJECTIVE 4 – PROTECT AND IMPROVE SURFACE WATER QUALITY

4.1 Water Quality

Methods

Overview of tasks

For all project phases I-III, we monitored water quality at a site in, or near, the project area and at one control site (Vierras) (Fig. 40). The Vierras control site is located near the mouth of the estuary and remained the same for all three phases. Site locations for individual phases were: Phase I, one site directly adjacent to the project site (elkmhwq). Phase II, one site directly adjacent to the project site (elkmcwq). Phase III, one site within the project site (elkhpwq) before restoration. We also used data from nearby sites monitored for the reserve (South Marsh) (Fig. 40), for occasional comparisons to the project site. We monitored water quality 5 years before, during, and 5 years after site restoration, whenever possible due to weather and construction activity constraints. We deployed YSI data loggers and monitored the following water quality parameters near the project site: temperature, salinity, turbidity, pH, dissolved oxygen.

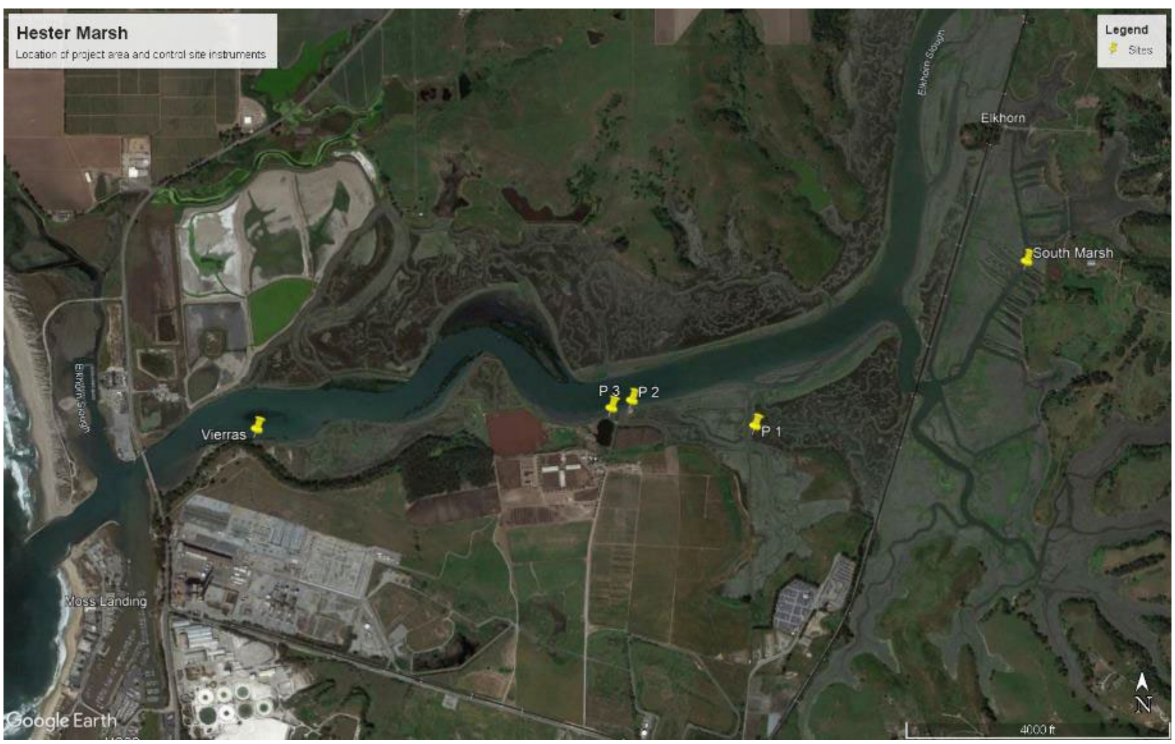


Fig. 40. Locations of water quality sondes at the restoration site (P1, P2, P3) and control sites (South Marsh, Vierras).

Materials
YSI EXO2 Data logger, KOR-EXO software.

Frequency
Water quality data were collected continuously, every 15 minutes, from 2013 to 2023.

Detailed Monitoring Methods

Location: The YSI sonde at Hester Marsh Phase I is located about 30 cm off the channel bottom at the project site. The sonde is held in place by being situated inside a 20 foot (6.1 m) long, 4 inch (12 cm) diameter PVC pipe, held in place by two metal fence posts and resting the top of the pipe on an earthen berm at the project site. The sonde was attached to a 25 foot (7.6 m) rope, and lowered into the PVC housing, until the stop, created by an orthogonal ½ inch PVC pipe at the bottom was reached.

The control site, Vierras (36°48'39.95"N, 121°46'45.22"W), is located at the mouth of the slough and is used as a reference site to compare water quality parameters at the project site relative to a long term monitoring site with oceanic influence. The YSI sonde associated with this site (collecting readings for the water quality dataset) is located approximately 30 cm off the bottom which is composed of compacted mud and sand due to strong tidal currents. This site receives drainage from the entire watershed due to its location at the mouth. There are several auto wrecking yards located approximately 2 km east of this site. An EXO2 sonde is deployed at this site.

Calibration and data management:
Approximately each month, we calibrated a sonde and deployed it at the project and control sites as described above. The parameters we measured were temperature, salinity, pH, turbidity, and dissolved oxygen. Data were downloaded using KOR-EXO software, and subsequently subject to quality assurance and quality control standard operating procedures in accordance with NOAA NERR protocols. Faulty probes or erroneous data were identified each month, and data flagged according to NERR protocol. For further details on sonde calibration and data processing, please see CDMO SOP protocol (NOAA).

Results

Dissolved oxygen
Minimum value of dissolved oxygen was lower before restoration than after restoration (Table 5), both during incoming and outgoing tides. After restoration, the amount of time where dissolved oxygen was below 3 mg/L was less than before the restoration (Table 5).

Table 5. Water quality in 2017 (before construction), and 2018-2020 (after construction). Dissolved Oxygen at Hester Marsh, Sept 1st to Oct 31st, before and after construction. Minimum oxygen levels increased, and hypoxic time decreased after construction. Instrument was removed after October 2020, due to construction/filling in the channel where the instrument was located.

Year	Minimum DO [mg/L]	Maximum DO [mg/L]	Average DO [mg/L]	Hypoxic time Sep-Oct [hrs. DO < 3 mg/L]
2017 (pre)	0.37	14.51	7.16	167.50
2018 (during)	1.87	13.25	7.12	7.50
2019 (post)	1.48	14.08	6.64	78.75
2020 (post)	1.71	11.49	6.73	26.00

Level of dissolved oxygen concentration

Low levels of oxygen concentrations occurred during both the incoming and outgoing tides. In 2017, 2018 and 2019 the lowest dissolved oxygen concentrations were on incoming tides, as opposed to outgoing tides. Pre-construction lowest oxygen levels in fall were close to 0 mg/L whereas post-construction, in fall, the lowest concentrations overall are about 2 mg/L higher than pre-construction levels.

This pattern could be attributed to capping of old mudflat in the restoration area. After restoration, the water body in the project area was exposed to a smaller area of mudflat during each tide than before restoration. Pre-construction mudflat area at a mid-tide was higher and thus capable to drawing down more oxygen over night as opposed to post-construction where area of mudflat at a mid-tide would be much less and thus have lower potential to draw down oxygen overnight. Comparisons were made in the months from September to December of 2017 (pre-construction) and 2018-2019 (post-construction) because tidal flow in the restoration area was obstructed from February 2018 to August of 2018.

Duration of hypoxia pre- and post- construction

Post-construction (2018-2020), hypoxia decreased in the water body by the outflow of Phase I, compared to pre-construction (2017) (Table 5, Fig. 41). Percent hypoxia was defined as the amount of time where dissolved oxygen level was below 3 mg/L. After August 2018 is considered post-construction because the area was returned to full tidal flow. Although percent hypoxia was highly variable at the project and control sites in Elkhorn Slough, percent hypoxia post-construction at the project site was lower than pre-construction (Table 5, Fig. 41).

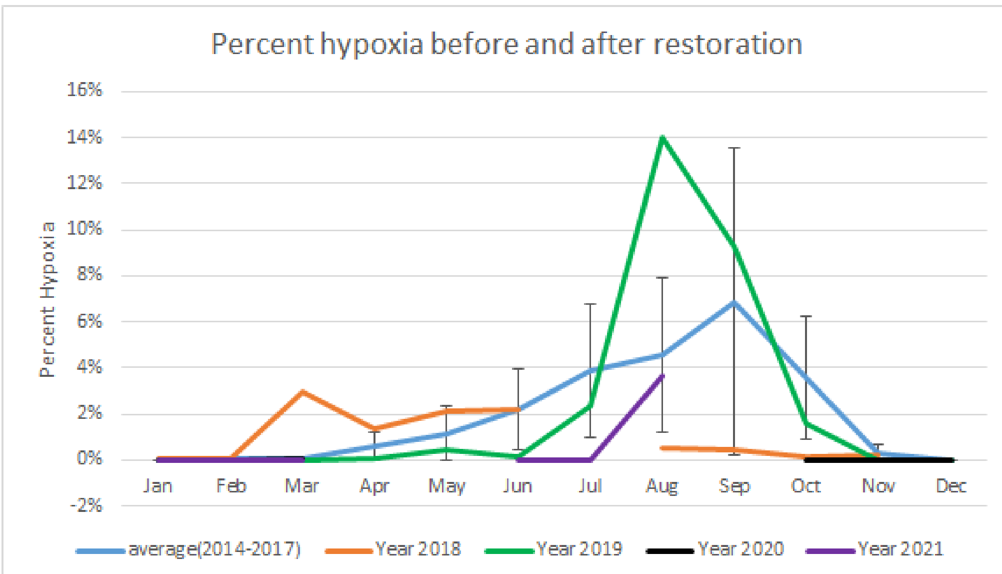


Fig. 41. Pre- and post-construction percent hypoxia, where dissolved oxygen (DO) was below 3 mg/L. Fall (Aug-Oct) post- construction hypoxia was below one standard deviation of the average of all years for 2018, 2020, and 2021 but above average for 2019. Nno data were collected from Aug. and Sept. 2020, and Sept, Oct 2021, due to phase II construction.

The post-construction lower percent hypoxia at the project site seemed unique to the project site, as we did not observe a similar pattern at control sites at Elkhorn Slough Reserve (Fig. 42, Fig. 43). At the control sites, data indicate a higher percentage of hypoxia occurring during July, August and September compared to previous years. This suggests that that the lower hypoxia at the restoration site was a unique occurrence and not a replicated pattern at other sites throughout the slough.

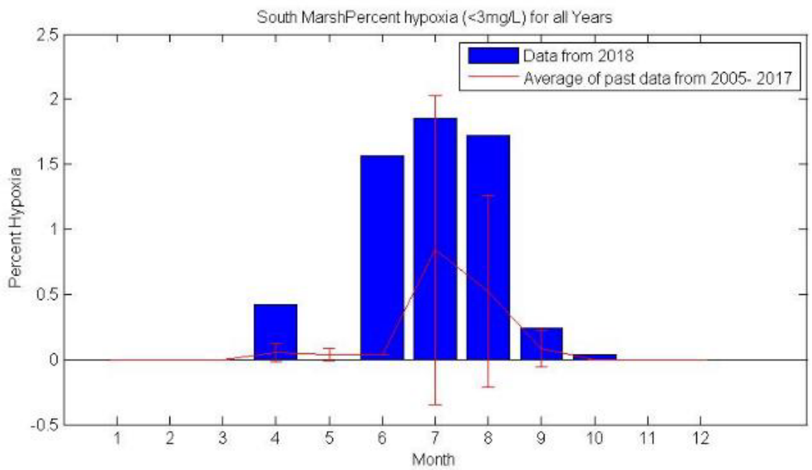


Fig. 42. Percent hypoxia during 2018 compared to historical data at control site, South Marsh (tidally unrestricted).

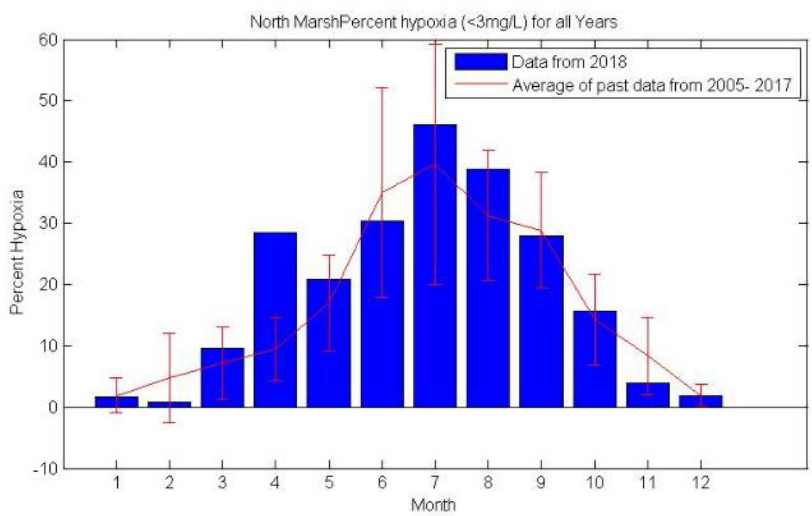


Fig. 43. Percent hypoxia during 2018 compared to historical data at control site, North Marsh (tidally restricted).

Turbidity

Average turbidity at project and control sites:

During the first year post-construction (2019), average turbidity at Hester was slightly higher than pre-construction (Fig. 44). During the second year, post-construction (2020), average turbidity was slightly below pre-construction values. Through 2018 and 2019, average turbidity higher, and more variable than pre-construction values. Then by 2020, average turbidity was lower than before construction, and by 2021 average turbidity and standard deviation was indiscernible to the turbidity at the Vierras control site (Fig. 44). During most months of the year, pre-restoration turbidity has been slightly higher during outgoing tides, than on incoming tides. In 2020 turbidity on incoming tides was slightly higher than on outgoing tides, in seven of ten months (Table 6). This change cannot automatically be attributed to marsh plants increasing sedimentation, as the marsh has yet to fully recolonize. It is possible that elevating the marsh plain, has caused hydrodynamic changes to decrease erosion from the project area.

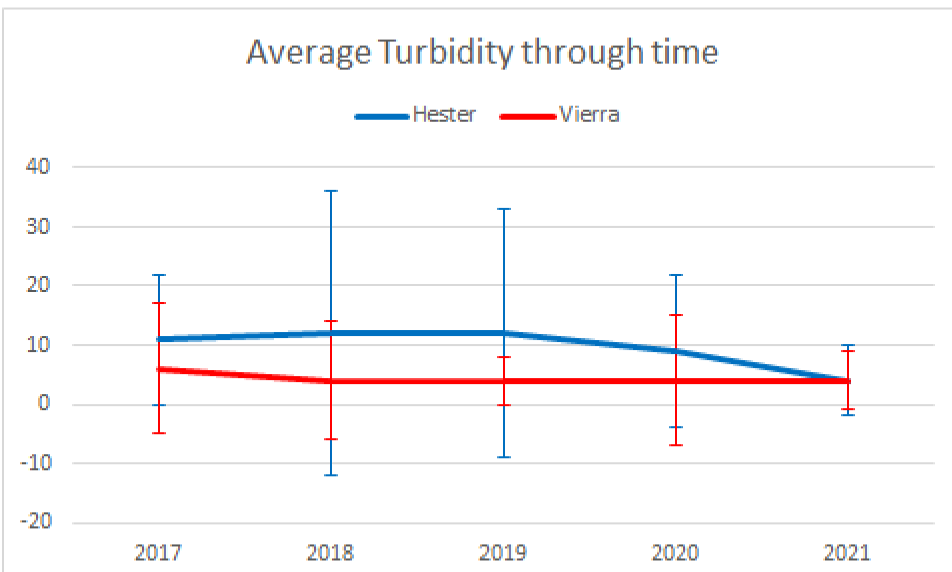


Fig. 44. Turbidity data from Hester project site (1/1/2017 to 10/4/2020) and the Vierra control site (1/1/2017 to 12/31/2020. Due to Phase II construction, the sonde had to be moved from Hester site P1 (Fig. 40) to site P2 in October 2020. Before construction of Phase I, Hester turbidity average was higher and more variable than turbidity at Vierra. After construction of Phase I, Hester turbidity decreased and was similar to turbidity at Vierra, the control site.

Table 6. Turbidity on incoming vs. outgoing tides, directly adjacent to the project area. Tidal flow was blocked from the project area, from February 2018 to September 2018. Green cells indicate that turbidity was higher on incoming than on outgoing tides.

Year	2016	2017	2018	2019	2020
Tide direction	NTU	NTU	NTU	NTU	NTU
In	10.9	12.77	9.53	7.79	6.00
Out	10.39	14.62	10.29	7.75	6.14
In	10.58	13.77	6.63	13.01	11.87
Out	10.6	16.44	5.82	13.05	11.92
In	13.71	11.01	9.24	12.94	5.68
Out	17.74	12.73	7.99	11.53	5.36
In	14.99	12.24	16.84	17.86	6.86
Out	16.67	14.53	13.29	16.96	6.72
In	6.98	10.91	11.98	15.14	5.10
Out	7.91	13.57	10.85	13.51	4.57
In	8.62	11.05	ND	13.34	11.57
Out	9.55	12.92	ND	11.67	14.45
In	8.01	11.26	ND	7.29	7.85
Out	9.08	12.79	ND	7.18	6.97
In	18.55	11.33	16.64	9.43	4.42
Out	17.91	12.31	14.67	8.53	4.19
In	8.71	7.67	54.65	13.37	4.35
Out	9.75	8.16	38.46	14.92	3.79
In	47.7	12.66	12.19	17.02	4.58
Out	52.1	9.34	12.09	17.93	4.04
In	8.29	8.03	11.17	7.49	ND
Out	8.04	7.78	14.46	7.75	ND
In	8.33	5.71	12.04	6.97	ND
Out	8.23	5.28	11.33	6.64	ND

Turbidity over time at project and control sites

We did not observe unusual values in water quality parameters at the project site, Hester, at the onset of construction compared to the control site Vierras.

Generally, turbidity values increase in the water column during rain events in the winter at all sites. Before construction began (on 12/11/2017), turbidity at Hester was higher on average than at Vierras. We did not see a spike in turbidity at the project site, or at the control site, immediately after construction began on 12/11/2017 (Fig. 45, Fig. 46)

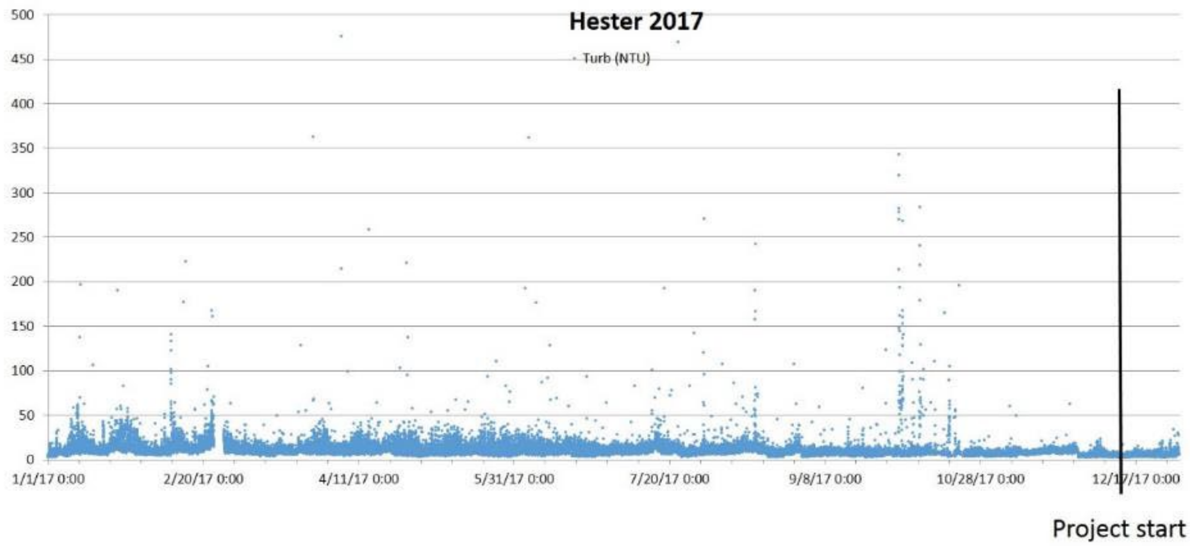


Fig. 45. Turbidity at Hester 1/1/17 to 12/31/17. Construction began 12/11/2017.

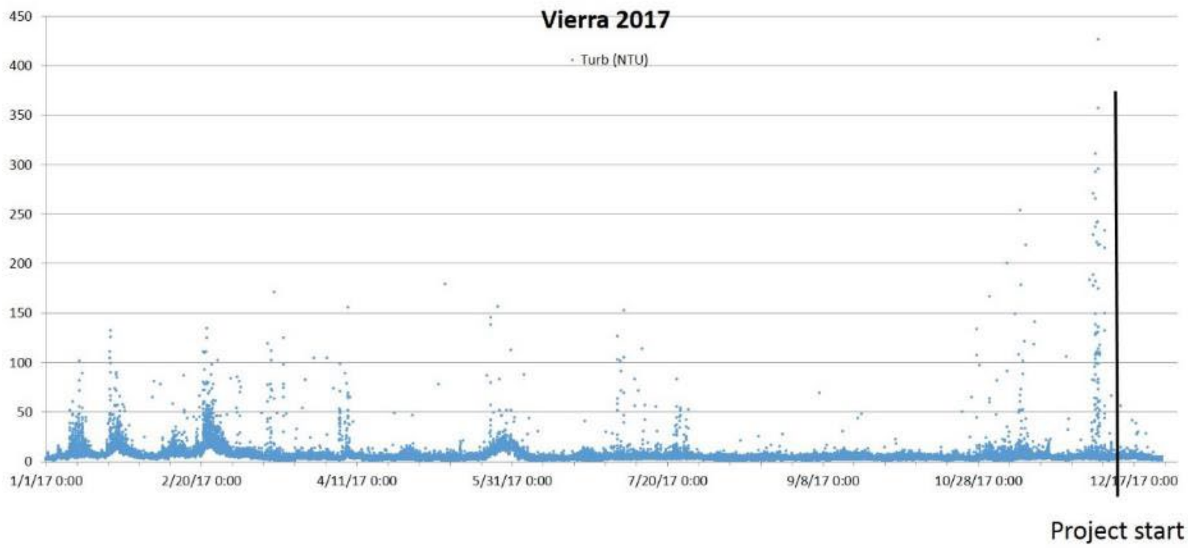


Fig. 46. Turbidity at Vierra 1/1/17 to 12/31/17. Construction began 12/11/2017

At the end of January (1/29/2018), construction of a containment berm to block tidal action at the project was initiated. Although we did observe temporarily increased turbidity near the project site (Fig. 47) we did not detect this turbidity spike at the control site (Fig. 48), indicating that the effect of increased turbidity was localized, short ranged, and short lived.

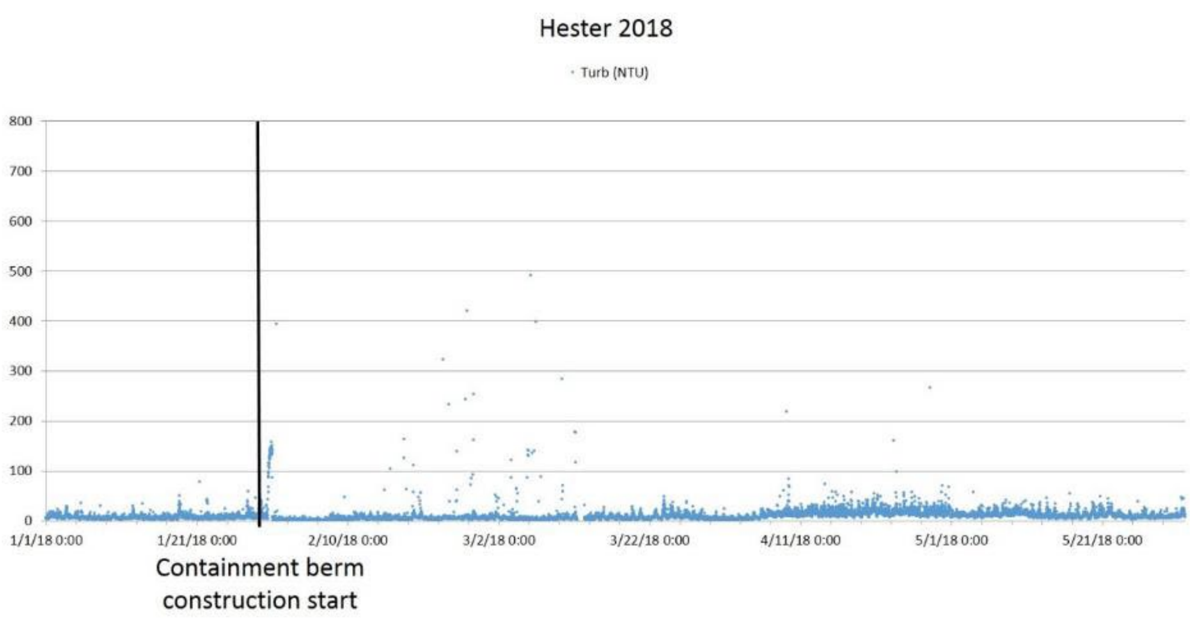


Fig. 47. Turbidity at Hester 1/1/2018 to 5/31/2018

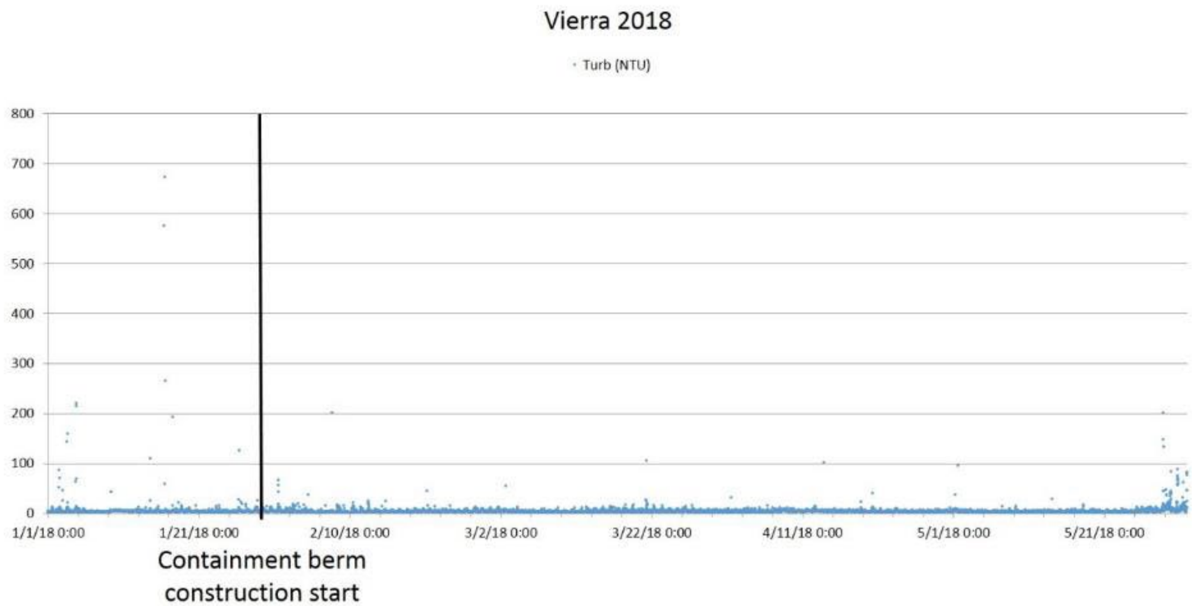


Fig. 48. Turbidity at Vierra 1/1/2018 to 5/31/2018

In conclusion, we did not observe unusual turbidity at the control site, that could be directly attributed to the construction activity. Overall, we did not detect any alarming water quality parameter values, associated with construction activity at Hester Marsh.

Key Personnel
John Haskins, Rikke Jeppesen

OBJECTIVE 5 – SUPPORT WILDLIFE

5.1. Improve Southern Sea Otter habitat

Methods

Overview of tasks

All pre- and post-construction otter observations were conducted in accordance with the Reserve Otter Monitoring Project (ROMP) monitoring protocol, which involves regular surveys by trained volunteers throughout the estuary (Appendix 10). All monitoring during construction was conducted in accordance with agency requirements specified in the best management practices (Appendix 5) and construction specific protocols (Appendix 2). Construction monitoring results from Phase I are reported in Appendix 3 and construction monitoring results from Phase II monitoring are reported in Appendix 12.

Materials

Spotting scope, tripod, binoculars, Kestrel instrument to record temperature and wind speed, signaling flags, air horn, and cellphones for communication, iPads for data entry, HanDBase software for data management.

<u>Frequency</u>

Pre-construction Monitoring was initiated in 2011, and areas finalized in 2013
Construction Monitoring was initiated in December 2017 and terminated in August 2018
Post-construction Monitoring of Hester Phase I has continued bimonthly since August 2018 to present, while pre-construction monitoring continues at Phase II and the Seal Bend Phase III area.

<u>Detailed monitoring methods</u>

Regular ROMP surveys involve trained observers located in 12 different Slough areas (Fig. 49) simultaneously, counting otters and seals and noting locations and behaviors, for two hours typically on two consecutive Tuesdays of each month (Appendix 10). ROMP has gradually expanded in staffing and spatial coverage since inception in 2011; initial emphasis was on the Yampah area and new observation areas were gradually phased in. Thus, monitoring results show no data for some sites in early years.

Fig. 49. Otter observation areas by ROMP monitoring.

During construction, contractor observers, approved by National Marine Fisheries Service and U.S. Fish and Wildlife Service, conducted daily monitoring including hourly counts starting 30 minutes before commencement of- and finishing 30 minutes after termination of construction for the day. Monitors also recorded any incident of disturbance observed during construction at the project site (Appendix 2, p. 13)

Results

Overall, the ROMP monitoring data provide detailed information on otter distribution and abundance in the estuary. Over the past decade, otter numbers have shown variability at most sites, but with no clear long-term trends (Fig. 50). For Yampah Marsh, the area closest to Hester Phase I, there were lower numbers in 2014-2018 than in the years before or after. Abundance patterns at Yampah show no clear relationship to Hester restoration (not consistently lower or higher after restoration).

All three restoration areas (Hester I and II and the phase III Seal Bend Restore area) had very low use of otters prior to restoration, since they were degraded high mudflats. But the adjacent areas (Yampah adjacent to Hester, Seal Bend adjacent to phase III) have high otter numbers, where intact marshes exist. We thus predict that there will be gradual increases over time post-restoration, as salt marsh and animal communities mature there.

Immediately after construction was completed at Hester Phase I, signs of otter activity in the project area were observed, with otter tracks traversing a levee between the main channel and the project area (Fig. 51). Overall, otter numbers in this area remain low; there have been <0.03 otters in Hester Phase I on average for the past decade, and there is no clear increase resulting from restoration yet (Fig. 52). We would predict that numbers in Phase I would increase over time if the current configuration remained. However, because the artificial entrance channel to Phase I was closed as a part of Phase II construction, Phase I will now be more distant from the main channel. Otters mostly remain within 300 m of the main channel (S. Espinosa 2018, M.S thesis, UCSC), so otter numbers in Phase I may decrease.

Overall, the high otter numbers observed in tidal creeks surrounded by dense salt marsh vegetation, such as at Yampah Creek, make it likely otters will gradually continue to increase in the restored marshes as they revegetate. In the future, after 50 cm of sea level rise, when most Elkhorn Slough marshes are gone, this restoration area will provide unique value to the otters, in particular for hauling out and resting.

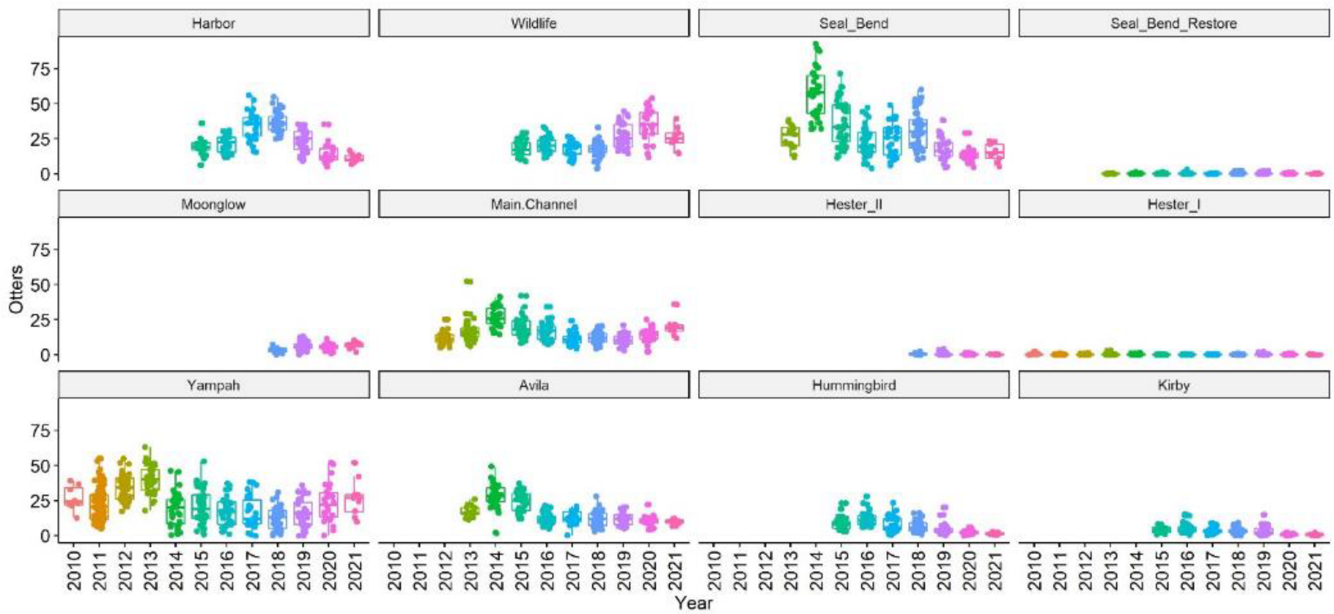


Fig. 50. ROMP otter counts across 12 different sites in the estuary. Numbers are consistently high in main channel and Yampah creek sites and consistently low in the restoration footprints (Hester I, Hester II, and Seal Bend Restore – Phase III). The data show variation over space and time, for instance with 2014-2015 having especially many otters at Seal bend, especially few at Yampah Creek.

Fig. 51. Otter tracks traveling from Hester to Yampah marsh

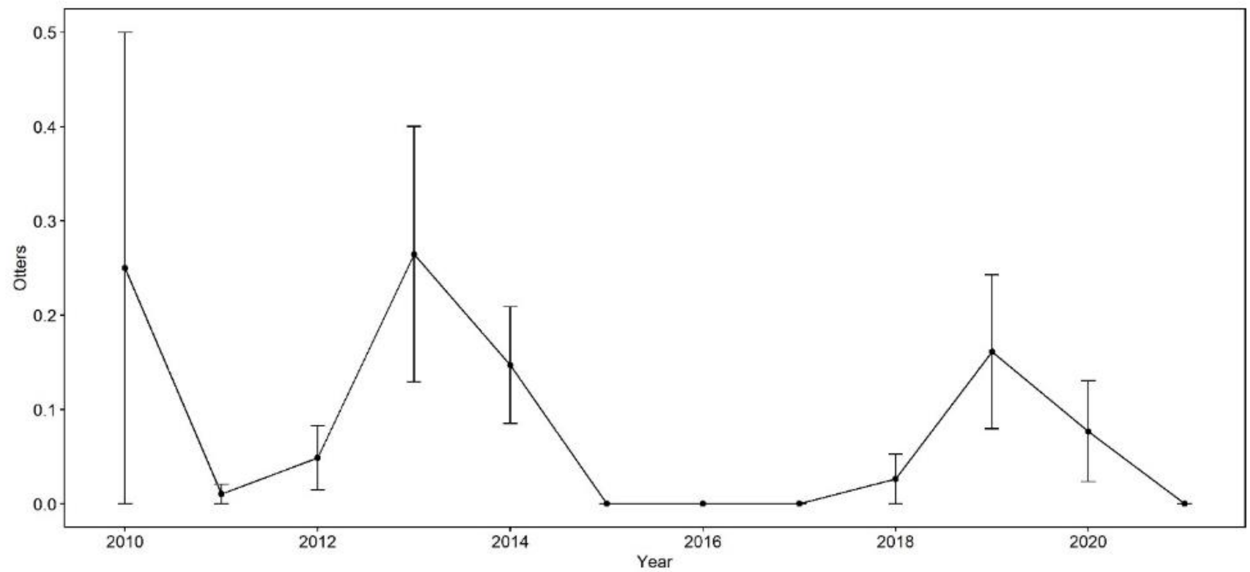


Fig. 52. Average number of otters per ROMP survey observed from 2010-2020. Numbers are always low and have not shown any clear long-term trends.

Key Personnel
Monique Fountain, Ron Eby, Susan Rosso, Kerstin Wasson

5.2. Maintain fish composition consistent with other tidal channels in Elkhorn Slough

Methods

Overview of tasks

Conduct pre- and post- construction fish surveys at the project site, assessing fish species identity and abundance in accessible channels.

Materials

22 ft. (7 m) long by 6 ft. 6 inches (2 m) deep purse fish seine, with a 1/10 inch (3 mm) mesh size, attached to one 6 ft. 6 inch (2 m) long, schedule 40 PVC pipe in each end of the seine to keep the seine in the correct position.

Frequency

Two surveys (spring and fall) two years prior to project start.
In 2019, we conducted two surveys (summer and fall).
In 2020, we conducted one survey (fall).
In 2021, we conducted two surveys (spring, summer).
In 2022, we conducted one survey (spring).

Detailed Monitoring methods

We surveyed three areas within the Phase I project site, M1, M2, and the channel by Dave's tree. After completition of Phase I, we sampled 2-4 sites along the new main channel in Phase I. We manually dragged the seine along the bottom of the survey area, for a three-minute tow, or until we reached the shore. All fish in each tow were identified to species, ten individuals of each species were measures (total length) and the remaining individuals were counted and recorded

Results

During the pre-construction surveys we captured three different fish species. The most abundant was top smelt (hundreds per seine) followed by arrow goby, and then staghorn sculpin (less than ten per seine). Three surveys have been conducted post construction. In late summer and fall of 2019, the most abundant was still top smelt followed by gobies, and then staghorn sculpin. In fall of 2020, the most abundant species were topsmelt, anchovy, and gobies. In spring of 2021 the most abundant species were topsmelt, gobies, staghorn sculpin, and pacific herring. Additionally, a few bay pipe fish, northern anchovy, and diamond turbot (first documented instance for the slough) were observed post-construction, in 2019 (Table 7).

Table 7. Pre- and post-restoration fishes at Hester Marsh. Species richness increased after restoration

Samples from pre- and post-restoration						
	Pre		Post			
	2014	2016	2019	2020	2021	2022
Top Smelt	X	X	X	X	X	X
Northern Anchovy	X		X	X	X	
Arrow Goby		X	X	X	X	X
Staghorn Sculpin	X	X	X		X	X
Shiner Surf Perch			X		X	
Pacific Herring			X		X	
Pacific Sardine				X		
Bat Ray			X			
Diamond Turbot			X			
Bay Pipefish				X	X	
Fantail Sole			X			
Plainfin Midshipman				X		
3-spine Stickleback			X			X
California Halibut						X
Species richness	3	3	10	6	7	5

Key Personnel

Monique Fountain, Rikke Jeppesen

5.3. Provide habitat for diverse waterbird communities

Methods

Overview of tasks

We quantified community composition, species diversity, and usage patterns prior to the restoration of the marsh and following the restoration. We conducted surveys of two marshes, Yampah (unrestored high marsh) and Hester Marsh Phase I (restoration site).

Materials

Two-member teams using spotting scopes and binoculars

Frequency

Pre-restoration surveys: January-June 2017. Post-restoration surveys: fall 2022

Tasks

Pre-construction survey of Yampah and Hester Marsh
Post-construction survey of Yampah and Hester Marsh

Detailed Monitoring Methods

Following a BACI design, surveys were conducted twice monthly at three subsections each of restored and unrestored (control) sites. A two-member team conducted approximately 20-minute snapshot surveys by scanning each area with binoculars and spotting scopes. After doing a preliminary assessment across all tides and times of day we determined certain parameters and limitations. We carried out surveys between tides ranging from approximately 1.0 to 5.5 foot (0.30 – 1.68 m) tides above MLLW. Extreme low and high tides have very little bird activity and low species diversity in both the restoration and control areas. We carried out these surveys before noon due to the glare of the sun making it impossible to identify or visually see birds, especially in the Minhoto/Hester Marsh area. We will conduct at least ten surveys prior to restoration and after restoration.

From October - December 2016, we conducted a pilot study of the Hester Marsh Phase I area and Yampah Marsh area to determine the best survey protocol. Five observation points on Yampah Island were found to give the best viewing of the restoration and control sites. From January - June 2017, a two-person team conducted 20-minute snapshot surveys, using binoculars and spotting scopes, on 11 separate days. The experimental areas were divided into three subsections. Surveys were conducted on rising and ebbing tides ranging from a low of 1.1 to a high of 4.8. All surveys were conducted before noon to minimize the extent of sun glare in the survey area. We used the three subsection surveys per site separately to give us 33 replicates. T-tests were done to compare total abundance, total richness, and abundance of shorebirds versus waterfowl between Hester and Yampah Marsh.

To determine how community composition varied by marsh, we used a suite of related multivariate techniques with the program Primer. We first square-root transformed the data to downgrade the effect of common species. We used Bray-Curtis to create a resemblance matrix. To visualize patterns, we plotted each site and survey date using non-metric multi-dimensional scaling. To test whether communities differed significantly across the two marshes, we employed ANOSIM. To determine which species contributed the most to differences, we used SIMPER.

Results

Mean number of birds observed in Hester Marsh Phase I during the survey period was 136.94 (SD=204.37). Mean number of birds observed in Yampah Marsh was 49.70 (SD=77.38). The mean number of birds differed significantly between sites (t-test; t=-2.29, P=0.027). Numbers of birds in Yampah Marsh may be under represented due to the topography of the marsh. Many birds may have been in the water channels below our visibility and hidden by the thick vegetation. In contrast, much of the Hester Marsh area was open mudflat and low marsh making birds more visible, except in the channels and back low marsh area.

Shorebird and waterfowl numbers were categorized separately to determine if one of these groups utilized the sites more frequently. Species that are commonly referred to in birding references as "shorebirds," those that wade or have long beaks, were categorized as shorebird. Egrets and gulls were not counted in this category. In Hester Marsh, the mean number of shorebirds observed was 75.44 (SD=92.75) (Fig. 53). These were mainly observed feeding on the exposed mudflats or waiting on high dikes for the tide to expose the mudflat. The mean number of shorebirds observed in Yampah Marsh was 44.03 (SD=75.16) (Fig. 53). Shorebirds were frequently observed in the high marsh areas of pickleweed with exposed pockets of mud as well as along water channels. The mean number of shorebirds between sites was not significant (t-test; t = -1.406, p = 0.165).

Mean number of waterfowl observed in Hester Marsh was 61.94 (SD=135.21) (Fig. 53). Waterfowl species were mainly observed using the back low marsh area and main channels. On one occasion over 730 wintering Green-winged Teal (*Ana crecca*) were observed mainly in the back low marsh area of Hester. In Yampah Marsh, the mean number of waterfowl observed was 1.18 (SD=3.02) (Fig. 53). Waterfowl were observed using Yampah Creek and other small channels. There was a significant difference in the mean number of waterfowl between sites (t-test; t = -2.581, p = 0.015).

Species Richness between Hester and Yampah Marsh was significantly different (t-test; t=-3.627; P=0.0007). The total number of species observed at Hester Marsh was 35, with a mean number of species observed per observation day of 12.64 (SD=4.80, n=11). Most frequently seen species at Hester Marsh were: Black-bellied Plover (*Pluvialis squatarola*), Willet (*Tringa semipalmata*), Marbled Godwit (*Limosa fedoa*), Long-billed Dowitcher (*Limnodromus scolopaceus*), Long-billed Curlew (*Numenius americanus*), Mallard (*Anas platyrhynchos*), Green-winged Teal, Gadwall (*Anas strepera*), and Ruddy Duck (*Oxyura jamaicensis*) (Fig. 54).

The total number of species observed at Yampah Marsh was 27, with a mean number of species observed per observation day of 7.18 (SD=2.75, n=11). The most frequently seen species at Yampah Marsh were: Willet, Marbled Godwit, Long-billed Curlew, Western Gull (*Larus occidentalis*), and Snowy Egret (*Egretta thula*) (Fig. 54).

Shorebird species composition was similar between Hester and Yampah Marsh with Long-billed Curlew, Willet, and Marbled Godwit observed on almost all observation days at both sites. For unknown reasons, counts of these three species were much lower on the last two observation days (May 24 and June 5, 2017). Egret species were observed occasionally at both sites with a high count of 42 Snowy Egrets in Yampah Marsh on one observation day.

Waterfowl species composition between Hester and Yampah Marsh differed. Green-winged Teal, Ruddy Duck, and Bufflehead (*Bucephala albeola*) were observed consistently in Hester Marsh. Only Bufflehead were observed in Yampah Marsh and less frequently during the same period. In Hester Marsh, waterfowl utilized the channels, low marsh areas and open mudflat, when covered with water; while in Yampah Marsh they were observed only in the channels.

Multivariate analyses revealed that the survey sites had some overlap in bird community composition, but that generally Hester and Yampah Marsh had different bird communities(Fig. 55). An ANOSIM revealed that this difference was significant (R = 0.2, P = 0.001). Four species together accounted for 50% of the dissimilarity between marshes in a SIMPER analysis: Willet (15%), Marbled Godwit (15%), Green-winged Teal (11%) and Long-billed Curlew (9%). The first three of these species were more common at Hester; the latter more common at Yampah.

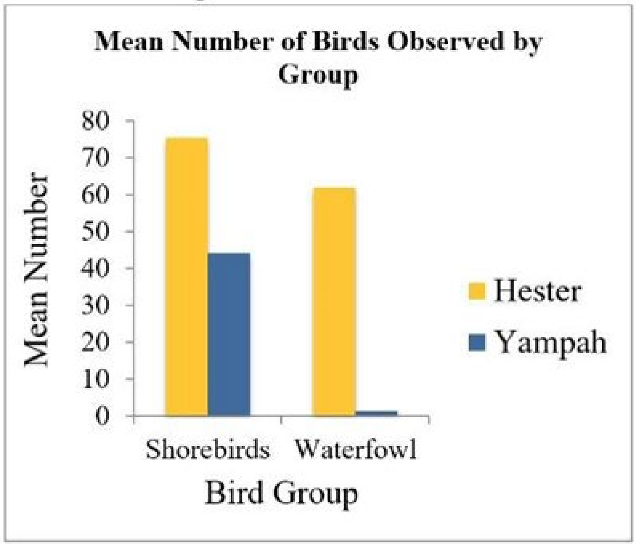


Fig. 53. Mean number of shorebirds and waterfowl observed in the two marshes

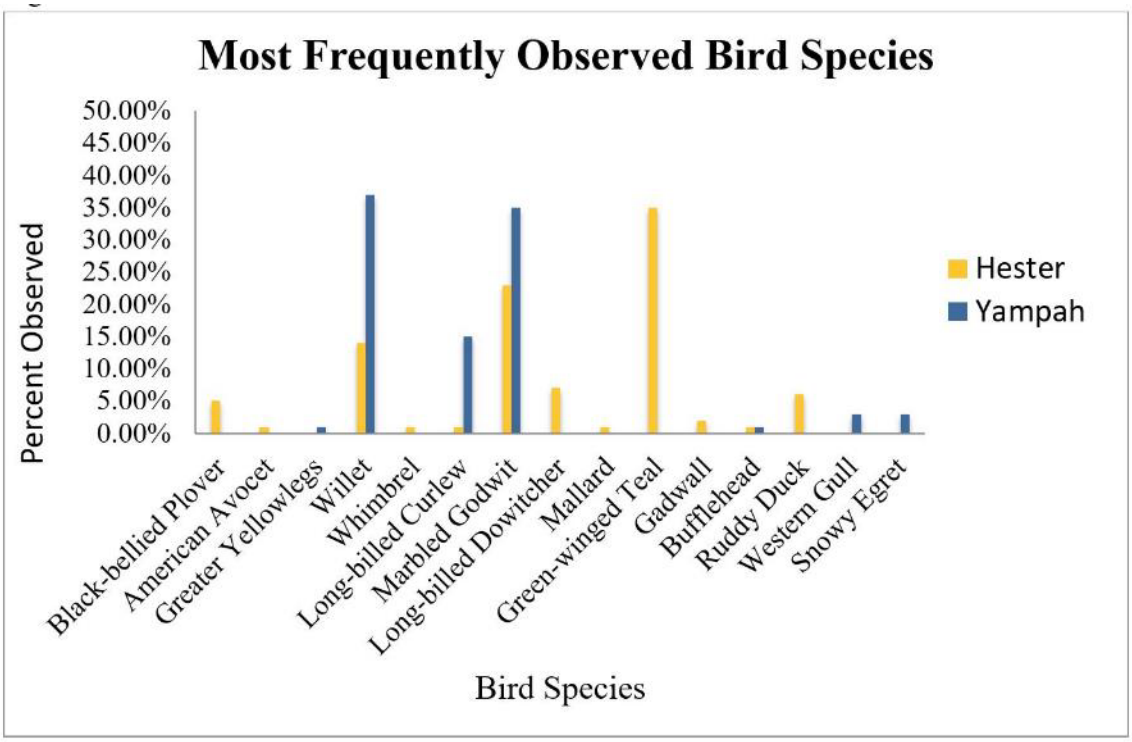


Fig. 54. Comparison of birds species between sites using percent number of birds observed for all surveys

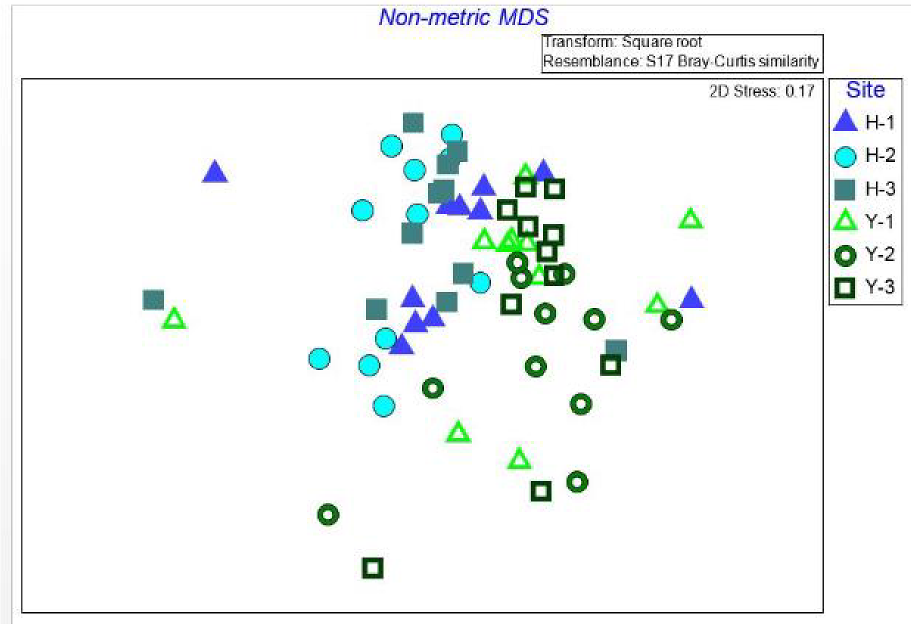


Fig. 55. Multivariate analyses revealed that the survey sites had some overlap in bird community composition, but that generally Hester and Yampah Marsh had different bird communities (open vs. closed symbols)

Key Personnel
Jennifer Parkin, Susie Fork

OBJECTIVE 7 - INCREASE BLUE CARBON FUNCTION

Methods

Overview of Tasks

- Collect aboveground biomass and analyze carbon content
- Collect sediment cores and analyze carbon content
- Estimate below-ground production with in-growth bags and estimate below ground decomposition with litter bags
- Analyze flux of greenhouse gases
- Estimate rate of sediment accretion

A summary of the spatial and temporal plan for sampling is in Table 8.

Table 8. Summary of the spatial and temporal plan for sampling

Type of site	Habitat Types	Aboveground biomass	Sediment cores	Gas fluxes	Sediment accretion	Litter & ingrowth bags
degraded, formerly diked sites: control & Hester pre-restoration	grassland high marsh low marsh mudflat	before 2015 after 2021	before 2015	before 2015 2017	before 2015-7 after 2018-21	after 2020-21
Hester post-restoration	bare (high) high marsh	after 2021	after 2018 2021	after 2021	after 2018-21	after 2020-21
reference sites	grassland high marsh mudflat	after 2021	after 2021	after 2021	after 2018-21	after 2020-21

Detailed Methods and Results

Appendix 11 provides comprehensive information on methods and results, and interprets the findings.

Key Personnel

Beth Watson, Monique Fountain, Kerstin Wasson, Cathy Wigand

Appendix 5

Mitigation, monitoring, and reporting program (MMRP)

Compiled CEQA and Permit Conditions for the Elkhorn Slough Tidal Marsh Restoration Project

Table 1 summarizes the avoidance, minimization, and mitigation measures and permit terms and conditions required to implement the Elkhorn Slough Tidal Marsh Restoration Project (project). Specifically, Table 1 provides a summary all avoidance, minimization, and mitigation measures provided in the Mitigation, Monitoring, and Reporting Program (MMRP) for the project, as well as each term, condition or measure provided in a federal, state, or local permit; the source document(s) the measure is summarized from; when the measure is required to be implemented (i.e., before, during, and/or after construction); and who is responsible for implementing the measure.

The information in Table 1 is intended to provide an overview of project requirements. Clarification on how or when a measure should be implemented should be derived from the source document(s). **A copy of all final permit applications must be maintained by the construction contractor at the project site throughout construction.**

Source documents referenced in Table 1 include the following:

- Initial Study / Mitigated Negative Declaration (IS/MND) for the Elkhorn Slough Tidal Marsh Restoration Project, July 2015 (State Clearinghouse Number 2015071023)
- U.S. Army Corps of Engineers (USACE), Nationwide Permit (NWP) Verification (File No. 2014-00395S), February 15, 2017 – Agency Contact: Greg Brown, (415) 503-6791, Gregory.g.brown@usace.army.mil
- Central Coast Regional Water Quality Control Board (RWQCB), 401 Water Quality Certification (WQC) (Cert No. 32716WQ09), July 25, 2016 – Agency Contact: Kim Sanders, (805) 542-4771, kim.sanders@waterboards.ca.gov
- National Marine Fisheries Service (NMFS) Incidental Harassment Authorization (IHA) for Harbor Seal, Issued: March 30, 2017, **Valid: August 1, 2017 to July 31, 2018** – Agency Contact: Stephanie Egger, (301) 427-8401, stephanie.egger@noaa.gov.
- NMFS Endangered Species Act (ESA) Concurrence Letter and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Response (LOC) (NMFS No. WCR-2016-4161), February 24, 2016 – Agency Contact: Brian Meux, (707) 575-1253, brian.meux@noaa.gov
- U.S. Fish and Wildlife Service (USFWS) IHA for Southern Sea Otter (IHA-17-01), Issued: June 15, 2017, **Valid: August 1, 2017 through July 31, 2018** – Agency Contact: Lilian Carswell, (805) 677-3325, lilian_carswell@fws.gov
- USFWS Biological Opinion (BO) (O8EVENOO-2016-F-0226), October 24, 2016 – Agency Contact: Jacob Martin, (831) 768-6953, Jacob_Martin@fws.gov
- California Department of Fish and Wildlife (CDFW) Lake or Streambed Alteration Agreement (LSA) (LSA No. 1600-2016-0095-R4), October 19, 2017 – Agency Contact: Carrie Swanberg, (559) 243-4014, x 246, carrie.swanberg@wildlife.ca.gov.

Notes:

- The California Coastal Commission issued a Coastal Development Permit (CDP) Waiver (3-16-0030-W) for the project on July 27, 2016.
- The California Office of Historic Preservation concurred with the USACE recommendations specific to cultural resource protection on August 11, 2016 (COE_2016_0201_001).

Table 1. Elkhorn Slough Tidal Marsh Restoration Project – Compiled CEQA and Permit Conditions

MEASURE	SOURCE DOUCMENT	TIMING	RESPONSIBILITY			
			LANDOWNER (CDFW/ESF)	CONSTRUCTION MANAGER (DU)	CONTRACTOR	TECH SPECIALIST
WATER QUALITY						
Establish erosion and sediment control measures on site prior to construction and keep available on site at all times in anticipation of rain events. Implement and maintain washout, trackout, dust control, and any other applicable source control BMPs in accordance with all specifications governing their proper design, installation, operation, and maintenance. To minimize the risk of ensnaring and strangling wildlife, only use erosion control materials composed entirely of natural biodegradable materials.	RWQCB-PR 3, PR 4, and PR 5; CDFW LSA AMM 2.8(a)	Before, during		Verify	Implement	
Cover stockpiled material not actively used and surround with linear sediment barrier.	RWQCB-PR 6; CDFW LSA AMM 2.7(b)	Before, during		Verify	Implement	
Isolate the work area from the tides using temporary berms to allow placement of fill at all tidal stages. Construct temporary berms from onsite materials installed at lowest predicted tides and/or sheetpiles. Dewater work area using a combination of pumps and passive drainage. Discharge pumped water into marsh adjacent to and outside the work area using a diffuser or other energy dissipation device, or into open water of Elkhorn Slough.	IS/MND Project Description; NMFS LOC; CDFW LSA Project Description and AMM 2.10(a)-(b), (d)	During		Verify	Implement	
During construction of the pilot project, monitor turbidity levels in accordance with the LSA.	CDFW LSA AMM 2.11(a)-(b)	During		Verify	Implement	
Use low-pressure ground equipment (LGP) or mats when constructing in the marsh, to the extent possible.	IS/MND Project Description; CDFW LSA Project Description	During		Verify	Implement	
Protect existing slough channels in place, to the extent feasible. Channel protection options, which include straw bales and silt fence, are provided on Sheet C-501 of the permit plan set Enclosure 1 to the USACE permit application.	USACE (Enclosure 1); IS/MND Project Description	During		Verify	Implement	
Construct channels to drain towards the closest existing channel at an approximate max slope of 0.5%.	USACE (Enclosure 1)	During		Verify	Implement	
All sediment and soils stockpiled onsite shall be sloped at an angle not steeper than 1.5:1 unless otherwise approved by a geotechnical engineer.	IS/MND GEO-1	During		Verify	Implement	
Minimize land disturbances that will adversely impact water quality. Vegetation disturbance and removal shall not exceed the minimum necessary. No trees shall be removed or cut.	RWQCB-PR 2; CDFW LSA AMM 2.5(a)	During		Verify	Implement	
Seed floodplain areas outside of marsh restoration area where vegetation is removed with a sterile cover crop to prevent erosion.	CDFW LSA AMM 2.8(b)	After	Implement			
Visually monitor the project site and adjacent area following construction and for one subsequent rainy season to ensure project is not causing excessive erosion or other water quality problems. Contact RWQCB if project causes water quality problems.	RWQCB-MRR 1	After (1 rainy season after)	Implement			
AIR QUALITY						
Minimize dust by watering all active construction areas and haul routes.	IS/MND AIR-1	Before, during		Verify	Implement	
Cover all trucks hauling soil, sand, and other loose materials with tarpaulins or other effective covers.	IS/MND AIR-1	During		Verify	Implement	
Maintain at least 2-feet of freeboard on haul trucks.	IS/MND AIR-1	During		Verify	Implement	
Limit traffic speeds along the unpaved haul route to 15 miles per hour.	IS/MND AIR-1	During		Verify	Implement	

MEASURE	SOURCE DOUCMENT	TIMING	RESPONSIBILITY			
			LANDOWNER (CDFW/ESF)	CONSTRUCTION MANAGER (DU)	CONTRACTOR	TECH SPECIALIST
Prohibit all grading activities during periods of high wind (over 15 mph).	IS/MND AIR-1	During		Verify	Implement	
Cover or seed inactive storage piles.	IS/MND AIR-1	Before, during		Verify	Implement	
Post a publicly visible sign which specifies the telephone number and person to contact regarding dust complaints. Include phone number of the Monterey Bay Unified Pollution Control District (Nuisance). Respond to complaints and take corrective action within 48 hours.	IS/MND AIR-1	Before, during		Implement		
Limit the area under construction at any one time.	IS/MND AIR-1	During		Verify	Implement	
Seed disturbed upland areas as soon as possible.	IS/MND AIR-1	After	Implement			
BIOLOGICAL RESOURCE MANAGEMENT						
Complete pre-activity surveys for potential rare, listed, or other sensitive species within 30 days prior to commencement of project activities. Surveys to be completed by qualified biologist and to include work areas and access routes.	CDFW LSA AMM 2.3(a)	Before		Verify		Qualified Biologist - Implement
Conduct a pre-construction survey for CTS and CRLF within 5 days prior to vegetation removal, stockpile placement, or disturbance of topsoil AND immediately prior to disturbance. If a listed species is observed, the biologist should attempt to passively guide the individual out of the construction work area of its own volition. If unsuccessful, biologist shall relocate the animal per USFWS-approved Relocation Plan.	USFWS BO-3; CDFW LSA AMM 2.3(b)(3)	Before, during	Dana Bland Corey Hamza			Qualified Biologist - Implement
Time construction activities to avoid the peak of the pupping season for sea otters (March and April) and harbor seals (May).	IS/MND BIO-1a; USFWS BO SEC. 5.3.8	Before	Monique Fountain			
Avoid nesting season disturbance by timing construction to occur between September 1 and January 31, if feasible. If not feasible, complete preconstruction surveys and implement buffer zones.	IS/MND BIO-2a; CDFW LSA AMM 2.4(c)	Before	Susie Fork Dave Feliz Jennifer Parkin			
Train all construction personnel on how to avoid effects on marine mammals, amphibians, other special-status species, and water quality before starting work. Make personnel aware of permits, terms and conditions applicable to project. If new construction personnel are added to the project, the contractor shall ensure the personnel receive the mandatory training before starting work. Follow-up training for water quality BMPs shall be conducted every 6 months until the project is completed.	IS/MND BIO-1b; RWQCB-PR 1; NMFS IHA-3(f) and 4(b) (Monitoring); USFWS BO-1 (p7); USFWS IHA-6(a); CDFW LSA Admin Measure 1.7	Before, during	Dana Bland Monique Fountain Mike Curthoys	Verify	Participate	Qualified Biologist - Implement
Identify the limits of all "work areas" using brightly colored flagging that is maintained for the duration of the project. Avoid disturbance outside work areas.	CDFW LSA AMM 2.2	Before, during		Verify	Implement	
Ensure that construction only occurs during daylight hours (i.e., sunrise to sunset) when visual marine mammal monitoring can be implemented.	NMFS IHA-4(a) (Mitigation); USFWS IHA-6(e); USFWS BO-10; CDFW LSA AMM 2.1	During		Verify	Implement	
To reduce the potential for fish to become entrained in isolated ponded areas, isolate the work area and block the tidal channels at low tides. Allow fish to leave the work area as water naturally drains. Incorporate a pipe or other one-way tide gate into berm to allow fish present in remaining surface water to exit work area with draining water.	IS/MND Project Description; CDFW LSA AMM 2.4(a)	During		Verify	Implement	
Conduct pile driving at low tide, to the extent practicable, to minimize underwater sound impacts. Sheet pile installation to last no more than 9 days, with piles installed over a maximum distance of 170 feet and driven to a depth of approximately 20 feet. Drive piles using vibration (versus impact hammer).	NMFS LOC; CDFW LSA Project Description	During		Verify	Implement	

MEASURE	SOURCE DOUCMENT	TIMING	RESPONSIBILITY			
			LANDOWNER (CDFW/ESF)	CONSTRUCTION MANAGER (DU)	CONTRACTOR	TECH SPECIALIST
Prior to commencement of new activities during the breeding season (February 1 to August 31), a qualified biologist shall conduct pre-construction surveys for nesting birds. Pre-construction surveys to be completed no earlier than 7 days prior to the initiation of new disturbance in any given area, and shall encompass all potential nesting habitats in the project area, and should include search radii corresponding to disturbance free buffer zones (i.e., 500-feet for non-listed raptors and 250 feet for non-raptors (where such areas are accessible).	IS/MND BIO-2b; CDFW LSA AMM 2.4(c)	Before	Susie Fork Jennifer Parkin	Coordinate		Qualified Biologist – Implement
Establish appropriate disturbance-free buffer zones around any active nests found in the vicinity of the project area. Monitor bird behavior to determine if construction within 100 feet of these nests are likely to result in abandonment of nest. If deemed safe, construction may proceed. Nesting deterrence, such as removal of vegetation or incomplete nests with no eggs or young, may be implemented by qualified biologists to minimize the potential for nesting birds to constrain project activities. See IS/MND BIO-2C and LSA AMM 2.4(c) for specific monitoring protocols.	IS/MND BIO-2c; CDFW LSA AMM 2.4(c)	Before, during	Dave Feliz			Qualified Biologist - Implement
All marine mammal monitoring must be completed by a qualified biologist (or protected species observer [PSO] approved by NMFS and USFWS. See NMFS IHA-4(a) (Monitoring) for qualification requirements. The biologist may not be responsible for other construction-related tasks while monitoring, and shall be provided the equipment necessary to effectively monitor (i.e., record species, behaviors, and responses to activities).	NMFS IHA-4(a), IHA-4(b)(i), IHA-4(b)(ii) (Monitoring)	During	Rikke Jeppesen	Verify		Qualified Biologist - Implement
Biological monitor will be present during all initial ground disturbance or initial placement of stockpile material to monitor for the potential presence of CTS and CRLF.	USFWS BO-4; CDFW LSA AMM 2.3(b)(5)	Before, during	Monique Fountain Rikke Jeppesen			Qualified Biologist – Implement
Biological monitor will inspect roadways for CRLF and CTS in the morning prior to, during, and within 24 hours after rain events. If individuals are present, biologist shall allow the animal to leave on its own volition or shall relocate the animal per approved Relocation Plan.	USFWS BO-5; CDFW LSA AMM 2.3(b)(6)	During	Monique Fountain			Dana Bland Bryan Mori
Cease construction in immediate vicinity if any life stage of CTS or CRLF are found by the biological monitor or construction personnel within the work areas. Resume construction after the individual moves on its own (if possible) or has been relocated (as detailed in an approved Relocation Plan) from the work area.	USFWS BO-6	During	Monique Fountain			Dana Bland Bryan Mori
At least one stable escape ramp constructed of earthen fill or wooden boards with no steeper than a 1:1 slopes shall be placed in excavated areas deeper than 6-inches and with slopes greater than 30 degrees.	CDFW LSA AMM 2.3(b)4)	During		Verify	Implement	
Begin construction activities gradually (e.g., move around the project area and start equipment sequentially), to avoid startling marine mammals with sound. Biological monitors will have authority to stop construction if marine mammals appear severely distressed or in danger of injury.	NMFS IHA-4(b) (Monitoring); USFWS IHA-6(c) and 7(c); USFWS BO-8; CDFW LSA AMM 2.3(c)(1) and 2.3(c)(3)	During	Rikke Jeppesen	Verify	Implement	Approved marine mammal observers
Biological monitoring will start ½ hour prior to start of construction and end ½ hour after construction and shall ensure adherence to suitably-sized disturbance-free buffer zones. Complete observations of the number, type(s), location(s) and behavior(s) of marine mammals. Monitor shall have the authority to stop project activities to prevent marine mammal harassment, or if marine mammals enter the exclusion zone during construction.	IS/MND BIO-1a, 1-c; RWQCB-PR 2; NMFS IHA-4(b)(iii) and IHA-4(b)(v) (Monitoring); USFWS BO-7; USFWS IHA-6(d) and IHA-7(f); CDFW LSA AMM 2.3(c)(3)	Before, during	Rikke Jeppesen			Approved marine mammal observers

MEASURE	SOURCE DOUCMENT	TIMING	RESPONSIBILITY			
			LANDOWNER (CDFW/ESF)	CONSTRUCTION MANAGER (DU)	CONTRACTOR	TECH SPECIALIST
Monitoring protocols for marine mammals shall be implemented at all times when work is occurring: 1) in-water; 2) north of a line starting at 36° 48’38.91 N 121° 45’08.03 W and ending 36° 48’38.91 N 121° 45’27.11 W; or 3) within 100 feet of tidal waters. When work is occurring in other areas, the monitoring protocols shall be implemented for the first 3 days of construction and anytime there is a significant change in activities or location of construction activities within the project area. If disturbance is noted at any time, then monitoring shall continue until there are 3 successive days of no disturbance. If there is a gap in construction activities of more than one week, the monitoring protocols shall again be implemented for the first three days that construction resumes. See NMFS IHA-4(b)(iv) (Monitoring) for specific data collection requirements.	NMFS IHA-4(b)(iv) (Monitoring); USFWS IHA-7(a)-(b); USFWS BO-7	During	Rikke Jeppesen			Approved marine mammal observers
An exclusion zone (shutdown zone) of 15m shall be established during pile driving. Pile extraction or driving shall not commence (or re-commence following shutdown) until marine mammals are not sighted within the exclusion zone for a 15-minute period. If a marine mammal enters the exclusion zone during sheet pile work, work shall stop until the animal leaves the exclusion zone or until 15 minutes have elapsed without observation of the animal within the zone.	NMFS IHA-4(d)(Mitigation); USFWS IHA-7(d); CDFW LSA AMM 2.3(c)(4)	During	Rikke Jeppesen	Verify	Implement	Approved marine mammal observers
If sheet piles are used to isolate construction activities from tidal action, a vibratory pile driver shall be used and an exclusion zone would be implemented. The radius of the exclusion zone would be set at a minimum of 49-feet diameter to assure compliance with the interim criteria for Sound Exposure Levels (SEL). Do not commence pile extraction or driving until marine mammals are not sighted within the exclusion zone for a 15-minute period. If a marine mammal enters the exclusion zone during sheet pile work, work shall stop until the animal leaves the exclusion zone	USFWS IHA-6(f); USFWS BO-11; CDFW LSA Project Description	During	Rikke Jeppesen	Verify	Implement	Approved marine mammal observers
Allow marine mammal to leave on their own volition if present within work area. If animal flushing is necessary, coordinate with NMFS or USFWS to ensure presence of government official during flushing. If a pup less than one week old comes within 20 meters of working heavy machinery, delay construction until the pup has left the area. If pup doesn't leave, consult with NMFS and/or USFWS to determine course of action.	NMFS IHA-4(b) and IHA-4(c) (Mitigation); USFWS BO-11; USFWS IHA-6(g); CDFW LSA AMM 2.3(c)(5)	During	Rikke Jeppesen	Verify	Implement	Approved marine mammal observers
The biological monitor shall have the authority to stop project activities if take exceeds the type or level of take anticipated. See USFWS IHA-3 for a listing of authorized take of southern sea otter.	USFWS IHA-7(d)	During	Rikke Jeppesen	Verify		Approved marine mammal observers
Monitor for fish, to the extent feasible, including listed species that may occur within the project site.	IS/MND BIO-1c	Before, during	Monique Fountain	Verify		Qualified Biologist - Implement
CULTURAL RESOURCE MANAGEMENT MEASURES						
Train all personnel before project start, outlining procedures to follow if an archaeological resource is unearthed or discoveries of human remains.	IS/MND CUL-1	Before	Identify Archaeologist			Qualified Archaeologist – Implement
If improvements to the access road in restoration area are proposed, establish an Archaeologically Sensitive Area around site CA-MNT-2432 and monitor all work in the area. The State site record shall be updated with the resulting information.	IS/MND CUL-1; USACE No. 4	Before, During	Identify Archaeologist			Qualified Archaeologist – Implement

MEASURE	SOURCE DOUCMENT	TIMING	RESPONSIBILITY			
			LANDOWNER (CDFW/ESF)	CONSTRUCTION MANAGER (DU)	CONTRACTOR	TECH SPECIALIST
If prehistoric or historic-period archaeological resources are encountered, all construction activities within 100 feet shall halt and USACE shall be notified. A qualified archeologist shall review the site with 24 hrs of discovery.	IS/MND CUL-2	During	Identify Archaeologist			Qualified Archaeologist – Implement
Consult qualified paleontologist if paleontological resources (e.g., fossilized bone, teeth, shell, tracks, trails, casts, molds, or impressions) are discovered during ground-disturbing activities. All ground disturbing activities within 100 feet of the find shall be halted until a qualified paleontologist can assess the significance of the find and, if necessary, develop appropriate salvage measures.	IS/MND CUL-3	During	Identify Archaeologist / Paleontologist			Qualified Archaeologist - Implement
Contact County Coroner, if human remains are encountered. No further disturbance shall occur until the County Coroner has made the necessary findings as to origin and disposition. If the remains are determined to be of Native American descent, the coroner has 24 hours to notify the Native American Heritage Commission.	IS/MND CUL-4	During	Oversee	Verify		Qualified Archaeologist – Implement
Following completion of the project, inspect site CA-MNT-2432 and the general vicinity to ensure that no project-related site disturbance occurred during implementation. The State record shall be updated.	IS/MND CUL-1	After	Identify Archaeologist			Qualified Archaeologist – Implement
HAZARDS AND HAZARDOUS MATERIALS MANAGEMENT						
Wash and dry all equipment (hand tools, mechanical devices) prior to entering work area to prevent movement of invasive species. Inspect equipment for invasive species prior to use onsite.	CDFW LSA AMM 2.6(a) and 2.6(e)	Before		Verify	Implement	
Designate staging areas for equipment and vehicle fueling, storage, and maintenance at least 100 feet from waterways, in a location where fluid or accidental discharges cannot flow into waterways. Stationary equipment located adjacent to a stream shall be positioned over drip paans.	RWQCB-PR 10 & PR-11; USFWS BO-13; USFWS IHA-6(h); CDFW LSA AMM 2.6(c)	Before, during		Verify	Implement	
Maintain all vehicles onsite and check daily for fuel, oil, and hydraulic fluid leaks or other problems that could result in spills of toxic materials.	RWQCB-PR 9; CDFW LSA AMM 2.6(b)	During		Verify	Implement	
Prevent raw cement, concreate, asphalt, drilling fluids or lubicants, paint, oil or other petroleum products from contaminating the soil and/or entering waters.	CDFW LSA AMM 2.9(b)	During		Verify	Implement	
Confine all trash and debris in closed bins and dispose of at an approved site at least weekly.	RWQCB-PR 8	During		Verify	Implement	
In the event of a release or spill of hazardous material, the contractor shall cease work, implement the "Preliminary Spill Prevention and Clean-up Plan", and notify the Monterey County Health Department and CDFW Elkhorn Office. The RWQCB and CDFW shall also be immediately notified of a spill and consulted regarding clean-up procedures.	IS/MND HAZ-1; RWQCB Adm. Condition No. 9, RWCB-PR 7; CDFW LSA AMM 2.9(c)	During		Verify	Implement	
Contaminated soils shall be excavated, tested, and disposed of, as appropriate, at a licensed disposal facility.	IS/MND HAZ-1	During		Verify	Implement	
Remove and clear all construction-related equipment, materials, and any temporary BMPs no longer needed from the site upon project completion.	RWQCB-PR 13	After		Verify	Implement	
REPORTING						

MEASURE	SOURCE DOUCMENT	TIMING	RESPONSIBILITY			
			LANDOWNER (CDFW/ESF)	CONSTRUCTION MANAGER (DU)	CONTRACTOR	TECH SPECIALIST
Prepare a Construction Traffic Control Plan prior to construction for review by the Monterey County Public Works and Planning Department and California DOT.	IS/MND Trans-1	Before	Verify	Implement		
Obtain all permits for work in road right of ways and use of oversized/overweight vehicles.	IS/MND Trans-1	Before	Verify	Implement		
Coordinate with Monterey County Public Works to ensure any imported sediment is substantially completed prior to the County's repaving project of Dolan Road. May need to coordinate repair / repaving of Dolan Road may be required if not possible.	IS/MND Trans-1	Before	Implement			
Notify RWQCB if mitigations in Cert. No. 32716WQ09 are altered by the imposition of subsequent permit conditions by any local, state or federal regulatory authority.	RWQCB-PR 14	Before	Implement			
Submit detailed dewatering/diversion plans to the RWQCB at least 21 days prior to any dewatering or diversion. Dewatering and diversion shall not commence until applicant has obtain RWQCB approval of the plan.	RWQCB-PR 12	Before (21 days)	Submit	Develop		
Submit final design plan specification of berm to CDFW no more than 1 week prior to the start of construction. Email to project contact and R4LSA@wildlife.ca.gov.	CDFW LSA AMM 2.10(c), Reporting Measure 3.2	Before (7 days)	Submit	Develop		
Request approval in writing of qualified biologist from USFWS and NMFS at least 30 days prior to the initiation of activities. Submit approved biologists to CDFW prior to start of project activity.	USFWS BO-RPM1; CDFW LSA AMM 2.3(b)(1) and 2.3(c)(2), Reporting Measure 3.2	Before (30 days)	Submit			
Submit a work schedule to CDFW prior to beginning construction. Email to project contact and R4LSA@wildlife.ca.gov.	CDFW LSA Admin Measure 1.7, Reporting Measure 3.2	Before	Implement			
Submit reports of pre-activity surveys to CDFW 1-week prior to the start of construction, including results of surveys for nesting birds if applicable. Email to project contact and R4LSA@wildlife.ca.gov.	CDFW Reporting Measure 3.2	Before (7 days)	Implement			
Notify RWQCB at least 7 days in advance of any ground disturbing or grubbing activities. Submit notification with start date to RB3_401Reporting@waterboards.ca.gov.	RWQCB -MRR 2	Before (7 days)	Implement			
Notify the Southern Sea Otter Recovery Coordinator at least 48 hours prior to the start of construction activities (805-677-3325).	USFWS IHA-4	Before (48 hours)	Implement			
Prepare a CRLF and CTS Relocation Plan for USFWS approval 30 days before construction begins. The Relocation Plan should include relocation methods, relocation site(s), and post-relocation monitoring if CRLF or CTS are observed within the construction area. Provide approved plan to CDFW prior to start of construction.	USFWS BO-2, RPM-2; CDFW LSA AMM 2.3.(b)(2) and Reporting Measure 3.2	Before (30 days)	Implement			Qualified Biologist - Assist
Maintain a log that documents numbers of marine mammals present before, during, and at the conclusion of daily activities. Record basic weather conditions and marine mammal behavior.	NMFS IHA-4(b) (Monitoring); USFWS IHA-7(g)	Before, during, after	Verify			Qualified Biologist – Implement
Contact USFWS, Ventura Fish and Wildlife Office at (805) 644-1766 if dead or injured CTS or CRLF found. Initial notification must be within 3 working days. Injured animals should be transported to a qualified veterinarian; the remains of any dead animal must be placed with the California Academy of Science Herpetology Department.	USFWS BO (Reporting)	During	Corey Hamza	Verify		Qualified Biologist – Implement

MEASURE	SOURCE DOUCMENT	TIMING	RESPONSIBILITY			
			LANDOWNER (CDFW/ESF)	CONSTRUCTION MANAGER (DU)	CONTRACTOR	TECH SPECIALIST
Contact NMFS, Office of Protected Resources at (301) 427-8401; NMFS West Coast Stranding Coordinator at (562) 980-3230; and USACE, Regulatory Office at (415) 503-6795, if marine mammals or anadromous fish are injured or killed as a result of the project. The finder should leave the animal alone, make note of any circumstances likely causing the death or injury, note the location and number of individuals involved, and, if possible, take photographs. Immediately cease the activity that resulted in injury or harm the protected species until NMFS is able to the review the circumstances.	USACE No. 2; NMFS IHA-5(b)(i) through (iii)	During	Monique Fountain	Verify		Qualified Biologist – Implement
Contact the Monterey Bay Aquarium at (831) 648-4840 if dead or injured sea otter and notify USFWS' Sea Otter Recovery coordinator at (805) 612-2793 within 24 hours. Written report must be submitted to USFWS within 3 working days.	USFWS BO (Reporting)	During	Ron Eby	Verify		Qualified Biologist – Implement
Notify Monterey Bay Aquarium's sea otter 24-hour emergency line (831-648-4840) immediately upon seeing an injured sea otter in the vicinity of the construction site, and the USFWS Soutehr Sea Otter Recovery coordinator within 1 hour of such a signting. Suspend all activities if construction activities cause of injury or death.	USFWS IHA-8(b)	During	Verify			Qualified Biologist - Implement
Notifiy CDFW upon completion of construction. Email to project contact and R4LSA@wildlife.ca.gov.	CDFW LSA Admin Measure 1.7	After	Implement			
Notify RWQCB within 7 days of completing construction. Submit notification with end date to RB3_401Reporting@waterboards.ca.gov.	RWQCB -MRR 3	After	Implement			
Submit Final Project Report to CDFW within 30 days of completing project. Report to address protective measures in LSA and to detail relocation of CTS and CRLF, as appropriate. Include photo documentation of the project site before, during, and after construction. Email to project contact and R4LSA@wildlife.ca.gov.	CDFW LSA Reporting Measure 3.2	After	Verify			Qualified Biologist - Implement
Submit a report to NMFS and USFWS within 90 days of the completion of marine mammal monitoring, or 60 days prior to the issuance of any subsequent IHA (if required), whichever comes first. The report shall detail monitoring protocols, summarize the data recorded during monitoring, and contain an estimate of marine mammals that may have been harassed.	NMFS IHA-5(a); USFWS IHA-8(a)	After	Verify			Qualified Biologist - Implement
Submit CTS and CRLF survey and monitoring report to USACE and USFWS within 90 days of project completion.	USFWS BO (Reporting)	After	Verify			Qualified Biologist – Implement
Complete annual monitoring in accordance with the Minhoto Monitoring Plan spreadsheet and RWQCB Certification for a minimum of 5 years. Annual monitoring reports should be submitted to USACE and RWQCB by May 31 of each year following project construction.	USACE No. 5; RWQCB-MRR 5	After	Implement			
Monitor project area for five years and provide reports to various agencies. See RWQCB Cert. No. 32716WQ09 for details.	RWQCB-MRR 1.2	After	Implement			
Within 7 days of verification of achievement of success criteria and completion of all monitoring, notify RWQCB in a final Annual Project Status Report. Submit to RB3_401Reporting@waterboards.ca.gov.	RWQCB – MRR 4	After	Implement			

Appendix 6

Environmental training pamphlet and sign-in sheet

California Red-legged Frog

- Lives in ponds and along creeks with deep pools and cover of vegetation for escape (e.g. willows, tules, cattails, large mats of pondweed or algae).
- Attaches large egg masses to submerged parts of plants in ponds or slow moving parts of streams during January to April.
- Can travel long distances (>1 mile) over land between streams and ponds during rainy periods.
- Adults most active at night; juveniles often seen during the day around edges of ponds.
- Range in size from 2 to 6 inches length.
- Belly and hind legs are salmon pink to bright red; dark blotches on back with background back color of brown, olive or reddish-brown.
- Presence of dorso-lateral folds on each side of back extending from the eye to the hind leg.
- White or cream colored stripe on upper lip.
- Federally listed as a "threatened" species; fully protected under the Endangered Species Act.

California Red-legged Frog

California Red-legged Frog

Photo: Bryan Mori Biological Consulting

CRLF Metamorph and Tadpoles

- Eggs hatch in 1-2 weeks depending on water temperature
- Tadpoles require up to 6 months to develop into terrestrial frogs
- Males reach maturity in 2 years and females by 3 years
- Adults can live 8-10 years
- Diet consists of smaller frogs, invertebrates, and occasionally small mammals

Steps to Avoid Impacts

- Do not handle the animals. Immediately contact project site supervisor, who will notify the site biologist. The biologist will relocate animals if necessary.
- If the animal is in an active construction area, work in that area is to cease until the animal either leaves of its own accord or can be relocated by the biologist. Flag the area to prevent construction equipment from harming the animal.
- If any dead or injured California red-legged frogs or California tiger salamanders are discovered in the work area, immediately notify the project foreman. Please place any dead specimens in a plastic ziplock bag and note the location where it was found. For an injured frog or salamander, place it in a bucket, add water, and keep it IN THE SHADE with the lid firmly closed, until the designated biologist can pick it up.
- The project foreman shall inform the construction personnel of the limits of the work area to prevent inadvertent entry into non- construction areas by heavy equipment.
- Collect all trash (especially food wrappers) on a daily basis and remove to a designated disposal site to prevent the trash from attracting predators such as raccoons.
- Fueling and maintenance of heavy equipment shall be at a designated area at least 20 meters (60 feet) from any watered parts of the pond.
- The project foreman shall advise all workers of preventative measures and emergency containment procedures, should a fuel spill occur.

Other Common Amphibians in Comparison with CRLF

Sierran Treefrog (1 - 2″)
(black mask across face)

Western Toad (2.5 - 5")
(white stripe down center of back)

Bullfrog (3.5 - 8")
(bright green snout, large "ear" structure)

California Red-legged Frog Juveniles

California Red-legged Frog (2 - 6")

Contact Persons:

Project Manager:

Biologist:
Dana Bland
Dana Bland & Associates
Office: 831.688.2104

California Tiger Salamander (7-8")

California Tiger Salamander (7-8")

California Tiger Salamander

- Black with discrete yellow spots
- Adults are large, total length is 7-8 inches
- Primarily a terrestrial salamander
- Lives in burrows in grasslands
- Migrates to ponds in winter to breed
- Larvae hatch from eggs and are aquatic
- Larvae take 3-6 months to transform to juveniles
- Feed mostly on insects
- State and federally threatened species

Dana Bland & Associates
Consulting Biologists

Burrowing Owl

- A California Species of Special Concern
- Occasional forager in tidal marshes and adjacent upland areas. Uses California ground squirrel burrows for roosting.
- We usually have one around for a few weeks in the winter.
- If you see one, give it space and please let us know.

Nesting Birds

- In the spring there may be nesting birds in non-mowed areas.
- If nests are found, let us know and we will fence them until fledged.

Species to Watch Out For

Yampah Island Ecotone

- The ecotone is the transition zone between wetlands and uplands. Rare native plants are often found in this sensitive habitat
- The east side of the project area has some of the nicest ecotone in all of Elkhorn Slough.
- We will protect these areas with orange fencing
- Do not go into these areas with any equipment

Marine Mammals

- We have both the southern sea otter and harbor seal in the project area
- Elkhorn Slough is an important place for these seals and otters to live and reproduce
- Mainly eat fish, shellfish and crustaceans
- Pupping is in spring and summer with peak pupping season in May but can occur anytime
- We have about 65 harbor seals that regularly use the project area and many more harbor seals just outside.
- Sea otters generally stay out of the project area but the harbor seals may be curious and also want to go back to their regular haul out sites.
- Both are protected under the Marine Mammal Protection Act and the southern sea otters are also protected under the Endangered Species Act (with only 3000 left).
- Especially loud noise can damage their eardrums - if they cannot hear, they cannot survive

Protecting marine mammals

- Seals and otters may be curious about construction activities. If either appears to be coming within 15 meters, pause construction activities until they have moved back beyond that zone.
- Slow starts are required.

Southern Sea Otter

Harbor Seal

Species to Watch Out For

Fish

- Elkhorn Slough is an important nursery area for many fisheries
- Not likely to see either species listed below – little freshwater
- If you see either species or any dead fish please alert your ESNERR 24 hour contact immediately.

- Steelhead, sea-run rainbow trout
- At least a few have been found in every coastal stream in Monterey County in the last ten years

- Slow growing long-lived fish
- Weigh up to 350 lb; 60-70 years
- Adults live nearshore, bays, and estuaries, spawn in freshwater
- Juveniles spend a few years in freshwater

Biological Monitors

- The biological monitors are required by the regulatory agencies to be on site when there is potential disturbance of marine mammals
- Please be alert and aware of what the monitors are doing
- They have the authority to stop construction if needed
- They may remind you of some of the many conditions of the permits ranging from general housekeeping to maintaining a buffer zone for marine mammals

If you have any questions or see anything that you think needs our attention please contact us:

ESNERR 24 hour contact:
Monique Fountain

monique@elkhornslough.org

Environmental Awareness Brochure for Tidal Marsh Restoration Construction in Elkhorn Slough, California

Elkhorn Slough Foundation Since 1982

Elkhorn Slough National Estuarine Research Reserve

PRE-CONSTRUCTION ENVIRONMENTAL AWARENESS TRAINING FOR THE ELKHORN SLOUGH TIDAL MARSH RESTORATION PROJECT

DATE:	PRINT NAME:	SIGNATURE:	COMPANY:
12/11-17	Warren Gomes Jr	[signature]	Galindo Construction
↓	Daniel Garcia	[signature]	—
	Travis S. Reynolds	[signature]	—
	George Sanchez	[signature]	—
12/11-17	Zachary Crouson	[signature]	—
↓	Ron Eby	[signature]	ESMRR
	Steve Carroll	[signature]	DU
	Don Glasco	[signature]	ESNERR
	Rhea Jeppesen	[signature]	—
12/11-2017	Monique Fountain		ESNERR
1/16-2018	John Morris	[signature]	Gomes
1/29-2018	Ruben Gomez	[signature]	Galindo
1/29-2018	Ron Galindo	[signature]	Galindo

Appendix 7

Spill prevention plan

Emergency Response Plan – Elkhorn Slough Project
Warren E. Gomes Excavating, Inc.

1.0 Introduction

The following procedures must be followed when responding to a fire or a spill involving hazardous materials on the jobsite. These procedures have been established to protect employees and ensure a safe resolution to accidents of this nature.

2.0 Fires

2.1 Employees should always attempt to put out a fire with an extinguisher when feasible. This must only be attempted when the employee has been trained and is confident that they are not putting themselves at undue risk.

2.2 When a fire cannot be put out using a fire extinguisher, everyone on the jobsite, must be notified immediately for evacuation.

2.3 Soon as possible, call 911 or the North County Fire District at 831-633-2578 for assistance.

2.4 All employees will meet outside at the front gate for a headcount after evacuating. If it is discovered that anyone is missing, notify the fire department when they arrive. Untrained rescuers can endanger themselves and those they are trying to rescue. During most emergencies, leave rescue work to professional responders who are appropriately trained and equipped.

3.0 Spills

3.1 The same personal protective equipment used while handling a certain material in normal conditions must also be worn while cleaning it up after it has been spilled.

3.2 When a spill is first identified, stop the leak at the source and try to prevent the spill from spreading. Immediately protect any drains so the liquid does not reach the water supply. Additional containment may be provided with the absorbent booms provided in the Spill Kit.

3.3 Eliminate all potential sources of ignition, until the flammability of the spilled liquid is determined.

3.4 Small spills of less than 10 gallons must be soaked up immediately using the granular absorbent provided in the Spill Kit. The granular absorbent must be placed in the proper waste container after it has been used. A shop vacuum with the filter removed may also be used to facilitate the clean up. The liquid in the vacuum must be placed in the appropriate waste or recycling container immediately following the clean up. WARNING: Do not attempt to vacuum gasoline or any other highly flammable liquid, as an explosion may occur. WARNING: Battery acid leaks must be treated with the neutralizer provided in the Spill Kit before using an absorbent.

3.5 Large spills over 10 gallons must be vacuumed off the ground with a vacuum truck. If possible, construction equipment must be used to prevent the spill from continuing to spread, by creating temporary berms. The remaining residue must be vacuumed and soaked up, using the shop vacuum and granular absorbent found in the Spill Kit. The liquid in the vacuum truck must be pumped into an appropriate waste or recycling container, or hauled to an appropriate waste treatment facility.

3.6 Large spills, that meet certain criteria, must be reported in accordance with the following guidelines.

4.0 Spill Notification and Reporting

4.1 If any of the following conditions are met, the California Governor's Office of Emergency Services (OES) at 800-852-7550 must be notified:

a) Any spill or other release of one barrel (42 gallons) or more of petroleum products.
b) Discharges of any Hazardous substances, oil, or petroleum products into or on any waters of the state.
c) Discharges that may threaten or impact water quality.

4.2 If the California OES determines that emergency response assistance is required, the owner or operator shall notify the local responding agency or the 911 emergency system.

a) Local Emergency Response Agency (or the Local Fire Department) at 911.
b) California Regional Water Quality Control Board at 916-255-3000.
d) California Department of Fish & Game at 916-355-0976.

4.3 The National Response Center must be contacted immediately at 1-800-424-8802 if any of the following conditions are met:

a) The oil spill/release will reach a navigable body of water or adjoining shoreline.
b) Water quality standards could be violated.
c) The spill/release could cause a film, "sheen," or discoloration.
d) The spill/release could cause a sludge or emulsion.
e) The spill/release exceeds Federal Reportable Quantities (CERCLA).

4.4 For releases to navigable waters or adjoining shorelines, the U.S. Coast Guard Marine Safety Office also will be contacted at 510-437-3073.

Appendix 8

Geotechnical assessment

Elkhorn Slough TMRP: surface and subsurface properties and settlement potential at Minhoto and Hester Marsh

Ivano W. Aiello

Summary

During the initial phase of the Elkhorn Slough Tidal Marsh Restoration Plan, about 45 acres of subsided marshes, intertidal mudflats and tidal channels at Minhoto and Hester Marsh (SA) will be restored to a 'healthy' elevation for marsh growth by sediment addition (the MHHW datum (1.76m or 5.8 ft NADV88). For the success of this restoration project it is essential that the final elevation (10+ years later) of the new marsh settle very close to the targeted elevation. However, adding sediments to an existing soil has mechanical and sedimentological implications that are dependent upon the thickness, extent and weight of sediment added, the relief of the area, the hydrology, and the geotechnical/physical characteristics and the thickness of compressible sediments that will be subjected to the increase in lithostatic stress caused by the overburden.

Through a combination of field, analytical, and modeling exercises, this study addresses four main questions, which are critical to the success of the restoration project. Note that the values provided by the model are for the M2, M3 and H1 subareas (~27 acres fill area; ESA, 2014) of the MHM (~36.4 acres) and that the phase I restoration also includes M1 (an additional 9.5 acres):

1) What is the subsurface lithology/stratigraphy of MHM?

Using a combination of sedimentological/physical properties analyses of core samples, field surveys using a modified dynamic cone penetrometer and available geotechnical reports and science literature, the subsurface of MHM can be described as a 4 layer system laying on a 'basement' which forms the bottom of the paleo-valley. From top to bottom: 1) a 'slurry' layer at the very top (~0-0.6m thick) that has high water content (>>~55%) and is above the Liquid Limit; this layer is thicker in lower relief habitats; 2) a 'plastic' layer (~0-0.6m thick) which is more cohesive and thicker in higher relief habitats; 3) a 'stiff' layer (~2m calculated thickness) which is the remnant of the previously dried marsh; 4) a normal consolidated layer which thickness is not known but was predicted using different modeling exercises.

2) What is the accommodation space currently occupied by the slurry?

The MATLAB model created for this project calculates the volume of sediments needed to fill the elevation between the uppermost cohesive surface (top of the plastic layer) and the target elevation (MHHW) based on 136 sites surveyed with a modified penetrometer and a Terrestrial Laser Scanner and extrapolating the results to the SA. The total volume of accommodation space in SA, if the slurry layer was to be completely removed, is 23,375 m^3 (33,967 cy) (Table 1).

3) How much settlement will occur after the predicted volume of sediments is added?

The oedometric empirical calculations for the total settlement that will occur after the overburden layer is added depend on the geotechnical characteristics (e.g. Compressibility Index Cc, and the Initial void ratio e_0) of the subsurface layers and their thickness. Note that for all the calculation done by the model the thickness of the overburden layer is calculated as the distance between the top of the plastic layer and the MHHW datum.

The geotechnical data available to calculate the settlement were limited and were based on the reports by ENGEO (2013) and Kleinfelder (2002) which analyzed boreholes at the nearby Parsons Bridge area. The Cc values reported by ENGEO were only for the uppermost layers and relative low, so the calculations for settlement presented in this memo are conservative (underestimates). Since the cores collected in the area are very shallow (max 4 m) the total thickness of compressible sediments above the ‘basement’ was modeled with MATLAB using and final target elevation of MHHW datum (1.76 m or 5.8 ft NADV88) and 3 different scenarios that describe different geometries: 1) ‘paleo-valley’, max thickness ~11m below the axis of the main channel; 2) ‘shallow bowl’, max thickness ~7.5 m below the axis of the main channel; 3) ‘shallow flat’, essentially a flat basement surface at a constant depth of 3m (Tables 1, 3 and 4). The average settlement of the 3 models is 21.15 cm and the average loss of volume for the SA is 15,170 m^3 (19,720 cy).

What is the total volume of sediment that needs to be added to the surface to attain the target elevation.

This is an iterative process, as the weight of additional overburden will cause additional consolidation of the underlying sediments. See Table 1 for the volume of sediment needed to reach a final target elevation of 1.76 m (5.8 ft) NAVD88 (including slurry and consolidation of underlying soils).

Adding the average settlement of the 3 models for the SA (15,170 m^3 or 19,720 cy) to the volume of the slurry layer (23,375 m^3) and the accommodation space between MHHW and the top of the slurry layer (73,093 m^3) extrapolated from the TLS surveys we obtain a total of 111,638 m^3 (145,129 cy), with values of 107,782 m^3 (140,117 cy) and 117,238 m^3 (152,410 cy) for the lowest and highest settlement estimate, respectively (Table 1).

The bottom of Table 1 also shows how the previous figures would change if the slurry layer is not removed and partially dried from ~70% to ~40% water content. Under this scenario, the slurry would turn into a more plastic layer with a volume of 10,264 m^3 (13,424 cy) which can be then subtracted to the previous estimates.

	SA (M2,M3,H1 only)		All (M1 = 35.32% of rest)	
	m3	cy	m3	cy
Slurry - complete removal	23,375	30,387	31,631	41,120
Slurry partially dried (~70% to ~40% water content)	10,264	13,343	13,889	18,056
Accomodation space (TLS)	73,093	95,020	98,909	128,582
Accomodation space+slurry	96,467	125,408	130,540	169,701
Total consolidation 1st&2nd settlement - lowest estimate (shallow flat)	11,315	14,709	15,311	19,905
Total consolidation 1st&2nd settlement - highest estimate (deep valley)	20,771	27,002	28,107	36,539
Total volume - lowest estimate (shallow flat)	107,782	140,117	145,851	189,606
Total volume - highest estimate (deep valley)	117,238	152,410	158,647	206,241
Most likely scenario (slurry partially dried and total consolidation)				
Total volume - lowest estimate (shallow flat)	97,518	126,774	131,962	171,550
Total volume - highest estimate (deep valley)	106,974	139,066	144,757	188,185

Table 1 - Overview of the model results

Introduction

This document describes the field, laboratory and modeling procedures used to reconstruct the surface and subsurface characteristics of Minhoto and Hester Marsh (MHM) in Elkhorn Slough (Figure 1). This study combine new collection of samples and field measurements, MATLAB modeling, the results of previous geotechnical work done at MHM and at the nearby Parsons Bridge site, as well as on cores and additional material previously collected in the area.

MHM is a ~36.4 ac of subsided pickleweed marsh, intertidal mudflats, tidal channels and remnant levees. The area has multiple cross-levees and both natural and dredged channels; the major channel runs north-south through the remnant marsh (close to 6611300 easting; Figure 1).

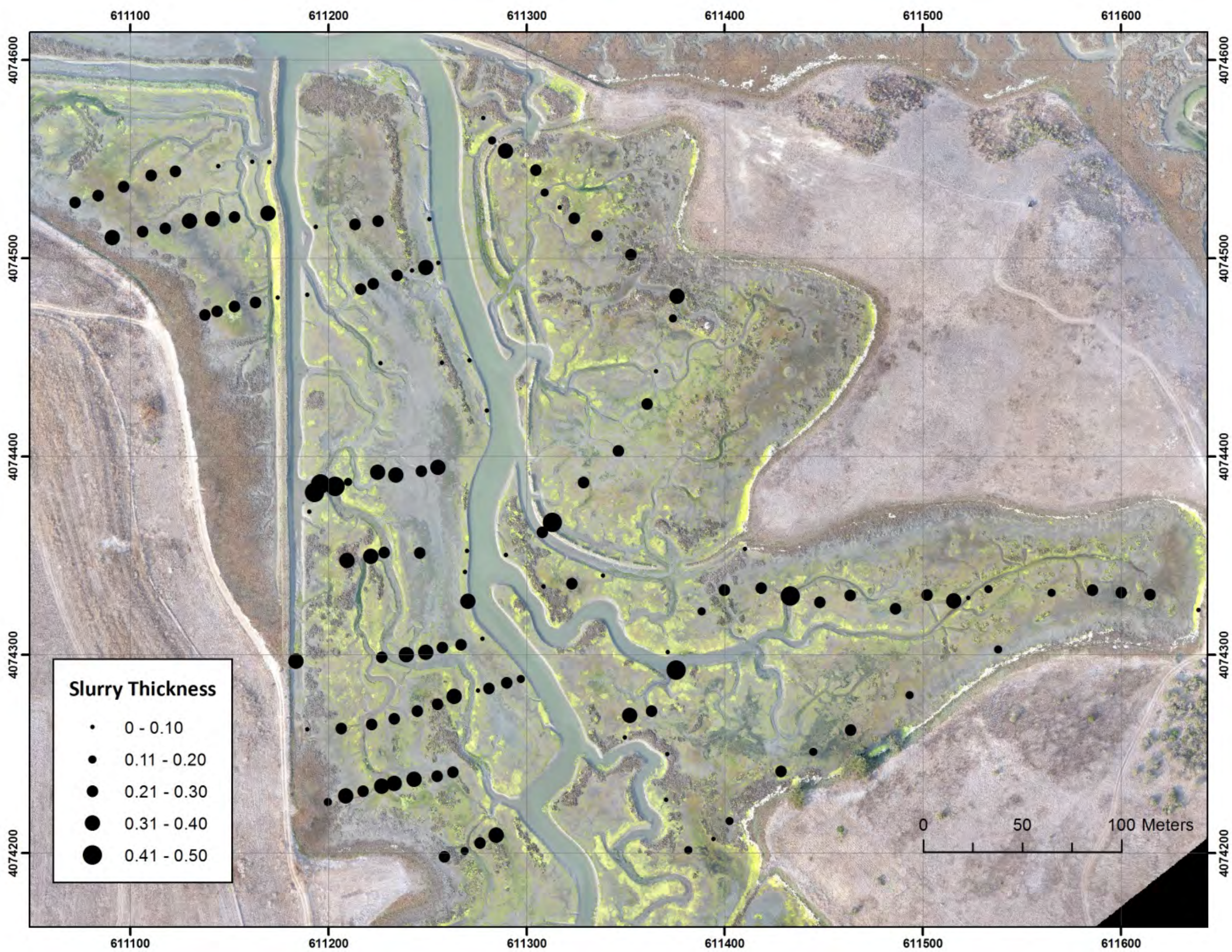


Figure 1 –Overview map of the MHM area and location of the 136 survey sites. The size of the circle at each site corresponds to the thickness of the 'slurry' layer

MHM has experienced ~70cm of subsidence after it was diked in the first part of the 20^{th} century if we assume that before diking the marsh was around MHHW (.1.76m) and now the average surface elevation is 1.09cm (see later for more details). The overall strategy of the Tidal Marsh Restoration Project (TMRP) to restore the MHM areas is to use imported and onsite sediments to raise marsh and mudflat elevations to MHHW and restore tidal marsh habitats in these areas.

For the success of this restoration project it is essential that the final elevation reached by the newly added sediments falls very close to the targeted elevation. However, adding sediments to an existing soil has mechanical and sedimentologically implications that are dependent upon the amount (thickness and weight) of sediment added, the relief of the area, the hydrology, and the geotechnical/physical characteristics and the thickness of compressible sediments that will be subjected to the increase in lithostatic stress.

Subsurface anatomy at Minhoto

The shallow subsurface of the MHM has been repeatedly investigated in the last few years using different types of coring tools by MLML's Geological Oceanography Lab and by ENGEO (2013) for geotechnical testing.

Figure 2 – Core table photograph showing the lithologic characteristics of the consolidated to over-consolidated sediments at Minhoto including alternations between laminated and homogenous intervals.

The vibracores collected by MLML as part of class exercises (in 2014 and 2015; Figure 2) cored until refusal which was ~4m below the surface. The vibracores did not recover the highly non-cohesive top layer ('slurry' layer see below), and undersampled the more cohesive but yet poorly consolidated layer beneath it ('plastic' layer see below). As a result, during both coring exercises a difference of ~1.5m between the depth reached by the liner and the actual length of the core recovered was measured. The core collected in 2014 was ~2.8m long, while the one is 2015 was ~2.9m. The portion of subsurface that was recovered presents plastic (towards the top) to indurated (middle-bottom) characteristics, and prominently laminated intervals alternating with homogenous intervals (Figure 2), more specifically: 1) darker, organic-rich, laminated intervals with mainly silt grain size and ~10-30% clay with abundant root matter (marsh deposition); 2 lighter-colored homogenous biogenic-rich clay (~50%) intervals (lagoon-open water). The latter have the highest porosities and moisture content (>50%). From top to bottom the layers include:

1) The upper ~0-60cm is a soupy mud (here referred as 'slurry layer') which has virtually no cohesion underlaid by 2) a more cohesive sediment with 'plastic' characteristics. The latter is in turn is underlaid by a 3) over-consolidated 'stiff' layer' (Figure 3). 4) The sediment column between the hard, incompressible substratum that composes the bottom of the sediment column 'basement' and the stiff layer is of unknown thickness and physical properties. The models used for this study assume that

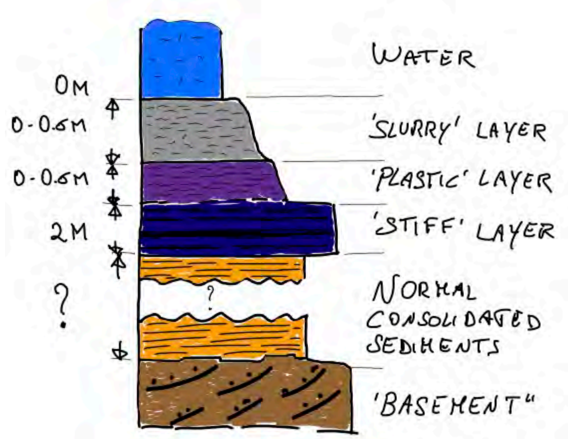


Figure 3 – Schematic lithologic column, showing thickness ranges, and relative consolidation (expressed by the width). See text for more details.

layer 4 is normal-consolidated and the thickness has been modeled using 3 different scenarios.

Study goals

There are many challenges associated with this type of restoration approach, some of which are addressed by this study:

1) This study describes the physical and geometrical characteristics of the ‘slurry’ and ‘plastic’ layers using field measurements with a cone penetrometer, and a MATLAB script that calculates the volume to account for the additional sediment addition needed if the slurry layer is entirely removed and/or dried during restoration. The thickness of the overconsolidated layer (‘stiff’ layer) beneath the plastic layer is estimated based on the amount of pore water loss proportional to subsidence.
2) The addition of a sediment layer (herein referred to as the ‘overburden layer’) will create an excess lithostatic load. According to Terzaghi’s theory of sediment consolidation, in fine soils (silts and clays) with low permeabilities the soil is undrained as the load is applied; slow seepage occurs and the excess pore pressures dissipate slowly, while consolidation settlement occurs. Different MATLAB scripts were created to calculate: a) the depth at which the sediment overburden will produce an excess stress using the Boussinesq equation; b) the amount of sediment settlement (compaction) for each of the layers shown in Figure 2 (using the oedometric formula and the available geotechnical measurements); c) the extrapolation of the amount of settlement and the volume loss caused by the sediment overburden to the entire MHM area based on 3 different model scenarios describing the thickness of sediments above a non-compressible (basement).

Methods and Results

Field surveys with the Terrestrial Laser Scanner (TLS) and data post-processing

In order to measure the thickness of the slurry layer and the plastic layer underneath it we used a Terrestrial Laser Scanner (TLS) and a survey rod with a 360º laser prism modified to be attached to the head assembly of a standard Dynamic Cone Penetrometer without the 8kg drop-weight. A total of 136 survey sites (approximately $1m^2$) were occupied in the zones M2, M3 and H1 covering different habitats of the Sample Area (SA) area (Figure 1).

At each of the 136 sites three surfaces were surveyed during low (<1m) tides including (Figure 3): 1) the ‘surface’ elevation (top of the slurry layer); 2) the bottom of the slurry layer using the free-fall penetration of the rod+penetrometer, assuming that the slurry layer is frictionless and non cohesive; 3) the bottom of the plastic layer using 'push' penetration, which is how far the operator was able to push the rod+penetrometer assembly before refusal.

A MATLAB code was created to transform the topographic datasets and to identify the 3 surfaces, for each $1m^2$ window. The MATLAB code uses an algorithm to detect and separate each surface type (all measurements were done continuously) and then places depth and thickness information in three different matrixes with the standard format (NAVD88, m): northing, easting, depth/thickness. Finally, the code calculates the thickness of the slurry and the plastic layer, and calculates various statistical parameters (means, SDs) and plots the measured parameters in histograms and bivariate plots (see results).

Sample collection, moisture content and grain size analysis

To obtain samples from the uppermost sediment layers samples were collected from the very surface (top of 'slurry') and from below the bottom of the slurry (using a plastic liner). The samples were then analyzed in the geology lab at MLML for moisture content and for particle sizes.

Moisture content

Moisture content was analyzed using a Mettler-Toledo HR83 Moisture Analyzer. The results are shown in Figure 4. The water content of the surface (slurry) samples ranges between ~54% and ~80%. The water content of the bottom samples (top of 'plastic' layer) ranges between ~40 and ~60%. The differential in water content between 'slurry' and 'plastic' layer samples ranges between ~6 and ~16%, average 11.12% (Figure 4).

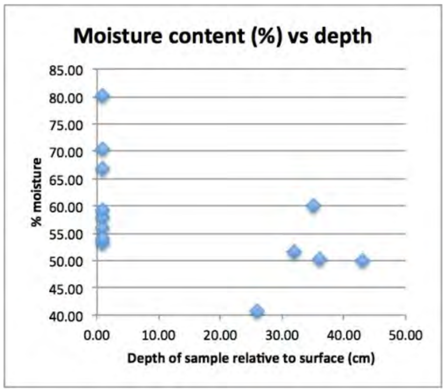


Figure 4 – The plot shows how the 'slurry' samples (o cm) have higher moisture content than the samples form the 'plastic' layer (~25-45cm).

Although it might seem small, the difference in water content between the two layers could account for dramatic differences in physical properties. For instance, if we consider the measurement at sampling site 2 (Table 1), the upper ~43cm of the slurry has ~67% water while the plastic layer below has 50% water.

The Attemberg limits provide a tool to describe the different consolidation behavior based on water content of a sediment: the liquid limit (LL) defines how much water makes the sediment behave like a fluid while the plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed without crumbling. According to the Kleinfelder (2002) report, based on the physical properties determined for Parsons Bridge borehole samples, the LL ranges between 54% and 70% water content while the PL ranges between 29 and 42%.

Hence, if we interpret the samples collected at Minhoto using the same approach as the samples tested at Parsons, the 'slurry' layer, which has water contents >~55%, is above the LL, while the sediment below is more plastic because water is ~<55%.

Particle sizes

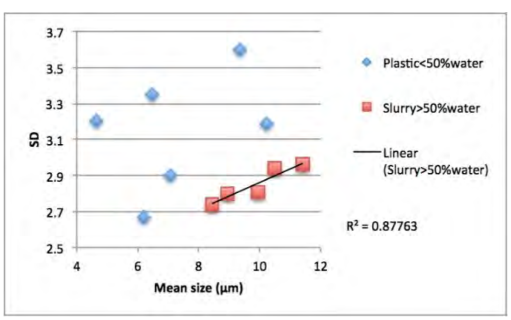


Figure 5 – Plot showing the relationships between mean size and SD for the 'slurry and 'plastic' samples.

The samples analyzed for water content were also analyzed for particle size distribution with a Beckman-Coulter LS 13 320 laser particle size analyzer (LPSA) attached to an aqueous module equipped with a pump and a built-in ultrasound unit.

All the samples analyzed for particle size from the 'slurry' are very similar (Table 2, Figure 5): they have the same mode, they are relatively well-sorted and there is clear positive relationship between mean size and SD (i.e. the coarser the less sorted) possibly indicating particle sorting by hydraulic energy. The SD of the slurry samples is generally lower (better sorted) than the SDs of the samples from the plastic layer. Conversely, the particle size data form the plastic layer is more scattered and thus heterogeneous (Figure 5).

Site #	Easting	Northing	Penetration (cm)	Sample	Mean	Median	Mode	SD
1	6111199	4074295	30	1_1	6.2	7.1	18	2.67
1	6111199	4074295	30	1_26	7.08	8.4	19.7	2.9
2	6111202	4074295	33	2_1	9.96	11.4	16.4	2.81
2	6111202	4074295	33	2_43	4.66	4.9	4.8	3.2
3	6111212	4074296	32	3_1	11.4	13.1	16.4	2.96
3	6111212	4074296	32	3_32	9.34	10.6	50.2	3.6
4	6111228	4074298	34	4_1	10.5	12	16.4	2.94
4	6111228	4074298	34	4_36	6.46	7.2	16.4	3.35
5	6111228	4074301	44	5_1	8.45	9.3	16.4	2.74
5	6111228	4074301	44	5_35	10.2	11.8	16.4	3.19
6	6111250	4074317	36	6_1	8.93	9.8	16.4	2.8

Table 2 – Results of the particle size analyses.

The previous observations support the moisture content analysis and the interpretation of the 'slurry' being a sediment above the LL: hence the slurry is a relatively homogenous hyperconcentrated fluid throughout the sampled region which is subjected to mixing probably due to a combination of tides and wind. Conversely the plastic layer reflects more local changes in sedimentation/habitats. The 'plastic' layer could be more representative to the original marsh surface that has been re-hydrated once Minhoto was re-opened to tidal action after desiccation. The 'slurry' layer could have a similar origin, although it experienced a larger amount of re-hydration, mixing and sorting as suggested above.

Models for settlement calculations: rationale and assumptions

A MATLAB model was developed to calculate the thickness of the layers. The model calculates the thickness of the overburden layer required to raise the elevation of the top of the plastic layer (which is the shallowest cohesive surface) in relation to the targeted MHHW datum for a healthy marsh growth (1.76m). Then the model calculates the settlement after the overburden layer is set in place, independently for each of the subsurface layers including plastic and stiff layers. Since the thickness of the normal consolidated layer below the stiff one is not known (Figure 2), three separate models were created which predict the thickness of this layer based on different basement scenarios: 1) v-shaped paleo-valley; 2) shallow bowl; 3) flat basement. Then each model calculates the settlement of the normal-consolidated layer, and finally the total settlement.

The settlement is calculated based on the oedometric formula:

(1) $S = H \times [(Cc/(1+e0))] \times \log [(dv+dvi)/dvi] \times Ip$

Where:

S=total settlement; dv = overburden stress; dvi = initial stress (kN/m^2); e0 = initial porosity ratio; Cc=coefficient of compressibility; H= thickness of overburden layer (m); Ip=Influence Coefficient.

Calculation of the Influence Coefficient (Ip) using the Boussinesq formula

The Influence Coefficient (Ip) is a very important parameter in any compaction/settlement study because it defines how deep/far the stress produced by a load added at the surface will propagate through the sediment column. The depth of propagation and the decrease of stress with depth are proportional to the force (mass times gravity) of the added load and to the area and shape of the overload's footprint.

Ip can be calculated with the Boussinesq formula:

(2) $Ip=1-(sqrt(1/(1+(a/z)^2))^3)$

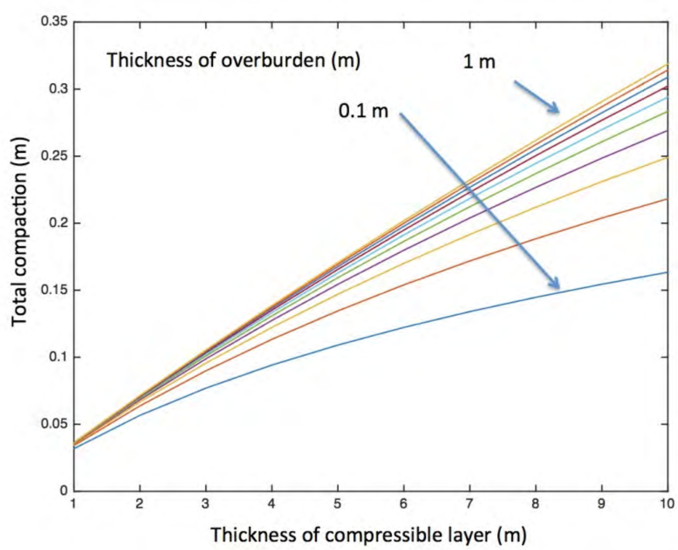


Figure 6 - The plot simulates the amount of compaction (y-axis) of a compressible layer (x-axis) due to the addition of a 100x100m soil amendment. The degree of compaction is mainly controlled by the thickness of the compressible layer while the thickness of the overburden layer is less significant.

For instance, if the thickness of compressible sediments is 10m, then the addition of 0.1m of sediments will generate a similar degree of compaction as the addition of 1m of sediment would on compressible sediments 5m thick.

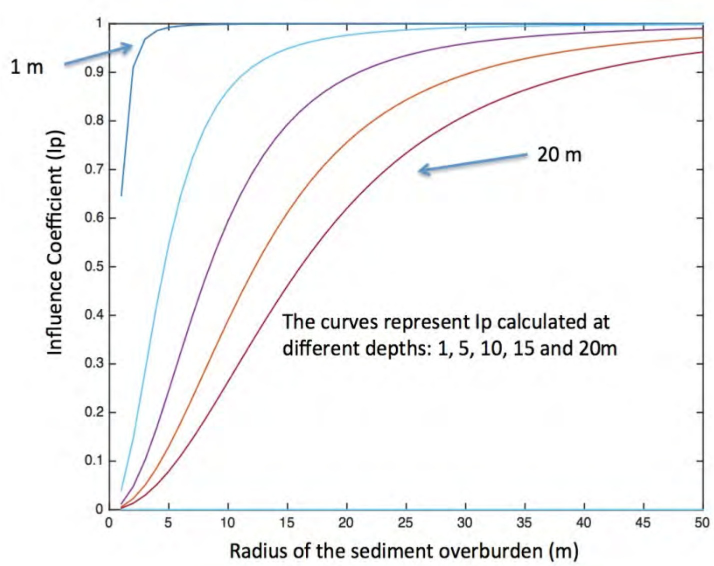


Figure 7 - The plot shows how the stress due to a sediment addition propagates with depth. The closer the Influence Coefficient Ip is to 1 the closer is the propagated stress to 100% of the load. The maximum thickness of compressible sediments predicted for Minhoto is about 10m.

The type of Boussinesq formula used is for a 'simplified' version of the problem since it addresses loads that have a circular shape whereby: Ip=influence coefficient (adimensional); a=radius of circle (m); z=target depth (m).

A MATLAB script was created to calculate Ip for a circular area with radius ranging between 1 and 50m and to calculate Ip for 4 different thickness of the compressible sediment column: 1, 5, 10 and 20m (Figures 6 and 7).

The plot in Figure 7 shows how the stress due to a sediment addition propagates with depth: the closer the Influence Coefficient Ip is to 1 the closer is

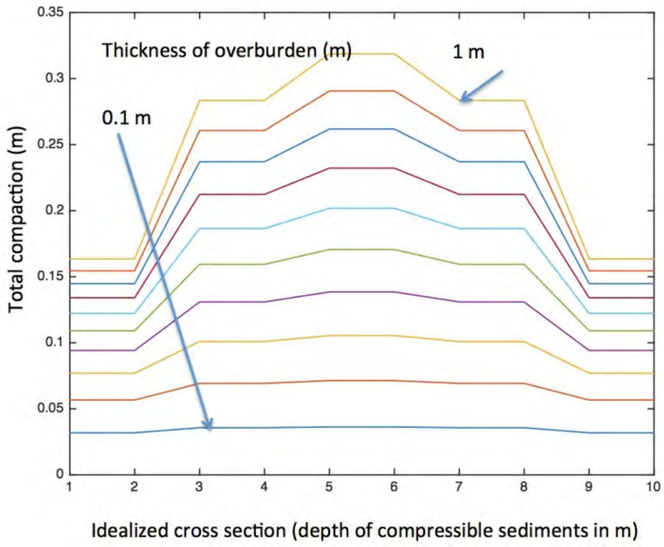


Figure 8- Idealized cross section across Minhoto; the differently colored curves represent different thicknesses of the overburden sediment as in Figure 6. It is obvious how the differences in consolidation between the margins and the center of the marsh becomes much larger with increasing thickness of the overburden layer.

stress propagation to 100% of the surface load. For a sediment addition of ~25m in radius and a sediment thickness of 10m (purple line in Figure 7; the maximum thickness of compressible sediments predicted for Minhoto) the stress propagates essentially unchanged throughout the sediment column, i.e. Ip=~1. Accordingly the model used for the settlement calculation uses Ip = 1.

The plot in Figure 8 shows the compaction differential between the center and the margins of the MHM area grows as the thickness of the overburden layer increases.

In other words, the overburden layer will be thicker towards the center of the marsh which will also result in further compaction.

Coefficients of compressibility (Cc) and initial porosity ratio (e0)

The coefficients of compressibility (Cc) is a fundamental parameter in oedometric studies and represent the degree of compaction exerted by a uniaxial stress: under the same stress field, a sediment with a higher Cc will settle more than a sediment with a lower Cc. The initial void ratio e_0, is the ratio between the initial volume of the voids and of the solids in the layer to be compressed. The addition of a vertical stress will produce a proportional change in the void ratio as pore waters are squeezed out (the volume of voids will decrease while the volume of solids will stay constant).

The Cc reported ENGEO (2013) ranges between 0.2 and 0.25 but the report does not specify the samples locations or depths and whether the index was calculated for the slurry, the plastic or the stiff layer. Thus, the Cc and e_0 values used in the models for Eq. 1 were obtained by combining, at the best of our abilities, the geotechnical data presented by ENGEO (2013) and the Kleinfelder (2002) data for the Parsons Bridge boreholes. There are several discrepancies between the datasets which increase the margins of error of the calculations. The paragraphs that follow analyze each layer in detail:

'Slurry' layer: Since this layer is well above the LL and has the characteristics of a fluid rather than of a sediment, the layer was not included in the calculation for compaction with the oedometric formula. In fact, the volume of this layer was added to the volume needed to reach the target elevation (MHHW). However, it should be noted that if this layer is partially dried so if the moisture content drops below the LL (<~55%), then this layer can become more plastic and cohesive like the plastic layer below and present a more consolidate behavior.

The volume of the slurry layer calculated by the model for the 136 sites is 29.09 m^3, which extrapolated to the SA covered by M2, M3 and H1 is 23,375m^3 (33,967 cy) (Table 3). If the slurry layer is not removed and partially dewatered from ~70% to ~40% water content (which would turn the slurry into a more plastic sediment) the volume would become 10,264 m^3 (13,343 cy).

'Plastic' layer: In the ENGEO (2013) report, this layer is described either: 1) as 'very soft highly organic clay' (sample S1@1'-2' at 1.75 feet), with a moisture content 94.4%, e_0=2.636, porosity=~72%; 2) as 'very soft with visible water' (sample S3@3'-4.5' at 4. 5 feet, which is the deepest sample that they have analyzed), with a moisture content 82.7%, e_0=2.242, porosity=~69%. If this layer of plastic clay is correlated to Kleinfelder's (2002) shallowest sample (B-1, 13.0 feet) the compression ratio would be $Cc/1+e_0$ = 0.235. Hence, if we calculate the Compressibility Index Cc for sample B-1 using the value of e_0 from the two ENGEO samples we would obtain values for Cc between 0.615 and 0.761 which would result in almost three times more compressible than Cc=2.5 reported by ENGEO. Note that using Kleinfelder's rather than ENGEO's Cc values would significantly affect the settlement and volume loss calculations (up to ~3 times larger).

'Stiff' layer: Although not clearly explained in the ENGEO's report, sample S2@0-24" at 1.67 feet (silty, clayey SAND and that has a e_0=0.667, and 22.4% moisture), could have been collected from the 'stiff' layer since it is much drier than any other sample analyzed. Since the compressibility of this layer is 1 order of magnitude smaller than normal consolidated sediments and to simplify the calculations, the model used here approximates this layer to incompressible.

Normal consolidated layer: this layer, which likely represents the bulk of the sediment between the 'basement' and the bottom of the stiff layer, is the least known amongst the layers that make up the sediment column at MHM. Although there is no direct geotechnical information from this depth, the model considers this layer as normal-consolidated and based on the analogy with the ENGEO samples, the value chosen is **Cc=2.5** as for the plastic layer.

In conclusion, given the lack of information on the Compressibility Indexes for the different layers at MHM, the model assumes the most conservative and lowest values (i.e. the settlement could be much higher) for both the plastic and normal consolidated layers (Cc=2.5) and no compression for the stiff layer.

To calculate the stress (kN/m^2) generated by the overburden layer the model uses the density value for dry clay or=1600 (kg/m^3);

Calculation of the thickness of the 'slurry' and the plastic layers

'Slurry' layer

The 'slurry' layer is the layer of non-consolidated material ~>55% water content and above the LL. The thickness of this layer was obtained by measuring the vertical distance of the free-fall of the rod+penetrometer assembly from the surface. A prominent linear correlation between slurry thickness and surface elevation (top of the 'slurry) is observed for the western side (M2 and M3) of Minhoto (~39%; Figure 9). However the correlation is less significant for the eastern side (H1; Figure 10; ~25%). In other words, at H1 there are low relief areas where the slurry is relatively thin and highs were is actually thicker.

Potential explanations for the different relationships between elevation and slurry thickness between M2&M3 vs. H1 include different influence from agricultural runoff and different land use practice: M2 and the North east area of Hesters marsh were duck ponds while the rest of the land was used for agricultural purposes.

'Plastic' layer

The 'plastic' layer is the layer of partially consolidated material with plastic characteristics and ~<55% water content occurring below the 'slurry', although in some higher relief areas is present at the surface. The thickness of this layer was obtained by pushing the rod+penetrometer assembly through the sediment until refusal. The plot in Figure 11 shows the comparison between the thickness of the 'slurry' and the 'plastic' layers which are clearly arranged into two

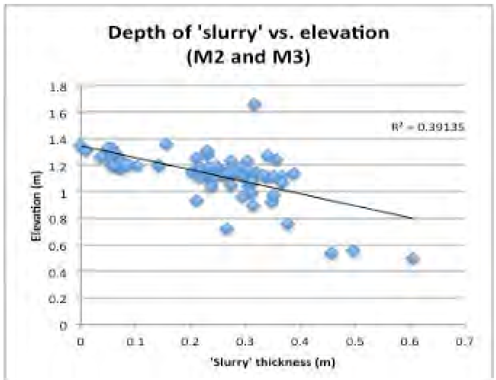


Figure 9 – correlation between thickness of the 'slurry' layer and topography at M2 and M3.

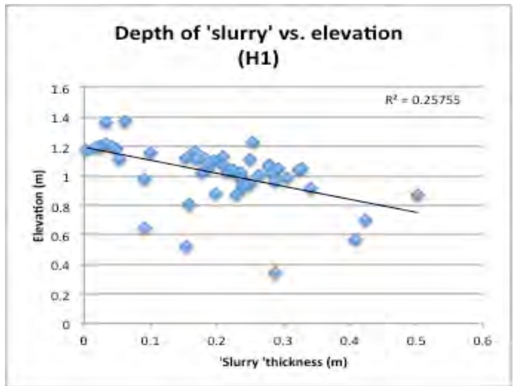


Figure 10 – correlation between thickness of the 'slurry' layer and topography at H1.

groups. The group with the thinner plastic layer (<0.20m) corresponds to relatively thick 'slurry' thicknesses which coincide with relatively low elevations; a second group with thicker plastic layers (>0.20m) corresponds to relatively thin 'slurry' thicknesses which coincide with relatively high elevations. As shown in the plots of Figure 11 and in Table 3, the thickness of the 'slurry' layer has two main modes, and the mean thickness of the slurry is 0.21m (M2, M3 and H1).

Calculation of the thickness of the overconsolidated (stiff) layer

To calculate the thickness of the layer of overconsolidated sediment we assume that the subsidence experienced by the marsh prior to diking was entirely caused by the desiccation of the soil (however it must be noted that other factors such as oxidation of organic matter and seismic event could have contributed to subsidence): by knowing the initial porosity of the soil precursor of the stiff layer, the total amount of subsidence, and the porosity of the stiff layer, then one can calculate how much of the initial soil has been overconsolidated and hence the thickness of the stiff layer.

Let's assume that the total subsidence has been 1m (this value, probably an overestimate, is based on the difference in elevation before and after desiccation assuming that before desiccation the marsh was at MHHW). The porosity of the stiff layer is based on the initial void ratio for the over-consolidated sample S2 (~2 feet) reported by ENGEO (2013) which is 0.667, which corresponds to a porosity of ~40%.

Then let's assume that the initial porosity of the sediment before desiccation was the same as the porosity measured by ENGEO (2-13) for the shallowest ‘soft’ sample S1; which void ration is 2.636, and porosity is ~72% (almost twice as much as S2). Thus, the difference in porosity before and after is a loss of ~29% volume during desiccation and pore collapsing.

Hence, 1 cubic meter of normal consolidated sediment after desiccation becomes 0.7 cubic meters, with a reduction in thickness of ~0.3m. Consequently, to account for 1m subsidence we will require a 3.3m thick layer of sediment before it is dried (1m/0.3m). The 3.3m layer will then become a 2.1m thick stiff layer after desiccation (because of the ~29% loss of porosity).

In conclusion, based on the previous geotechnical work, the known physical properties of the sediment and the subsidence history of the area a ~2m thickness for the stiff layer seems a realistic number, and this is the thickness that was used in the models.

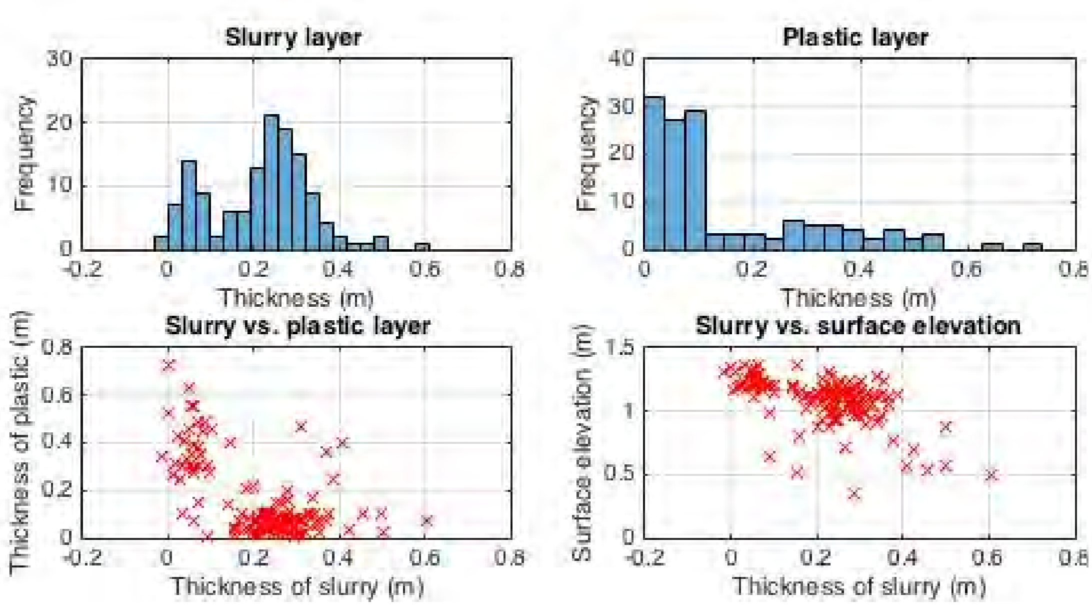


Figure 11 – Multipanel figure from the Matlab calculations: top row shows histograms of thickness distribution of the ‘slurry’ and ‘plastic’ layers. Middle row is similar to figures 7 and 8. Bottom row shows histograms of frequency distribution of the thickness of the overburden layer (left) and the total settlement after the overburden layer is applied (right).

Total settlement calculated for different ‘basement’ models

As shown previously, the thickness of compressible sediments (H in the oedometric formula, Eq. 1) is a very important parameter in determining the final compaction of the sediments (see Figure 6) and is more influential than the thickness of the overburden load (proportional to ‘dvi’ in the oedometric formula, Eq. 1). MATLAB models were developed to calculate the total thickness of sediments relative to the underlying incompressible ‘basement’ based on three hypothetical basement scenarios: 1) v-shaped valley, 2) shallow bowl, 3) flat basement. A script example of the MATLAB model (model run 2_4) is reported in Appendix I.

For each of these scenarios the total compaction and the total volume loss after compaction were calculated first for the 136 survey sites and then extrapolated to the areas M2, M3 and H1.

Restoration area M1 was not included in the penetrometric surveys and thus there are not direct calculations of slurry volume or compaction for this area.

To extrapolate the settlement calculations from the 136 surveyed sites to the SA (M2, M3 and H1) we used the information referenced in Table 1 of the report "Elkhorn Slough Tidal Marsh Restoration Project”. The total fill area of M2, M3 and H1 is 27 acres (or ~101,265 m^2) (Table 3), which, according to the ESA (2014) will require ~103,000 cy of sediment (~78,750 m^3). Note that the ~103,000 cy figure reported by ESA is the LiDAR-based calculation of the accommodation volume between the surface (top of slurry) and the MHHW datum. This value is slightly higher than the one that we have calculated based on the extrapolation of the 136 surveys to the entire area.

Our calculations are based on an extrapolation of the results obtained from 136 survey sites using the survey rod+penetrometer and the consolidation following the overburden calculated by the MATLAB algorithm for each of the three basement scenarios. Each site is considered to represent a 1m^2 area. In this calculation we assume that the 136 sites are randomly chosen and thus are representative of the entire SA. An extrapolation to the entire restoration area that includes M1 (~9.5 acres fill area, ESA 2014) was done by adding 35.32% (the relative extent of M1 compared to M2, M3 and H1), as shown in the examples of Tables 1, 3 and 4.

Calculation of thicknesses and volumes used for the consolidation calculations

As explained before the thickness of the overburden layer (the sediment load that creates and increased stress at depth) was obtained by calculating the difference between the MHHW datum and the shallowest most cohesive surface, i.e. the top of the plastic layer. This is calculated by adding the accommodation space (difference between MHHW and the surface of the slurry) and the thickness of the slurry. As shown in Table 3, the overburden layer has a mean thickness of 0.89m (n=136). The total volume obtained for the 136 sites (which corresponds to an area of 136

Summary of model calculations

Mean surface elevation (m) (136 sites)	1.09	
Mean thickness of slurry (m) (136 sites)	0.22	
Mean thickness of plastic layer (m) (136 sites)	0.15	
Mean thickness overburden (accommodation space+slurry) (m) (136 sites)	0.89	
Thickness of 'stiff' layer (m)	2.00	
Total surveyed area m2	136.00	
Total Study Area (M2+M3+H1, 27 Acres fill area) (m2)	109,265	
Total Restoration Area (M2+M3+H1+M1, 36.4 Acres fill area) (m2)	147,306	
	m3	cy
Accommodation space (MHHW-surface slurry) (136 sites)	91	92
Volume of slurry (136 sites)	29	30
Accommodation space (M2+M3+H1)	73,093	95,480
Volume of slurry (M2+M3+H1)	23,375	30,573
Overburden layer (accommodation space+slurry) (M2+M3+H1)	96,467	126,054
Accommodation space (M2+M3+H1)+M1	98,909	129,368
Volume of slurry (M2+M3+H1)+M1	31,631	41,372
Overburden layer (accommodation space+slurry) (M2+M3+H1)+M1	106,579	139,400

Table 3

m^2) is ~119 m^3. The ratio between surveyed area and SA is ~109,000 m^2/136 m^2 = ~803. Thus each volume calculation done for the 136 sites can be extrapolated to the SA by multiplying by 803. A further extrapolation to the whole restoration area that includes M1 can be done by adding 35.32%.

The calculation of the volume loss do to settlement using the oedometric formula was done in two phases: 1) a first phase that accounts for the thickness of the sediment needed to fill the distance between the top of the plastic layer and the target MHHW elevation; 2) a second phase that accounts for the extra burden caused by the sediment needed to account for the settlement created by phase 1. As Table 4 shows, the second total settlement is only of few cm compared with the >10 cm of the first one.

The 'paleo-valley' scenario (Model 2_4)

This scenario describes the 'basement' underneath the compressible sediments at Minohoto as v-shaped as for a drowned stream valley and the deepest location of the basement corresponds approximately to the location of the present deepest tidal channel. The depth of the basement at the deepest point is ~12m (based on the maximum acoustic basement depth calculations done elsewhere in Elkhorn Slough (Garcia-Garcia et al. 2013), the minimum sediment thickness is 3m.

The 'shallow bowl' basement scenario (Model 2_5)

This scenario describes the 'basement' underneath the compressible sediments at Minohoto as v-shaped as for a drowned stream valley but with a much shallower, bowl-shaped profile, than in Model 1_4. The deepest location is ~7.5m.

The 'shallow flat' basement scenario (Model 2_6)

This scenario describes the 'basement' underneath the as flat surface which attains very shallow depths (3 m).

Basement Model	Model 2_4 (v-shaped)		Model 2_5 (shallow bowl)		Model 2_6 (shallow flat)	
Mean 1st settlement plastic layer (m)	0.029		0.029		0.029	
Mean settlement normal-consolidated layer (m)	0.128		0.098		0.078	
Mean total 1st settlement (plastic+normal layers) (m)	0.157		0.127		0.107	
Mean total 2nd settlement (plastic+normal layers) (m)	0.039		0.029		0.023	
Total surveyed area m^2	136.000		136.000		136.000	
Study Area						
	m3	cy	m3	cy	m3	cy
Overburden layer (accommodation space+slurry) (M2+M3+H1)	96,467	126,054	96,467	126,054	96,467	126,054
Total consolidation 1st settlement (136 sites)	20.65	26.85	16.71	21.72	14.08	18.31
Total consolidation 2nd settlement (136 sites)	5.20	6.76	3.81	4.96	2.99	3.89
Total consolidation: 1st+2nd settlement (M2+M3+H1)	20,771	27,002	13,425	17,453	11,315	14,709
Total consolidation 1st+2nd settlement (M2+M3+H1)+M1	28,107	36,539	18,167	23,617	15,311	19,905
Accommodation space+slurry layer+1st+2nd settlement (M2+M3+H1)	117,238	152,410	109,893	142,861	107,782	140,117
Accommodation space+slurry layer+1st+2nd settlement (M2+M3+H1)+M1	158,647	206,241	148,707	193,319	145,851	189,606

Table 4

References Cited

ENGEO, 2013. Elkhorn Slough Tidal Marsh Restoration Project Watsonville, California: FINDINGS OF LIMITED SUBSURFACE EXPLORATION. 23 pp.

ESA, 2014, Final Elkhorn Slough Tidal Marsh Restoration Project Restoration Plan, July 1, 2014.

Garcia-Garcia, A., Levey M.D, and Watson, E.B., 2013, High resolution seismic study of the Holocene infill of the Elkhorn Slough, central California. Continental Shelf Research, V 55, 108-118.

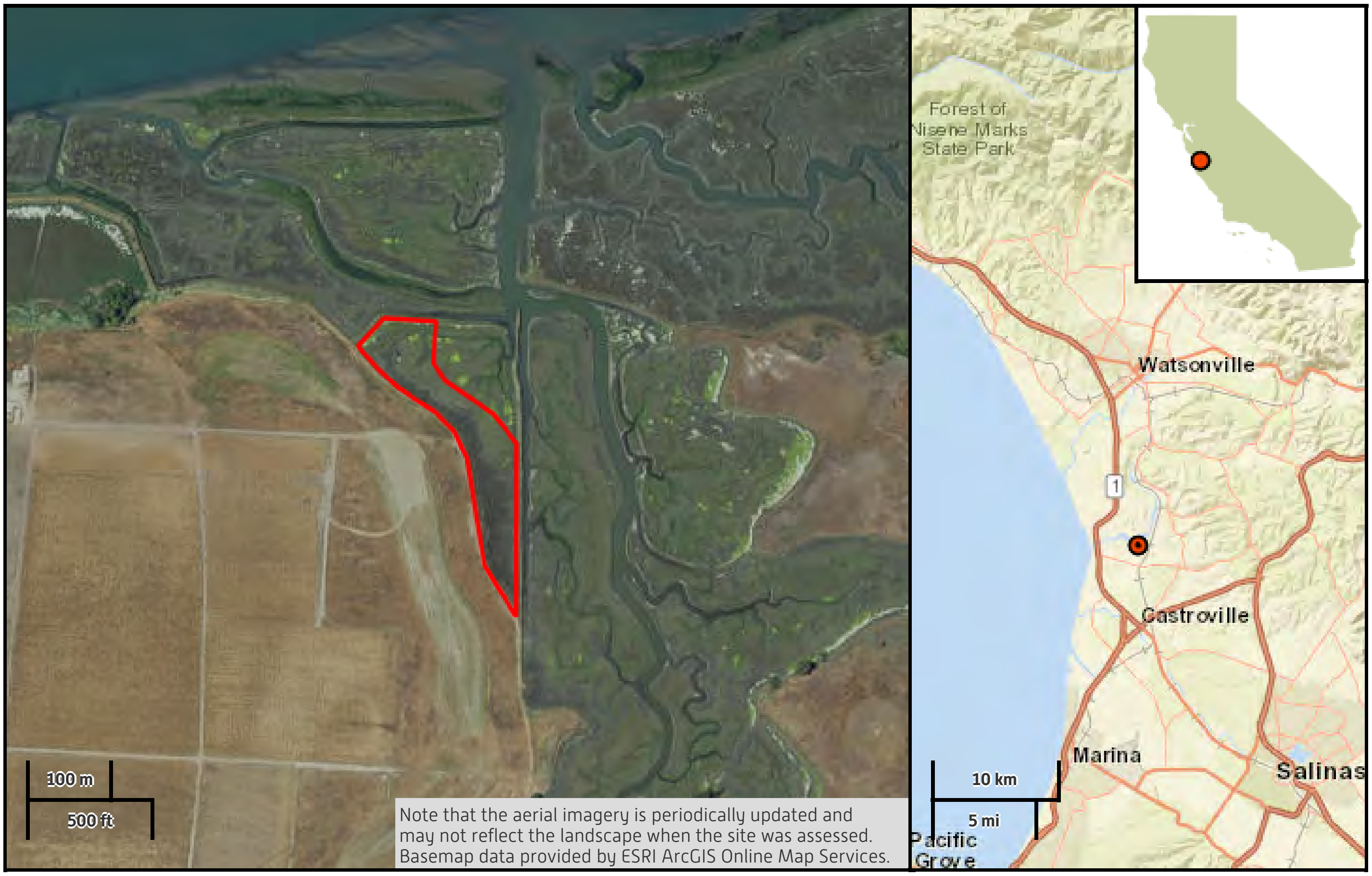
Kleinfelder, 2002. GEOTECHNICAL ENGINEERING INVESTIGA TION FOR UNION PACIFIC RAILROAD BRIDGE (103.27 COAST) REPLACEMENT PROJECT AT PARSONS SLOUGH IN MONTEREY COUNTY, CALIFORNIA. I0-3012-84/GEO (1011 R877)/jb. 233 pp.

Appendix 9

California rapid assessment method (CRAM) report

Summary Assessment Report

California Rapid Assessment Method



Basic Information

eCRAM ID	5389
Assessment Area Name	Minhoto Restoration Project: pre-implementation site #1
Project Name	CC_Local
Assessment Area ID	
Project ID	
Wetland Type	estuarine perennial saline
CRAM Version	6.1
Visit Date	2016-10-03

AA Category	restoration
Practitioners	Kevin O'Connor (lead practitioner), Cara Clark (other practitioner)
Other Practitioners	
County	Monterey
Ecoregion	central coast
AA Centroid Latitude	36.80957
AA Centroid Longitude	-121.75434
AA Size (Hectares)	1.37360
Tidal Stage	low
Mouth Condition	
AA Encompasses	
Is this a public record?	Yes
Comments	Project info: http://www.elkhornslough.org/tidalwetland/downloads/Tidal_Marsh_Restoration_Project_Overview_and_FAQ.pdf

Metric Scores

Attribute	**Buffer And Landscape Context**	**80.79**
	Aquatic Area Abundance	B (9)
	Percent Of AA With Buffer	A (12)
	Average Buffer Width	A (12)
	Buffer Condition	B (9)
Attribute	**Hydrology**	**83.33**
	Water Source	B (9)
	Hydroperiod	A (12)
	Hydrologic Connectivity	B (9)
Attribute	**Physical Structure**	**50.00**
	Structural Patch Richness	B (9)
	Topographic Complexity	D (3)
Attribute	**Biotic Structure**	**44.44**
	Number Of Plant Layers Present	C (6)

	Number Of Co-Dominant Species	D (3)
	Percent Invasion	A (12)
	Plant Community Score	7
	Horizontal Interspersion And Zonation	D (3)
	Vertical Biotic Structure	C (6)
Index Score		**65**

Stressors **9** total, **3** with significant negative effect - *indicated below with **

Attribute	**Biotic Structure**
	Lack of treatment of invasive plants adjacent to AA or buffer*
Attribute	**Buffer And Landscape Context**
	Active recreation (off-road vehicles, mountain biking, hunting, fishing)
	Commercial feedlots
	Dairies
	Industrial/commercial
	Passive recreation (bird-watching, hiking, etc.)
Attribute	**Hydrology**
	Dike/levees*
	Non-point Source (Non-PS) discharges (urban runoff, farm drainage)
Attribute	**Physical Structure**
	Nutrient impaired (PS or Non-PS pollution)*

This report was created on Monday October 17, 2016, 1:50 PM using the SFEI eCRAM Mapper at www.cramwetlands.org

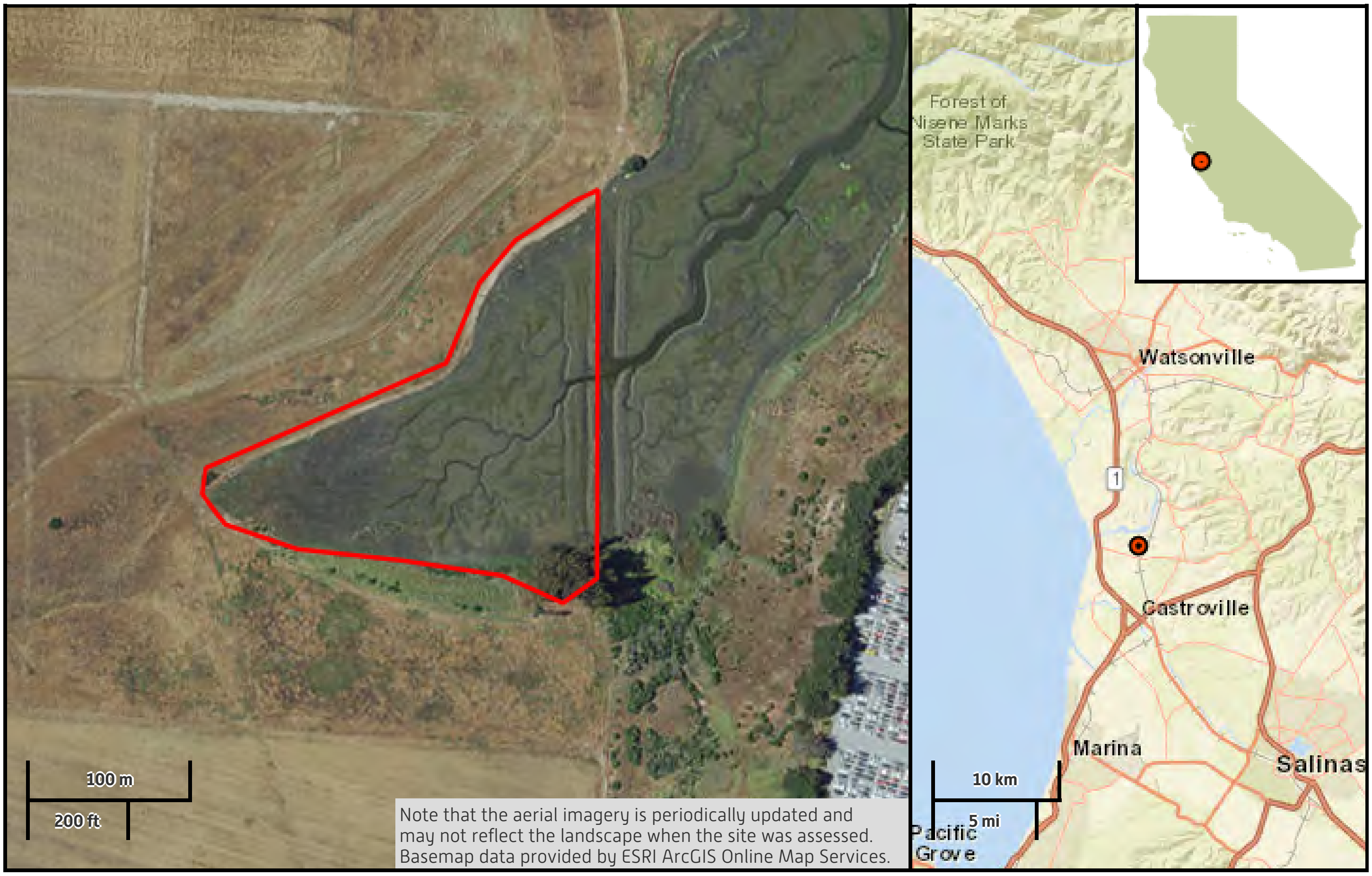
The data provided in this report is for informational purposes only and may not be sufficient for the purposes of fulfilling the requirements of a regulatory permit. Please see "Using CRAM (California Rapid Assessment Method) To Assess Wetland Projects As an Element of Regulatory and Management Programs" CWMW, Oct. 13, 2009.

WWW.CRAMWETLANDS.ORG

CRAM

California Rapid Assessment Method

Summary Assessment Report



Basic Information

eCRAM ID	5390
Assessment Area Name	Minhoto Restoration Project: pre-implementation site #2
Project Name	CC_Local
Assessment Area ID	
Project ID	
Wetland Type	estuarine perennial saline
CRAM Version	6.1
Visit Date	2016-10-03
AA Category	restoration
Practitioners	Kevin O'Connor (lead practitioner), Cara Clark (other practitioner)
Other Practitioners	

County	Monterey
Ecoregion	central coast
AA Centroid Latitude	36.80505
AA Centroid Longitude	-121.75446
AA Size (Hectares)	2.11100
Tidal Stage	low
Mouth Condition	
AA Encompasses	
Is this a public record?	Yes
Comments	

Metric Scores

Attribute	**Buffer And Landscape Context**	**47.88**
	Aquatic Area Abundance	D (3)
	Percent Of AA With Buffer	A (12)
	Average Buffer Width	A (12)
	Buffer Condition	C (6)
Attribute	**Hydrology**	**83.33**
	Water Source	B (9)
	Hydroperiod	A (12)
	Hydrologic Connectivity	B (9)
Attribute	**Physical Structure**	**50.00**
	Structural Patch Richness	B (9)
	Topographic Complexity	D (3)
Attribute	**Biotic Structure**	**44.44**
	Number Of Plant Layers Present	C (6)
	Number Of Co-Dominant Species	D (3)
	Percent Invasion	A (12)
	Plant Community Score	7
	Horizontal Interspersion And Zonation	D (3)
	Vertical Biotic Structure	C (6)
Index Score		**56**

Stressors **7** total, **3** with significant negative effect - *indicated below with **

Attribute	**Biotic Structure**
	Lack of treatment of invasive plants adjacent to AA or buffer*

Attribute	Buffer And Landscape Context
	Active recreation (off-road vehicles, mountain biking, hunting, fishing)
	Industrial/commercial
	Passive recreation (bird-watching, hiking, etc.)
Attribute	**Hydrology**
	Dike/levees*
	Non-point Source (Non-PS) discharges (urban runoff, farm drainage)
Attribute	**Physical Structure**
	Nutrient impaired (PS or Non-PS pollution)*

This report was created on Monday October 17, 2016, 2:00 PM using the SFEI eCRAM Mapper at www.cramwetlands.org

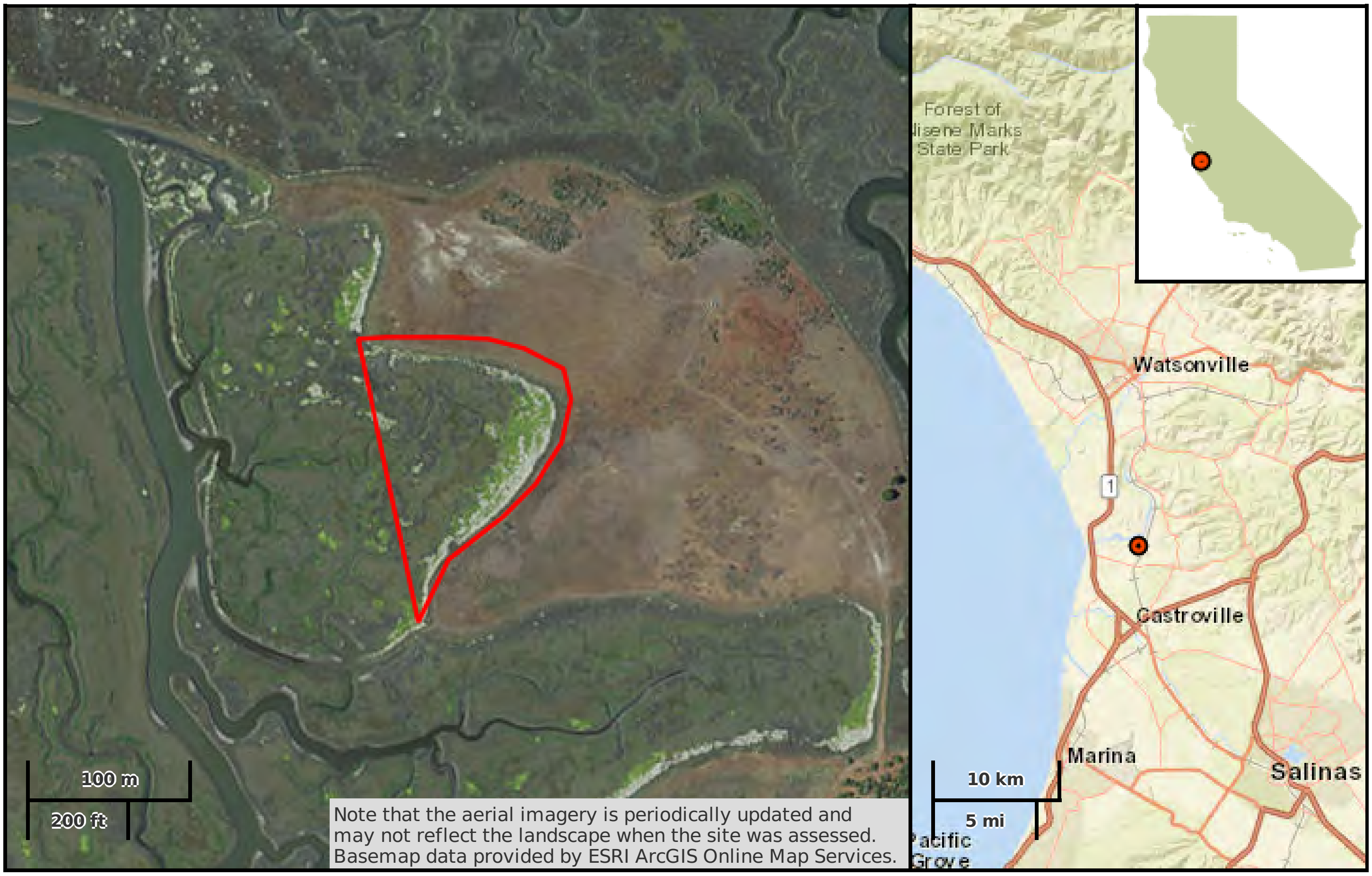
The data provided in this report is for informational purposes only and may not be sufficient for the purposes of fulfilling the requirements of a regulatory permit. Please see "Using CRAM (California Rapid Assessment Method) To Assess Wetland Projects As an Element of Regulatory and Management Programs" CWMW, Oct. 13, 2009.

WWW.CRAMWETLANDS.ORG

CRAM

California Rapid Assessment Method

Summary Assessment Report



Note that the aerial imagery is periodically updated and may not reflect the landscape when the site was assessed. Basemap data provided by ESRI ArcGIS Online Map Services.

Basic Information

eCRAM ID	5423
Assessment Area Name	Minhoto Restoration Project: pre-implementation site #3
Project Name	CC_Local
Assessment Area ID	
Project ID	
Wetland Type	estuarine perennial saline
CRAM Version	6.1
Visit Date	2016-10-20
AA Category	restoration
Practitioners	Kevin O'Connor (lead practitioner), Sarah Stoner-Duncan (other

	practitioner)
Other Practitioners	
County	Monterey
Ecoregion	central coast
AA Centroid Latitude	36.80941
AA Centroid Longitude	-121.75083
AA Size (Hectares)	0.90171
Tidal Stage	low
Mouth Condition	
AA Encompasses	
Is this a public record?	Yes
Comments	

Metric Scores

Attribute	**Buffer And Landscape Context**	**80.79**
	Aquatic Area Abundance	B (9)
	Percent Of AA With Buffer	A (12)
	Average Buffer Width	A (12)
	Buffer Condition	B (9)
Attribute	**Hydrology**	**83.33**
	Water Source	B (9)
	Hydroperiod	A (12)
	Hydrologic Connectivity	B (9)
Attribute	**Physical Structure**	**62.50**
	Structural Patch Richness	B (9)
	Topographic Complexity	C (6)
Attribute	**Biotic Structure**	**58.33**
	Number Of Plant Layers Present	B (9)
	Number Of Co-Dominant Species	C (6)
	Percent Invasion	A (12)
	Plant Community Score	9
	Horizontal Interspersion And Zonation	C (6)
	Vertical Biotic Structure	C (6)
Index Score		**71**

Stressors

6 total, **2** with significant negative effect - *indicated below with* *

Attribute	Buffer And Landscape Context
	Active recreation (off-road vehicles, mountain biking, hunting, fishing)
	Industrial/commercial
	Passive recreation (bird-watching, hiking, etc.)
Attribute	**Hydrology**
	Dike/levees
	Non-point Source (Non-PS) discharges (urban runoff, farm drainage)*
Attribute	**Physical Structure**
	Nutrient impaired (PS or Non-PS pollution)*

This report was created on Thursday October 27, 2016, 4:10 PM using the SFEI eCRAM Mapper at www.cramwetlands.org

The data provided in this report is for informational purposes only and may not be sufficient for the purposes of fulfilling the requirements of a regulatory permit. Please see "Using CRAM (California Rapid Assessment Method) To Assess Wetland Projects As an Element of Regulatory and Management Programs" CWMW, Oct. 13, 2009.

Appendix 10

Reserve otter monitoring program (ROMP) protocol

Reserve Otter Monitoring Project (ROMP)

10/26/2018

Reserve Otter Monitoring Project

Contents

Introduction

This document provides an overview of the Reserve Otter Monitoring Project (ROMP), conducted by the Elkhorn Slough National Estuarine Research Reserve (ESNERR) throughout Elkhorn Slough and Moss Landing Harbor, CA. In addition to background information, the document includes specific guidance and methodology for identifying the areas monitored and for collecting data.

ROMP objective and significance

The objective of ROMP is to monitor the number, locations, and activities of otters in Elkhorn Slough, so changes can be tracked over time. While other researchers may conduct more intensive short-term studies of otters in Elkhorn Slough, the Reserve is committed to providing this backbone of consistent long-term observations.

Elkhorn Slough is currently the only estuary significantly colonized by southern sea otters. ROMP observations provide insight into otter use of this estuarine environment and may provide guidance on identifying other similar environments suitable for otters. Variables that influence otter numbers and movements include:

- Time of day
- Tide
- Time of year
- Food availability
- Human disturbances
- Location of eelgrass beds
- Availability of secluded creeks

Other factors may also influence otter numbers and activities. Part of the goal of ROMP is to continue to monitor the otters in Elkhorn Slough identifying other factors and reviewing long- term variations of otter numbers and behaviors.

Data collected are readily available to other researchers, so they can apply their expertise to help determine the driving factors behind otter behavior. Data collected over an extended period may support a variety of studies such as examinations of population fluctuation, birth rates, carrying capacity of the slough, preferential areas for resting versus foraging, important movement corridors, etc.

History of the study

ROMP began as an outgrowth of two years of marine mammal monitoring in support of the Reserve's Tidal Wetland Project in 2011. A team of 10 qualified observers observed marine mammals to ensure there were no disturbances that would endanger marine mammals during construction of the Parsons Sill. The team constructed two raised shelters on each side of the Parsons Slough railroad bridge to provide observers with a clear view of the construction area for the low sill. Using these shelters, observers could view otters in areas not usually visible without the added height. Observations revealed that otters used Yampah Creek on a regular basis, mostly resting and often hauling out. The intensive use of this creek and high frequency of hauling out was not noted previously.

These observations prompted a study of the otters in Yampah Creek. Volunteers began monitoring the otters in Yampah Creek from Yampah Hill in 2011. Yampah Hill has a 10-meter elevation which enables the team to observe otters in Yampah Creek even at lower tides. Initial monitoring was quite intensive with the goal of gathering baseline information on otter usage of Yampah Creek.

Two years later, sufficient data had been collected and analyzed to clearly demonstrate that the behavior of these otters was significantly different from their coastal counterparts. This analysis was presented to scientists from US Geological Survey, University of California-Santa Cruz, California Department of Fish and Wildlife, the Monterey Bay Aquarium and others. Based on findings, the group decided to conduct a collaborative three-year study of otters in Elkhorn Slough. This study nicknamed the Elkhorn Slough Otter Project (ESOP) began in September of 2013 and continued through September of 2016. Initially 20 otters were captured, biological samples taken, instrumented, and tagged. Later an additional six were also instrumented and tagged. Each otter was sighted daily when possible, biweekly distribution surveys were conducted along with 12-hour activity budgets and foraging bouts. Volunteers from the Reserve participated in the ESOP, and also began enlarging their coverage area to ultimately cover the entire slough. The ESOP ended in September 2016 and it was decided that Reserve volunteers would continue to monitor sea otters throughout the entire slough, indefinitely. Reserve volunteers also continue to monitor those individual study animals that were part of the ESOP and that still have active transmitters or tags.

Current data collection effort

The ROMP current data collection effort builds on previous studies and takes advantage of knowledge obtained by the study leads and observers familiar with the area. The monitoring program is designed to describe spatial patterns of sea otter abundance and behavior, and how these change over time.

Study leads

Robert Scoles, Susan Rosso, and Ron Eby lead the data collection effort under the guidance of Kerstin Wasson. Contact information: robertscoles@sbcglobal.net, susanrosso@comcast.net, roneby3@gmail.com, kerstin.wasson@gmail.com.

Monitoring approach

The primary methodology consists of surveys in which teams of trained observers use binoculars and spotting scopes to systematically search all potential habitat areas (i.e. water and adjacent mudflats and salt marsh), counting and recording the position of all sea otters (adults, large pups and small pups are tabulated separately). For each group or individual sea otter, the observers also record the microhabitat (e.g. marsh, tidal creek, eelgrass bed, open water) and their associated behavior (e.g. resting, foraging, travelling, interacting, hauled out). Observers make repeat counts and behavioral assessments every 30 minutes for two hours. During observations, otters will be tallied by individual areas as specified on the data sheets. (This observation period may be shortened based on preliminary analyses.)

Observers also record the number of watercraft in the observation area to allow future analyses of the relationship between human activities and sea otter behavior and abundance. Additionally, if observers see a disturbance, they record the type of disturbance (head raise, flee, flush) and the number and type of animals (sea otter, harbor seal, bird) affected. Observers also count the number of harbor seals in each area.

Starting in fall 2018, at the request of USGS otter researchers, the team will also mark the exact location of each otter behavior seen on the hard copy of an aerial photograph, and these maps will be made available for future USGS analyses. This additional spatial monitoring is a pilot and will only be continued if it is deemed worth the effort.

Each year, the team will re-evaluate and tinker with monitoring methodology and database structure to keep improving clarity and organization.

Spatial extent

Monitoring surveys are conducted simultaneously from multiple vantage points, with results combined to span the Elkhorn Slough estuary (excluding diked regions,) and areas outside Elkhorn Slough including the North Harbor, South Harbor, and Jetty Road areas. The Reserve will continue to monitor from the same vantage points used by ESOP and SORAC (Harbor, Wildlife Area, Seal Bend, Upper Dairy, Yampah, Avila, Hummingbird Island, Kirby) in the long term. In the short term, monitoring will also occur at Hester I and II, to track otter colonization/use of the restored marsh ecosystems there. See “Survey Areas” for more information.

Frequency of surveys

At the present, trained volunteers conduct observations under the guidance of the study leads at least twice monthly on two consecutive weeks. This schedule allows the team to capture otter numbers and movements on alternating low and high tides. Team leads also hold a monthly team meeting and may request additional focused observations at designated locations during a specific month as deemed necessary.

In the future, if bandwidth of organizers or size of team dwindles, the frequency of surveys may decrease. The Reserve is committed to conducting Slough-wide surveys at least quarterly (four times a year) for the indefinite future.

Team size

Team size is a minimum of 10 observers. Team members observe from eight different long-term areas (plus two restoration sites being tracked for a few years). A team of 10 allows for coverage when a member is not available as well as for cross training at different locations.

Complementary observations

In addition to the regular monitoring designed to track spatial patterns, further focused monitoring may be conducted as needed. This can include 12-hour observations in the Harbor to determine when otters leave the harbor raft, or 12-hour observations at areas such as Avila that seem heavily influenced by the time of day and tide.

Foraging surveys

Currently, there is no long-term monitoring of foraging success or diet. ESNERR hopes to develop such a program in partnership with MBA. The goal would be to detect very broad changes in diet and foraging success, not a fine-scale assessment such as student thesis work can accomplish. Instead, we hope simply to be able to detect major changes such as a shift away from large clams as the dominant prey base, if these were depleted over time.

At least once a year, trained observers could collect otter foraging data. At least 20 otters would be observed for twenty successful dives to determine frequency of successful prey capture and the number, identity and size of prey items. At a minimum, this observation should be conducted in the lower Slough from observation areas in the Moss Landing Wildlife Area and from the Seal Bend portion of ESNERR, along a berm near Moonglow Dairy. If possible, observations will also be conducted in the upper estuary, such as from Kirby Park. Methods would be simplified from standardized protocols (used in previous studies conducted by USGS, MBA, UCSC and others: for details see Tinker et al 2012), and ESNERR observers will be trained by MBA and/or USGS staff.

Otter ages and identifying activities

The study uses the following definitions to identify otters and activity:

Age:

- Adult
- Large pup. Smaller than the mother, but more than half her size. They may still be riding with the mother but not held in the mouth or high on her chest. They are often floating right next to her or foraging with her. Large pups are 10 weeks or older.
- Small pup. Half the size of the mother, often riding up high on the mother's chest or carried in the mother's mouth. Too buoyant to dive. Small pups are less than 10 weeks old.

Activity in the water:

- Resting (often in rafts)
- Grooming (blowing in fur, combing fur, rolling)
- Foraging (diving, eating)
- Traveling (swimming in a continuous direction)
- Interacting (rolling together, fighting, play fighting (juveniles), mating.) Make a note of mating.

Activity on land:

Hauled out. Hauled out otters are often difficult to see. Carefully scan the marsh, particularly near the edges of creek banks.

Survey areas

The slough and harbor counts include 14 different areas. Some areas are additionally divided into east and west or north as south as is appropriate. See Appendix A, "Area Specific Information," for additional location and observation guidelines.

The following provides a list of locations organized from the harbor upstream to Kirby Park. See the map following this list for a geographic orientation.

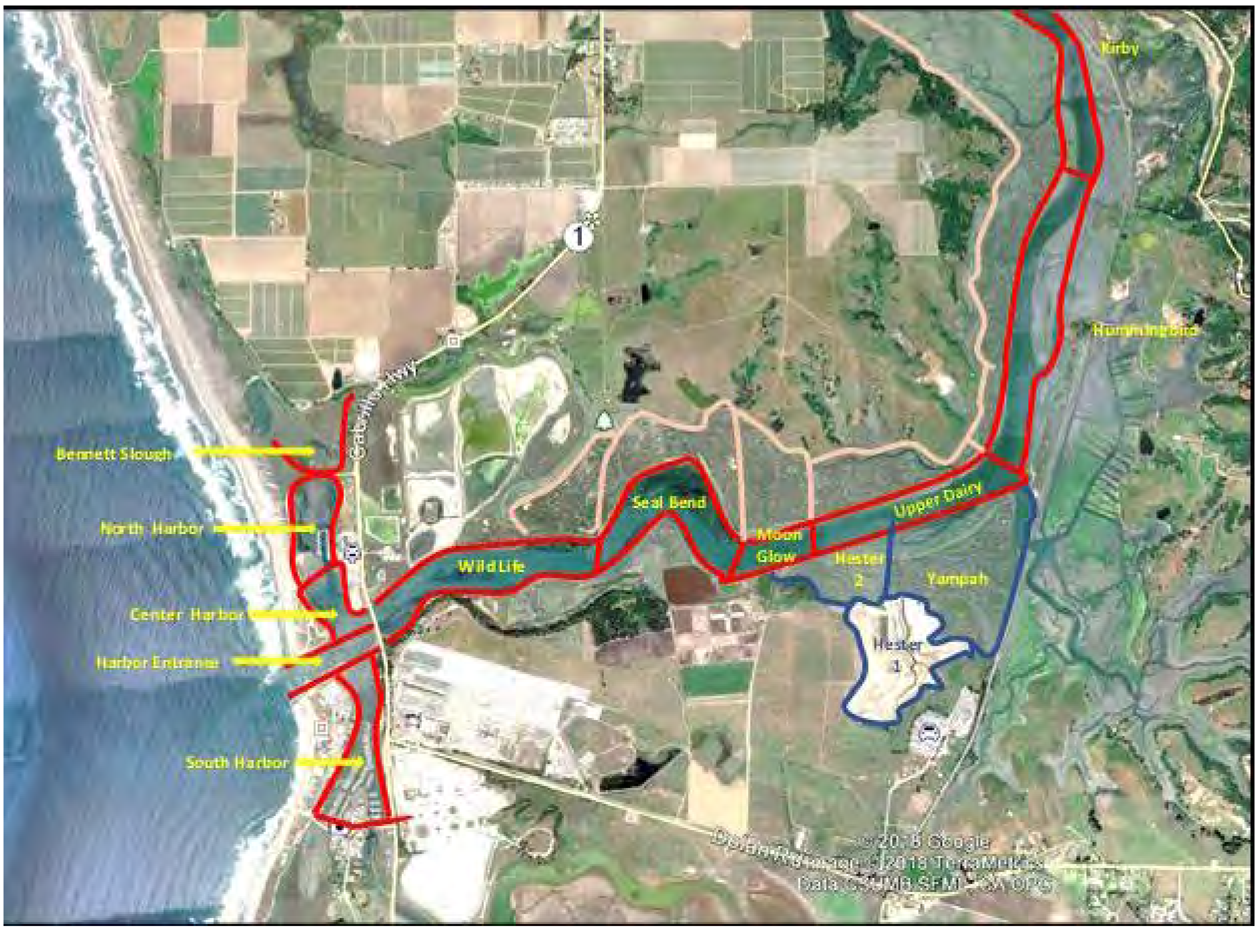
Moss Landing Harbor

1. Bennett Slough – area at the north end of the harbor north of the bridge on Jetty Road
2. Harbor North –area between the Jetty Road parking lot and Bennett Slough
3. Harbor Central – area in front (east) of the Jetty Row parking lot
4. Harbor Entrance —harbor channel entrance and water to the Highway 1 bridge
5. Harbor South—area south of the harbor entrance and south jetty

Elkhorn Slough

1. Wildlife viewing—on the east side of Highway 1, across from Monterey Bay Kayak (MBK) from the east observation deck of the CDFW Moss Landing Wildlife Area (MLWA)
2. Seal Bend—on the slough across from Seal Bend and including parts of MLWA under the Packard property, accessing ESNERR marsh via the Moon Glow Dairy

3. Moonglow —the main channel between Seal Bend and Hester II, and the Rubis Creek and associated marsh, assessed from vantage point on ESNERR (and named for the Dairy that is upland of this general area)
4. Hester– two restoration sites on ESNERR accessed via Moonglow entrance
5. Main channel — the main channel between Hester II and the Parsons Slough
6. Yampah—within the ESNERR on Yampah hill overlooking the Yampah marsh at the end of Via Tanques Road and the Upper Dairy (main channel). Note: *it is critical to clean shoes before entering this area to avoid the spread of hoary cress, and never drive onto island.*
7. Avila—within the ESNERR (south side) from the Sam Farr bench
8. Hummingbird Island—within the ESNERR (north side)
9. Kirby Park Outlook—the pull-out just south of the Kirby Park entrance on Elkhorn Road
10.



Required forms and equipment

Observers complete preliminary forms when they first join the observation team. Equipment is required for each observation.

Forms

As an observer, your safety and contribution of time are critical. All observers complete the following forms:

Safety form: Before you participate in an observation, complete all safety forms and provide them to your team leader. Information includes contact names and numbers of spouse/friend to call in case of emergency. If you have a known medical issue, such as an allergy to bees or potential for a diabetic collapse, please include the information on the form.

Vehicle information: If you observe at locations on the Reserve and will use your car to access such locations, complete vehicle information and provide the form to your team leader before going to any of the locations. When parking on the reserve, display the parking placard provided to you by your team leader.

Time sheet: Enter your hours and sign the timesheet so that your generous contribution is recorded and can be used by the Reserve as a match for grants. File completed forms in the volunteer notebook in the visitor center library.

Equipment

Equipment for each monitoring session includes:

- Data collection forms specific to the area
- Pencils
- Clip board
- Scope and or binoculars
- Parking placard (if on ESNERR property)
- Radio (channel 14)
- Sun screen, hat and insect repellent are recommended

Counting methodology

Observers complete counts based on defined methodology.

Otter counting methodology

Observers generally count otters between 10 am-noon on a Tuesday. For each observation session, observers do the following:

1. Using the data sheet specific to the designated area, record the date, the observer names, and the visibility in the area. Add other notes such as tides, wind, etc. if helpful for explaining observations.
2. Using a spotting scope and or binoculars, take the first count at 10:00 am. If you have two people, one can count, and the other record.
3. Scan and count consistently through the area, such as from the west to the east.
4. Use tick marks to record the number of otters (adults, large pups and small pups are counted separately), such as lll for three, in the column that reflects their behavior, such as resting or foraging.
5. At the end of the count for a time period, subtotal the otters by age; subtotal the large pups, small pups and adults; and then total otters for the entire area in the designated boxes.
6. For areas that have additional columns to identify specific habitats, such as eel grass, record the number of otters in these habitats, as a subset of the count. For example, you might record a total of 10 otters resting in the west. Of those otters, two may be resting in the eel grass.
7. Repeat the process every 30 minutes, until the end of the two-hour observation shift.

8. During one count period, observers will also indicate exact location on a map along with details of micro habitat, activity etc. Put an asterisk at the otter location and indicate on the map or in the margin the number of otters, age class and activity as indicated in the "Example map for recording exact otter location" (below).
9. At the end of the counting shift, return forms to the team leader at a pre-specified location.

Watercraft and disturbance counting methodology

During each 30-minute count, observers also record the watercraft in the area and disturbances if they occur, to allow future analyses of the relationship between human activities and sea otter behavior and abundance.

To count watercraft:

- Using the data sheet specific to the designated area, indicate the total number of each type of watercraft in the area at the time of the count. Types include Kayak, Hydro bike (H bike), Stand up paddle board (SUP), Boat, Canoe, Hunter.

Note: Fishing boats are not considered hunters.

To record disturbances:

- Using the data sheet specific to the designated area, indicate disturbances (if any) at the time that they occur. Record as follows:
  - Specific time
  - The area, such as West or East
  - The species disturbed: (Harbor Seal (HS), Sea Otter (SO), Sea Lion (SL), Other, such as bird (O)
  - The type of disturbance: Head raise (HR), Flee (move away) FL (flush – dive or return to water), and the number disturbed
  - The type and number of watercraft involved in the disturbance

Seal counting methodology

During each 30-minute count, observers also count the total number of harbor seals in each of the areas.

Example data sheet

The following is an example of the data recording sheet for the Seal Bend area. In the west for otters, it indicates one small pup resting, one large pup resting, one large put traveling, eight adults resting, two adults grooming, one adult traveling, and two adults interacting.

In the east, it indicates one small pup resting, no large pups, four adults resting, two adults grooming, and two adults foraging. For the eel grass, of the otters counted, two were grooming, three foraging, and eight resting.

For seals, a total of 17 were observed. At the time of the observation five kayaks and one hydro bike went through the area. At 10:15 three kayakers caused three otters to raise their heads.

Date 10/9/2018 Observers RON EBY / ROBERT SCOLES Visibility 100%

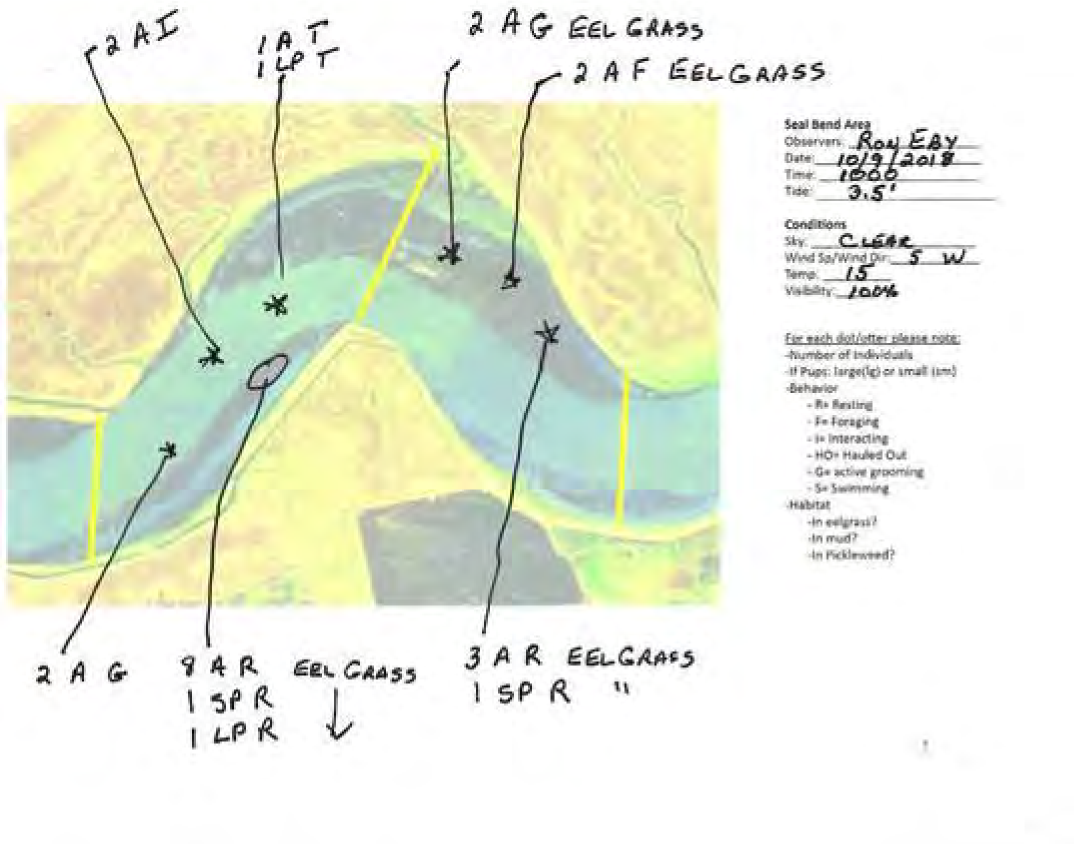
Time	Age	West R (Water)	West G (Water)	West F (Water)	West T (Water)	West I (Water)	West H (Land)	West Total otters by Age	West Total P+A	Age	East R (Water)	East G (Water)	East F (Water)	East T (Water)	East I (Water)	East H (Land)	East Total otters by Age	East Total P+A	Total Otters by Age	Otters in Eel Grass	Seals (in all areas)	Watercraft by Type (in all areas)
1000	Small Pups	I						1		Small Pups	I						1		2	R 8 G 2	Pups	Kayak 5 H Bike 1 SUP ___
	Large Pups	I			I			2		Large Pups							Ø		2	F 2		
	Adults	III 𝍸	II		I	II		13	16	Adults	III	II	II				7	8	20	T Ø I Ø	Adults 17	Boat ___ Canoe ___ Hunters ___
	Small Pups									Small Pups										R ___ G ___	Pups	Kayak ___ H Bike ___ SUP ___
	Large Pups									Large Pups												
	Adults									Adults										F ___ T ___ I	Adults	Boat ___ Canoe ___ Hunters ___
	Small Pups									Small Pups										R ___ G ___	Pups	Kayak ___ H Bike ___ SUP ___
	Large Pups									Large Pups												
	Adults									Adults										F ___ T ___ I	Adults	Boat ___ Canoe ___ Hunters ___
	Small Pups									Small Pups										R ___ G ___	Pups	Kayak ___ H Bike ___ SUP ___
	Large Pups									Large Pups												
	Adults									Adults										F ___ T ___ I	Adults	Boat ___ Canoe ___ Hunters ___
	Small Pups									Small Pups										R ___ G ___	Pups	Kayak ___ H Bike ___ SUP ___
	Large Pups									Large Pups												
	Adults									Adults										F ___ T ___ I	Adults	Boat ___ Canoe ___ Hunters ___

Otter Activity Key	Species Key
R: Rest	HS: Harbor Seal
G: Groom	SL: Sea Lion
F: Forage	SO: Sea Otter
T: Travel	O: Other (e.g. bird)
I: Interact	**Disturbance Key**
H: Hauled Out	HR: Head Raise
	Flee: Move Away
	FL: Flush/Dive

Time	Area	Species and Number	Disturbance	Watercraft Type and Number
	Comments (If disturbance, circle and enter appropriate information.)			
1015	(W)/E	HS/SL/(SO)/O # 2	(HR)/FLee/FL	(Kayak)/H Bike/SUP/Boat/Canoe # 3
	W/E	HS/SL/SO/O # ___	HR/FLee/FL	Kayak/H Bike/SUP/Boat/Canoe # ___
	3 KAYAKS CAME TOO CLOSE TO OTTERS CAUSING 2 OTTERS TO DO A HEAD RAISE			

Form dated 10/2/2018

Example map for recording exact otter locations



Data archiving

Data are currently entered onto a paper spreadsheet and then compiled in an Excel spreadsheet stored in a shared Dropbox. The marked up maps will be archived for future use by USGS, which requested them. The Reserve is committed to sharing all data. Ideally, past ESOP and SORAC and ESNERR data can all be combined with future ESNERR data into one single, clearly comprehensible database with clear metadata, so any researcher can easily make sense of all data and analyze trends.

Data analysis

The team reviews seasonal trends in abundance and reports findings in the volunteer newsletter and in the Reserve's State of the Estuary report. Beyond this, data can be used in future analyses of sea otter abundance and behavior.

The ROMP data is further compared to data from the ESOP and from other sources such as the annual USGS surveys from 1994 to present, Elkhorn Slough Safari data from 1994 to present, and ESOP data from September 2013 to September 2016. Combining data from these various sources validates data collected by different methodologies and allows for further in-depth analysis of daily, weekly, annual, temporal and tidal variations.

Appendix A: Area Specific Information

This appendix provides maps of the different locations and descriptions of the counting boundaries within a location. The locations appear organized from the Harbor upstream to Kirby Park.

Harbor

The Harbor includes multiple areas in the north and one in the south. Observers for the Harbor Entrance, Harbor Center, Harbor North, and Bennett Slough can park in the parking lot at the end of Jetty Road (Moss Landing State Beach Park). Observers for Harbor South can park along Moss Landing or Sandholt Road. Harbor North and Bennett, and Harbor South are usually covered by one person walking the designated area.

Harbor Bennett

Usually, one observer covers Harbor North and Bennett.

Directions

1. Exit Highway 1 to Jetty Road.
2. Park on the east side of the bridge on Jetty Road before Highway 1 or the Jetty Road parking lot, and then walk back to the bridge.

Observation area and boundaries

Look up the water on the north side of the bridge, including the area that meanders west. Check culverts on this side of the bridge and across the road.

Harbor Center

Directions

1. Exit to Jetty Road off Highway 1.
2. Drive to the end of the road and park in the parking lot.
3. Set up the scope in the parking lot.

Observation area and boundaries

From the parking lot, look directly in front of you in the harbor, from the north towards Monterey Bay Kayak (MBK) and south to as far as the jetty. Include the area east of the jetty that extends across to the dock.

Harbor Entrance

Directions

1. Exit to Jetty Road off Highway 1.
2. Drive to the end of the road and park in the parking lot.
3. Walk from the parking lot to the end of the road and past the large sign.

Observation area and boundaries

Position yourself where you can best observe otters in the inlet and straight up towards the Highway 1 bridge.

Harbor North

Usually, one observer covers Harbor North and Bennett.

Directions

1. Exit to Jetty Road off Highway 1.
2. Drive to the end of the road and park in the parking lot.

3. Walk back north to the bend in the road.

Observation area and boundaries

At the bend on Jetty Road, look directly in front of you in the harbor, at the sand bar and across to the marina. Walk down towards Bennett Slough and check water that extends south from the bridge to the Kayak Connection dock.

Harbor South

Directions

1. Exit Highway 1 to Moss Landing Road.
2. Park your car at the pull-out across from the Whole Enchilada Restaurant (at the east corner of the marina).
3. Walk back north along the path that parallels Highway 1.

Observation area and boundaries

1. As you walk the path, observe otters in the marina, along docks and by boats.
2. From the top of the path at the pull-out on Highway 1, look across at the south harbor to the south jetty.
3. Look north at the entrance to the south harbor, in the area south of the channel markers.

Elkhorn Slough

Wildlife viewing

The Moss Landing Wildlife Viewing (MLWA) area belongs to California Department of Fish and Wildlife (CDFW). The gate might be closed before 9am and after 4pm. If the gate is closed, open the gate to drive though, and then reclose the gate. If the caretaker for this area questions you, let him know that you are part of the Reserve otter monitoring team. Do not leave any valuables in sight; this area has had break-ins. Park near the wildlife informational placard

Directions

1. Exit Highway 1, into the driveway directly across from Monterey Bay Kayak. A sign for Wildlife Viewing area marks the location.
2. Drive through the gate.
3. Drive right around the backside/slough side of the large tin barn to the parking lot.
4. Walk down the path to the furthest east viewing platform that extends over the water.

Observation area and boundaries

Note: Wildlife has two datasheets to accommodate east, west, and marsh.

West—Observe otters between the bridge and the observation deck.

East—Observe otters from the observation deck to the end of the levy at Seal Bend.

Wildlife Marsh – Observe otters that appear in the marsh north east of the viewing platform, in the MLWA beneath the Packard property. These otters are often hauled out.


Gate
Park Here
RT 1
West Observation Area
East Observation Area

Seal Bend

The house and the dairy are privately owned, but the Eucalyptus grove and the levee are owned by ESNERR and home to many birds and other animals. You can drive to the Eucalyptus trees, but the observation spot requires a 15-minute walk.

Directions

1. From Highway 1, exit to Dolan road.
2. Turn left at the Moon Glow dairy main gate.
3. Drive down the dirt road, and then turn left between the two white picket fences. The road is between cows and piles of manure. A large tree is on the left side of the fence. (If you get to a green house, you have gone too far.)
4. Continue to the end of the road, and then turn right.
5. Drive to the end of the road and park by the eucalyptus trees.
6. Walk straight down the path, and then veer right onto the bank next to the slough.
7. Turn left at the cut-through that has a narrow levee that leads out to the main channel.

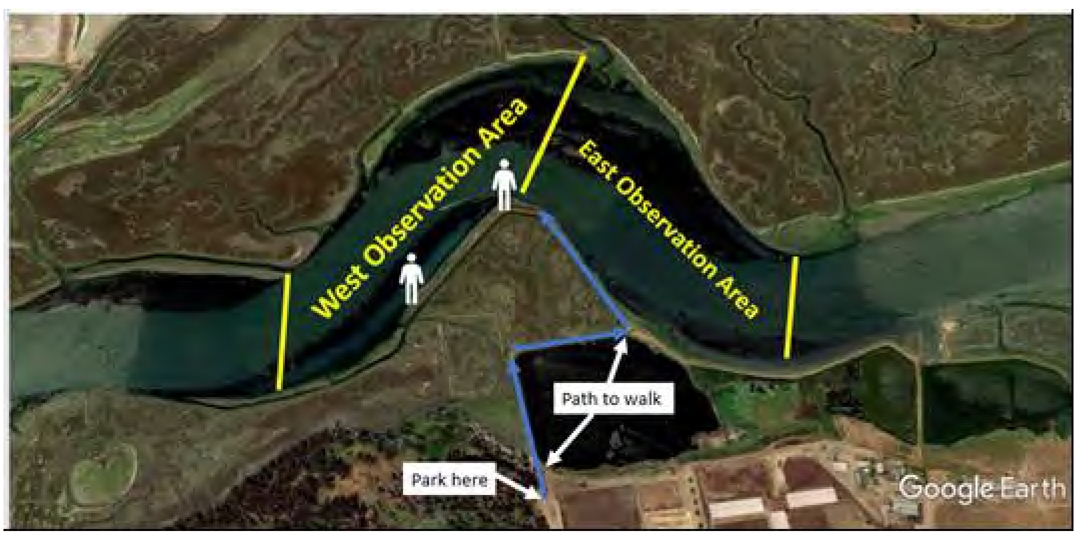
Observation area and boundaries

Note: Seal Bend has two datasheets to accommodate east and west, and marsh.

East — Set the scope up where the narrow path starts to turn left on the main channel. Look for otters to your right (east) from the spit of land on the far bank across to the dairy side. (The spit of land is the boundary for the Yampah counters). Then, from the spit of land, look left until you are about half way across the channel.

West — Set the scope up at the far west point of the bank at the place where three PVC pipes appear in the water, and a building appears straight across on the far bank. Count otters from your far left, out to the spit of land on the left, across to the far bank. Extend this area up to the halfway point that you used for the border of your east count.

Packard Marsh – count otters that appear in the marsh directly across from the west and east areas. These otters may be hauled out.



Moonglow

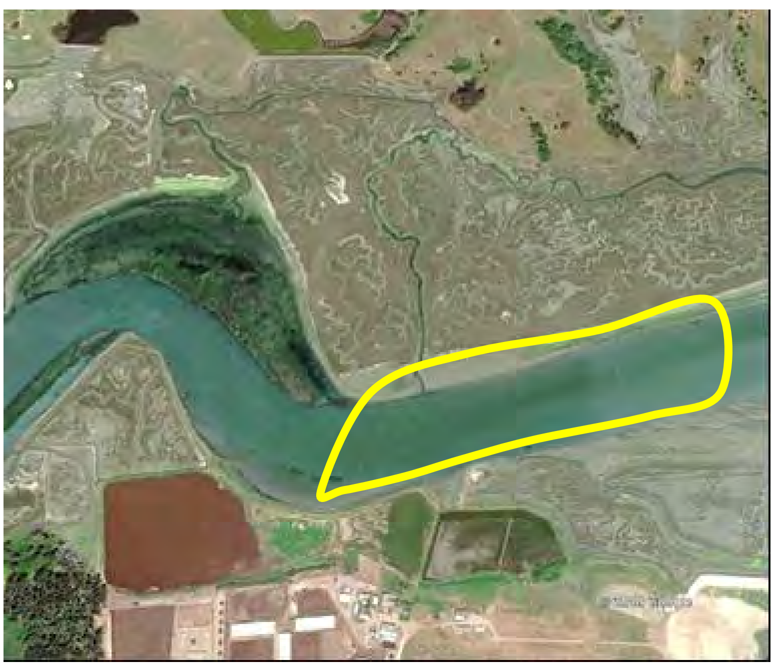
Moon Glow monitors the main channel between Seal Bend and Hester II as well as Rubis Creek and associated marsh that is directly across from the viewing spot. (see overview map at beginning of Slough section)

Directions

1. From Highway 1, exit to Dolan road.
2. Turn left at the Moon Glow dairy main gate.
3. Drive down the dirt road to the end, and then turn right.
4. Park by the old building overlooking the slough.

Observation areas and boundaries

Position yourself by the building overlooking the slough. Count otters west of your location to seal bound, and then north to the Yampah boundary. Also observe any otters in Rubis creek, directly across from your location.



Hester

Hester 1 and Hester 2 are marsh areas that are being restored as part of the Hester project. Monitoring of these areas provides information on how quickly otters and seals begin using the restored areas. Observations will typically be made from Yampah Island, especially during construction while access is limited. However, after construction, and after significant colonization of the areas by sea otters, observations may be made from the Hester area:

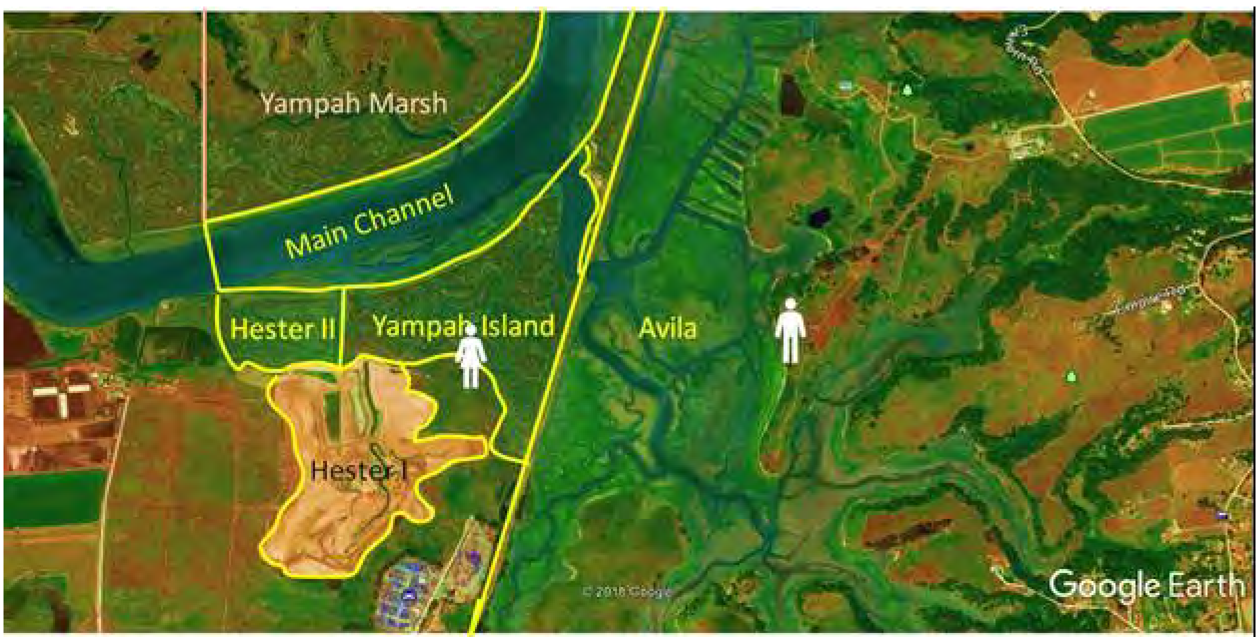
Directions

1. From Highway 1, exit to Dolan road.
2. Turn left at the Moon Glow dairy main gate.
3. Drive down the dirt road to the end, and then turn right.
4. Drive down the end of the road to the end, and park your car.

Observation areas and boundaries

Hester 1 – the area south of the inlet.

Hester 2 – the area north of the inlet.



Yampah and adjacent Main Channel

Yampah Island is part of the ESNERR but is not drivable. You will park and walk 20 minutes to the location. Do not leave valuables in sight in your car; this area has had break-ins.

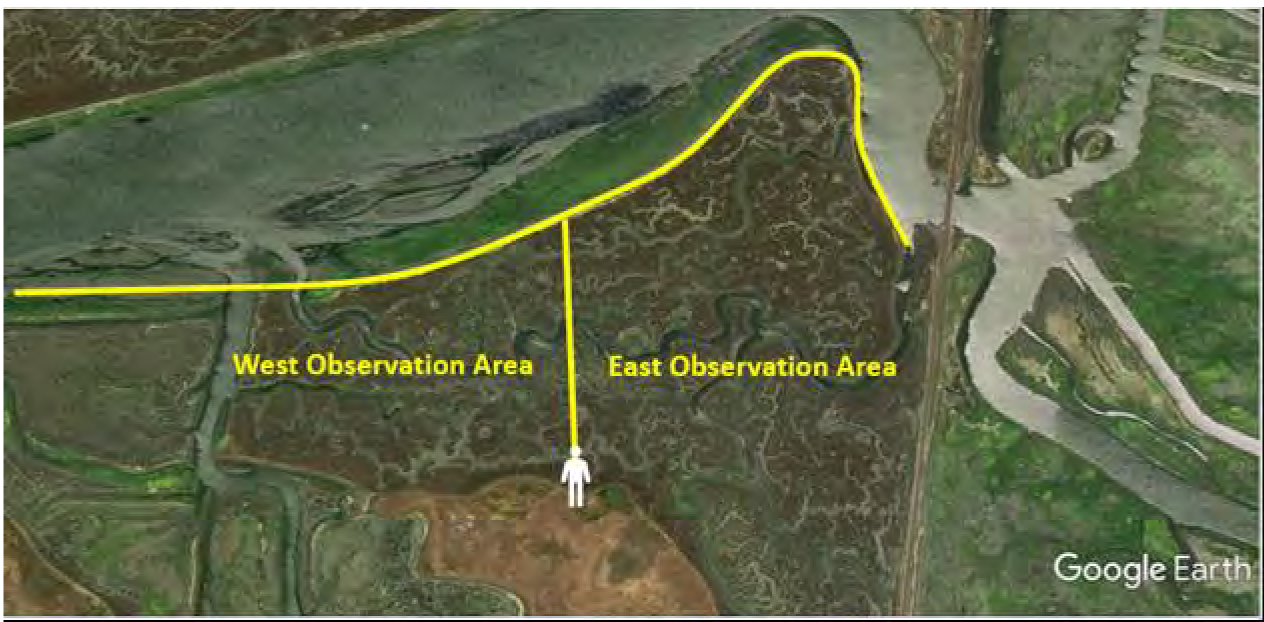
Important: Before entering Yampah Island, clean your shoes thoroughly. There is highly invasive hoary cress on the hillside leading down to entrance, but not on the island. Please prevent introduction of this and other invasive plants by taking the time to clean the soles of your shoes every time you enter.

Directions

1. From Highway 1, exit to Dolan Road.
2. Turn left on Via Tanques Road. (This is the road that leads to Pick-n-Pull.)
3. Drive to the end of the road and park by the open field area.
4. Walk down the path in front of the road, and then enter the island.
5. Follow the path out to the top of the island surrounded by salt marsh. A small wooden enclosure with a bench marks the spotting site.

Observation area and boundaries for Yampah inlets

Use the Yampah location to count the east and west inlets.



Observation area and boundaries for Main Channel

Use the Yampah location to count the Main channel from Hester II to Parsons Slough entrance.

Avila (Sam Farr Bench)

Avila is located on the ESNERR. Please check with the team leader to ensure roads are drivable especially during the rainy season. Make sure that you have the ESNERR parking permit on your dash when driving on the Reserve. You can drive to the bench and work from your car.

Directions

1. Enter the ESNERR. (If the ESNERR is closed, enter the code to open the gate. The gate code will be provided.)
2. Drive down the road that is to the left of the visitor station, and to the right of the ESF trailer buildings.
3. Continue until you reach the South Marsh trail that goes to the left just before the observation area with the telescopes.
4. Continue south on the road heading west towards the Sam Farr bench.
5. Park at the Sam Farr lookout noted by a bench.

Observation area and boundaries

Include otters that are east of the railroad trestle; do not include otters under the trestle or on the west side of the trestle.

Hummingbird Island

Hummingbird Island is located on the ES Reserve. Please check with the team leader to ensure roads are drivable especially during the rainy season and make sure that you have an ESNERR parking permit on your dash when driving/parking on the Reserve. Hummingbird island is drivable until the levee and then requires a 20-minute walk to the observation spot.

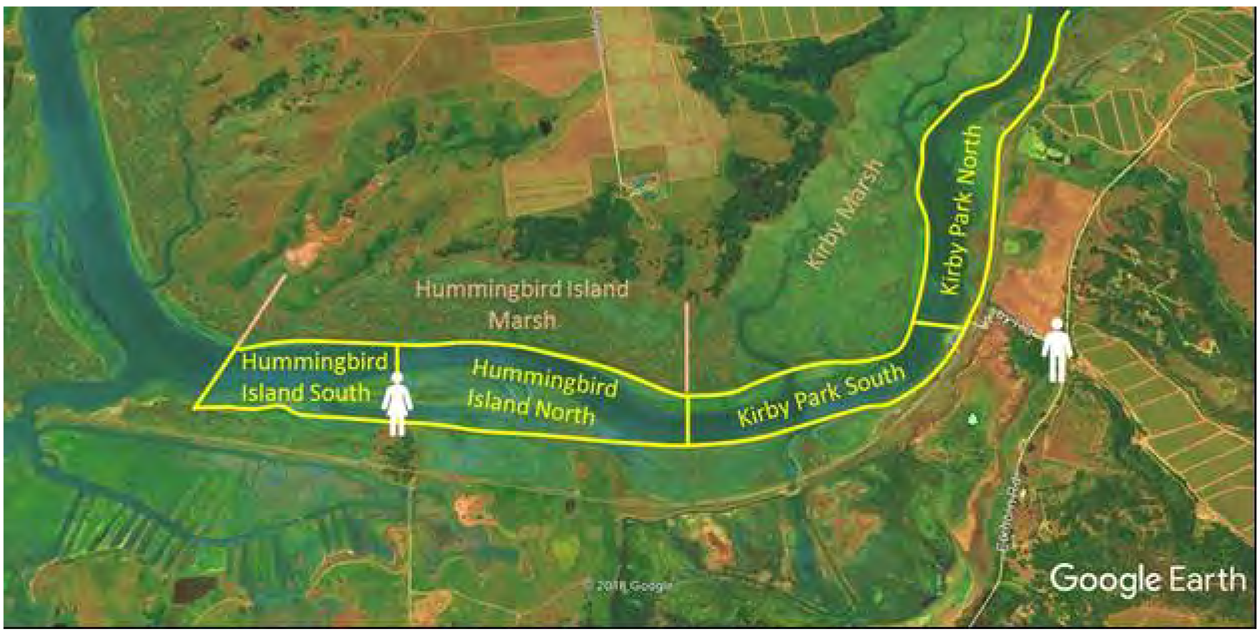
Directions

1. Enter the ESNERR at the green gate located at 1460 Elkhorn Road. The gate combo will be provided.
2. Close and lock the gate, and then drive right heading north until the road turns west (left). DRIVE SLOWLY.
3. Continue until you come to the intersection with the North Marsh trail.
4. Turn left and continue until you reach the next intersection, and then turn right and head west. Park off the trail by the bench before the levee to Hummingbird Island.
5. Walk across the levee bearing right until you see the Hummingbird sign marking the path.
6. Follow the path up a short set of stairs; pass a teepee type of structure on your left and a small man-made pond on your right until you reach the shore.

Observation area and boundaries

Move the scope to complete observations: North – Carry the scope down to the right on the shore.

South – Set up for the count at the downed Eucalyptus trees.



Kirby Park Outlook

Kirby Park is a county park open to the public. However, it remains closed due to road construction. During the closure complete observations from the road outlook. When Kirby Park reopens, observe from the Kirby Park parking lot instead of from the outlook.

Directions

On Elkhorn road, park in the pull-out just south of the entrance to Kirby Park.

Observation area and boundaries

The Kirby Park dock divides the observation areas into north and south. See boundaries on the following image.

Appendix 11

Evaluation of blue carbon function

Appendix 11

Salt marsh restoration and greenhouse gas mitigation: evaluation of blue carbon function of restored and natural habitats at Elkhorn Slough, California

Elizabeth B. Watson[1], Monique Fountain[2], Charlie Endris[3], Cathleen Wigand[4], John Haskins[2], Kathryn Beheshti[5], Brittany Wilburn[1], Habibata Sylla[1], Sophia Larson[1], Elisabeth Powell[6], Abbey Rosato[1], Jenna Shikuzawa[2], other students & staff TBD, Kerstin Wasson[2,5]

[1] Department of Biodiversity, Earth & Environmental Sciences and the Academy of Natural Sciences, Drexel University, Philadelphia, PA, USA

[2] Elkhorn Slough National Estuarine Research Reserve, Watsonville, CA 95076, USA

[3] Moss Landing Marine Laboratories, Moss Landing, CA 95039, USA

[4] U.S. EPA, Atlantic Coastal Environmental Sciences Division, Narragansett, RI, United States

[5] Ecology and Evolutionary Biology Department, University of California, Santa Cruz, CA 95064, USA

[6] Department of Geographical Sciences, University of Maryland, College Park, MD, 20742, USA

Note: this is a draft document that still will be edited and improved as final data are collected and analyzed, and peer review incorporated.

This Appendix serves as a temporary repository for this draft information until a paper is published on these results.

Abstract

On an acre by acre basis, coastal marshes typically sequester more carbon than terrestrial forests. Thus their conservation and restoration may contribute to enhancing ecosystem-based carbon storage to mitigate greenhouse gas emissions and combat climate change. Characterizing spatial patterns and variability in carbon storage has been identified as a key need for blue carbon research, and thorough assessments of carbon sequestration by restoration projects is lacking. Here, we assessed the climate change mitigation function of a very high marsh restored with soil addition, nearby references marshes, and marshes that were previously diked and subsided, focusing on mudflat, high marsh, and the marsh-upland ecotone. Three years after soil addition with 29% vegetated cover, our results suggested that emissions of nitrous oxide and methane were greater at lower elevations, but higher elevations were typically sinks for these gases. Nitrous oxide emissions - though small and variable - appeared to offset a significant portion of the climate change mitigation function of these wetlands due to its high global warming potential. We expect that once fully vegetated these emissions will be reduced. Reducing nitrogen inputs into coastal estuaries would likely have important climate change mitigation benefits. Our results also suggest that drowned marshes may preserve their carbon sequestration function even as they convert to mudflats and bare ground, although we suggest that more study is needed to confirm this finding due to the unvegetated aspect of these marshes. Overall, this project built a high marsh that we expect to be resilient to the next century of change in an estuary where marshes are losing vegetation and drowning. We will continue to study the progress of this restoration project to adaptively manage where possible to achieve targets, and to inform future restoration projects.

Introduction

Tidal marshes are highly productive ecosystems that provide myriad services of value to people, including nursery habitat for fished species and shoreline protection (Costanza et al., 1997; zu Ermgassen et al., 2021). In the past centuries, these services have declined as tidal marshes have undergone widespread loss due to land use changes, in particular diking and draining to “reclaim” wetland for human uses (Gedan et al., 2009). Looking to the future, accelerated sea-level rise (SLR) and further anthropogenic alterations to coastal systems are likely to lead to additional, extensive loss of tidal marsh habitat (Gilby et al., 2020; Kirwan & Megonigal, 2013).

To address past loss of tidal marshes, restoration projects are underway around the world (Waltham et al., 2021). In the past decades, the most common restoration approach was to restore tidal exchange to previously diked wetlands (Burdick & Roman, 2012). More recently, an increasing number of projects are taking a different approach, raising elevation with sediment addition, both to restore elevation that has been lost from human-induced subsidence, and to prepare for accelerated SLR (Stagg & Mendelssohn, 2010; Thorne et al., 2019). These coastal restoration projects have a variety of objectives -- restoration of the foundation species themselves, as well as provision of various ecosystem services, including carbon sequestration (Bayraktarov et al., 2020).

Vegetated habitats can play a key role taking up carbon dioxide and thus mitigating the increase in greenhouse gas emissions that is driving climate change (Reich, 2011). In the past decades, coastal vegetation has increasingly been recognized as important to global carbon sequestration (Chmura et al., 2003). “Blue carbon” is a term coined in 2009 to highlight the important role of marine habitats in carbon sequestration (Nellemann & Corcoran, 2009), and the concept motivated numerous investigations of the potential role of coastal habitats in climate change mitigation (Lovelock & Duarte, 2019). In temperate zones, tidal marshes have some of the highest potential for greenhouse gas mitigation (Chmura et al., 2003; Mcleod et al., 2011). Therefore, the past loss of tidal marshes and projected future loss in the face of SLR is associated with loss of blue carbon function (Pendleton et al., 2012).

As tidal marsh restoration projects expand, designed to undo past losses and enhance resilience to SLR, it is important to determine whether restored marshes provide blue carbon function similar to natural ones, and if so, how quickly this blue carbon function is restored. Addressing these questions is urgent because blue carbon benefits of coastal restoration projects are being promoted as a method of mitigating climate change, including tidal marsh restoration (Wylie et al., 2016). Governments are already investing in wetland restoration for greenhouse gas mitigation. For instance, in California, USA, a cap-and-trade program generates a greenhouse gas reduction fund, of which $47M has been invested in wetland restoration to date (https://www.caclimateinvestments.ca.gov/about-cci). Likewise, a consortium of states in the eastern US has developed the Regional Greenhouse Gas Initiative (https://www.rggi.org/) that invests in habitat restoration. Marsh restoration through restoring tidal flow to diked marshes can increase carbon storage and reduce methane emissions (Kroeger et al., 2017). Marsh restoration through sediment addition has been less frequently assessed in terms of blue carbon function. While avoided gas emissions from tidal restoration can occur immediately, benefits associated with carbon storage by vegetation colonizing sediment addition sites will accrue more slowly. A mature marsh community is often slow to develop, and restored marshes typically differ from reference sites for decades (Armitage, 2021; Moreno-Mateos et al., 2012; Zedler & Callaway, 1999). There is some evidence of carbon storage in marshes created by sediment addition, but often at lower levels than reference sites (Abbott et al., 2019; Craft et al., 2003; Shiau et al., 2019).

Characterizing spatial patterns and variability in carbon storage has been identified as a key need for blue carbon research (Mcleod et al., 2011). Furthermore, to thoroughly assess blue carbon function, carbon sequestration rates should be assessed as well as carbon storage, and gas flux monitored to ensure that emissions of methane and nitrous oxide don’t negate carbon storage benefits (Lovelock & Duarte, 2019). To assess whether marsh restoration can successfully provide blue carbon function, a thorough characterization of all these dimensions of blue carbon function must be compared for high functioning, natural reference marshes, degraded marshes, and restored marshes. In addition, for greenhouse gas modeling of effects of SLR, a better understanding is needed of how habitats along elevational gradients perform blue carbon functions, from mudflat positioned below marsh to low marsh to high marsh to upland habitats immediately above marsh. Understanding sustainability of blue carbon function in face of SLR thus requires excellent understanding of elevations and tidal datums (Chmura, 2013). Very few such comparisons of habitats within the same landscape exist, both in terms of habitat condition (reference, degraded, restoration) and across an elevational gradient at the same site.

The goal of our investigation was to enhance understanding of blue carbon functions of tidal wetlands within a California estuarine ecosystem. One specific objective was to compare 1) natural, healthy high marsh reference sites, 2) degraded, formerly diked, subsided sites, and 3) a sediment addition site restoring lost elevation to a formerly degraded wetland. We also quantified the changes over time within the 20-hectare footprint of this restoration site, comparing blue carbon function pre-restoration, when the site was degraded and subsided, to function three years after sediment addition, to likely future function when the site is fully vegetated. Another specific objective was to compare coastal habitats along an elevational gradient, from low elevations (below the lower limit of marsh vegetation) to high elevations (above the upper limit of marsh vegetation), to better understand the consequences of future SLR and of restoration across the coastal landscape. We employed a diverse suite of metrics in order to thoroughly assess different dimensions of blue carbon function and to make recommendations for best monitoring and estimation approaches for future projects tracking the blue carbon consequences of tidal marsh restoration.

Methods

Study system: Elkhorn Slough estuary

The Elkhorn Slough estuary is located in central Monterey Bay, California, USA (Fig. 1; Table S1). The mean daily tidal range is 1.6 m, with an annual maximum of 2.5 m (Raposa et al., 2016). Salinity in the estuary averages 30-32 ppt year-round due to strong marine influence, although it can drop temporarily during heavy rainfall events. The climate is Mediterranean, with almost all significant rainfall occurring between October and May. The watershed around the estuary is highly agricultural, and the estuary is moderately to highly eutrophic (Hughes et al., 2011).

Tidal marshes at Elkhorn Slough are dominated by pickleweed (*Salicornia pacifica*), which forms a virtual monoculture in mid to low elevations on the marsh plain. Other native marsh plants (e.g. *Distichlis spicata*, *Frankenia salina*) are found at the highest intertidal elevations, mostly between Mean Higher High Water and the King Tide line (Wasson & Woolfolk, 2011).

Tidal marshes have been present in the estuary for thousands of years; in the past, they were less dominated by pickleweed likely due to greater freshwater influence (Watson et al., 2011). Elkhorn Slough has lost about half of the salt marsh area that was evident on maps 150 years ago, mostly due to diking and draining that occurred during the early 1900s (Van Dyke & Wasson, 2005). In recent decades, natural tidal exchange has been restored to some of the marshes that formerly were diked. Diking and draining led to significant compaction of wetland soils at Elkhorn Slough, with substantial loss of elevation. Where natural tidal exchange has been restored to such marshes, most of the former marsh area is too low to sustain marsh vegetation, due to excessive inundation duration -- what remains is a narrow bathtub ring of marsh on the steep hills adjacent to the former marsh plain. Tidal marshes that were never diked also have lost significant marsh cover over time and are low in the tidal frame (Raposa et al., 2016; Van Dyke & Wasson, 2005). They are also negatively impacted by algal mats resulting from eutrophication (Wasson, 2017).

Hester Marsh restoration

The Elkhorn Slough Tidal Wetland Program (TWP) is a collaborative effort to develop and implement strategies to conserve and restore estuarine habitats in the Elkhorn Slough watershed (Wasson et al., 2015). The TWP is coordinated by the Elkhorn Slough National Estuarine Research Reserve (ESNERR) with support from the Elkhorn Slough Foundation. It involves over a hundred coastal resource managers, representatives from key regulatory and jurisdictional entities, leaders of conservation organizations, scientific experts and community members.

The goals of the project include restoration of salt marsh to historically diked and drained areas to improve habitat, reduce tidal scour, and improve water quality, in an area of marsh that was diked, subsided, and became a poorly functioning mudflat covered by blooms of opportunistic macroalgae (Fig. 2). Greenhouse gas mitigation goals include: sequestration of 129 Mg atmospheric CO_2 y^{-1} in marsh sediments in addition to pre-restoration conditions, for at least 100 years and sequestration of 156 Mg atmospheric CO_2 in standing biomass of marsh vegetation in addition to pre-restoration conditions, for at least 100 years.The Elkhorn Slough Tidal Marsh Restoration Project will ultimately restore about 48 ha of salt marsh ecosystem in Monterey County, ranging from tidal creeks to salt marsh to adjacent grassland. Phase I, which we focus on in this study, aims to restore 19 ha of degraded marsh, create 5.7 ha of new marsh, and 2 ha of marsh-upland ecotone and native grassland within the buffer area. Upland soil from the adjacent hillside and a nearby flood control project conducted to enhance capacity on the nearby Pajaro River, was utilized to raise the degraded marsh plain 0.6-0.9 m (mean = 0.69 m). Phase I earth moving was completed in 2018, Phase II was completed in 2021, with Phase III estimated to reach completion in 2022.

Figure 1 - **Location of sampling sites.** Location of sites sampled for this study: including the restoration area (Hester), control areas, where marsh was diked and subsided, but where sediments were not deposited to raise the marsh elevation, and reference sites; areas which support high quality high marsh.

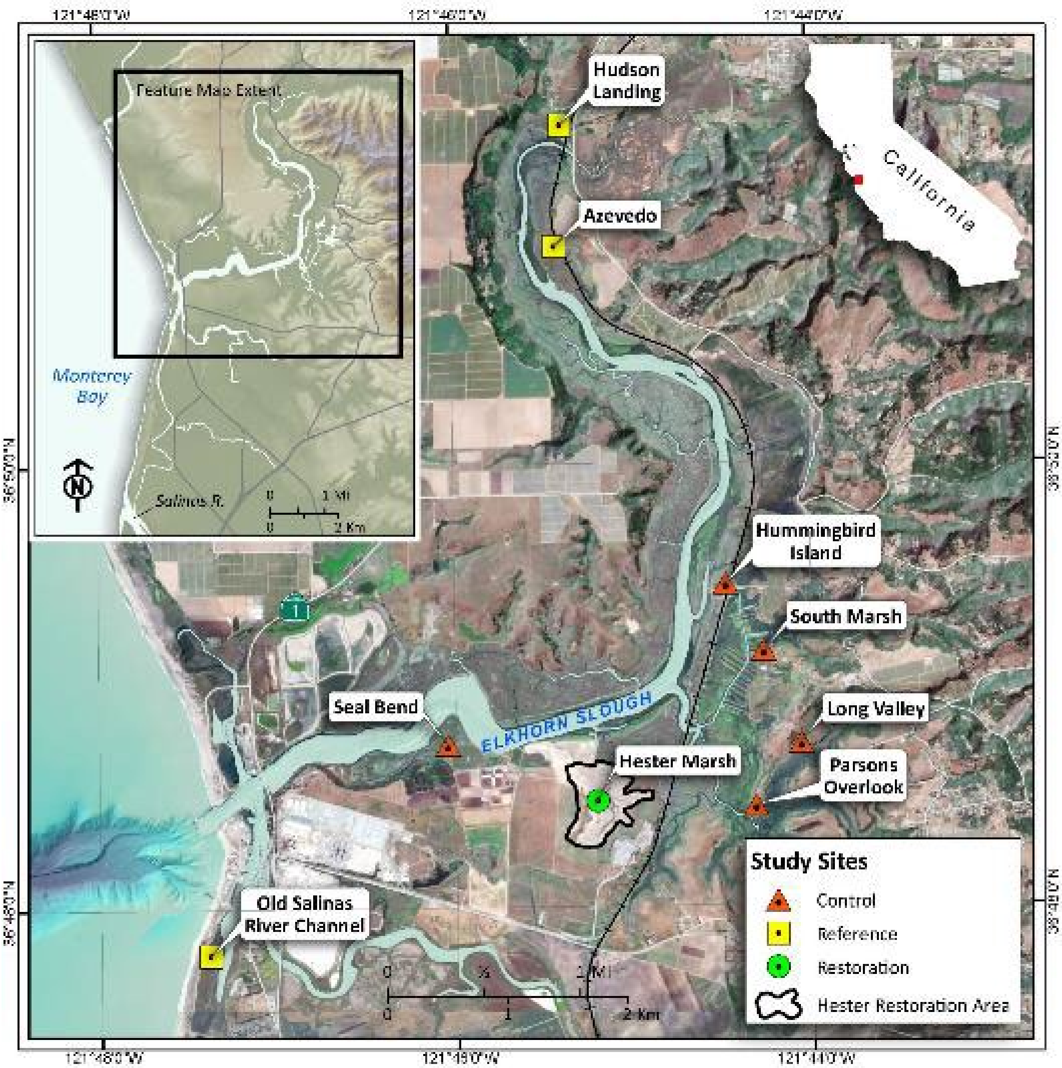


Figure 2 - **Overview of Hester Marsh restoration site (A) before; and (B) after restoration.**
Pre-restoration, the site had little marsh vegetation and was covered by blooms of opportunistic macroalgae. Post-restoration (footprint outlined in yellow), site began as bare sediment, but was colonized by vegetation starting in the first spring, with vegetation most prevalent around the marsh-upland border and adjacent to the main tidal channel. The area that was recolonized by vegetation cover [2021] averages 29%. Images courtesy of (A) Ivano Aielo, 2016, and (B) John Haskins, 2020.

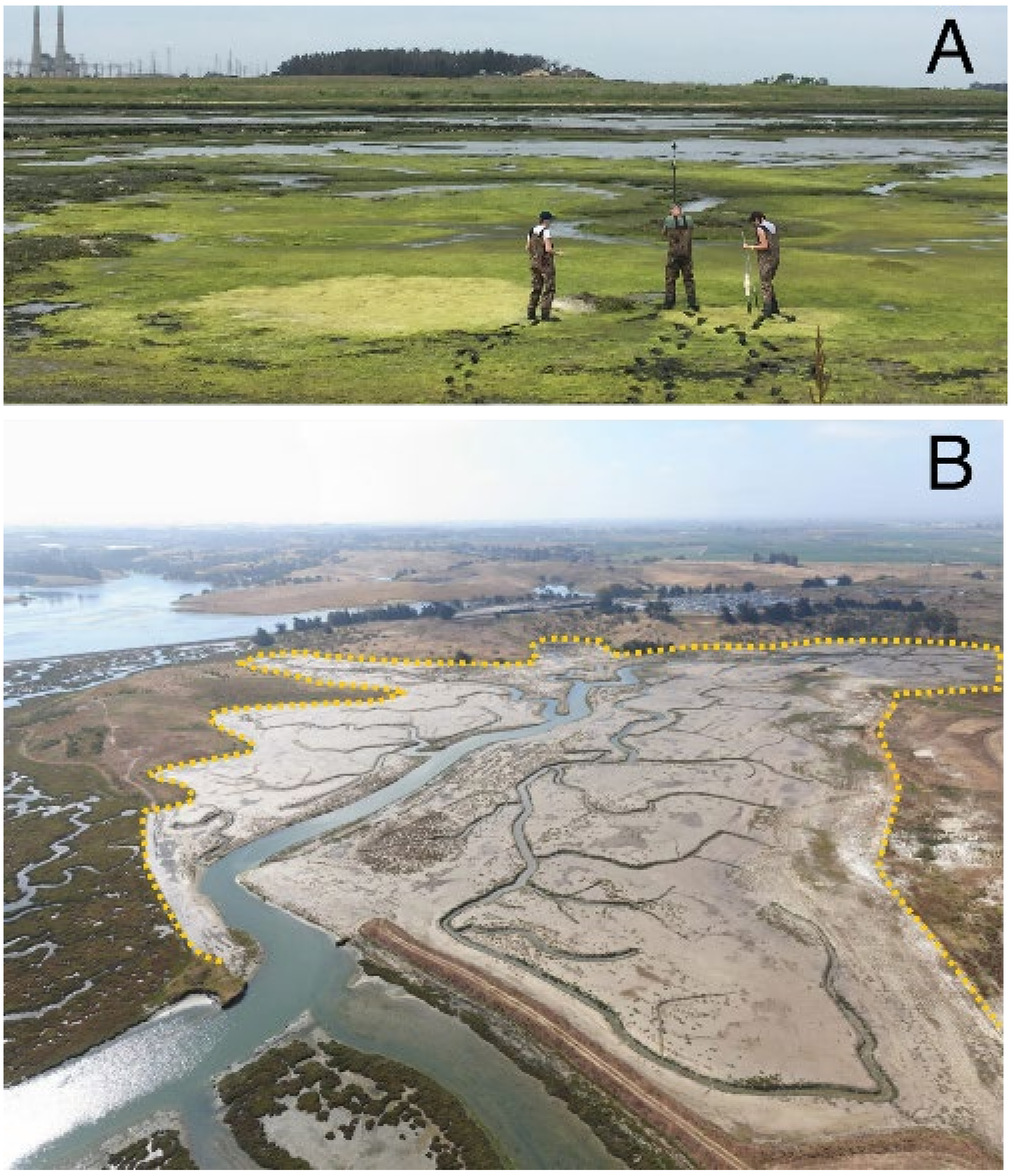
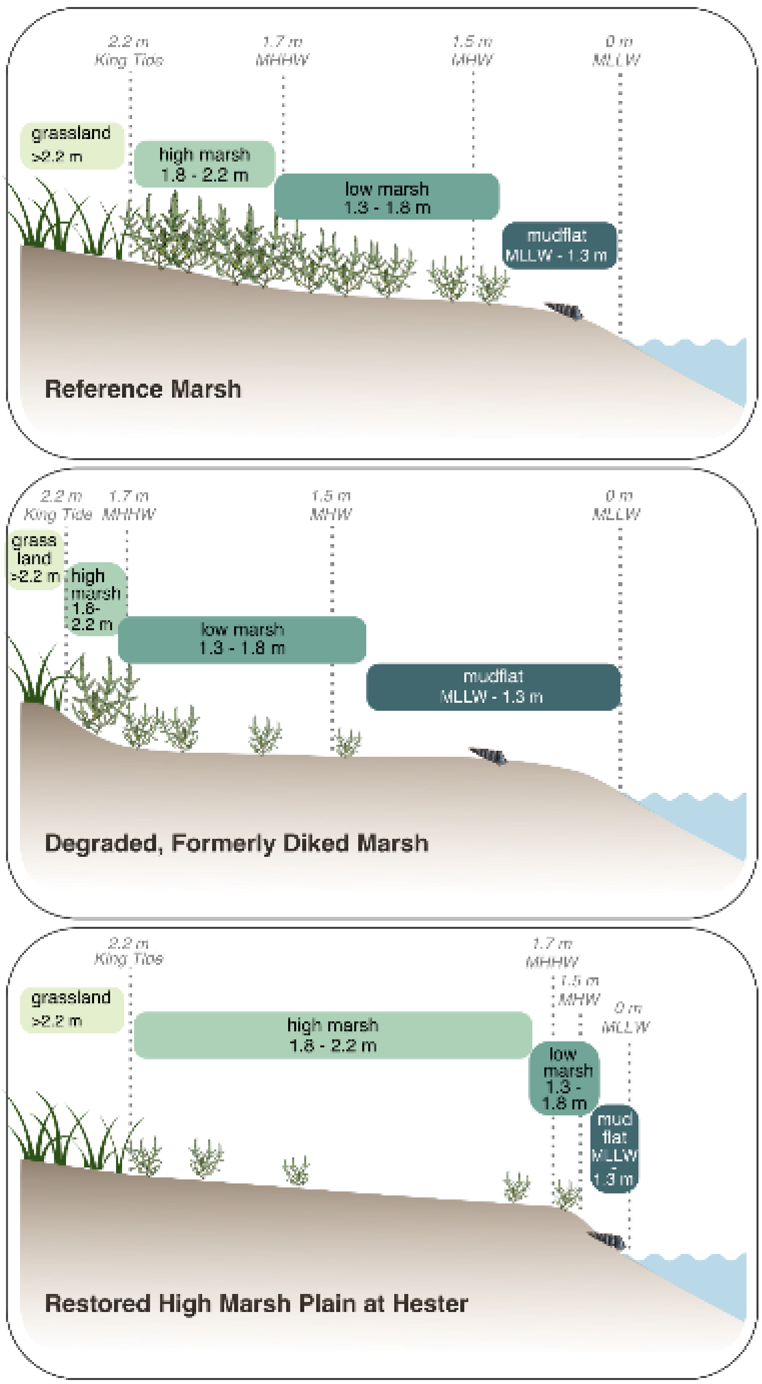


Figure 3 - Typical elevational profiles for habitat distribution at Elkhorn Slough marshes.
Top: healthiest reference marshes at Elkhorn Slough, with substantial low and high marsh; *Middle*: degraded, formerly diked marshes, dominated by intertidal mudflat *Bottom*: new high marsh plain created with sediment addition at Hester Marsh; eventually the site should be dominated by high marsh but three years after construction colonization by high marsh is in early stages. Elevations are shown in meters NAVD88 along with tidal datums (MLLW = Mean Lower Low Water, MHW = Mean High Water, MHHW = Mean Higher High Water, King Tide = highest annual tide).



Spatial and temporal monitoring design for assessing blue carbon function

Characterizing habitat types typical of degraded marsh sites

In order to characterize the blue carbon function of degraded, formerly diked marshes, we sampled five sites at Hester marsh prior to restoration and five nearby formerly diked marsh sites that served as controls (Fig. 1). For some parameters, we sampled the control sites in both the period before Hester restoration and after restoration (Table 1). For all parameters, we found no significant differences in t-tests comparing Hester pre-restoration to control sites, or in paired t-tests comparing control sites in the early vs. late sampling period. Therefore, we used all nine sites (five pre-restoration at Hester, four control sites) as replicates for the "Degraded marsh" category, and averaged data for the entire time series at the control sites in order to incorporate all data and provide the most robust estimates of function. Of note, one control site was dropped post-construction as it became part of a second phase of restoration work.

One objective of our sampling was to characterize blue carbon function across an elevational gradient, so that we can project how it may change either as the relative elevation of the marsh plain decreases due to global sea-level rise, or as the relative elevation of the marsh plain increases due to sediment addition projects. At each of the nine degraded marsh sites, we thus sampled four habitat types across the elevational gradient (Fig 3 middle). We sampled mudflat at an average elevation of 1.2 m NAVD88, which is typical of formerly degraded marshes, an elevation only slightly below the tolerance of marsh. We sampled low marsh at an average elevation of 1.6 m; this was typical of the dominant marsh elevation of degraded marsh sites and was an elevation where marsh was waterlogged and vegetation sparse due to excessive inundation. We sampled high marsh at an elevation of 2.0 m, which is where marsh is tallest and most dense; there is only a narrow bathtub ring of such high marsh at formerly diked sites. We sampled coastal grassland immediately above the landward boundary of the marsh, at an average elevation or 2.2 m.

Characterizing reference high marsh conditions

In order to characterize the blue carbon function of healthy, reference marshes we sampled at three never-diked marsh sites (Fig 1). Each of these sites had a permanent transect with 10 quadrats evenly spaced from the landward to the seaward boundary of the marsh as a part of consistent NERR sampling protocol. These marshes had substantial representation of both low and high marsh (Fig 3). Our focus was to examine locations of similar elevation to the newly created Hester Marsh plain. We thus sampled only at the quadrats with comparable elevation (1.7-2.2 m), which consisted of five quadrats at one reference site, and three at each of two others. These 11 sampling locations were used as the replicates for reference high marsh. In addition, we sampled a mudflat location just seaward of the marsh boundary at each of these three reference sites in order to determine whether never-diked mudflats differ from formerly diked. We also added one additional grassland location landward of the first quadrat for selected parameters of interest. The reference sites were sampled only in the period after Hester restoration (Table 1).

Characterizing Hester Marsh conditions post-restoration

To characterize the blue carbon function of Hester marsh post-restoration, we established three permanent transects using NERR protocols with 10 quadrats evenly spaced across the newly created marsh plain, from the king tide elevation (2.2. m) to the edge of a creek. We assessed surface sediment accretion at all 30 of these quadrats, and collected sediment samples for carbon analysis immediately following construction and three years later (n=30 for these analyses). For other parameters, we sampled at four quadrats along each transect, because these appeared to provide sufficient representation of elevation and vegetation conditions at the site (*n*=12 for these analyses). Sampling period varied by parameter; for time series of sediment accretion the entire period from completion of restoration to final sampling (2018-2021) was included; for time series of decomposition and root production, a single year was used; for sediment carbon, sampling occurred immediately after construction and after three years (2018 & 2021); for above-ground carbon storage and gas flux, sampling occurred only after three years (2021) (Table 1).

Table 1. Summary of sampling sites and times.

Type of site	Habitat Types	Aboveground biomass	Sediment cores	Gas fluxes	Sediment accretion	Litter & ingrowth bags
degraded, formerly diked sites: control & Hester pre-restoration	grassland high marsh low marsh mudflat	before 2015 after 2021	before 2015	before 2015 2017	before 2015-7 after 2018-21	after 2020-21
Hester post-restoration	bare (high) high marsh	after 2021	after 2018 2021	after 2021	after 2018-21	after 2020-21
reference sites	grassland high marsh mudflat	after 2021	after 2021	after 2021	after 2018-21	after 2020-21

Comparison of blue carbon function of Hester Marsh footprint over time

In order to estimate the temporal trajectory of blue carbon function of Hester Marsh, we conducted a GIS analysis to determine area of different habitat types in four different periods - baseline historical conditions, conditions immediately prior to restoration, conditions three years after restoration, and likely conditions in future when the marsh plain is fully colonized. We then multiplied the average value for specific metrics related to blue carbon function by the area of each habitat type represented. We used exactly the same boundary for the restoration area in all periods: this was determined by generating a king tide (2.2 m NAVD88) contour around the site based on the 2018 post-construction digital elevation map, and transferring that to aerial imagery for all periods. This enabled us to estimate the total blue carbon function for the entire tidal footprint in different periods. We did this for net blue carbon function (see Ecosystem Blue Carbon Function section below) as well as for individual metrics. For instance, above-ground carbon storage within the restoration footprint [C_{ag}] for one period was calculated by summing the products of the areas covered the four habitat categories [*A*] and the carbon density of the aboveground biomass [C] in each of these four different habitat categories (mudflat, low marsh, high marsh, and grassland):

$$C_{ag} = \sum_{i=1}^{4} A_i C_i$$

Analysis of each of the four periods is briefly described below:

<u>Baseline:</u> We used aerial photography from 1931 to estimate recent historical conditions (Table 2). The boundaries between grassland, marsh, mudflat and channels are clearly visible in this image and were used to calculate area of each of these habitat types within the 2021 marsh restoration contour. The marsh plain appears to be high, given the dense vegetation and narrow creeks, so we categorized all marsh vegetation as high marsh. We multiplied the area

of mudflat, high marsh and grassland by the average blue carbon values for these habitats obtained from our field sampling of degraded formerly diked and reference sites. Since we could not readily conduct field sampling of subtidal habitats for gas flux and other blue carbon functions this habitat type was excluded from the analysis for this and all periods.

Before restoration: We used aerial imagery, collected by Tombolo Mapping Lab using an E384 fixed-wing unoccupied aerial vehicle in October 2015, combined with a digital surface model from the same flight to estimate the area of different habitat types immediately prior to restoration. Using ArcPro v2.8.3 (ESRI, Redlands, CA, USA), we used a supervised object-based classification method to segment the image into groupings of neighboring pixels that exhibited similar spectral characteristics. We developed training sample polygons of vegetated, bare (including mudflat and water), and algae-covered areas of the marsh. We selected a support vector machine classifier that appeared to produce the best results for classifying the imagery. We merged the algae and bare classes into a single “bare” class and used a reclassifier tool to change misclassified pixels to the correct class (either “bare” or “vegetated”). Grasslands and marsh channels were eliminated from the supervised classification results above using a manually digitized polygon mask; the mask was used to calculate the areas for these habitat types. Lastly, we ran an accuracy assessment of the vegetated- and bare-classified pixels by comparing them to 200 points that were randomly created, using a stratified random sampler, and manually classified by close inspection of the UAV imagery. Fit was assessed using a confusion matrix, and calculation of the kappa statistic, and 90% confidence intervals were generated for habitat classes (Oloffosn et al. 2014). Areas for the above classes were then calculated within a reclassified digital surface model to determine vegetated areas above and below 1.8 m (NAVD88). We considered marsh vegetation below 1.8 m NAVD88 to be low marsh, vegetation between 1.8-2.2 to be high marsh, and vegetation above 2.2 m to be grassland. We multiplied the area of mudflat (“bare”), low marsh, high marsh and grassland by average blue carbon values for these habitat types obtained from our field sampling of degraded formerly diked sites (Hester and control).

Three years after construction: We used aerial imagery we collected with our DJI Phantom 4 Pro quadcopter unoccupied aerial vehicle in both September 2020 and August 2021 combined with a digital surface model generated by structure-from-motion corrected with ground-control points immediately after construction in 2018, as we have described elsewhere (Haskins et al., 2021). We used the same elevation boundaries for habitat types as described above for pre-restoration and generally followed a similar classification method (object-based support vector machine) and accuracy assessment. We separately calculated the area of high marsh that had survived from before-restoration at the fringes of the restoration site from the area of newly colonized high marsh vegetation, because the former was much taller and denser than the latter. We also calculated the area of still bare habitat on the new high marsh plain. We multiplied the area of mudflat, existing high marsh and grassland by the average blue carbon values obtained from field sampling of these habitat types for both degraded and reference sites. We multiplied the area of newly colonized marsh vegetation and areas that were still bare on the new high marsh plain by the average blue carbon values obtained from field sampling of these habitat categories at Hester post-restoration.

Future: We estimated the area of the different habitat types that will likely be present after the marsh plain is fully colonized. This was done using the 2018 digital elevation model described above, and assuming that the new marsh plain would be fully vegetated with high marsh. We did not account for changes in tidal datums that will result from sea-level rise over 30 years. We multiplied the area of mudflat, low marsh, high marsh and grassland by the average blue carbon values obtained from field sampling of these habitat types at reference sites.

Table 2. Aerial photography imagery sources, showing analyzed imagery, including spectral and pixel resolution, horizontal accuracy and imagery source. Imagery collected by the Elkhorn Slough National Estuarine Research Reserve staff is abbreviated ESNERR.

Date	Type	Aircraft	Pixel resolution (m pixel^{-1})	Horizontal registration accuracy (m)	Source
May 1931	Panchromatic	-	0.63	1	Western Gulf Oil Co/ Fairchild Aerial surveys
Oct 2015	3 band	E384 Event Unmanned Systems, Inc	0.03	0.1	Tombolo Mapping Lab
Sept 2020	3 band	DJI phantom 4 pro quadcopter	0.008	0.013	ESNERR
Aug 2021	3 band	DJI phantom 4 pro quadcopter	0.008	0.013	ESNERR

Methods for quantifying parameters related to blue carbon function

Carbon content of above ground vegetation

Aboveground biomass was harvested from clip plots (0.15 x 0.15 m or 0.25 x 0.25 m) in July 2015 from the control and restoration sites (pre-restoration) (*n*= 40 locations, including 20 pre-restoration; 20 control), and from the control, reference, and restoration sites in July 2021 (*n*= 59 locations, including 30 restoration; 16 control; 13 reference). Samples were washed over a 60 μm sieve to remove salt and soil; dried to constant weight, and weighed. Carbon content in aboveground biomass was assessed as the product of aboveground biomass and carbon content. Carbon content was measured on sub-samples of aboveground biomass ground to pass through #40 standard mesh (0.425 mm) on a Wiley mini-mill (Thomas Scientific). Samples were analyzed for total carbon on a Flash EA 113, using analysis of duplicates, blanks, and standard reference materials.

Belowground Production

Belowground production was measured using ingrowth bags (Neill 1992) deployed from December 2020 to December 2021. Mesh bags for root and rhizome ingrowth were constructed using fiberglass window screen (1.5 mm mesh) that measured 15 cm in length and 4.5 cm in diameter. Ingrowth bags were tubular in shape, open at the top and sewn closed at the bottom. Bags were filled with sand obtained commercially. Three ingrowth bags were placed per monitoring location (*n* = 41 locations, including 12 restoration; 16 control; 13 reference; total 123 bags). After collection, root and rhizome material was separated from sand, dried to constant weight, and weighed. Weights were scaled to reflect productivity at 1-m^2. Carbon content was measured as above.

Decomposition

Decomposition was measured for surface litter at the surface and at two sub-surface depths using a bag design with several separate pouches (0-5cm above ground; 0-2.5 cm & 20-22.5 cm belowground), filled with aboveground biomass in the surface pouch and belowground biomass in subsurface pouches; biomass was *Salicornia pacifica* collected from Elkhorn Slough. Six bags were deployed at each monitoring location (*n*= 41 locations, including 12 restoration; 16 control; 13 reference; total 246 bags) in February of 2020, two bags each were collected in

February and December 2021. Decomposition rates were calculated from the percentage of dry mass remaining.

Carbon content of sediment

Soil cores 30-cm of depth were collected to measure soil carbon density in 2015 pre-restoration (*n*=80, 40 control; 40 reference), in 2018 when the restoration was complete but prior to revegetation (*n* = 30; t_0 restoration samples) and in 2021 post-restoration (*n*=43, 30 restoration; 13 reference). Soil sample intervals were analyzed for 2-cm intervals for 2015 samples and for 5-10 cm intervals for 2018 and 2021 samples and analyzed for bulk density loss on ignition (Heiri et al. 2001). Organic carbon content was measured after pre-treatment with 48 hour fumigations with hydrochloric acid to remove inorganic carbon (Harris et al. 2001). More than 450 samples were analyzed for organic carbon using a Flash EA 1112 elemental analyzer. Where samples were not analyzed for organic carbon, we used a site-specific empirical relationship to estimate percentage of soil carbon based on soil loss on ignition data (r^2=0.92, y=0.4038x; where *y* is percent organic carbon; *x* is percent loss on ignition) (Fig. S1). We analyzed the top 5-cm and top 30-cm of soil profiles. We measured increases in soil carbon at Hester by comparing 2018 with 2021 soil profiles collected to a depth of 30-cm along three transects (30 locations).

Sediment deposition rate at surface

To quantify surface deposition of carbon across habitats, we installed feldspar marker horizons (approximately 25 x 25 cm) and ceramic tiles (approximately 15 x 15 cm) at the focal monitoring stations. These were monitored annually in summer 2015-2018 at Hester and degraded control sites, and 2018-2021 at all sites (Hester, degraded control, reference). Feldspar and tiles generally showed similar patterns, so we used feldspar only, except in instances where the feldspar horizon was lost, when tile data were used instead. In 2016, 2017, 2018, and 2021, we collected sediment samples from the tiles and quantified bulk density and estimated organic carbon density, using loss on ignition. We used this value to correct sediment deposition rate to rate of carbon deposition.

To assess compaction or swell of sediments in the top meters of these habitats, we inserted 3 m lengths of conduit pipe into the sediment, leaving about 1 m above the surface. We annually measured how much was extending above the surface, 2015-2021 at degraded control sites, and 2018-2021 at Hester and reference sites. If less pipe length was protruding over time, this either is a result of deposition or swell of sediments in the top two meters; if less pipe length was protruding over time, this either is a result of erosion or compaction of sediments in the top two meters.

Gas fluxes

To better understand whether the greenhouse gas mitigation function was significantly altered by changes in methane and nitrous oxide emissions, methane and nitrous oxide exchange were measured. Pre-restoration measures were made in 2015 (*n*=358, 180 control; 178 pre-restoration), in reference and restoration sites in 2017 (*n*=57, 14 control; 27 reference; 16 pre-restoration), and in control, reference, and restoration sites in 2021 (*n*=410, 160 control; 130 reference; 120 restoration).

Measures of CH_4 and N_2O exchange were made using a Picarro G2508 cavity ringdown spectroscopy analyzer (Picarro, Santa Clara, CA, USA), while measures of CH_4 were made using a LGR ultra-portable greenhouse gas analyzer (ABB-Los Gatos Research, San Jose, CA, USA). Nylon tubing and static flux chambers were used to create a closed system, and the gas concentration change over time was used to compute fluxes (Martin and Moseman-Valtierra

2015). A backflow prevention valve controlled pressure equilibration within the static chambers. Gas fluxes were measured for 5 minutes, and during light and dark conditions, to quantify contributions of plant vs soil mediated gas fluxes. All GHG measures were performed during low tide, and the ideal gas law (*PV=nRT*) was used to calculate changes in gas concentration over time using field-measured air temperature and atmospheric pressure. Where in-significant changes in gas concentration over time were identified (slope p>0.05), fluxes were assigned a value of zero. For the restoration area, where vegetation was patchy, a 5 x 5 plot was demarcated and sampling locations were chosen haphazardly by throwing an object into the plot. Photos of collars were taken to estimate plant cover. Relationships between gas fluxes, depth to groundwater at low tide, and porewater salinity, and DIN (described below) were tested for using linear regression. Methane and nitrous oxide emissions were compared between light and dark measures to provide insight into the role of plant mediated emissions. For the restoration area, emissions were also compared within plant cover categories (bare vs. vegetated. Greenhouse gas measures were made in the post-restoration area only during summer of 2021 when emissions are likely highest.

Porewater

Low-tide depth to water table, porewater pH, salinity, and nutrient concentrations were measured in 2015 (*n* = 40 locations, including 20 pre-restoration; and 20 control) and in 2021 post-restoration (*n* = 41 locations, including 12 post-restoration; 16 control; 13 reference). Porewater salinity and pH were measured using a YSI EXO2 sonde. Porewater samples were analyzed for dissolved nutrient concentrations (nitrate, nitrite, ammonium, phosphate) using a Lachat Instruments QuickChem 8000. Depth to the water table was measured at low tide.

Fig 4. Field methods. A - sediment sampling via coring at Hester prior to restoration, B - sediment sampling at Hester immediately after construction was completed by collection from auger holes, C - location where above-ground biomass was harvested with clippers, D - pouring feldspar marker horizons at Hester immediately following construction, E - sediment accretion on feldspar "brownie" at reference marsh site, F - monitoring greenhouse gas emissions at Hester 3 yrs after construction *Draft here - please re-arrange or replace with your preferred photos and Kerstin can pretty up and finalize*

Calculating net blue carbon function

Construction Emissions

Emissions associated with construction were estimated based on the California Air Resources Control Board- California Emissions Estimator Model (Breeze Software, 2020). Calculations were based on the number of days worked, and equipment used, which in turn was a function of the volume and distance of sediment moved on site.

Ecosystem Blue Carbon Function

Three different methods were used to calculate blue carbon function (Fig. 5). First, we estimated carbon sequestration as the sum of the difference between belowground production and decomposition on a yearly basis, carbon accumulation through surface sediment deposition, and carbon dioxide equivalents emitted through emissions of methane and nitrous oxide, represented as:

$$[p_c - d_c] + sed_c - CO_2eqv \qquad \text{Eqn 1}$$

Where p_c represents the yearly carbon fixed in belowground biomass, d_c represents the fraction of belowground biomass carbon remineralized on a yearly basis, sed_c represents the amount of carbon accumulation that occurred through allochthonous sediment deposition, and CO_2eqv represents carbon dioxide equivalent emissions of methane and nitrous oxide using global warming potentials of 34 and 298 respectively from IPCC 2013 (100-year time horizon, including climate-carbon feedbacks: Myhre et al. 2013). This first approach was applied to reference marshes, degraded and formerly diked control marshes, and the restoration footprint at Hester Marsh. The second approach calculated carbon sequestration at Hester marsh as the difference between soil carbon density at the completion of earth moving with that three years later, again adjusting for other greenhouse emissions:

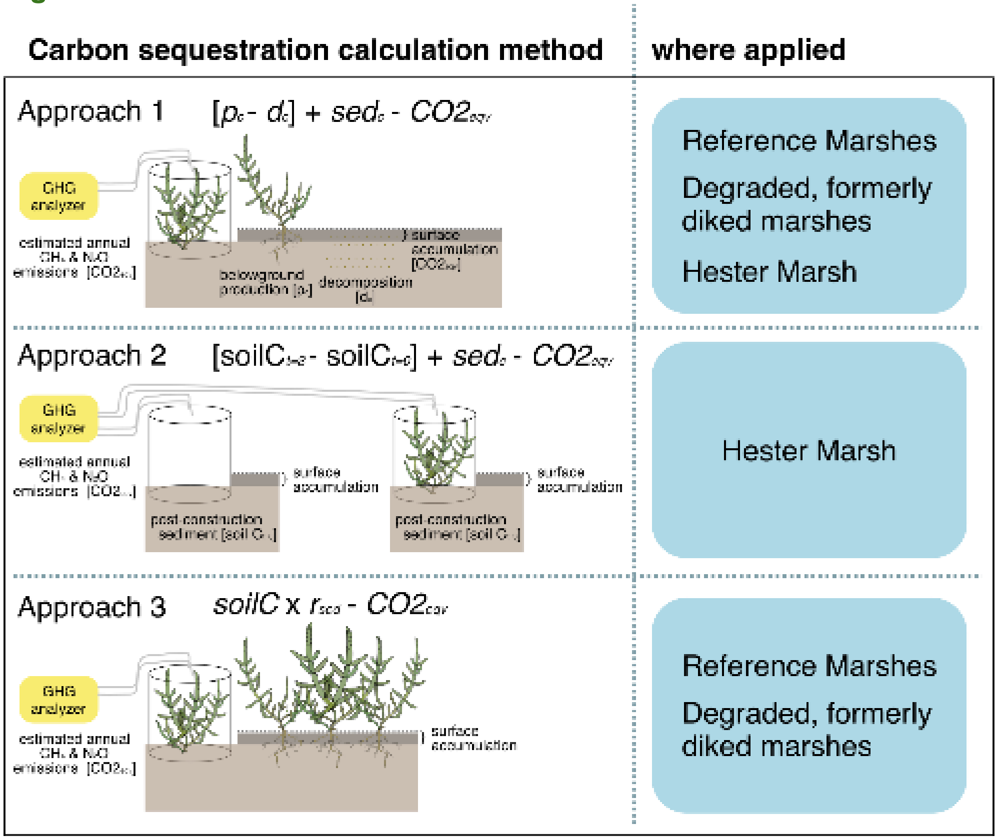
$$[soilC_{t=3} - soilC_{t=0}] - CO_2eqv \qquad \text{Eqn 2}$$

where $soilC_{t=3}$ is soil carbon density at year 3, and $soilC_{t=0}$ is soil carbon density at year zero. While we did not expect that soil carbon density would increase measurably over three years - even high rates of production would be associated with soil carbon percentage increases of 0.5% and likely lost in soil heterogeneity - we did however conduct this analysis. The third approach calculated carbon sequestration as the product of soil carbon density and yearly accumulation rate:

$$soilC \times r_{sed} - CO_2eqv \qquad \text{Eqn 3}$$

where $soilC$ is soil carbon density, and r_{sed} is the sediment accumulation rate in mm yr^{-1}. These three approaches involve several assumptions, and are somewhat more relevant to analyses conducted on contrasting time scales. First, we are assuming that emissions measures we made are representative. Second, we are assuming the allochthonous soil carbon deposited in surface sediments wetlands has a relatively long turnover time. Third, calculating soil carbon accumulation as the difference between belowground production and decomposition is only relevant for short term studies. Lastly, the method of calculating carbon accumulation rates using sediment accumulation rates is likely reflecting carbon accumulation on a longer time-scale than that estimated using Eqn 1. This analysis was applied only for control and reference sites, as the soil carbon pools at the restoration site were not yet developed.

Figure 5 - Methods used to calculate blue carbon function.



Lastly, to compare carbon sequestration across different time periods, we multiplied habitat-based estimates of carbon sequestration by their areal extent at Hester marsh. We conducted this analysis for 1931, before diking and subsidence, for 2015, prior to the restoration project inception, for 2018, three years after the restoration, and for ca. 2050, 30 years post-restoration, at which point we estimate the project will have achieved its targets.

Results

Geospatial Analyses

Restoration activities resulted in changes in the areal extent of habitats at Hester Marsh (Table 2; Fig. 6). Prior to restoration in 2015, the footprint contained 57% bare habitat, 3.2% high marsh, and 9.1% low marsh, in contrast with 1931 when the area was 77% marsh. By 2021, only three years post-construction, the project footprint contained 28% high marsh, a substantial increase in the areal extent of high elevation marshlands. We anticipate that when the restoration area is fully vegetated, it will support 84% marsh vegetation. Accuracy assessments found overall accuracy of classification of 2015 and 2021 imagery at 91% and 90.5%, respectively with kappa values indicating substantial agreement (Table S2; S3). In 1931, prior to significant anthropogenic impacts, the area largely supported marsh vegetation, in 2015 after diking, subsidence, and dike failure, the area supported a low percentage of marsh cover, but large areas of unvegetated tidal flat. The restoration project was finished in August 2018; by 2021 approximately 28% of the newly restored habitat had revegetated.

Table 3. Areal extent of habitat types at Hester Marsh before diking and subsidence, prior to the restoration, just after restoration, and after complete re-vegetation.

	1931	**2015**	**2021**	**Future**
Total marsh area	18.6 ha	29,819 m^2 2.98 ha	68,209 m^2 6.82 ha	204,210 m^2 20.4 ha
Low Marsh (<1.8 m)	-	22,079 m^2 2.21 ha	0 m^2 0 ha	0 m^2 0 ha
High Marsh (1.8-2.2 m)	-	4,065 m^2 0.407 ha	64,535 m^2 6.45 ha	200,536 m^2 20.1 ha
High Marsh non-restored	-	3,674 m^2 0.367 ha	3,674 m^2 0.367 ha	3,674 m^2 0.367 ha
Bare	3,302 m^2 0.330 ha	137,791 m^2 13.8 ha	136,001 m^2 13.6 ha	0 m^2 0 ha
Grassland	38,810 m^2 3.88 ha	39,838 m^2 3.98 ha	847 m^2 0.847 ha	847 m^2 0.847 ha
Channels	13,468 m^2 1.34 ha	34,140 m^2 3.41 ha	36,531 m^2 3.65 ha	36,531 m^2 3.65 ha
Total area assessed	241,589 m^2 24.2 ha	241,589 m^2 24.2 ha	241,589 m^2 24.2 ha	241,589 m^2 24.2 ha

Habitat type comparisons

Carbon content of aboveground vegetation

Excluding the restoration area, aboveground vegetation was found to support the highest carbon density in the high marsh, which was significantly greater than aboveground carbon storage in the low marsh and the grassland / ecotone (p=3.5 x 10^{-6}; Fig. 7). In the restoration area, mean aboveground carbon density averaged 74% less than found in control and reference sites - and this is only including sites supporting vegetation. Excluding the restoration area, we found aboveground carbon density at 327 ± 58.3 g C m^{-2} (mean±SE) in the grassland / ecotone habitat, 743± 65.0 g C m^{-2} in the high marsh, and 316± 54.9 g C m^{-2} in the low marsh. These patterns were driven by and tightly correlated with aboveground biomass (r^2=0.99; p<0.001); however, there were also trends in percent carbon of biomass that varied with elevation (Fig. 8). The percentage of carbon in grassland / ecotone plant tissues was 39.6± 0.72% in the grassland/ ecotone, 36.0± 0.56% in the high marsh, and 33.1± 0.91% in the low marsh.

Values in the restoration area had a wider range than those found in ecotone, high marsh, and low marsh habitat (22.7 to 40.5%). For the restoration site, there was a trend towards higher values at higher elevations and lower values at lower elevations (Fig. S2), although this only partially explained trends (r^2=0.36, p=0.31). Standing aboveground biomass in the high marsh exceeded 2,060 ± 176 g m^{-2} at reference and control marshes, but was 529 ± 98 g m^{-2} at Hester, again only considering vegetated locations (Fig. S3).

Figure 7 – Aboveground biomass-associated carbon storage in at Elkhorn Slough research sites.
Highest values were found in high marsh at reference and degraded sites. Even at sites where vegetation has recolonized at Hester marsh (less than a third of the marsh plain), aboveground biomass carbon is lower than at reference and degraded sites.

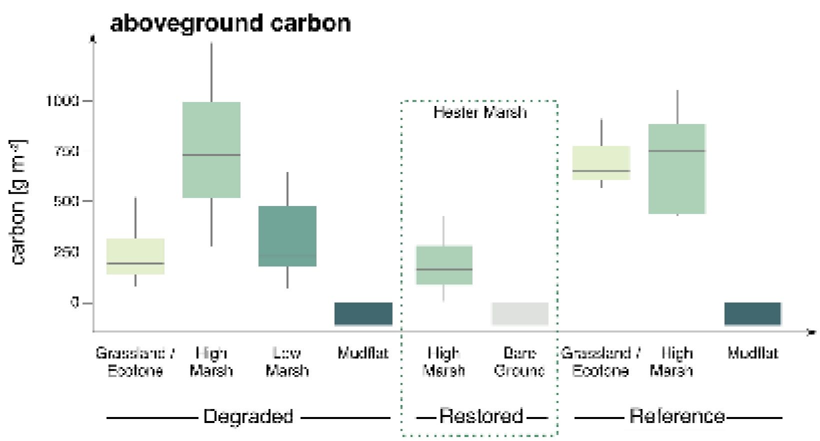
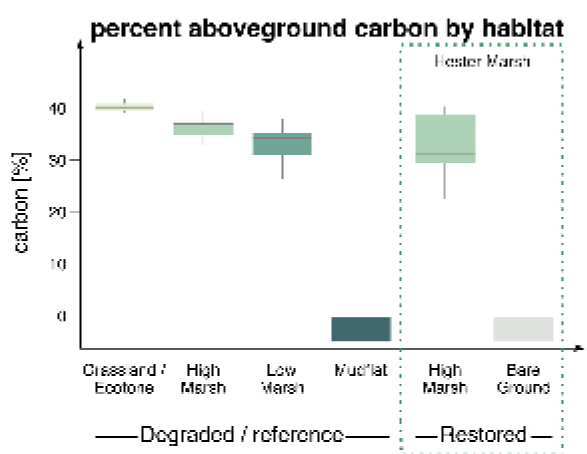


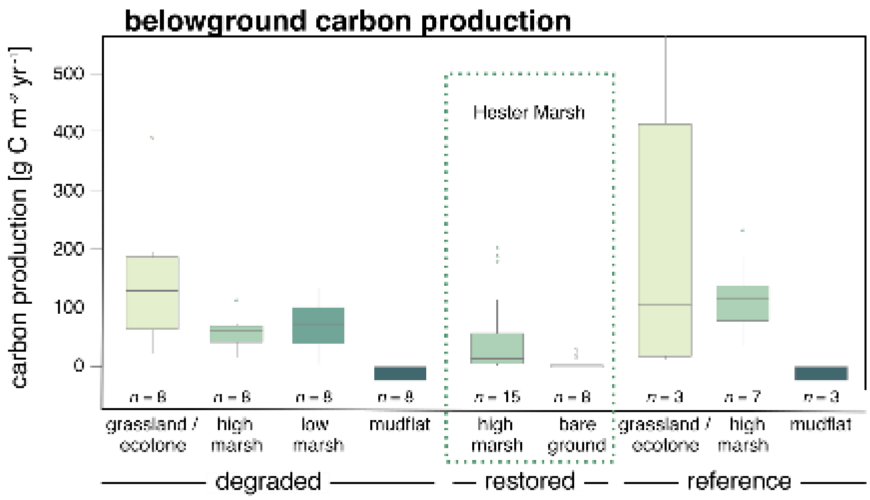
Figure 8 – Percent carbon in plant tissue across habitats
Highest values were found at the most terrestrial habitat, lowest values were found at the low marsh. Values at Hester Marsh were more variable than found in other habitats.



Belowground production

Carbon associated with belowground production measured on an annual basis was highest for the grassland / ecotone zone habitat (208 ± 64.6 g C m^{-2}; mean±SE), followed by the high marsh (97.8± 8.74 g C m^{-2}), and low marsh (70.3 ± 12.5 g C m^{-2}). The grassland / ecotone zone habitat had greater carbon production rates than the high and low marsh (based on a Tukey HSD post-hoc test; p=0.0.016 for the ecotone-high marsh comparison; p=0.0185 for the ecotone-low marsh comparison), but the low and high marsh were not significantly different from each other (p=0.91). Within the high marsh category, carbon associated with belowground production for the reference sites was three times higher (118 ± 10.5 g C m^{-2} vs 39.0± 7.54 g C m^{-2}) than for control and restoration sites, which were not found to be significantly different from each other (p=0.25). Like values for aboveground biomass carbon, belowground biomass carbon was strongly driven by production (r^2=0.81; p<0.001), although less strongly than for aboveground biomass. While there were some differences in carbon density of belowground biomass by habitat, they were likely obscured by contaminants entering the bags that had similar density and appearance to soil macro-organic matter.

Figure 9 – Annual belowground biomass carbon production across habitats
Highest values were found at the grassland/ecotone habitat, with high marsh and low marsh not distinguishable from each other. Within the high marsh category, the reference site had greater values than restoration and control sites.

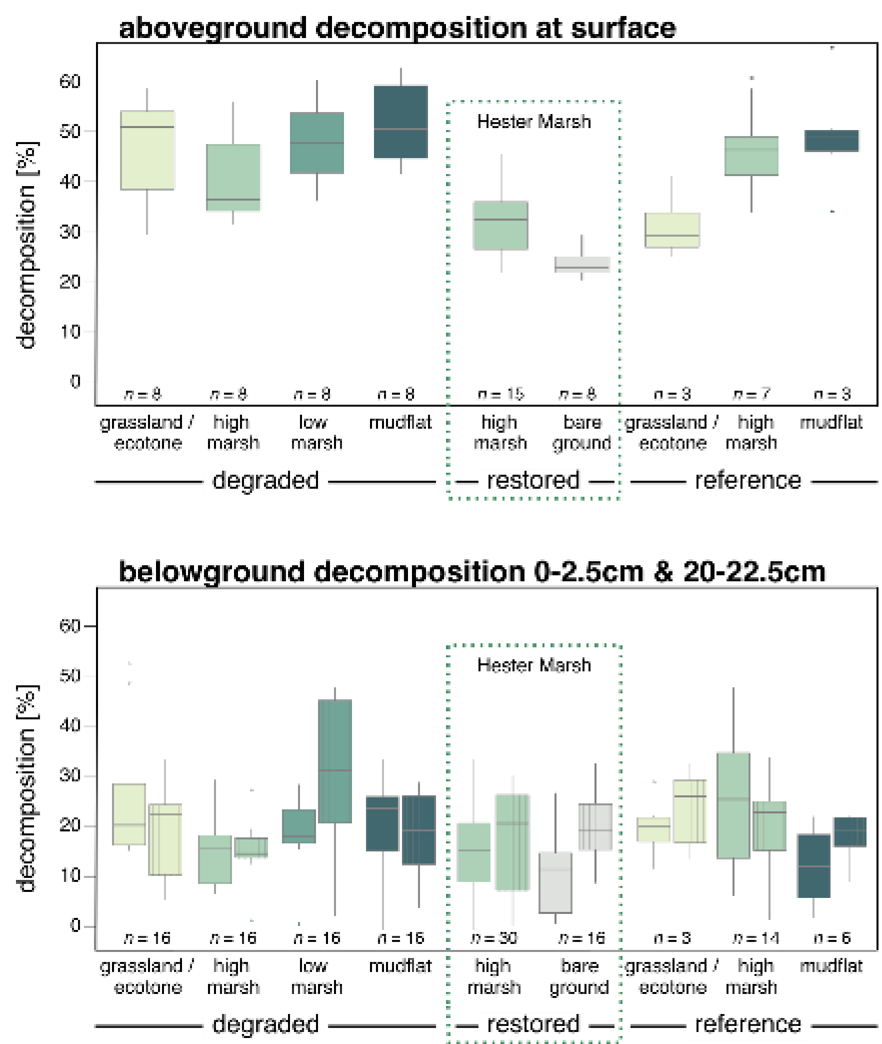


Decomposition

Mean aboveground decomposition rates, expressed as fraction mass loss per year, and excluding values measured at Hester Marsh, ranged from 0.40 ± 0.031 (±SE) in the grassland / ecotone, 0.44 ± 0.019 in the high marsh, 0.48 ± 0.030 in the low marsh to 0.51 ± 0.024 in the mudflat (Fig. 10). Generally there was a trend towards greater decomposition rates at the lowest elevations and slowest rates at the highest elevations, although the only categories that were significantly different from each other were grasslands and mudflats (p = 0.02). The Hester restoration footprint had the lowest rates of aboveground decomposition, with bare areas having mass losses of 0.23 ± 0.020 and areas that were revegetated having mass losses of 0.32 ± 0.016, a significantly greater value (p = 0.0027).

Overall belowground one-year mass loss rates were significantly lower than aboveground decomposition rates (0.19 and 0.20 for belowground vs. 0.41 for aboveground; t=12.07; p< 2.2e-16 for near-surface depth and t=11.72; p< 2.2e-16 for deeper depth based on paired tests). With respect to belowground decomposition at the near surface depth (0-2.5cm), we saw a trend towards higher rates of decomposition in the high marsh (0.23 ± 0.043) and grassland / ecotone zone (0.23 ± 0.032) than in the low marsh (0.18 ± 0.030) and mudflat (0.17 ± 0.027), which was the opposite pattern as found for aboveground biomass. Similarly, the Hester marsh restoration site showed a trend indicative of lower decomposition rates than found in other habitats (0.13 ± 0.019), with no difference found between vegetated areas and those lacking in vegetation (t = 0.36). For the deeper depth we saw less variability between sites, aside from the low marsh which was characterized by high variability. There was no significant difference in belowground mass loss rate between the near surface (0-2.5 cm) and deeper depth (ca. 20 cm) for the one year incubation period (t=0.45; p = 0.652).

Figure 10 – Decomposition at Elkhorn Slough research sites.
Above (top figure) and belowground (lower figure) decomposition at Elkhorn Slough research sites. Belowground decomposition mass loss lates for 0-2.5 cm of depth are shown in open box plots; while those for depths of 20-22.5 cm of depth are shown using hatched box plots.



Carbon content of sediment

We report on soil sediment carbon pools for both the top five and thirty cm of depth (Fig. 11). For both the five and thirty cm depth intervals, we found significantly different carbon pools for the restoration area, reference, and degraded sites (F = 13.35; p=1.86 x 10^{-7}), with greatest values in reference sites (1930 ± 292 g C m^{-2} for 0-5cm; 11,900 ± 1820 g C m^{-2} for 0-30cm) followed by degraded sites (1350 ± 70.8 g C m^{-2} for 0-5cm; 7,480 ± 387 g C m^{-2} for 0-30cm) , with the restoration area showing the lowest values (743 ± 60 g C m^{-2} for 0-5cm; 5,510 ± 335 g

C m^{-2} for 0-30cm). For both depth intervals, we did not see significant differences between habitat types. However, for the five-cm depth interval, there was a trend such that the highest soil carbon densities were found in the grassland / ecotone or high marsh habitat, with values declining to the mudflat. For the 30-cm depth interval, a similar trend was found for the reference sites, but for the degraded habitats, there was a trend towards increasing sediment carbon from the ecotone to the mudflat, with the mudflat having the greatest soil carbon inventories. There was no difference in soil carbon at the restoration site between vegetated and bare areas. Indeed, a spatial analysis shows that the transect with the most minimal vegetation cover (transect 9) had the greatest soil carbon gains (Fig. 12)

Figure 11 – Sediment organic carbon pool across habitats

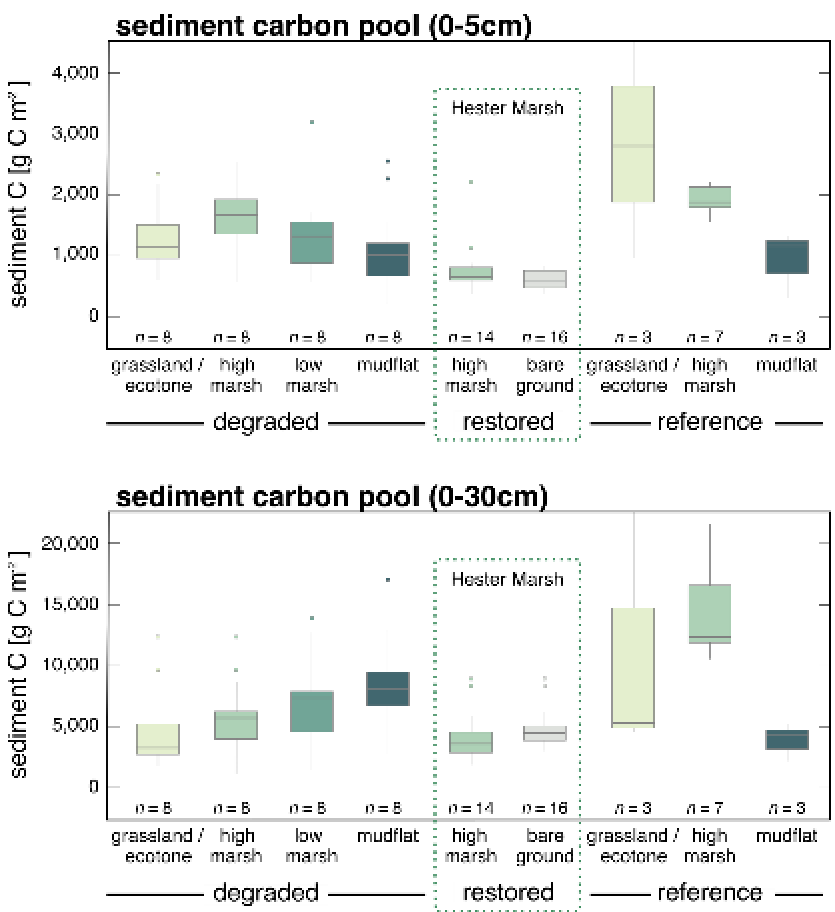
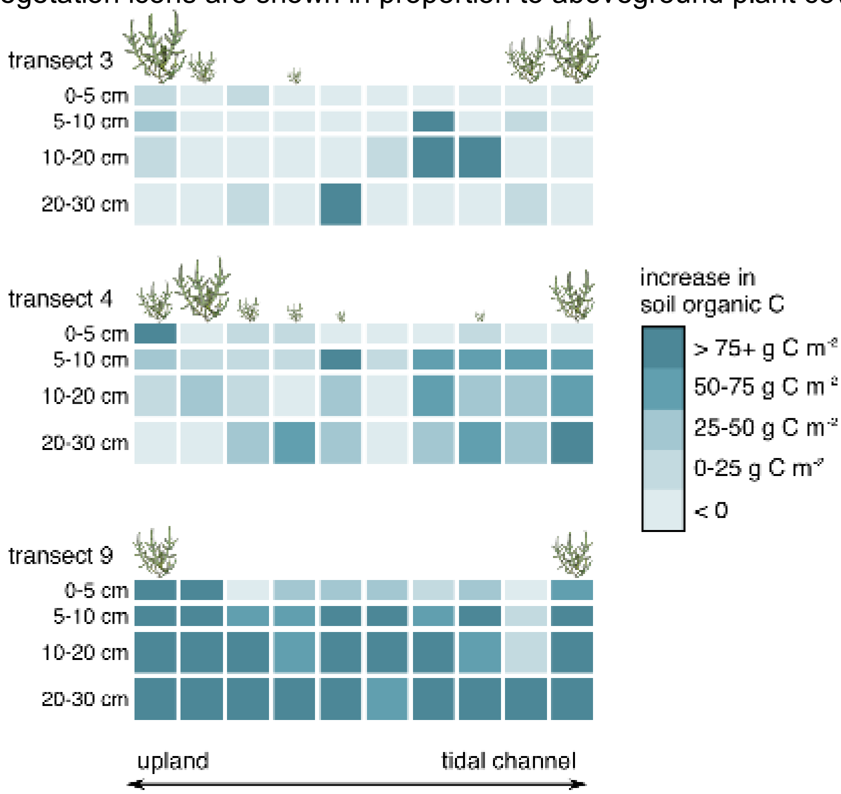
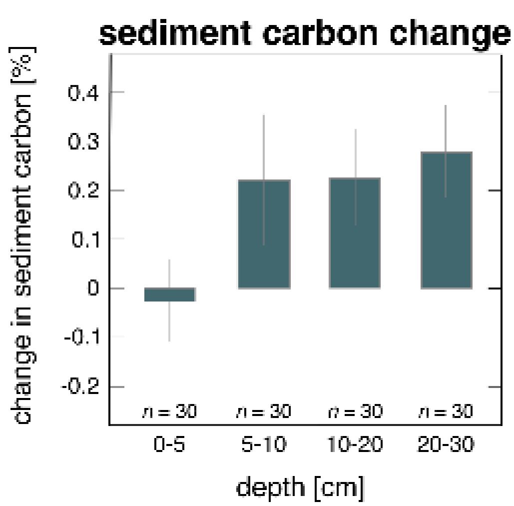


Figure 12 – Change in soil organic carbon values at Hester Marsh between 2018, when the project was first constructed, and 2022.
Marsh vegetation icons are shown in proportion to aboveground plant cover.



Overall, we found soil organic carbon at Hester Marsh increased 0.2% between 2018 and 2022. A pair t-test conducted on sediment core locations and depths found significant positive increases (t = 3.946; p = 0.0013). We found soil carbon increased at depth but not at the surface (0-5cm) (Fig. 13)

Figure 13 **– Change in sediment carbon at Hester Marsh as a function of depth.**



Sediment deposition rate at surface

Surface sediment deposition drove rates of carbon accumulation that varied with tidal depth, with low elevation plots receiving more sediment and carbon than higher elevation plots. Excluding the Hester Marsh restoration area, the grassland / ecotone received 0.53 ± 0.22 mm yr^{-1} (±SE) of sediment deposition, corresponding to 31 ± 13 g C m^{-2} yr^{-1}. The high marsh received 1.3 ± 0.25 mm yr^{-1} of sediment deposition, corresponding to 70 ± 15 g C m^{-2} yr^{-1}. The low marsh received 3.3 ± 0.74 mm yr^{-1} of sediment deposition, corresponding to 140 ± 29 g C m^{-2} yr^{-1}. Mudflats received 12 ± 2.1 mm yr^{-1} of sediment deposition, corresponding to 360 ± 73 g C m^{-2} yr^{-1}. Hester marsh received 1.5 ± 0.35 mm yr^{-1} of sediment deposition, corresponding to 26 ± 9.1 g C m^{-2} yr^{-1}, with slightly higher rates of deposition in bare areas (t = 4.92; p = 3.14 x 10^{-5}). There was no difference noted between reference and degraded high marsh, or grassland / ecotone, although the degraded mudflat had a higher rate of sediment deposition (4.5 ± 2.3 mm yr^{-1} at reference sites vs. 13.9 ± 2.4 mm yr^{-1} at degraded sites). Generally, accumulated sediments had a lower fraction of organic matter on mudflats than in the marsh and ecotone (Fig. 15), and there was a strong negative relationship with sediment deposition (Fig. 16)

Figure 14 – Surface sediment accumulation and carbon density
Carbon accumulation through sediment accretion was found to be greatest at lower elevations, and lower at higher elevations.

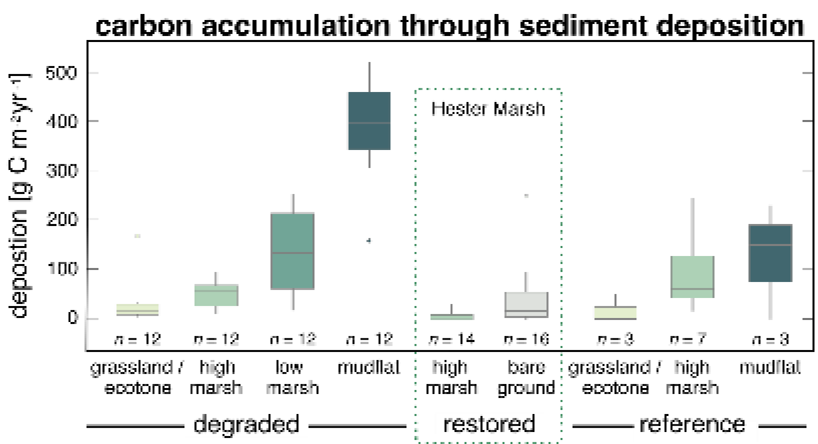


Figure 15 – Fraction organic carbon of accumulated sediments across habitats

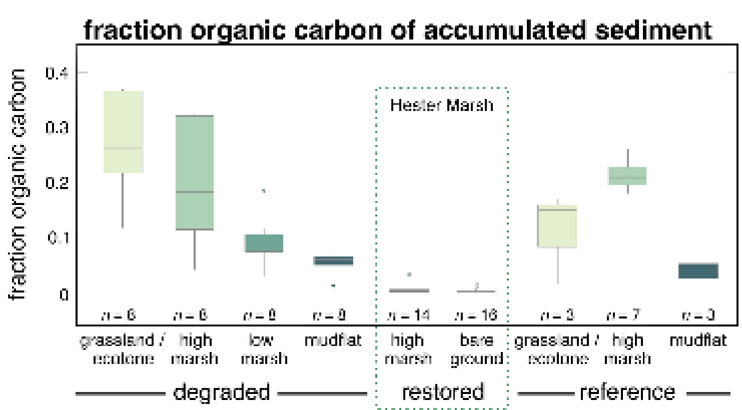
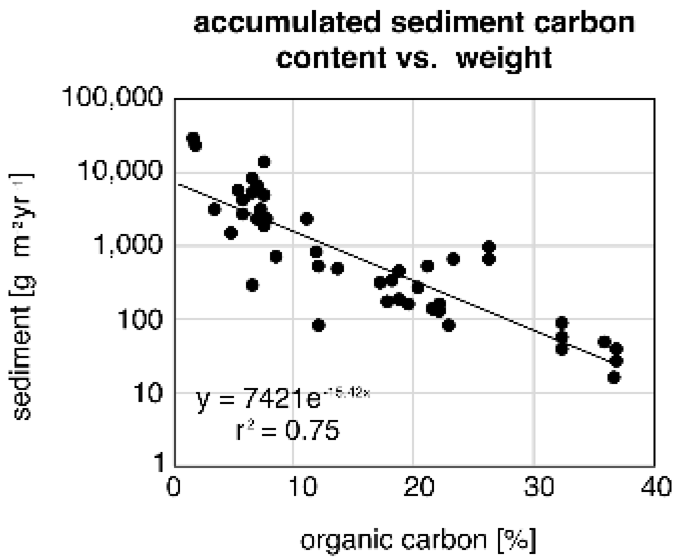


Figure 16 – Carbon content of accumulated sediment by weight



Gas Fluxes

Methane - Although the range of methane emissions measured was quite broad, most methane effluxes were found to range from -2.0 - 6.0 μM m^{-2} hr^{-1} (Fig. 17). Habitats varied somewhat in methane emissions, with mudflats generally supporting the highest methane emissions (2.45 ± 0.54 μM m^{-2} hr^{-1}) (mean ± SE), low marsh having moderate methane emissions (0.81 ± 0.71 μM m^{-2} hr^{-1}), and high marsh and grassland having low or negative methane emissions (-0.085 ± 0.33 μM m^{-2} hr^{-1} for high marsh and -0.89 ± 0.96 μM m^{-2} hr^{-1} for grasslands). Reference mudflats were found to have higher methane emissions than degraded and pre-restoration mudflats (5.4 ± 0.65 μM m^{-2} hr^{-1} for reference sites vs. 2.5 ± 0.54 μM m^{-2} hr^{-1} for control sites). For the restoration area, methane emissions were dependant on whether vegetation cover had been established or not, with areas supporting vegetation having negative methane fluxes (-1.7 ± 0.65 μM m^{-2} hr^{-1}), but areas lacking vegetation contributing methane emissions (2.3 ± 0.50 μM m^{-2} hr^{-1}). Comparison of vegetated and unvegetated locations at Hester marsh revealed methane emissions that were greater in bare areas and lower in areas where there was plant cover (Fig. 18; p=0.0046). Comparing methane emissions during light and dark incubations where plants had full cover using a sign test revealed no statistically significant difference (z = 1.466; p =0.14).

Overall, significant methane emissions were observed from mudflats and from unvegetated areas of the restoration site, and it is not possible to resolve whether marshlands nor grasslands were a sink or source of methane. Vegetated areas of the restoration site were found to be significant methane sinks. Scaled to a yearly basis, carbon dioxide equivalents of methane emissions were found to range from 3.3 to 25.2 g CO_2-equivalent yr^{-1} for mudflats, and 5.9 to 12.5 g CO_2-equivalent yr^{-1} for bare areas (Table 4). Restored areas at Hester were sinks for methane, sequestering a CO_2-equivalent of 2.5 - 10.9 g yr^{-1}.

Nitrous oxide - Nitrous oxide emissions generally ranged from -4.0 to 5.0 μM m^{-2} hr^{-1} (Fig. 17). Habitats varied somewhat in nitrous oxide emissions. Significant sources of nitrous oxide were mudflats, which where found to emit 0.81 ± 0.71 μM m^{-2} hr^{-1} of N_2O, high marsh (including the restored areas) where emissions were 0.60 ± 0.16 μM m^{-2} hr^{-1} of N_2O, and grassland where emissions were 0.45 ± 0.31 μM m^{-2} hr^{-1} of N_2O. Emissions were not found to be significantly greater than zero for the low marsh, where emissions were 0.24 ± 0.32 μM m^{-2} hr^{-1} of N_2O. Within the restoration area, there was a trend towards greater emissions from recolonized areas than bare areas although the trend was not statistically significant (Fig. P; p = 0.19) Comparing nitrous oxide emissions during light and dark incubations using a sign test revealed statistically greater nitrous oxide emissions during light conditions than dark conditions (z = -2.658; p =0.0079).

Using a 90% confidence interval, significant nitrous oxide emissions were observed from the high marsh and mudflat, with emissions that were not statistically significant for low marsh. Scaled to a yearly basis, carbon dioxide equivalents of nitrous oxide emissions were found to range from 42 to 130 g CO_2-equivalent yr^{-1} for mudflats, and 34 to 152 g CO_2-equivalent yr^{-1} for the high marsh, including the restored area (Table 4).

Figure 17 – Methane and nitrous oxide fluxes from different habitat categories

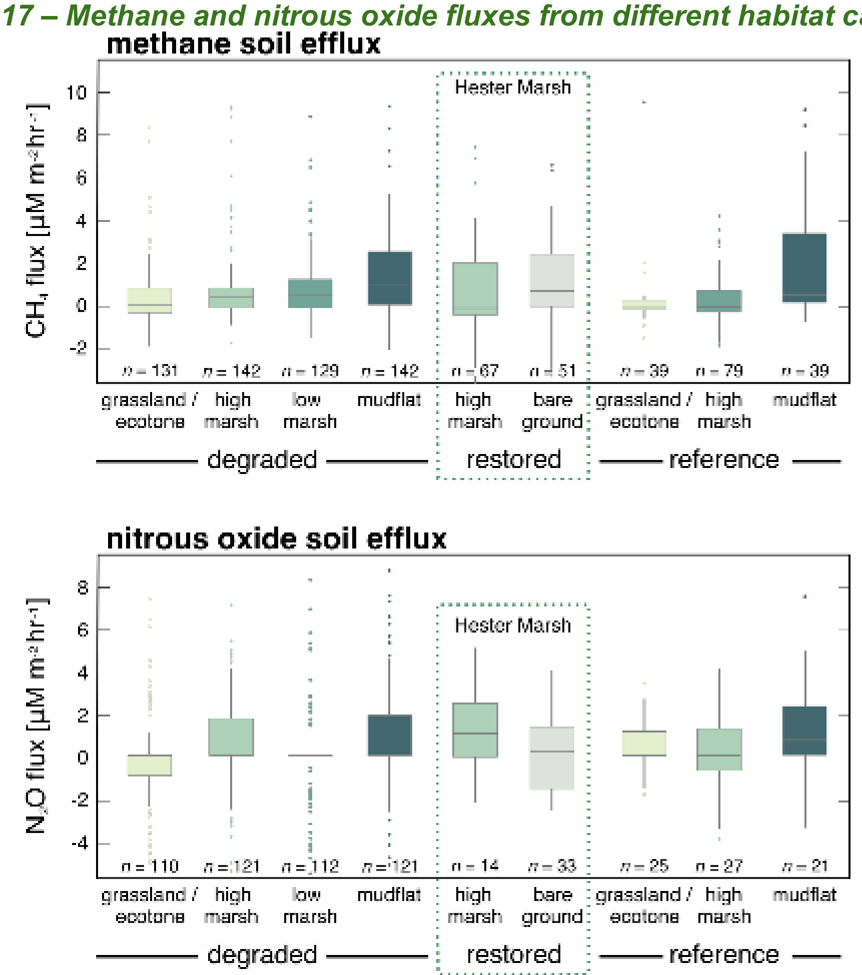
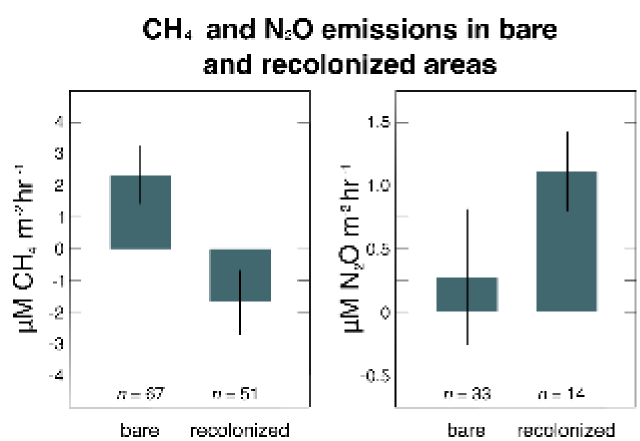


Table 4. Summary of methane and nitrous oxide emissions, scaled to a yearly basis, and carbon dioxide equivalents. Where significant differences were not observed between categories (e.g., degraded and reference grassland/ecotone), they were pooled.

Class	CH_4 emissions (g m^{-2} yr^{-1})	CO_2-equiv methane emissions (g m^{-2} yr^{-1})[a]	N_2O emissions (g m^{-2} yr^{-1})	CO_2-equiv nitrous oxide emissions (g m^{-2} yr^{-1})[b]
Degraded	Mean ± 90% CI	Mean ± 90% CI	Mean ± 90% CI	Mean ± 90% CI
Grassland / Ecotone	-0.13 ± 0.22	-4.4 ± 7.5	0.17 ± 0.19	51 ± 57
High Marsh	-0.012 ± 0.076	-0.41 ± 2.6	0.23 ± 0.10	69 ± 30
Low Marsh	0.81 ± 1.2	28 ± 41	0.093 ± 0.21	28 ± 63
Mudflat	0.23 ± 0.11	7.8 ± 3.7	0.29 ± 0.14	86 ± 42
Restored				
Bare	0.33 ± 0.12	11 ± 4.0	0.23 ± 0.10	69 ± 30
Vegetated	0.24 ± 0.15	8.2 ± 5.1	0.23 ± 0.10	69 ± 30
Reference				
Grassland / Ecotone	-0.13 ± 0.22	-4.4 ± 7.5	0.17 ± 0.19	51 ± 57
High Marsh	-0.012 ± 0.076	-0.41 ± 2.6	0.23 ± 0.10	69 ± 30
Mudflat	0.75 ± 0.15	26 ± 5.1	0.29 ± 0.14	86 ± 42

[a] Calculated based on a CH_4 global warming potential of 34 (100-yr time horizon)(IPCC, AR5)
[b] Calculated based on a N_2O nitrous oxide global warming potential of 298 (100-yr time horizon) (IPCC, AR5)

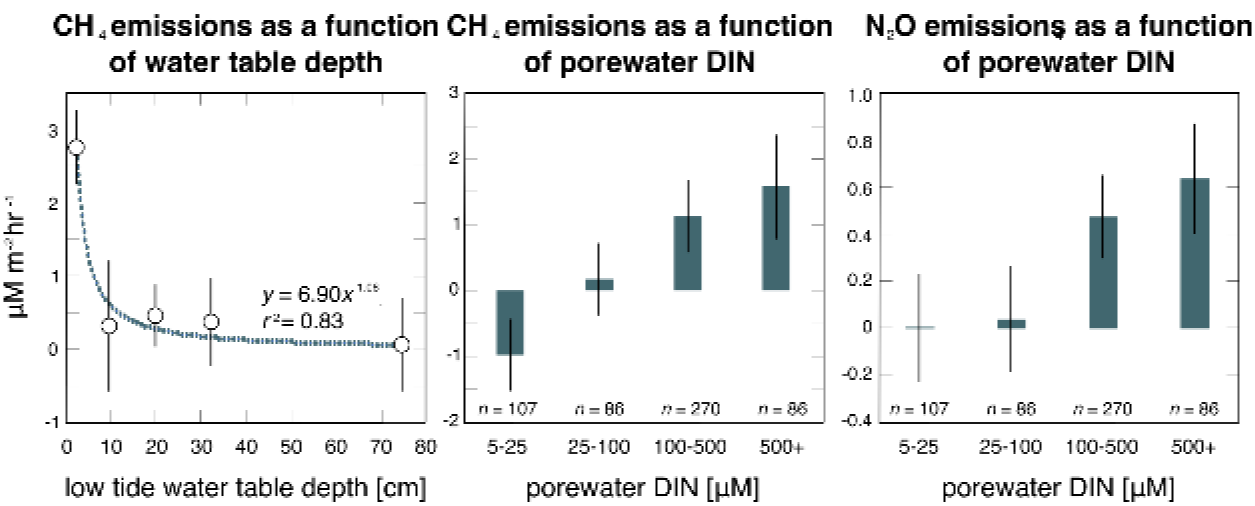
Figure 18. Mean methane and nitrous oxide emissions were found to be significantly different between bare and recolonized areas.



There was an association between methane emissions and low tide depth to groundwater, such that greater emissions of methane occurred when soils were saturated even at low tide (Fig. X). Generally, there was a threshold relationship such that methane emissions were similar when groundwater levels were below 5-cm of depth, however, the deepest groundwater levels (0.5+ m) were also associated with the lowest methane emissions (0.04 μM CH_4 m^{-2} h^{-1} vs. 0.35 μM CH_4 m^{-2} h^{-1} for water table depth 0.05-0.5m). There was also a relationship observed between methane fluxes and porewater DIN values, with higher methane emissions associated with greater DIN porewater concentrations. There were no significant relationships observed between methane emissions and salinity (r = -0.05, p = 0.23).

Higher porewater DIN levels were associated with greater nitrous oxide emissions (Fig. 19). There was no association between nitrous oxide emissions and salinity (r = -0.02, p = 0.65) or depth to water table (r = 0.00, p = 0.95). There was however a relationship between DIN levels and groundwater depth, such that greater groundwater depths were associated with greater DIN levels (r = -0.55, p < 0.0001).

Figure 19. Environmental controls on methane and nitrous oxide emissions. Methane emissions were found to vary as a function of depth to the groundwater table at low tide, and nitrous oxide and methane emissions were found to vary as a function of porewater DIN. Higher DIN levels were associated with greater greenhouse gas emissions. Values shown are mean and standard errors. Bins for water table depth are 0-5cm, 5-15 cm, 15-25cm, 25-50cm, and 50cm+.

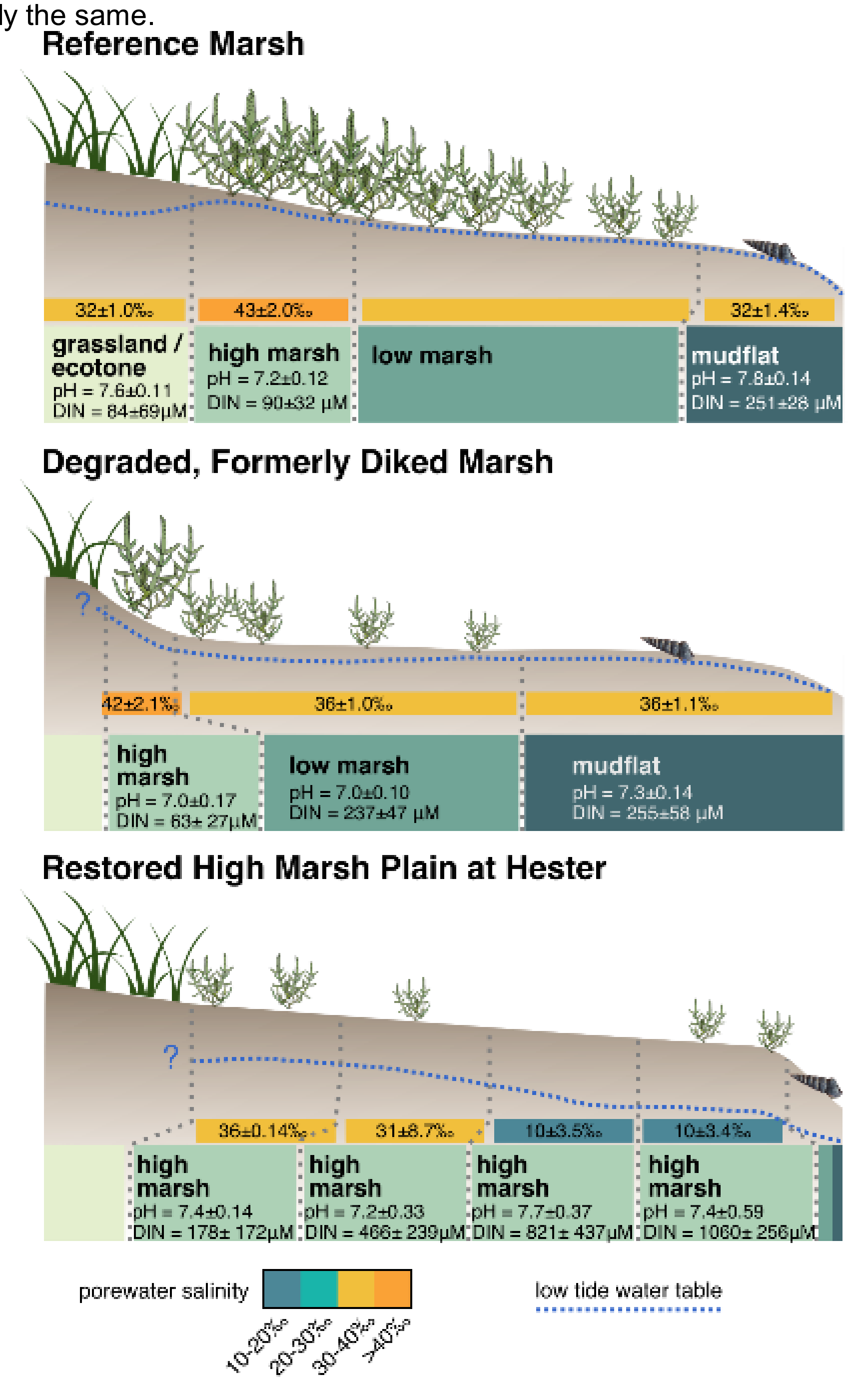


Processing steps of nitrous oxide and methane fluxes identified slope values that were deemed non-significant (p > 0.05), and assigned a zero value. For methane, 14% of values were assigned a zero value; while for nitrous oxide 43% of slopes were assigned a zero value. Two outliers were removed prior to data analysis: a methane flux of 235 uM µM m^{-2} hr^{-1} and one nitrous oxide flux of 103 µM m^{-2} hr^{-1}. Because extreme values are important in developing overall budgets, we tended towards retaining all values. Also, if we did not count small fluxes, even those below detection limit, this might lead to over-estimating emissions.

Porewater

Comparing the groundwater depth and porewater at control, reference, and restored sites revealed substantial differences. First, the restoration site had a water table that was substantially greater, at 50-100 cm below the soil surface, than found at reference and control sites, where the water table depths were typically within 20cm of the soil surface (Figure U). At reference, control sites, and the restoration site, porewater DIN values were greater at lower elevations. With respect to porewater salinity, reference and control sites supported hypersaline salinities for the upper marsh (40-45‰). The restoration site roughly followed the same pattern, although salinities were reduced compared with control and reference sites. There were no substantial differences in porewater pH between reference, control, and restoration areas, with pH ranging 7-8.

Figure 20. Conceptual model of reference, degraded and restored marsh at Elkhorn Slough. Generally, the upper marsh is hypersaline, and DIN increases towards the low marsh, as plants are less able to assimilate nutrients due to flooding stress. The water table in the restored high marsh is significantly lower (~1m vs. ~20cm) than the water table in reference and degraded high marshes, even though the elevations are roughly the same.



Blue Carbon Function

These data can be used to compare the blue carbon function of different habitats (Table 5). We found that for degraded sites, there was a greater amount of carbon stored by mudflats than by marshes regardless of the method used. For reference marshes, we saw divergence according to the method. By calculating carbon sequestration as the product of the deposition rate and soil carbon density, we found that mudflats stored more carbon than marshes on annual basis in reference marshes as well. However, by using an approach that more specifically accounted for belowground production and decomposition, it appeared the ecotone or marsh had higher rates of carbon sequestration. There was also a difference between the carbon deposition rates calculated using the various methods for the ecotone zone. Using a deposition based method, rates of estimated carbon sequestration were relatively low; measurement of production and decomposition suggested high rates of carbon sequestration. Lastly, we noted that offsets in greenhouse gas mitigation resulting from emissions of methane and nitrous oxide increased from grasslands towards mudflats, with higher values of methane and nitrous oxide emissions at lower elevations.

We estimated that our marsh plain would re-vegetate, supporting aboveground biomass levels and aboveground biomass carbon densities similar to those found at reference and control sites. In 2021, with the marsh plain 29% re-vegetated, we are storing 52.6 ± 6.0 Mg of atmospheric carbon dioxide in aboveground biomass at the restored Hester Marsh (±90%CI). We anticipate that the marsh plain will fully re-vegetate. If the marsh plain continues to support the current mean biomass levels when revegetated, which are lower than found in reference and control sites, we would store 119 ± 44.8 Mg of atmospheric carbon dioxide in aboveground biomass when the marsh plan is fully re-vegetated. If the marsh plain was fully revegetated, with similar levels of biomass found in reference and control sites, we would store 558 ± 80.2 Mg of atmospheric carbon dioxide in aboveground biomass in the Phase 1 restoration area when revegation is achieved. Our goal was to store Mg 156 Mg atmospheric CO_2 in standing biomass in addition to pre-restoration conditions. The amount of carbon in standing biomass in 2015 was 46.7 ± 8.1 Mg. Whether this goal is achieved is dependent on whether the marsh plain comes to support similar aboveground biomass and carbon stocks similar to reference marshes.

We estimated that associated with marsh plain re-vegetation, we would store soil carbon at yearly rates similar to those found in reference and control areas, with a target of 129 Mg of atmospheric CO_2 y^{-1} (Table 6). In 2022, with the marsh plain 29% re-vegetated, we estimate that we are storing 21.0 ± 26.0 Mg C yr^{-1} of atmospheric carbon dioxide in soil carbon at the restored Hester Marsh (computed using eqn 1 to calculate the difference between soil carbon production and decomposition on an annual basis, and also taking into account surface deposition). This includes offsets from GHG emissions. Calculating the difference in soil carbon storage (Eqn 2), we estimate that we are storing 99 ± 23.7 Mg yr^{-1} of atmospheric carbon dioxide in soil carbon at the restored Hester Marsh.

To estimate carbon sequestration under a fully vegetated condition (using eqn 1), if the marsh obtains the belowground production levels found in reference sites when the marsh plan is fully vegetated, we estimate we would store 99.0 ± 23.7 Mg of atmospheric carbon dioxide per year in soil if the marsh plan was fully revegetated (Eqn 1), or 23.1 ± 14.6 Mg C per year using accretion rates (Eqn 3).

Table 5. Blue carbon function of reference and degraded mudflat, marsh, and grassland / ecotone habitats. Values are mean ± 90% CI. GHG refers to emissions of methane and nitrous oxide, expressed in CO_2 equivalents. Here GHG emissions are expressed using negative numbers where emissions are positive, as they are offsetting soil carbon sequestration. Categories were pooled (for the grassland/ecotone for degraded and reference sites) where no significant differences were found.

	Soil C sequestration (g C m^{-2} yr^{-1})		GHG (g CO_2 m^{-2} yr^{-1})	Net blue carbon function (g CO_2 m^{-2} yr^{-1})	
Degraded	Eqn1	Eqn3		Eqn 1	Eqn 3
Grassland / Ecotone	186 ± 110	19 ± 14	-46 ± 57	636 ± 406	23 ± 77
High Marsh	110 ± 20	41 ± 14	-68 ± 30	334 ± 79	81 ± 61
Low Marsh	157 ± 31	90 ± 19	-55 ± 75	520 ± 136	273 ± 101
Mudflat	368 ± 50	306 ± 59	-94 ± 42	1254 ± 188	1029 ± 222
Reference					
Grassland / Ecotone	186 ± 110	19 ± 14	-46 ± 57	636 ± 406	23 ± 77
High Marsh	143 ± 26	49 ± 17	-68 ± 30	457 ± 99	112 ± 68
Mudflat	106 ± 28	99 ± 26	-112 ± 42	277 ± 110	251 ± 104

Comparison of blue carbon function at Hester before/after restoration

Gas flux offsets.Estimated emissions associated with construction were 380 megagrams of CO_2 equivalents, and included emissions of both carbon dioxide as well as a small amount of methane, and other tracked emissions, such as particulates (Table S4).

Table 6. Estimated blue carbon function of Hester marsh prior to anthropogenic disturbance, before restoration, three-years post construction, and when the marsh becomes fully recolonized. Area of tidal channels were eliminated from analysis. Values represent the mean ± a 90% confidence interval. Error was propagated for sums using the sum of the root sum of squares of individual absolute uncertainties, and for products using the root sum of squares of individual relative uncertainties. Values do not include aboveground biomass, but focus on soil carbon sequestration.

		Net blue carbon function (Mg CO_2 yr^{-1})		
	Area (ha)	Eqn 1	Eqn 2	Eqn 3
Pre-impact (1931)				
Grassland / Ecotone	3.88	24.7 ±15.7	—	0.89 ± 2.99
Marsh	18.6	85.0 ±18.4	—	20.8 ± 12.6
Mudflat	0.33	0.91 ± 0.36	—	0.82 ± 0.34
Total	22.8	111 ± 24.2		22.5 ± 13
Pre-restoration (2015)				
Grassland / Ecotone	3.98 ± 0.176	25.3 ± 11.4	—	0.91 ± 3.1
Low Marsh	2.21 ± 0.0982	11.5 ±1.29	—	6.0 ± 2.2
High Marsh	0.774 ± 0.0344	2.5 ± 0.26	—	0.62 ± 0.47

Mudflat	13.8 ± 0.613	173 ± 11.5	—	142 ± 31
Total	20.8	212 ± 11.7	—	150 ± 31.3
Post-restoration (2021)				
Grassland / Ecotone	0.85 ± 0.030	5.4 ± 2.4	0.19 ± 0.65	—
Marsh	6.82 ± 0.241	11.4 ± 5.5	79 ± 41	—
Bare	13.6 ±0.477	4.2 ± 18.1	158 ± 82	—
Total	21.3	21.0 ± 26.0	237 ± 124	—
Fully re-vegetated				
Grassland / Ecotone	0.847	5.4 ± 3.5	—	0.19 ± 0.65
High Marsh	20.47	93.5 ± 20.3	—	22.9 ± 13.9
Total	21.3	99.0 ± 23.7	—	23.1 ± 14.6

Discussion

Our investigation was unusual in quantifying multiple metrics of blue carbon function across multiple habitat types and conditions in a single estuary. Overall, our study revealed strong contrasts in blue carbon function along an estuarine elevation gradient (from mudflats to marsh to coastal grassland) and among sites with different management histories -- reference, never diked marshes vs. degraded, formerly diked marshes vs. a new sediment addition restoration site. Different components of blue carbon function were optimized in different habitats, for instance surface accretion of carbon was highest in mudflats, but carbon storage in above-ground biomass was highest in the high marsh. A mosaic of habitat types thus might be desirable to represent the optima for different functions. Three years after sediment addition to a degraded marsh created a bare, new high marsh plain in the estuary, blue carbon function of the restoration site was still fairly limited. If new, high marsh plains are constructed to provide blue carbon function in the future when existing marshes have been drowned due to rising seas, it is critical to begin construction of them soon, to allow sufficient time for blue carbon function to develop fully.

Contrasts among habitat types in blue carbon function

To better conserve and restore blue carbon, we need a better understanding of spatial variability, including along tidal gradients (Mcleod et al., 2011). Our investigation was explicitly designed to examine variation in blue carbon function along an elevation gradient of estuarine habitat types, from mudflat to low marsh to high marsh to adjacent grasslands. The two methods we used to estimate carbon sequestration across reference habitats yielded contrasting results. Our data suggested that by focusing on measuring soil carbon accumulation through sediment deposition, and belowground production and decomposition (Eqn 1), mudflats sequestered the least carbon, followed by high marsh, with the grassland/ecotone zone sequestering the greatest amount of carbon. In contrast, by estimating soil carbon accumulation using marker beds and soil carbon density (Eqn 3) (similar to that measured by radiometric approaches; e.g., Hopkinson et al. 2012) our data suggested that mudflats sequester the most carbon, followed by high marsh, and the grassland / ecotone area. Rates of carbon sequestration generally all fell within ranges reported in the literature (e.g., 41-152 g m^{-2} y^{-1}; Drake et al. 2015; 72-456 g m^{-2} y^{-1}; Chmura et al. 2003; 29-210 g m^{-2} y^{-1}; Hopkinson et al. 2012), apart from the sediment-based measure for the ecotone, which was estimated at somewhat lower (19 g m^{-2} y^{-1}).

This contrast highlights opposing factors which affect carbon accumulation in soils. At low elevations, there are greater sediment deposition rates because the greater inundation duration increases the time available for deposition to occur (e.g., Baustian et al. 2012). In addition to greater sediment deposition at lower elevations, more flooded marsh zones tend to have more anoxic soils which tend to slow belowground decomposition (Neckles and Neill 1994). In contrast, at higher elevations including both the high marsh and marsh-upland ecotone, there is greater plant biomass (e.g., Fig. S3), but also less anoxic soils, which can promote soil carbon remineralization. In addition to the more oxidized conditions, plant presence can also enhance the decomposition of soil organic matter (Mueller et al. 2015), which was also reflected in data from the Hester restoration site (Fig. 10).

Most previous studies comparing salt marsh carbon accumulation by habitat have focused on low and high marsh or indicative vegetation zones. While some studies have found no difference in carbon accumulation by habitat (Kelleway et al. 2017; Gailis et al. 2021), other studies have found contrasts. In the Bay of Fundy marshes, the high marsh was found to have greater carbon accumulation rates (Connor et al. 2011), while in Maryland and Rhode Island, there was greater carbon accumulation or uptake found in the lower elevation *Spartina alterniflora* zone (Elsey-Qirk 2011; Moseman-Valtierra et al. 2016). The genus *Spartina* specifically has also been identified as providing high carbon accumulation benefits (Ouyang and Lee 2014). Comparisons of carbon pools or accumulation are more rare across marsh-upland gradients. Elsey-Quirk reported reduced soil carbon pools in the *Baccharis* zone (found along the marsh-upland ecotone), as compared with marsh vegetation zones in Maryland, while in a southern California marsh, habitat-based measures estimated the highest carbon accumulation rates for the low marsh, followed by the mudflat, with lower levels of carbon accumulation in the high marsh and upland (grassland/scrub) (Bear 2017).

Our results suggest that transgression of habitats with sea level rise will provide unpredictable impacts on carbon sequestration at Elkhorn Slough, depending on whether plant productivity or sediment accumulation rates are the key variable controlling carbon accumulation and storage. To help resolve this issue, we plan to continue to monitor plant decomposition to more accurately measure refractory carbon, as well as integrate analysis of dated sediment cores from various habitat zones. However, understanding how transgression in relation to sea level rise will affect carbon sequestration is an emerging concern in the study of coastal habitats. Studies have suggested that as salt marshes, with their higher carbon storage rates, replace upland habitats, carbon accumulation will increase (Van Allen et al. 2021). In addition, because carbon accumulation is a function of accumulation rates which increase with tidal flooding, it is thought that sea level rise will increase carbon burial, perhaps even in degrading marshes (Herbert et al. 2021). However, it is important not to discount the carbon storage capacity of adjacent habitats. In the Eastern U.S. where coastal forests often abut marshes, the loss of aboveground forest carbon stocks may overwhelm modest increases in belowground carbon storage (Smith and Kirwan 2021). Studies also suggest that salt water intrusion may deplete belowground carbon stocks through addition of sulfate as an abundant terminal electron receptor, or through altering other aspects of carbon cycling (Charles et al. 2019). And in California, shrub and grassland habitats are also systems known to sequester significant volumes of carbon, at rates that may be broadly similar to Mediterranean salt marshes (Hungate et al. 1996; Luo et al. 2007).

Turning now to carbon storage in degraded marshes, which were formerly diked and subsided, our data suggested that degraded mudflats account for the greatest rates of carbon accumulation, regardless of the calculation method applied (Table 5). Our ambitious estimates for post-restoration carbon sequestration assumed that carbon accumulation in these habitats was negligible, yet these zones saw the greatest accumulation rates of any habitat studied. Data on mudflat accumulation from other systems is quite variable. In nearby San Francisco Bay, it has been suggested that mudflats are rather stable, as the critical sheer stress for erosion is often reached, limiting permanent mudflat accumulation (van der Wegen et al. 2017). Other studies have reported high and variable accumulation rates on mudflats (e.g., 1-5 cm yr^{-1}; Yang and Chun 2001; Cundy et al. 2007), although several studies suggest accumulation concentrates along the marsh-mudflat border, which was where our marker beds were located (Van der Wegen et al. 2017). It is an outstanding question whether plots further from the marsh edge would support lower rates of accumulation. Another point of consideration is the timescale of accretion. Studies have typically observed much higher rates of mudflat accumulation using marker beds or sediment-traps than longer-term accumulation using radioisotope dating (e.g, Richard 1978). While this is a general feature of the sediment record, where accumulation rates are known to be a negative power function of the time scale under consideration (Sadler 1999), it appears that mudflat sediment accumulation is particularly subject to intermittent high rates of accumulation and erosion. Lastly, the high rates of mudflat accumulation may be supported by retreat of the marsh edge (Hopkinson et al. 2018). If it is marsh erosion that is supporting mudflat accumulation, this accumulated carbon is not new allochthonous carbon being sequestered by the system, and should not be accounted for as such.

Regardless of the context, this observation that drowned marshes are sequestering the most carbon is crucial if restoration is done specifically for their short term carbon sequestration function. If drowning marshes with concomitantly higher accumulation rates (Gonneea et al. 2019) actually sequester larger quantities of carbon than reference high marsh, then restoring marshes to a higher elevation may not be the advised path, at least from the perspective of carbon sequestration. This is especially true if the restoration site is recolonized by plants slowly (Brooks et al. 2015) as would happen in a restoration set high in the tidal frame for resilience to sea-level rise. Typically, numerical models also tend to assume that when marshes convert to unvegetated mudflats, their carbon sequestration capacity declines to zero (Kirwan and Mudd 2012). Again, that is not what was observed by this study, should be tested in other research sites, and the implications should be explored using numerical approaches. Additionally, the timescale of carbon sequestration is important. Even if marshes that have lost vegetation and converted to mudflats are sequestering high levels of carbon at the present, at some point, their carbon sequestration capacity will likely decline.

Gas fluxes and important drivers

Our study suggested that emissions of greenhouse gasses at our project site may significantly offset the carbon sequestration benefits of restoration as found in previous studies (Adams et al. 2012). Methane emissions were higher for mudflats, and the low marsh, where the water table was near the surface (Fig. 19). The high marsh and grassland/ecotone were sinks for methane rather than sources (Table 4). The overall methane emissions were not higher than expected considering the saline conditions (salinity >18 ‰), where emissions of 1 ± 2 g CH_4 m^{-2} yr^{-1} are expected (Poffenbarger et al. 2011). Although the high marsh was generally a sink for methane, restored areas tended to have significant methane emissions, with higher emissions in bare areas than re-vegetated locations (Fig. 18). Vegetation can influence soil methane emissions in various ways: by providing labile carbon that fuels methane emissions (Whiting and Chanton 1993), by oxidizing the soil which promotes methane oxidation (van der Nat and Middelburg 200), and by acting as a conduit for methane formed deeper in the soil profile, where conditions are more reducing (Henneberg et al. 2012). In this case, it appears that vegetation cover reduces methane emissions; thus we may expect that methane emissions will decline as the restoration site re-vegetates.

Nitrous oxide emissions accounted for a larger percentage of our observed carbon sequestration offsets than methane, due to the higher global warming potential. Similar to methane, there were greater observed nitrous oxide emissions at lower and more flooded elevations as well as areas with greater porewater dissolved inorganic nitrogen concentrations (Table 4; Fig. 19). Nitrous oxide emissions have been noted in salt marshes exposed to episodic or chronic nitrogen (Moseman-Valtierra 2011; Martin et al. 2018), and also in the managed realignment of agricultural land (Blackwell et al. 2010). Although there is no evidence that nitrous oxide emissions increased in response to restoration, it is important to consider that a large portion of the carbon sequestration benefits that may accrue due to salt marsh restoration may be offset by other greenhouse gas emissions (Adams et al. 2012). In addition, the emission reduction benefits should be considered in the context of managing coastal nutrient inputs more broadly. Improved wastewater treatment or reductions in over-fertilization of agricultural areas are likely to improve coastal water quality and habitats while simultaneously reducing nitrous oxide emissions, and it is appropriate to explore incentives to achieve these goals.

Restoration trajectory of blue carbon function

Coastal restoration is increasingly being recognized as a tool for climate mitigation (Wylie et al., 2016). Restoring more natural processes such as hydrological connectivity can enhance blue carbon function (Macreadie et al., 2017). Restoration of hydrological connectivity is fairly straightforward and can be almost immediate -- dikes can be breached, culverts replaced with large unobstructed channels, etc. However, for systems like Elkhorn Slough, such hydrological restoration may not return the full blue carbon function. Formerly diked marshes in this estuary are dominated by mudflats even 40 years after breach of dikes and water control structures. Due to limited sediment supply and marsh plain subsidence, Elkhorn Slough marshes are not very resilient even to existing rates of SLR (Raposa et al., 2016; Wasson et al., 2019).

In addition to bringing back wetlands that have been lost to past human alterations, projects are being designed to create climate-adapted wetlands, including marshes resilient to future SLR. Hester Marsh is one such restoration project, where the target elevation for sediment addition was chosen to be near the highest reaches of the intertidal, and where the adjacent hillside was contoured with a gentle slope to allow for future marsh migration. The marsh plain at Hester Marsh is currently inundated only 3% of the time at lowest elevations to 2% at highest elevations (ESNERR, unpublished monitoring data). This is much higher than any other marsh in the estuary and will ensure that the marsh persists longer in the face of SLR, but also means conditions are especially challenging for colonizing vegetation which is subject to desiccation, in addition to the difficult growing conditions posed by highly compacted sediments low in organic matter.

We found that carbon sequestration is occurring at Hester Marsh, at very low rates in bare areas and higher rates in areas where plants have colonized. However, three years after construction was completed, blue carbon function of the entire project footprint is still dramatically lower than it was historically when fully vegetated, and also much lower than it was in the unrestored, degraded state immediately prior to restoration. Three years is clearly much too short a monitoring period to determine the long-term trajectory of the site. Early assessments of functions in restored *Spartina* marshes in the eastern USA found that above-ground vegetation was restored in 5-15 years, but estimated that below-ground carbon pools would take 30-300 years to restore (Craft et al., 2003). Recent analyses of restored marshes in the southeastern USA high spatial variability in carbon accumulation, with no clear effect of marsh age (Abbott et al., 2019); another study in this region found less above- and below-ground carbon storage in a constructed vs. reference marsh after 30 years (Smyth, 2020). A meta-analysis of over 600 wetlands across all ecosystem types (not just tidal marshes) found biochemical functions recover more slowly than biological ones, and typically remain lower even after decades at restoration sites (Moreno-Mateos et al., 2012). To determine whether this is simply a matter of a very slow, gradual recovery trajectory or whether restoration sites represent an alternate stable state, continued monitoring of Hester and similar tidal marsh restoration sites is needed, tracking the slope of the recovery rate to determine if it flattens with time or continues to increase.

Tidal marsh restoration can successfully restore ecosystem functions and services (Broome et al., 2019). However, our results suggest that coastal managers and funders must set realistic expectations as to the temporal trajectory of restoration of blue carbon function. Indeed persistent areas of bare ground in restoration projects has been noted as an issue, and particularly attributed to topographic uniformity as well as sediment compaction (Brooks et al. 2015). For the coming decades, existing tidal marshes must be protected and enhanced, because they will far outperform newly created marsh restoration sites.

Challenges and recommendations for monitoring blue carbon function of marshes

Measuring blue carbon function in created, reference, and degrading marshes provided a variety of challenges related to spatial and temporal variability in metrics, as well as presenting philosophical choices about which variables to focus on. Most variable were greenhouse gas emission measurements. Although we conducted nearly a thousand chamber-based greenhouse gas measures, our results were still quite variable. And our measures were only undertaken during summer of 2015, winter of 2017, and summer of 2021, meaning that we did not fully capture seasonal differences. And because our data suggests that greenhouse gas emissions offset a significant portion of carbon sequestered by restoration projects (Adams et al. 2012), this uncertainty in gas flux data makes the blue carbon function of different habitats difficult to calculate, and difficult to compare. We can recommend the use of open path greenhouse gas analyzers to calculate yearly budgets to help reduce uncertainties in emission of methane and nitrous oxide in restoring marshes. And while not all projects could afford or should deploy such analyzers, their targeted use in a few restored and reference marshes subject to high nutrient loads may help better clarify the relative importance of nitrous oxide emissions in coastal marshes.

A second challenge was measuring surface sediment accumulation. Measuring accumulation rates was a key component of this project, to estimate carbon accumulation. We found that feldspar marker beds often did not persist in the areas lacking vegetation, and while we complemented these marker beds with erosion pins and sediment tiles, these three different methods yielded different results, and were not interchangeable. Ideally, we would recommend monitoring particulate organic carbon entering and leaving the marsh through the tidal channel as a more robust method for accretion monitoring (Shiau et al. 2019). Given our results suggest that drowned marshes sequester more carbon than reference marshes, it is clear that more research is needed to understand processes of sediment and carbon accumulation in drowning and drowned marshes. This might include installing SETs in disintegrating marshes, or using shorter lived radio-isotopes (^{234}Th, ^{7}Be) or tracers to measure accumulation in these environments.

A final difficulty in this project involved collecting sediment. Because the sediment at the restoration site was spread by heavy equipment, the soil was quite compacted and impossible to collect using traditional coring techniques. While we initially were able to collect sediment using a gasoline-powered auger, we were unable to accurately measure the bulk density of the collected sediment. Similarly, we were able to penetrate the soil with narrow augers; but these narrow augers caused a large amount of soil compaction; again making it difficult to measure bulk density for specific depths. To help address these issues, we used a sediment sampler designed for firm soils (Eijkelkamp sample ring kit, model C, Eijkelkamp Soil and Water, The Netherlands). A recommendation from this project is to collect bulk density data as accurately as possible, as it is key in accurate carbon accounting. Use of the soil rings typically used in soil science is recommended.

Comparing our approach with other similar projects undertaken recently shows that our monitoring approach was exceptionally robust, although differences were observed (Table 7). First, it appears more typical to focus on belowground biomass through collection of sediment cores and separation of live and dead roots. We chose to measure root production with ingrowth bags as restoration projects that collect sediment core material after an intervention are at risk of measuring soil characteristics (e.g., dead biomass) that are a legacy of soil characteristics before the intervention. Secondly, we find it difficult to separate dead and live roots and rhizomes of *Salicornia*, and the sequential harvests of biomass are very time consuming. However, it is important to note that ingrowth bags tend to under-estimate root production for deployments of less than three years (Makkonen and Helmisaari 1999). Thus, they are better suited for comparing habitats than absolute carbon production measures. Similarly, we used a litterbag with a fine mesh to measure long-term refractory carbon (similar to Staver et al. 2020). However, our estimates of aboveground decomposition were much lower than measured in a previous study using a coarser mesh material (Watson et al., submitted). Again, this divergence highlights that various metrics are more effective at comparing differences between habitats than estimating absolute values.

Table 7. Metrics measured in similar restoration studies which focused on carbon sequestration. Popular Island was a restored marsh island built from dredge sediments, the Stillaguamish Estuary and Pamlico Sound restorations involved dike removal. NR = measured; but not reported. Sources: [a] Poppe and Rybczyk 2021; [b] Staver et al. 2021; [c] Shaiu et al. 2019

Metrics	Elkhorn Slough, CA	Poplar Island, MD[a]	Stillaguamish River Estuary, WA[b]	Pamlico Sound, NC[c]
aboveground biomass	C density	X	C density	C density
belowground biomass		X	C density	C density
belowground biomass production	C density			
plant cover	X	X		
root/shoot ratio		X		
benthic algal production		X		
sediment deposition	C density			
sediment radiometric dating	NR		X	
greenhouse gas exchange	CH_4, N_2O	CH_4		CH_4, N_2O, CO_2
soil carbon density	X		X	X

decomposition	Above & belowground	Aboveground		
SETs	NR	X	X	
tidal sediment flux		X		Dissolved + particulate
sediment particle size			X	
salinity	X		X	sulfate
dissolved nutrients	X	NR		X
pH	X	NR		
groundwater table depth	X	NR		

A second area of divergence between our work and others is that, in contrast with Shiau et al. 2019, we did not use the net ecosystem exchange of carbon dioxide to measure production. This approach requires seasonal or monthly carbon dioxide measures which we were not able to commit to, although this approach combined with water column TOC measures provided an exceptionally robust understanding of the fate of fixed carbon in the restoration area. A recent understanding that has emerged in the last few years, however, is that accurately accounting for methane emissions requires monitoring of groundwater discharge of methane (Schutte et al. 2020). Thus, accurate accounting for methane emissions could necessitate monitoring dissolved methane in groundwater.

Finally, we would strongly recommend several approaches we took with this study. First, the use of drone imagery to successfully characterize plant cover in the restoration footprint was extremely helpful for understanding patterns of plant recruitment, designing new strategies to improve success, and upscaling our results (Haskins et al. 2021; Thompsen et al. 2022). Secondly, the use of comparisons with both reference and control sites permitted robust characterization of contrasts among these habitats. We also recommend comparison of the water table in reference, control, and restoration sites to understand hydrologic function. Here, we only monitored water table depth along with greenhouse gas measures to understand relations with greenhouse gas emissions, which as products of anoxic metabolism were found to be higher in more flooded habitats. However, this measure in the restoration area revealed an exceptionally low water table compared to reference marshes at the same elevation (Fig. 20). We believe that a plow pan created by the use of heavy equipment created an aquitard layer that both prevents drainage, causing the surface soil to vacillate between very moist and very dry, and may be contributing to slow vegetation recovery. Lastly, our analysis of plant carbon density revealed that environment flooding gradients were reflected in the carbon density of plants, with higher elevation plants having a greater carbon fraction (Fig. 8). While similar studies have assumed a carbon density of 0.35 (Poppe and Rybczyk 2021) and not measuring this value would only have changed our results slightly, this work uncovered a potential new method metric to assess plant stress from flooding.

Overall, our approach identified important implications of successfully characterized contrasts in blue carbon function among habitat types and condition, and we recommend this sort of approach for other estuarine systems. We tracked plant recovery and associated changes in soil carbon in the restoration site, helping to set a realistic time scale for plant recovery in sediment addition projects. Our results suggest that drowned marshes may preserve their carbon sequestration function even as they convert to mudflats, which is an important baseline scenario to account for in calculation of carbon sequestration benefits of restoration. However this is likely unstable as without vegetation these drowned marshes may be subject to periodic erosion events. We found that greenhouse gas emissions significantly offset greenhouse gas sequestration benefits of our restoration project however the data was highly variable. Finally, we identify areas that should receive further research attention: nitrous oxide balance, groundwater transport of methane, hydrologic function of restored marshes, and sedimentation processes on drowning marshes.

Acknowledgements

We are grateful to many students, volunteer and NERR staff members who helped with the field and laboratory work, often under challenging conditions: A. Doucoure, S. Fork, R. Jeppesen, L. Ibrahem, R. Martin, H. Carlton, D. Njie, A. Chatman, R. Pausch, E. Ruiz, L. Saephan, M. Gannon, L. Smith, F. Rahman, and A. Woolfolk. Funding for the Hester restoration project was provided by California's Climate Investments (CCI) administered by California Department of Fish and Wildlife's Wetlands Restoration for Greenhouse Gas Reduction Program, California Department of Water Resources, California State Coastal Conservancy, and USFW National Coastal Wetlands Conservation Program. Primary funding for this investigation came from California's Climate Investments (CCI) administered by California Department of Fish and Wildlife's Wetlands Restoration for Greenhouse Gas Reduction Program.

References

Abbott, K. M., Elsey-Quirk, T., & DeLaune, R. D. (2019). Factors influencing blue carbon accumulation across a 32-year chronosequence of created coastal marshes. Ecosphere, 10(8), e02828. https://doi.org/10.1002/ecs2.2828

Adams, C. A., Andrews, J. E., & Jickells, T. (2012). Nitrous oxide and methane fluxes vs. carbon, nitrogen and phosphorous burial in new intertidal and saltmarsh sediments. Science of the Total Environment, 434, 240-251.

Adams, C. A., Andrews, J. E., & Jickells, T. (2012). Nitrous oxide and methane fluxes vs. carbon, nitrogen and phosphorous burial in new intertidal and saltmarsh sediments. Science of the Total Environment, 434, 240-251.

Armitage, A. R. (2021). Perspectives on Maximizing Coastal Wetland Restoration Outcomes in Anthropogenically Altered Ecosystems. Estuaries and Coasts. https://doi.org/10.1007/s12237-021-00907-4

Bayraktarov, E., Brisbane, S., Hagger, V., Smith, C. S., Wilson, K. A., Lovelock, C. E., Gillies, C., Steven, A. D. L., & Saunders, M. I. (2020). Priorities and Motivations of Marine Coastal Restoration Research. Frontiers in Marine Science, 7, 484. https://doi.org/10.3389/fmars.2020.00484

Bear TM. Soil carbon sequestration and carbon market potential of a Southern California tidal salt marsh proposed for restoration. University of California, Los Angeles; 2017.

Blackwell, M. S., Yamulki, S., & Bol, R. (2010). Nitrous oxide production and denitrification rates in estuarine intertidal saltmarsh and managed realignment zones. Estuarine, Coastal and Shelf Science, 87(4), 591-600.

Breeze Software. (2020). California Emissions Estimator Model version 2020.4.0. Prepared for the California Air Pollution Control Officers Association. http://www.aqmd.gov/caleemod/home

Brevik, E. C., & Homburg, J. A. (2004). A 5000 year record of carbon sequestration from a coastal lagoon and wetland complex, Southern California, USA. Catena, 57(3), 221-232.

Brooks, K. L., Mossman, H. L., Chitty, J. L., & Grant, A. (2015). Limited vegetation development on a created salt marsh associated with over-consolidated sediments and lack of topographic heterogeneity. Estuaries and Coasts, 38(1), 325-336.

Bulmer, R. H., Stephenson, F., Jones, H. F. E., Townsend, M., Hillman, J. R., Schwendenmann, L., & Lundquist, C. J. (2020). Blue Carbon Stocks and Cross-Habitat Subsidies. Frontiers in Marine Science, 7, 380. https://doi.org/10.3389/fmars.2020.00380

Burdick, D. M., & Roman, C. T. (2012). Salt marsh responses to tidal restriction and restoration. In Tidal marsh restoration (pp. 373–382). Springer.

Charles, S.P., Kominoski, J.S., Troxler, T.G., Gaiser, E.E., Servais, S., Wilson, B.J., Davis, S.E., Sklar, F.H., Coronado-Molina, C., Madden, C.J. and Kelly, S., 2019. Experimental saltwater intrusion drives rapid soil elevation and carbon loss in freshwater and brackish Everglades marshes. Estuaries and Coasts, 42(7), pp.1868-1881.

Chastain, S. G., Kohfeld, K., & Pellatt, M. G. (2018). Carbon stocks and accumulation rates in salt marshes of the Pacific coast of Canada. Biogeosciences Discussions, 1-45.

Chmura, G. L. (2013). What do we need to assess the sustainability of the tidal salt marsh carbon sink? Ocean & Coastal Management, 83, 25–31. https://doi.org/10.1016/j.ocecoaman.2011.09.006

Chmura, G. L., Anisfeld, S. C., Cahoon, D. R., & Lynch, J. C. (2003). Global carbon sequestration in tidal, saline wetland soils. Global Biogeochemical Cycles, 17(4). https://doi.org/10.1029/2002GB001917

Chmura, G. L., Kellman, L., Van Ardenne, L., & Guntenspergen, G. R. (2016). Greenhouse gas fluxes from salt marshes exposed to chronic nutrient enrichment. PloS one, 11(2), e0149937.

Chmura, G.L., S.C. Anisfeld, D.R. Cahoon, and J.C. Lynch. 2003. Global carbon sequestration in tidal, saline wetland soils. Global Biogeochemical Cycles 17: 1–22.

Connor, R. F., G. L. Chmura, and C. Beth Beecher. 2001. “Carbon Accumulation in Bay of Fundy Salt Marshes: Implications for Restoration of Reclaimed Marshes.” Global Biogeochemical Cycles 15 (4): 943–954. doi:https://doi.org/10.1029/2000gb001346.

Costanza, R., d’Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O’Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & van den Belt, M. (1997). The value of the world’s ecosystem services and natural capital. Nature, 387(6630), 253–260. https://doi.org/10.1038/387253a0

Craft, C., Megonigal, P., Broome, S., Stevenson, J., Freese, R., Cornell, J., Zheng, L., & Sacco, J. (2003). The Pace of Ecosystem Development of Constructed Spartina Alterniflora Marshes. Ecological Applications, 13(5), 1417–1432. https://doi.org/10.1890/02-5086

Cuellar-Martinez, T., Ruiz-Fernández, A.C., Sanchez-Cabeza, J.A., Perez-Bernal, L.H. and Sandoval-Gil, J., 2019. Relevance of carbon burial and storage in two contrasting blue carbon ecosystems of a north-east Pacific coastal lagoon. Science of The Total Environment, 675, pp.581-593.

Drake, K., Halifax, H., Adamowicz, S. C., & Craft, C. (2015). Carbon sequestration in tidal salt marshes of the Northeast United States. Environmental Management, 56(4), 998-1008.

Elsey-Quirk, T., D. Seliskar, C. Sommerfield, and J. Gallagher. 2011. “Salt Marsh Carbon Pool Distribution in a Mid-Atlantic Lagoon, USA: Sea Level Rise Implications.” Wetlands 31 (1): 87–99. doi:https://doi.org/10.1007/s13157-010-0139-2.

Fountain, M., Jeppesen, R., Endris, C., Woolfolk, A., Watson, E., Aiello, I., Fork, S., Haskins, J., Beheshti, K., Tanner, K., Thomsen, A., Wilburn, B., Krause, J., Eby, R., Wasson, K. Hester Marsh Restoration. Annual Report 2021. Elkhorn Slough National Estuarine Research Reserve.

Gailis, M., Kohfeld, K. E., Pellatt, M. G., & Carlson, D. (2021). Quantifying blue carbon for the largest salt marsh in southern British Columbia: implications for regional coastal management. Coastal Engineering Journal, 63(3), 275-309.

Gedan, K. B., Silliman, B. R., & Bertness, M. D. (2009). Centuries of human-driven change in salt marsh ecosystems. Annual Review of Marine Science, 1(1), 117–141. https://doi.org/10.1146/annurev.marine.010908.163930

Gilby, B. L., Weinstein, M. P., Baker, R., Cebrian, J., Alford, S. B., Chelsky, A., Colombano, D., Connolly, R. M., Currin, C. A., Feller, I. C., Frank, A., Goeke, J. A., Goodridge Gaines, L. A., Hardcastle, F. E., Henderson, C. J., Martin, C. W., McDonald, A. E., Morrison, B. H., Olds, A. D., … Ziegler, S. L. (2020). Human Actions Alter Tidal Marsh Seascapes and the Provision of Ecosystem Services. Estuaries and Coasts. https://doi.org/10.1007/s12237-020-00830-0

Gonneea, M. E., Maio, C. V., Kroeger, K. D., Hawkes, A. D., Mora, J., Sullivan, R., ... & Donnelly, J. P. (2019). Salt marsh ecosystem restructuring enhances elevation resilience and carbon storage during accelerating relative sea-level rise. Estuarine, Coastal and Shelf Science, 217, 56-68.

Haskins, J., Endris, C., Thomsen, A. S., Gerbl, F., Fountain, M. C., & Wasson, K. (2021). UAV to Inform Restoration: A Case Study From a California Tidal Marsh. Frontiers in Environmental Science, 9, 642906. https://doi.org/10.3389/fenvs.2021.642906

Hemes, K. S., Chamberlain, S. D., Eichelmann, E., Knox, S. H., & Baldocchi, D. D. (2018). A biogeochemical compromise: The high methane cost of sequestering carbon in restored wetlands. Geophysical Research Letters, 45(12), 6081-6091.

Henneberg, A., B. K. Sorrell, and H. Brix (2012), Internal methane transport through juncus effusus: Experimental manipulation of morphological barriers to test above- and below-ground diffusion limitation, New Phytol., 196, 799–806.

Herbert, E. R., Windham-Myers, L., & Kirwan, M. L. (2021). Sea-level rise enhances carbon accumulation in United States tidal wetlands. One Earth, 4(3), 425-433.

Hopkinson, C. S., Cai, W. J., & Hu, X. (2012). Carbon sequestration in wetland dominated coastal systems—a global sink of rapidly diminishing magnitude. Current Opinion in Environmental Sustainability, 4(2), 186-194.

Hopkinson, C. S., Morris, J. T., Fagherazzi, S., Wollheim, W. M., & Raymond, P. A. (2018). Lateral marsh edge erosion as a source of sediments for vertical marsh accretion. Journal of Geophysical Research: Biogeosciences, 123(8), 2444-2465.

Hughes, B. B., Haskins, J., & Wasson, K. (2011). Identifying factors that influence expression of eutrophication in a central California estuary. Marine Ecology Progress Series, 439, 31–43.

Hungate, B.A., R.B. Jackson, C.B. Field, and F.S. Chapin III. 1996. Detecting changes in soil carbon in CO2 enrichment experiments. Plant and Soil, Vol. 187, pp. 135-145.

Kelleway, J. J., N. Saintilan, P. I. Macreadie, J. A. Baldock, and P. J. Ralph. 2017. "Sediment and Carbon Deposition Vary among Vegetation Assemblages in a Coastal Salt Marsh." Biogeosciences 14 (16): 3763–3779.

Kirwan, M. L., & Megonigal, J. P. (2013). Tidal wetland stability in the face of human impacts and sea-level rise. Nature, 504(7478), 53–60. https://doi.org/10.1038/nature12856

Kroeger, K. D., Crooks, S., Moseman-Valtierra, S., & Tang, J. (2017). Restoring tides to reduce methane emissions in impounded wetlands: A new and potent Blue Carbon climate change intervention. Scientific Reports, 7(1), 11914. https://doi.org/10.1038/s41598-017-12138-4

Lovelock, C. E., & Duarte, C. M. (2019). Dimensions of Blue Carbon and emerging perspectives. Biology Letters, 15(3), 20180781. https://doi.org/10.1098/rsbl.2018.0781

Luo, H., Oechel, W. C., Hastings, S. J., Zulueta, R., Qian, Y., & Kwon, H. (2007). Mature semiarid chaparral ecosystems can be a significant sink for atmospheric carbon dioxide. Global Change Biology, 13(2), 386-396.

Macreadie, P. I., Nielsen, D. A., Kelleway, J. J., Atwood, T. B., Seymour, J. R., Petrou, K., Connolly, R. M., Thomson, A. C., Trevathan-Tackett, S. M., & Ralph, P. J. (2017). Can we manage coastal ecosystems to sequester more blue carbon? Frontiers in Ecology and the Environment, 15(4), 206–213. https://doi.org/10.1002/fee.1484

Magenheimer, J. F., T. R. Moore, G. L. Chmura, and R. J. Daoust. "Methane and carbon dioxide flux from a macrotidal salt marsh, Bay of Fundy, New Brunswick." Estuaries 19, no. 1 (1996): 139-145.

Makkonen, K., & Helmisaari, H. S. (1999). Assessing fine-root biomass and production in a Scots pine stand–comparison of soil core and root ingrowth core methods. Plant and soil, 210(1), 43-50.

Martin, R. M., Wigand, C., Elmstrom, E., Lloret, J., & Valiela, I. (2018). Long-term nutrient addition increases respiration and nitrous oxide emissions in a New England salt marsh. Ecology and Evolution, 8(10), 4958-4966.

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., Lovelock, C. E., Schlesinger, W. H., & Silliman, B. R. (2011). A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO 2. Frontiers in Ecology and the Environment, 9(10), 552–560. https://doi.org/10.1890/110004

Moreno-Mateos, D., Power, M. E., Comín, F. A., & Yockteng, R. (2012). Structural and Functional Loss in Restored Wetland Ecosystems. PLOS Biology, 10(1), e1001247. https://doi.org/10.1371/journal.pbio.1001247

Moseman-Valtierra S, Abdul-Aziz OI, Tang J, Ishtiaq KS, Morkeski K, Mora J, Quinn RK, Martin RM, Egan K, Brannon EQ, Carey J. Carbon dioxide fluxes reflect plant zonation and belowground biomass in a coastal marsh. Ecosphere. 2016 Nov;7(11):e01560.

Moseman-Valtierra, S., Gonzalez, R., Kroeger, K. D., Tang, J., Chao, W. C., Crusius, J., ... & Shelton, J. (2011). Short-term nitrogen additions can shift a coastal wetland from a sink to a source of N2O. Atmospheric Environment, 45(26), 4390-4397.

Mueller, P., Jensen, K., & Megonigal, J. P. (2016). Plants mediate soil organic matter decomposition in response to sea level rise. Global Change Biology, 22(1), 404-414.

Neckles, H. A., & Neill, C. (1994). Hydrologic control of litter decomposition in seasonally flooded prairie marshes. Hydrobiologia, 286(3), 155-165.

Nellemann, C., & Corcoran, E. (2009). Blue carbon: The role of healthy oceans in binding carbon: A rapid response assessment. UNEP/Earthprint.

Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V., Woodcock, C. E., & Wulder, M. A. (2014). Good practices for estimating area and assessing accuracy of land change. Remote Sensing of Environment, 148, 42-57.

Ouyang, X., and S. Y. Lee. 2014. “Updated Estimates of Carbon Accumulation Rates in Coastal Marsh Sediments.” Biogeosciences 11 (18): 5057–5071. doi:https://doi.org/10.5194/bg-11-5057-2014.

Pendleton, L., Donato, D. C., Murray, B. C., Crooks, S., Jenkins, W. A., Sifleet, S., Craft, C., Fourqurean, J. W., Kauffman, J. B., Marbà, N., Megonigal, P., Pidgeon, E., Herr, D., Gordon, D., & Baldera, A. (2012). Estimating Global “Blue Carbon” Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems. PLOS ONE, 7(9), e43542. https://doi.org/10.1371/journal.pone.0043542

Phang, V. X. H., Chou, L. M., & Friess, D. A. (2015). Ecosystem carbon stocks across a tropical intertidal habitat mosaic of mangrove forest, seagrass meadow, mudflat and sandbar. Earth Surface Processes and Landforms, 40(10), 1387–1400. https://doi.org/10.1002/esp.3745

Poffenbarger, H. J., Needelman, B. A., & Megonigal, J. P. (2011). Salinity influence on methane emissions from tidal marshes. Wetlands, 31(5), 831-842.

Poppe KL, Rybczyk JM (2021) Tidal marsh restoration enhances sediment accretion and carbon accumulation in the Stillaguamish River estuary, Washington. PLoS ONE 16(9): e0257244. https://doi.org/10.1371/journal.pone.0257244

Radabaugh, K. R., Moyer, R. P., Chappel, A. R., Powell, C. E., Bociu, I., Clark, B. C., & Smoak, J. M. (2018). Coastal blue carbon assessment of mangroves, salt marshes, and salt barrens in Tampa Bay, Florida, USA. Estuaries and Coasts, 41(5), 1496-1510.

Raposa, K. B., Wasson, K., Smith, E., Crooks, J. A., Delgado, P., Fernald, S. H., Ferner, M. C., Helms, A., Hice, L. A., Mora, J. W., Puckett, B., Sanger, D., Shull, S., Spurrier, L., Stevens, R., & Lerberg, S. (2016). Assessing tidal marsh resilience to sea-level rise at broad geographic scales with multi-metric indices. Biological Conservation, 204, 263–275. https://doi.org/10.1016/j.biocon.2016.10.015

Reich, P. B. (2011). Taking stock of forest carbon. Nature Climate Change, 1(7), 346–347. https://doi.org/10.1038/nclimate1233

Richard, G. A. (1978). Seasonal and environmental variations in sediment accretion in a Long Island salt marsh. Estuaries, 1(1), 29-35.

Sadler, P. M. (1999, June). The influence of hiatuses on sediment accumulation rates. In GeoResearch Forum (Vol. 5, No. 1, pp. 15-40).

Schutte, C. A., Moore, W. S., Wilson, A. M., & Joye, S. B. (2020). Groundwater-driven methane export reduces salt marsh blue carbon potential. Global Biogeochemical Cycles, 34(10), e2020GB006587.

Shiau, Y. J., Burchell, M. R., Krauss, K. W., Broome, S. W., & Birgand, F. (2019). Carbon storage potential in a recently created brackish marsh in eastern North Carolina, USA. Ecological Engineering, 127, 579-588.

Shiau, Y.-J., Burchell, M. R., Krauss, K. W., Broome, S. W., & Birgand, F. (2019). Carbon storage potential in a recently created brackish marsh in eastern North Carolina, USA. Ecological Engineering, 127, 579–588. https://doi.org/10.1016/j.ecoleng.2018.09.007

Smith, A. J., & Kirwan, M. L. (2021). Sea Level-Driven Marsh Migration Results in Rapid Net Loss of Carbon. Geophysical Research Letters, 48(13), e2021GL092420.

Smyth, E. (2020). Differences in Biological Structure and Organic Matter Cycling Between Constructed and Natural Tidal Marshes [M.S., The University of Alabama]. https://www.proquest.com/docview/2454635810/abstract/19CE1433DF44CD9PQ/1

Stagg, C. L., & Mendelssohn, I. A. (2010). Restoring Ecological Function to a Submerged Salt Marsh. Restoration Ecology, 18, 10–17. https://doi.org/10.1111/j.1526-100X.2010.00718.x

Staver, L. W., Stevenson, J. C., Cornwell, J. C., Nidzieko, N. J., Staver, K. W., Owens, M. S., ... & Malkin, S. Y. (2020). Tidal marsh restoration at Poplar Island: II. Elevation trends, vegetation development, and carbon dynamics. Wetlands, 40(6), 1687-1701.

Thorne, K. M., Freeman, C. M., Rosencranz, J. A., Ganju, N. K., & Guntenspergen, G. R. (2019). Thin-layer sediment addition to an existing salt marsh to combat sea-level rise and improve endangered species habitat in California, USA. Ecological Engineering, 136, 197–208. https://doi.org/10.1016/j.ecoleng.2019.05.011

Van Allen, R., Schreiner, K. M., Guntenspergen, G., & Carlin, J. (2021). Changes in organic carbon source and storage with sea level rise-induced transgression in a Chesapeake Bay marsh. Estuarine, Coastal and Shelf Science, 261, 107550.

Van der Wegen, M., Jaffe, B., Foxgrover, A., & Roelvink, D. (2017). Mudflat morphodynamics and the impact of sea level rise in South San Francisco Bay. Estuaries and Coasts, 40(1), 37-49.

Van Dyke, E., & Wasson, K. (2005). Historical ecology of a central California estuary: 150 years of habitat change. Estuaries, 28(2), 173–189.

van der Nat, F. -J., and J. J. Middelburg (2000), Methane emission from tidal freshwater marshes, Biogeochemistry, 49, 103–121.

Waltham, N. J., Alcott, C., Barbeau, M. A., Cebrian, J., Connolly, R. M., Deegan, L. A., Dodds, K., Goodridge Gaines, L. A., Gilby, B. L., Henderson, C. J., McLuckie, C. M., Minello, T. J., Norris, G. S., Ollerhead, J., Pahl, J., Reinhardt, J. F., Rezek, R. J., Simenstad, C. A., Smith, J. A. M., … Weinstein, M. P. (2021). Tidal Marsh Restoration Optimism in a Changing Climate and Urbanizing Seascape. Estuaries and Coasts. https://doi.org/10.1007/s12237-020-00875-1

Wang, F., Sanders, C. J., Santos, I. R., Tang, J., Schuerch, M., Kirwan, M. L., Kopp, R. E., Zhu, K., Li, X., Yuan, J., Liu, W., & Li, Z. (2021). Global blue carbon accumulation in tidal wetlands increases with climate change. National Science Review, 8(9). https://doi.org/10.1093/nsr/nwaa296

Wasson, K. (2017). Eutrophication decreases salt marsh resilience through proliferation of algal mats. Biological Conservation, 23.

Wasson, K., & Woolfolk, A. (2011). Salt Marsh-Upland Ecotones in Central California: Vulnerability to Invasions and Anthropogenic Stressors. Wetlands, 31(2), 389–402. https://doi.org/10.1007/s13157-011-0153-z

Wasson, K., Ganju, N. K., Defne, Z., Endris, C., Elsey-Quirk, T., Thorne, K. M., Freeman, C. M., Guntenspergen, G., Nowacki, D. J., & Raposa, K. B. (2019). Understanding tidal marsh trajectories: Evaluation of multiple indicators of marsh persistence. Environmental Research Letters, 14(12), 124073. https://doi.org/10.1088/1748-9326/ab5a94

Wasson, K., Suarez, B., Akhavan, A., McCarthy, E., Kildow, J., Johnson, K. S., Fountain, M. C., Woolfolk, A., Silberstein, M., & Pendleton, L. (2015). Lessons learned from an ecosystem-based management approach to restoration of a California estuary. Marine Policy, 58, 60–70.

Watson, E. B., Wasson, K., Pasternack, G. B., Woolfolk, A., Van Dyke, E., Gray, A. B., Pakenham, A., & Wheatcroft, R. A. (2011). Applications from paleoecology to environmental management and restoration in a dynamic coastal environment. Restoration Ecology, 19(doi: 10.1111/j.1526-100X.2010.00722.x), 1–11. https://doi.org/10.1111/j.1526-100X.2010.00722.x

Whiting, G. J., and J. P. Chanton (1993), Primary production control of methane emissions from wetlands, Nature, 364, 794–795.

Wylie, L., Sutton-Grier, A. E., & Moore, A. (2016). Keys to successful blue carbon projects: Lessons learned from global case studies. Marine Policy, 65, 76–84. https://doi.org/10.1016/j.marpol.2015.12.020

Yang, B. C., & Chun, S. S. (2001). A seasonal model of surface sedimentation on the Baeksu open-coast intertidal flat, southwestern coast of Korea. Geosciences Journal, 5(3), 251-262.

Zedler, J. B., & Callaway, J. C. (1999). Tracking Wetland Restoration: Do Mitigation Sites Follow Desired Trajectories? Restoration Ecology, 7(1), 69–73. https://doi.org/10.1046/j.1526-100X.1999.07108.x

zu Ermgassen, P. S. E., Baker, R., Beck, M. W., Dodds, K., zu Ermgassen, S. O. S. E., Mallick, D., Taylor, M. D., & Turner, R. E. (2021). Ecosystem Services: Delivering Decision-Making for Salt Marshes. Estuaries and Coasts. https://doi.org/10.1007/s12237-021-00952-z

Salt marsh restoration and greenhouse gas mitigation: evaluation of blue carbon function of restored and natural habitats at Elkhorn Slough, California

Supplemental Figures and Tables

Table S1. Location of study sites samples for this study

Table S2. Confusion matrix representing 200 random check points for the 2015 image classification. PA = producer's accuracy; UA = user's accuracy; OA = overall accuracy; the kappa value of 67.4% indicates substantial agreement between the manual and object-based classification.

Table S3. Confusion matrix representing 200 random check points for the 2020-2021 image classification. PA = producer's accuracy; UA = user's accuracy; OA = overall accuracy; the kappa values of 77.4% indicates substantial agreement between the manual and object-based classification.

Table S4. Emissions associated with the Hester restoration construction operations, in metric tons.

Figure S1. Empirical relationship between sediment organic content (percent loss on ignition) and sediment organic carbon content, as determined through elemental analysis of acidified samples

Figure S2. Relationship between landscape position and percent carbon in plant tissue at Hester Marsh restoration site.

Figure S3. Aboveground biomass at Elkhorn Slough research sites.

Table S1. Location of study sites samples for this study. Control sites were formerly diked & subsided. Reference sites are locations that support healthy high marsh. Habitats are abbreviated mudflat (mf), low marsh (lm), high marsh (hm), grassland (gr), bare (br), and vegetated (veg).

Location	**Type**	**Areas Sampled**	**Location**	
Hummingbird Island	Control	mf, lm, hm, gr	36.8244°	-121.7415°
Parson's Overlook	Control	mf, lm, hm, gr	36.8076°	-121.7387°
T-Dock	Control	mf, lm, hm, gr	36.8192°	-121.7378°
Long Valley	Control	mf, lm, hm, gr	36.8122°	-121.7344°
Seal Bend	Control	mf, lm, hm, gr	36.8123°	-121.7674°
Hudson's Landing	Reference	mf, hm, gr	36.8596°	-121.7563°
Azevedo	Reference	mf, hm, gr	36.8502°	-121.7571°
Old Salinas River Channel	Reference	mf, hm, gr	36.7964°	-121.7903°
Hester Marsh	Restoration	Before: mf, lm, hm, gr After: br, veg	36.8085°	-121.7532°

Table S2. Confusion matrix representing 200 random check points for the 2015 image classification. PA = producer's accuracy; UA = user's accuracy; OA = overall accuracy; the kappa value of 67.4% indicates substantial agreement between the manual and object-based classification.

	Manual Classification				
Automated Classification	Vegetated	Bare	Total	UA	
Vegetated	24	6	30	80.0%	
Bare	12	158	170	92.9%	
Total	36	164	200		
PA	66.7%	96.3%		OA: 91.0%	Kappa 67.4%

Table S3. Confusion matrix representing 200 random check points for the 2020-2021 image classification. PA = producer's accuracy; UA = user's accuracy; OA = overall accuracy; the kappa values of 77.4% indicates substantial agreement between the manual and object-based classification.

	Manual Classification				
Automated Classification	Vegetated	Bare	Total	UA	
Vegetated	51	10	61	83.6%	
Bare	9	129	138	93.5%	
Total	60	139	199		
PA	85.0%	92.8%		OA:	Kappa
				90.5%	77.4%

Table S4. Emissions associated with the Hester restoration construction operations, in metric tons.

compound	Metric tons		compound	Metric tons
ROG*	0.11		PM_{10} exhaust	0.03
CO	1.64		PM_{10} fugitive	2.21
NO_X	0.69		PM_{10} total	2.22
SO_2	0.00		$PM_{2.5}$ exhaust	0.03
CO_2	374.94		$PM_{2.5}$ fugitive	0.33
CH_4	0.10		$PM_{2.5}$ total	0.36
CO_2 - equiv	379.80			

*reactive organic gases

Total Project Emissions in Metric Tons - Mitigated

Model	ROG	CO	NOX	SO2	PM10 Exhaust	PM10 Fugitive	PM10 Total	PM2.5 Exhaust	PM2.5 Fugitive	PM2.5 Total	CO2	CH4	CO2e	Comments	Average over 30 years
DU Phase	0.11	1.64	0.69	0.00	0.03	2.21	2.22	0.03	0.33	0.36	374.94	0.10	379.82	DU Phase I	

Figure S1. Empirical relationship between sediment organic content (percent loss on ignition) and sediment organic carbon content, as determined through elemental analysis of acidified samples

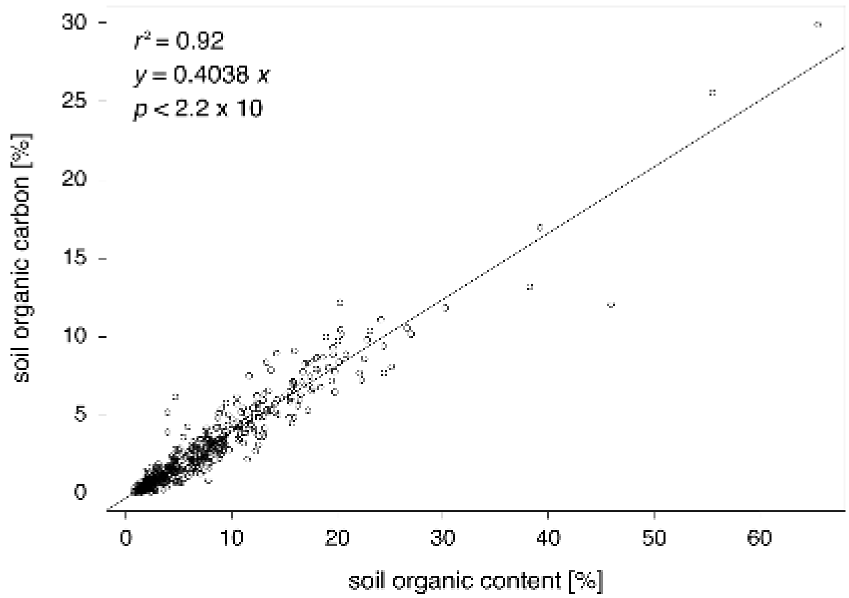


Figure S3. Relationship between landscape position and percent carbon in plant tissue at Hester Marsh restoration site.

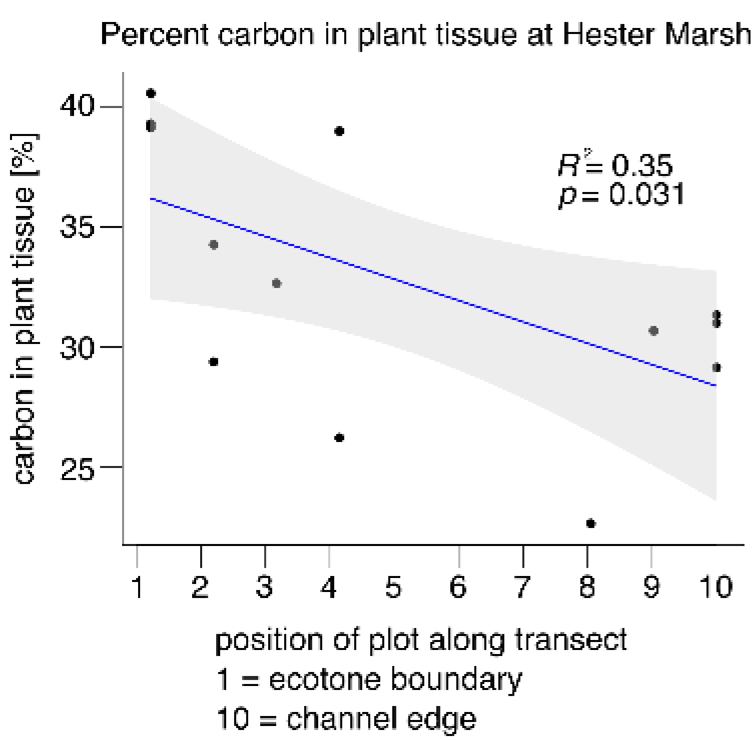
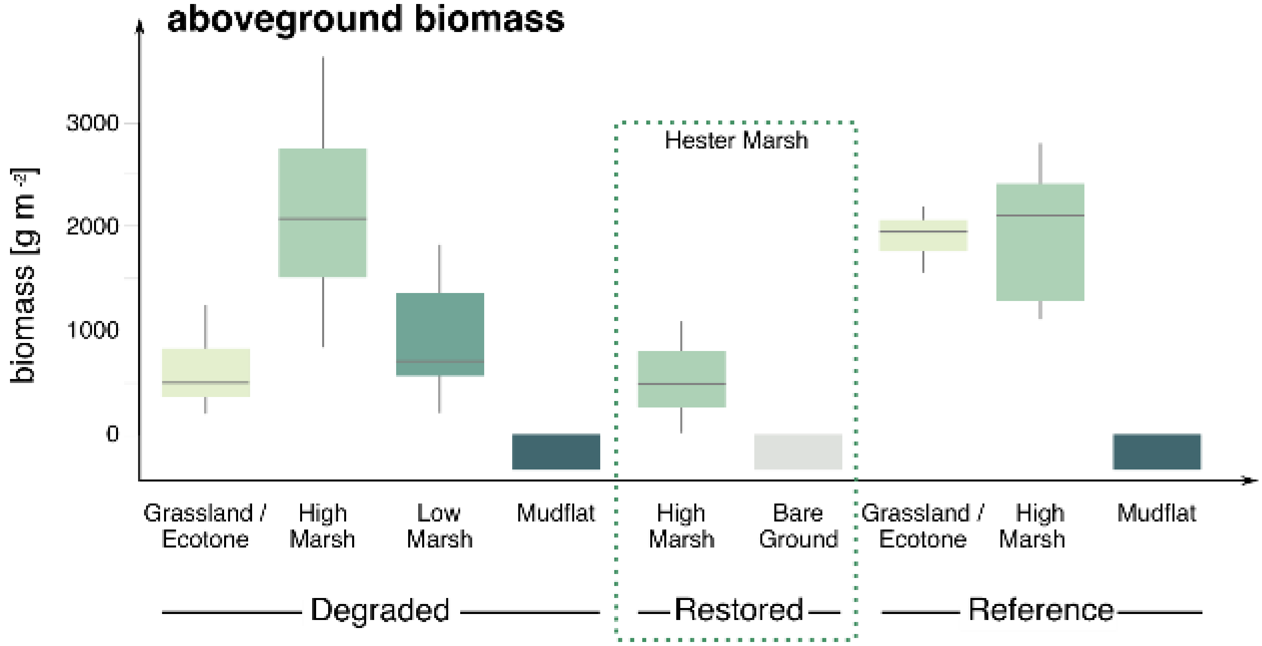


Figure S3. Aboveground biomass at Elkhorn Slough research sites.



Appendix 12

Harbor Seal Incidental Harassment Agreement Report

Elkhorn Slough Tidal Marsh Restoration Project Phase II

Draft Post Construction Marine Mammal Monitoring Report

3/2022

List of tables

List of figures

List of acronyms and abbreviations

ESF – Elkhorn Slough Foundation

ESNERR – Elkhorn Slough National Estuarine Research Reserve

IHA - Incidental Harassment Agreement

Executive summary

The Elkhorn Slough Tidal Marsh Restoration was a large-scale estuarine restoration project undertaken in Elkhorn Slough, Monterey County, central California. The project is a 147-acre (60 ha) restoration of an integrated coastal landscape, ranging from tidal creeks to salt marsh to adjacent grassland. Phase I was implemented in 2018 and included 61 acres (24 ha) of tidal marsh and 5 acres (2 ha) of coastal grassland. Phase II was completed in the fall of 2021 and includes an additional 29 acres (12 ha) of tidal marsh and 5 acres (2 ha) of coastal grassland. Phase III includes a final 29 acres (12 ha) of tidal marsh and 3 acres (1.2 ha) of coastal grassland. This report covers the marine mammal monitoring activities associated with the Incidental Harassment (IHA) permit issued by NOAA. No Level A take was Observed and actual Level B take was well below take estimates in the IHA of 6755.

Introduction

Phase II of the Elkhorn Slough Tidal Marsh Restoration project will restore 58 acres of subsided marsh and tidal channels, including 29.4 acres associated with the Minhoto-Hester Restoration Area and 28.6 acres associated with the Seal Bend Restoration Area (Figure 1). To date, earthwork at the Minhoto-Hester Restoration Area has been completed, including earthwork in subareas M4a, M4b and M5 and M6. Outstanding work includes the Seal Bend area.

CDFW was granted an Incidental Harassment Agreement (IHA) on xx for the project by the National Oceanic and Atmospheric Administration (NOAA). The IHA was valid from xx to xx. NOAA grant Level B harassment of a seals xxx. The takes for this project were based upon stock assessments completed by Elkhorn Slough National Estuarine Research Reserve. Work at the Minhoto-Hester Restoration Area began in August 2021. Between August 2020 and May 2021 (an approximate 9-month period), the construction contractor worked a total of 126 days. Work stopped during the IHA renewal process and then commenced August 24, 2021 finishing October 20, 2021 for a total project work days of 162. Marine mammal monitoring was required on 87 days and implemented on 113 of the 162 construction days. Additional monitoring days were added for training and when in water work was conducted. See the monitoring protocol (methods section) for details on monitoring locations.

Goals

1. Ensure that marine mammals are not subject to injury under the Marine Mammal Protection Act and the Federal Endangered Species Act.
2. Collect field data about the movement and activity of marine mammals during construction monitoring, which will inform NMFS and USFWS on marine mammal sensitivity to disturbance and provide reference for future construction projects.

Objectives

1. Ensure that construction activity is halted when there is a reasonable possibility that marine mammals will enter the exclusion zone in order to avoid any potential for physical injury.
2. Ensure that presence, distribution, movement and behavior of harbor seals and sea otters within the project area and surrounding vicinity is recorded when

there is a reasonable possibility that marine mammals will experience behavioral harassment.

The above objectives were met through following the marine mammal monitoring protocols developed in conjunction with NMFS and USFW. Other project goals and objective related to the restoration and the details on how they were met can be found in the annual monitoring report (Fountain et al 2021).

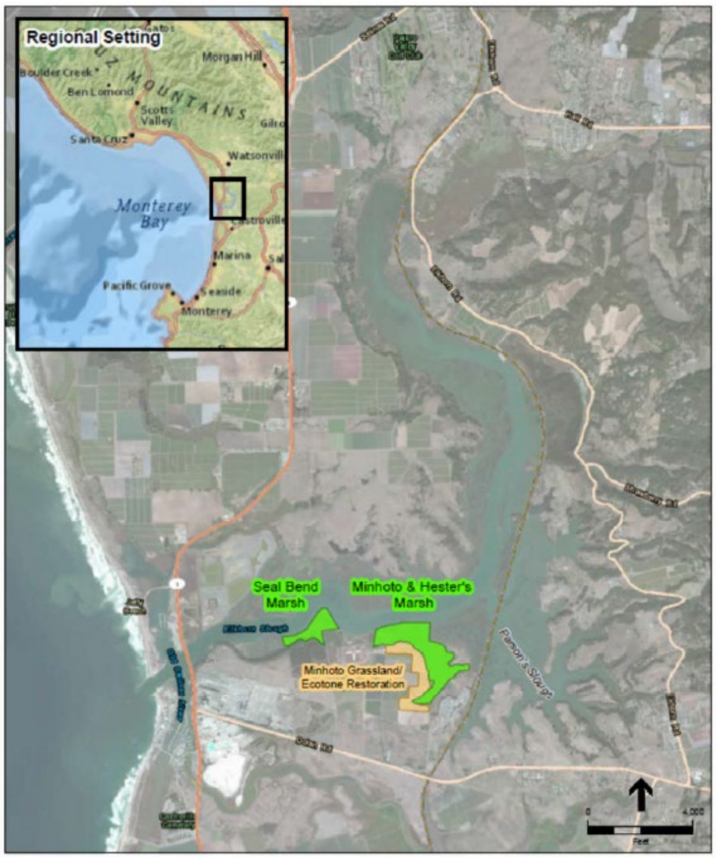


Figure 1. Regional setting

Methods

Monitoring protocol

The following outlines the methods used to monitor marine mammals during the project.

Observation location (Figure 2)

Monitoring during construction will occur from one observation area at Yampah Island. It is accessed by foot and provides a vantage point of the entire construction area, main channel of Elkhorn slough, Yampah marsh and Parsons. This includes the entire area within which harbor seals and sea otters present might reasonably be expected to experience disturbance due to construction activities.

Monitoring protocol

A Service- and NMFS- approved biological monitor will monitor for marine mammal disturbance. Monitoring will occur:

4.b (iii) When construction activities occur either, (1) in water or (2); within the boundaries of the two tidal restoration areas, Minhoto-Hester and Seal Bend identified in Figure 1, monitoring must occur every other day when work is occurring.

4.b.(iv) When construction activities occur near the "borrow" areas where marsh fill material is gathered, monitoring must occur every fifth day when work is occurring, unless the borrow area is more than 300 m from any area where marine mammals have been observed. Occurrence of marine mammals within the Level B harassment zone must be communicated to the construction lead to prepare for the potential shutdown when required.

The biological monitor had the authority to stop project activities if marine mammals approach or enter the exclusion zone. Biological monitoring will begin 0.5-hour before work begins and will continue until 0.5-hour after work is completed each day. Work will not commence if marine mammals are present in the exclusion zone.

Pre and post construction daily censuses - A census of marine mammals in the project area and the area surrounding the project will be conducted 30 minutes prior to the beginning of construction on monitoring days, and again 30 minutes after the completion of construction activities. Data was recorded on ipads.

Hourly counts - Conduct hourly counts of animals hauled out and in the water.

- Data collected will include:

    - Meta data including: date/time, monitor, monitoring location, visibility, construction activity
    - Numbers of each species spotted
    - Number of mom/pup pairs and neonates observed
    - Zone (distance)
    - Status (in water or hauled out)
- Notes may include any of the following information to the extent it is feasible to record:
    - Age-class
    - Sex
    - Unusual activity or signs of stress
    - Any other information worth noting
    - Notable behaviors, including foraging, grooming, resting, aggression, mating activity, and others
    - Tag color and tag location (and tag number if possible)—for sea otters, note right or left flipper and location between digits (digits 1 and 2 are inside; digits 4 and 5 are outside)

Construction related reactions- Record reaction observed in relation to construction activities including:

- Date/Time of reaction
- Concurrent construction activity
- Reaction code (see below)
- Distance from the noted disturbance.
- Activity before and after disturbance
- Status (in water or hauled out) before and after disturbance

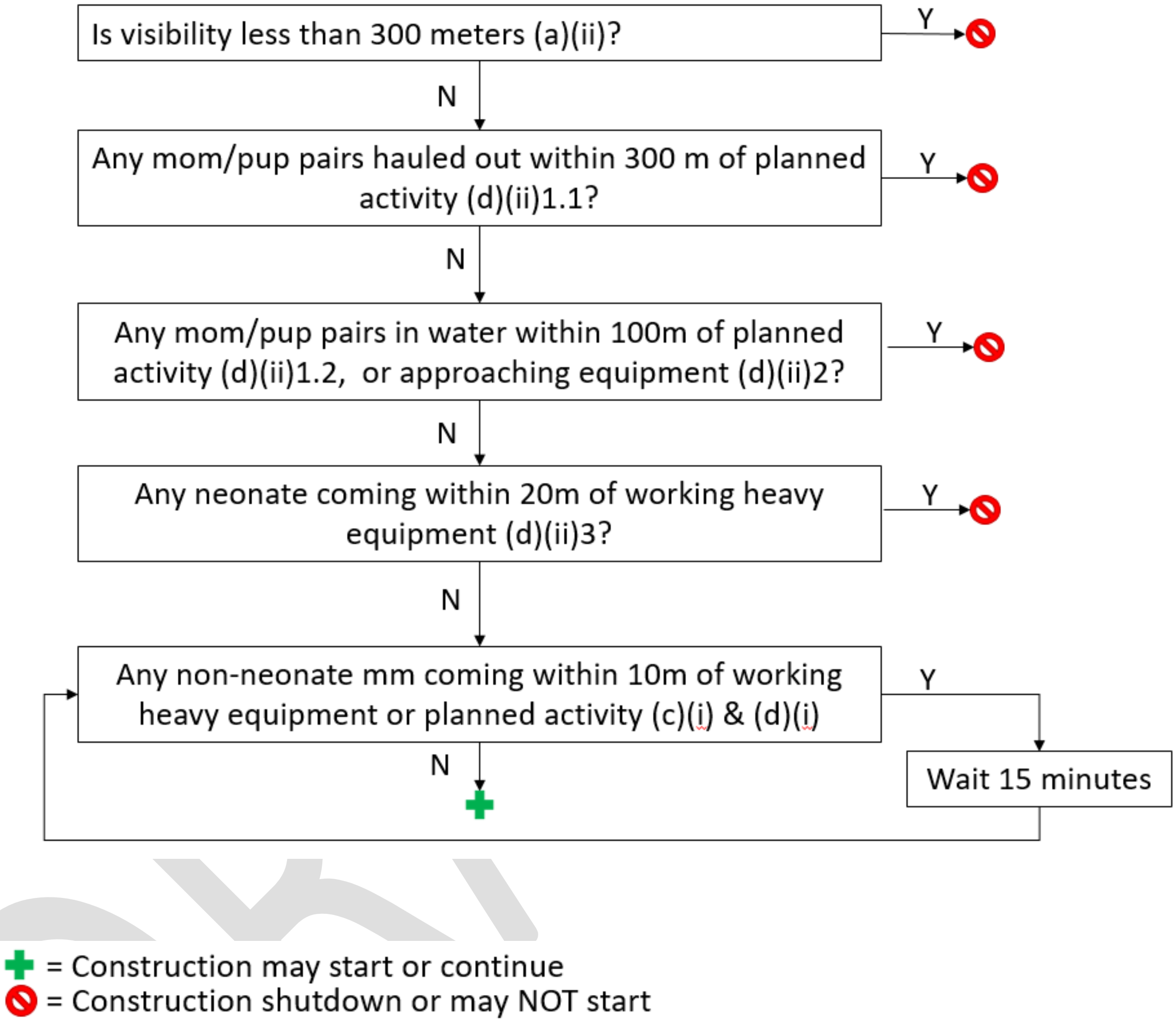
Code reactions:

Level	Type of response	Definition
1	Alert	Seal head orientation or brief movement in response to disturbance, which may include turning head towards the disturbance, craning head and neck while holding the body rigid in a u-

Level	Type of response	Definition
		shaped position, changing from a lying to a sitting position, or brief movement of less than twice the animal's body length.
2 *	Movement	Movements in response to the source of disturbance, ranging from short withdrawals at least twice the animal's body length to longer retreats over the beach, or if already moving a change of direction of greater than 90 degrees.
3 *	Flush	All retreats (flushes) to the water.

* Only Levels 2 and 3 are considered take, whereas Level 1 is not.

Construction shutdown decision tree



Steps for shutting down and resuming construction

1. Alert construction foreman of animal via text (use 1 blow from air horn if needed)
2. Record the construction activity and the time of shutdown
3. Record the reaction and location of the animal
4. Give clearance for construction activities to resume with a text
5. Record the time construction resumes

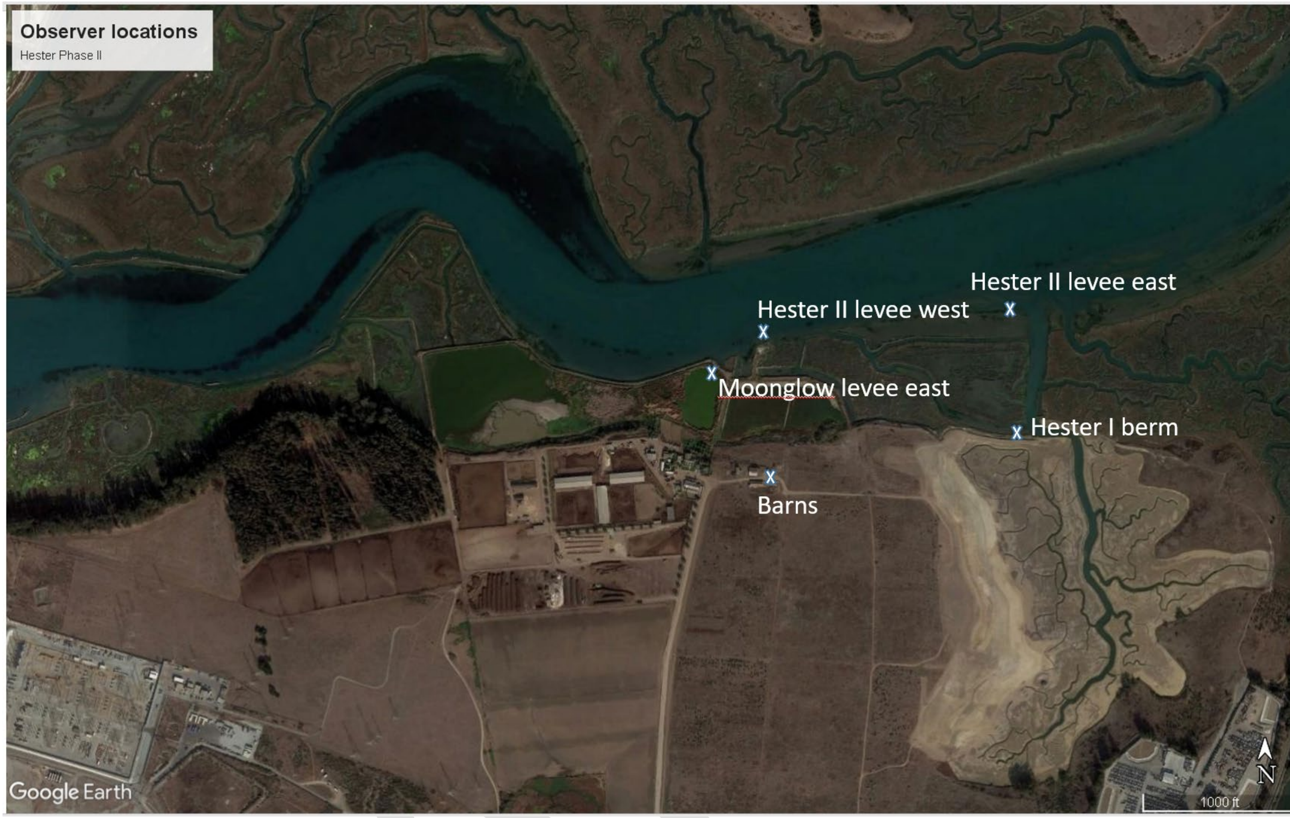


Figure 2. Observation posts.

Note: Some areas within the marshes cannot be seen at low tides which necessitated observers moving throughout the project area.

Daily Protocol

AM shift

1. Arrive at ESNERR about 45 minutes before on-site shift starts

2. Pick up the iPad and check that you have the equipment you need in the field [equipment list]

3. Download the most recent HanDBase data bases from drop box [iPad sync instructions]

- there are two different databases, the mmData.PDB for hourly counts and the incident
log named disturbance.PDB

4. Go to field site

5. By the green gate, please wipe your feet on the brush to remove any seeds from your footwear

6. If the gate is locked, the combo is xxxx, this is also the combo for the porta-potty

When you get to the field site and have arrived at the green box:

7. Put on a high visibility vest

8. Put up red flag

9. Note the time and conduct the pre count

10. Text contractor xxx-xxx-xxxx that construction is OK to start (7:30am)

11. Put up the green flag

12. Get your scope or binoculars ready for the first hourly observation

For the hourly observations:

13. Count all areas from near the green box on top of the hill unless you must be elsewhere

14. Record data on iPad

15. Rinse and repeat ☺

For incidents/disturbances:

16. From your hourly count, you'll know which animals are were. When construction begins in the morning, or resumes after lunch, or after a break, watch the animals to see if they are disturbed by the change in construction equipment activity (disturbance = head lift, flush, etc. see Key for definitions)

17. Leave site when PM shift arrives but first

- Hand off iPad to next observer
- give brief report of anything next observer should know

18. If the afternoon person doesn't show up, call Monique xxx-xxx-xxxx or Rikke xxx-xxx-xxxx

PM shift

1. Arrive at field site about 10-15 minutes before shift starts

2. Get iPad and equipment from AM observer

3. Be ready to collect marine mammal data according to protocol at shift start time

4. Follow marine mammal protocol for monitoring

5. Text contractor 30 mins before sunset, if equipment is still moving, and ask them to please stop construction.

6. Put up the red flag at this time

7. Conduct your post count 0.5 hrs after construction ended

8. Put the flags, tripod, scope, chair etc. in the green box

9. Take the iPad(s) with you and

10. Lock the green gate behind you

8. Go to ESNERR

9. Synchronize HanDBase TWO databases with Drop Box [iPad sync instructions]

10. Plug in iPad(s) for charging

Methods Review

Since this was essentially the third time we have followed this monitoring protocol there were no aspects that were not completed. Complications continue to include monitors being responsible for about a third of disturbances through checking areas during low tides, triangulating distance from marine mammals to construction equipment and shifting the observers from looking at distance rather than zone. We had monitors in the highest and best location for visibility but they were not always exactly where the equipment was making it difficult to triangulate distance. This was mitigated with a map and a calibrated set of rings printed on a transparent material which allow for quick and accurate triangulation.

Results

a. Environmental conditions

Cloud cover ranged from zero to 100% throughout the project. Fog occasionally occurred in the early mornings when the least number of seals were present. 96% of the time visibility was over 300m from the top observation post. When visibility declined due to fog, monitors move to the location of the equipment for observation. This likely reduced hourly counts but ensured disturbance events were recorded. There were several rain events that shut construction down for days or weeks depending on how long it took for the soil to dry enough to be manipulated.

b. Summarized behaviors of Harbor Seals

Hourly counts

Harbor seal counts during the daytime (6AM - 6PM) ranged from 0 to 118 individuals within 300 m of construction activity in the project area and from 0 to 250 individuals in the entire observation area. The average number of seals per hourly count, within 300 m of construction activity in the project area was 7 seals/hr and 20 seals/hr for the entire observation area. Pre- and post- construction counts had lower average and maximum numbers of seals, than regular hourly counts (Figure 3). No tags individuals were observed.

Fewer seals were observed during the pre and post counts compared to the hourly counts during construction (Figure 3).

The number of individuals observed within 300 m of construction activity varied throughout the day. An average count of seals per hour shows the general trend that seals moved into the area throughout the morning peaking around 10-11am and then slowly moved out of the area in the evening, repeating the pattern each day (Figure 4).

Since this phase of the project spanned most months of the year we were able to look at average numbers of seals present within 300m of construction by month and see the general pattern of seals in the area. The maximum average number of seals recorded was in April (Figure 5).

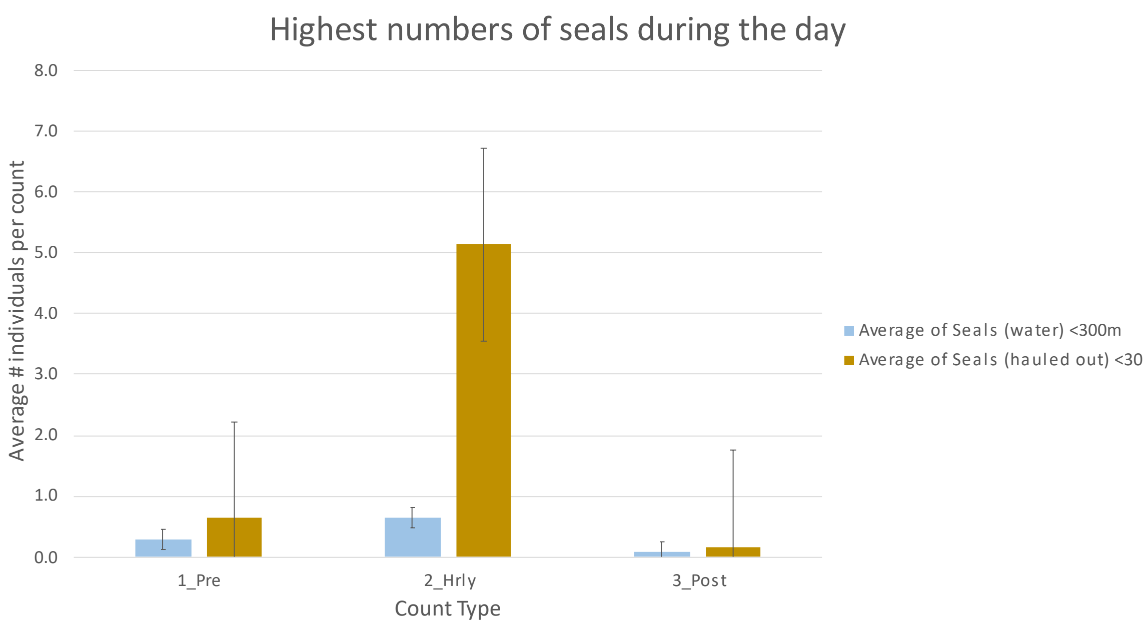


Figure 3. Average seal abundance around construction time.

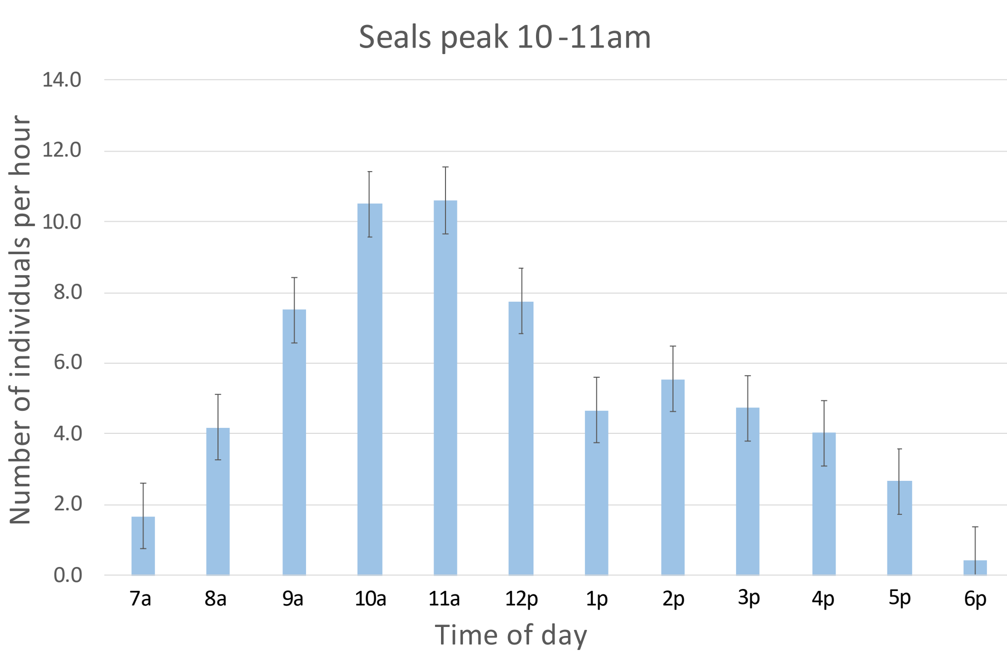


Figure 4. Seal counts, before construction starts, throughout the day, after construction ends.

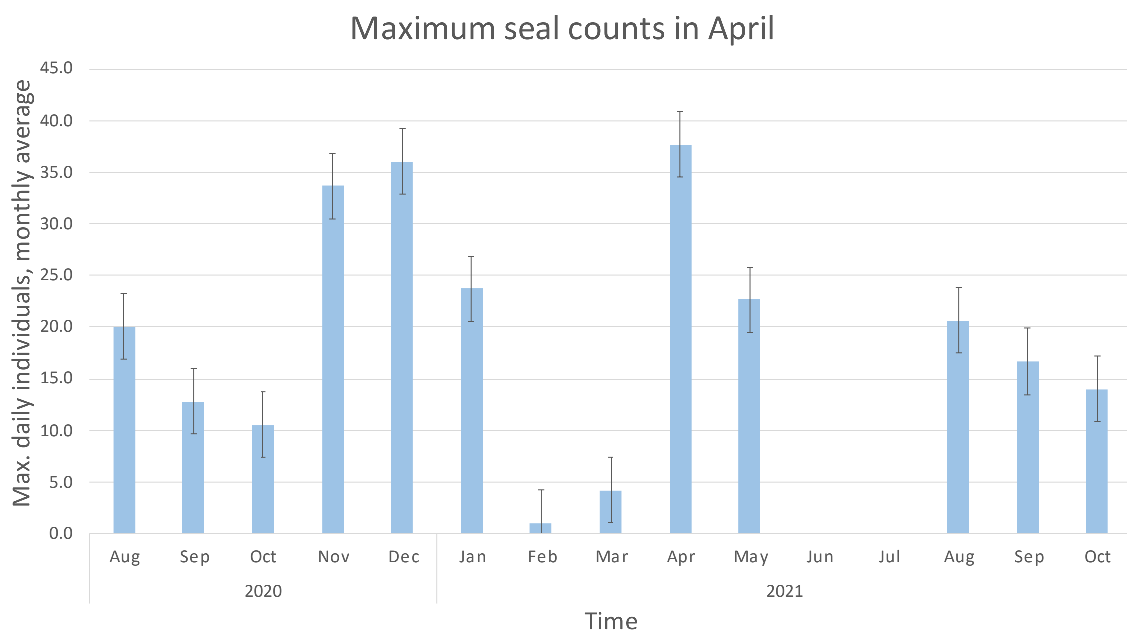


Figure 5. Maximum daily Harbor seal observations by month.

c. Mitigation measures implemented

All mitigation measures outlined in the IHA were implemented. This included:

Timing: work only during daylight hours and when shutdown area is visible

Visual monitoring: by qualified and NOAA and USFW approved monitors on the days required.

Pre-construction clearance and ramp up: as outlined in the IHA

Shutdown: All shutdown requirements were adhered to.

Construction activities: Environmental training and all construction initiation precautions were adhered to.

d. Observation results

i) *Mortalities*

There were no mortalities observed during the course of the project.

ii) *Level A takes for authorized stocks*

(1) Observed takes

There were no Level A takes observed during the course of the project.

(2) Extrapolated takes

With no Level A takes observed the extrapolated value is also zero.

iii) *Level B takes for authorized stocks*

(1) Observed takes

Thirteen (13) incidents of Level B harassment of harbor seals (flushing or movement) were recorded by the monitors (Table 1). Of these, 7 incidents representing harassment of 15 individual seals were attributed to construction activities; the remaining 6 incidents representing harassment of 20 seals were attributed to marine mammal monitoring activities.

We looked at the abundance of seals during different types of activities and found that 84% of seals counted occurred during excavating and filling activities (Table 2).

We also looked at the cause of seal disturbance by distance and reaction (including alerts and found that recreationists and PSO (human activity) caused disturbance in closer proximity than equipment (Figure 6 & 10).

Table 1. Level B take events

Incident #	Date	Reaction	Trigger	Construction activity	Distance (m)	Total Seals in Vicinity	Total Seals Reacted	Total Seals within 300m*
1	09/21/2020	Flush	Construction (Sound and Visual)	Excavating & filling	60m	4	2	35
2	11/09/2020	Movement	Construction (Sound)	Tractors starting	300m	3	1	3
3	03/17/2021	Movement	Construction (Sound)	Equipment moving	200m	5	5	5
4	03/24/2021	Flush	Construction (Sound and Visual)	Equipment moving	60m	1	1	1
5	03/24/2021	Flush	Construction (Sound and Visual)	Equipment moving	60m	1	1	4
6	04/14/2021	Flush	Construction (Sound and Visual)	Equipment moving	80m	2	2	45
7	05/17/2021	Flush	Construction (Sound and Visual)	Equipment moving	100m	6	3	7
			subtotal Construction			**22**	**15**	**100**
8	09/03/2020	Flush	Observer (Visual)		20m	1	1	6
9	09/08/2020	Flush	Observer (Visual)		80m	8	8	8
10	10/19/2020	Flush	Observer (Visual)		40m	2	2	2
11	12/03/2020	Flush	Observer (Visual)		80m	1	1	1
12	12/16/2020	Flush	Observer (Visual)		60m	7	7	10
13	05/19/2021	Flush	Observer (Visual)		10m	1	1	
			subtotal Observers			**20**	**20**	**27**
Total						**42**	**35**	**127**

* Based on hourly counts to the nearest hour as seals were unlikely to move entirely out of the observation area.

Table 2. Abundance of harbor seals by construction activity

Construction Activity	Count
Excavating	140
Excavating and Filling	7101
Filling	203
Other	676
People only	309
Grand Total	**8429**

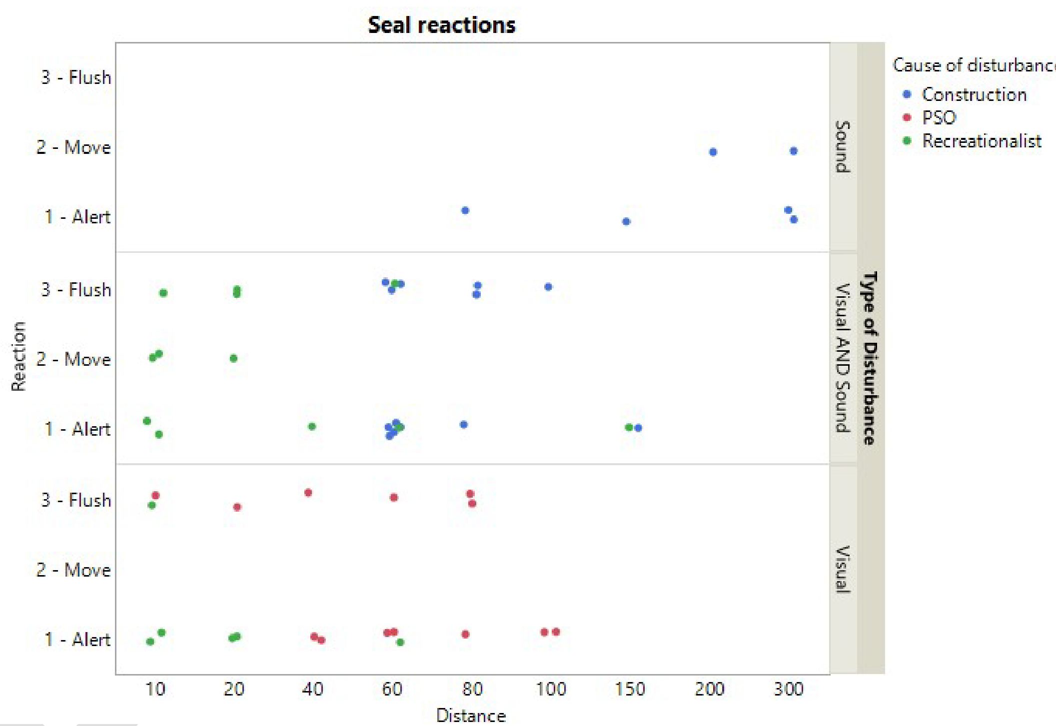


Figure 6. Cause and type of seal reactions by distance.

(2) Extrapolated takes

It is estimated that project construction has resulted in the take of 35 seals in 113 monitoring days, or less than 1 (0.31) seal per day. If an estimate of take of 0.31 seals per day is applied to the 49 construction days when monitoring did not occur (i.e., 0.31 x 49), an additional 15 seals may also have been subject to Level B harassment, for a total take to date of 64 seals.

iv) *Shutdowns*

While both the construction crew and monitors were in constant communication and ready at all times to shut construction down, no shutdowns occurred. During the short initial stage when the containment berm went in, heavy equipment was close enough to the water that seals might have moved into the exclusion zone at high tide. The rest of the time work was far enough away that seals could not physically get near enough unless they crossed a mudflat or climbed onto the berms, which they never did.

v) *Changes in behavior of other stocks*

Sea Otters, counts

Under the MMPA, Level B harassment is the potential to disturb through changes in patterns of behavior. Determining at what temporal scale a pattern is defined and when it has been disrupted is within agency discretion and USFW has directed us to report our monitoring results in terms of changes in behavior or reaction of sea otters but that this does not constitute take (Table 3).

Sea otter counts during the daytime (6AM - 6PM) ranged from 0 to 36 individuals within 300 m of construction activity in the project area and from 0 to 111 individuals in the entire observation area. The average number of otters per hourly count, within 300 m of construction activity in the project area was 4 otters/hr and 14 otters/hr for the entire observation area. Pre- and post- construction counts had lower average and maximum numbers of otters, than regular hourly counts (Figure 7). The average number of otters were calculated within 300m for time of day (Figure 8) and by month (Figure 9). August had the highest average of otters.

Over about a thousand hourly counts (1186) we observed a total of 20 otter change in behavior events. 12 were most likely caused by construction or construction monitoring, 8 events were caused by recreational- or boat users of Elkhorn Slough.

We looked at the abundance of otters during different types of activities and found that 84% of disturbances occurred during excavating and filling activities (Table xx).

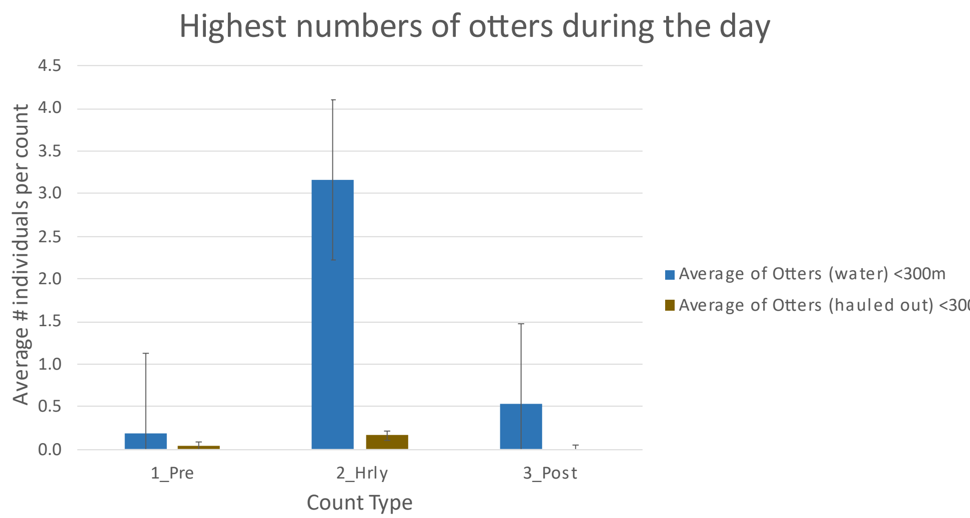


Figure 7. Average seal abundance around construction time.

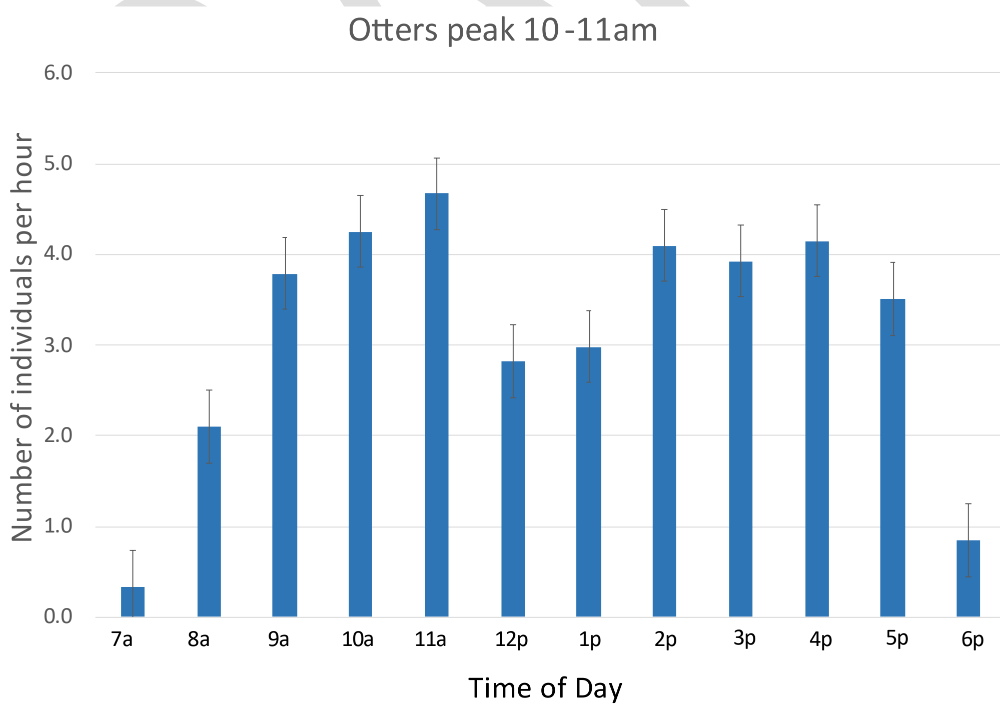


Figure 8. Otter counts, before construction starts, throughout the day, after construction ends.

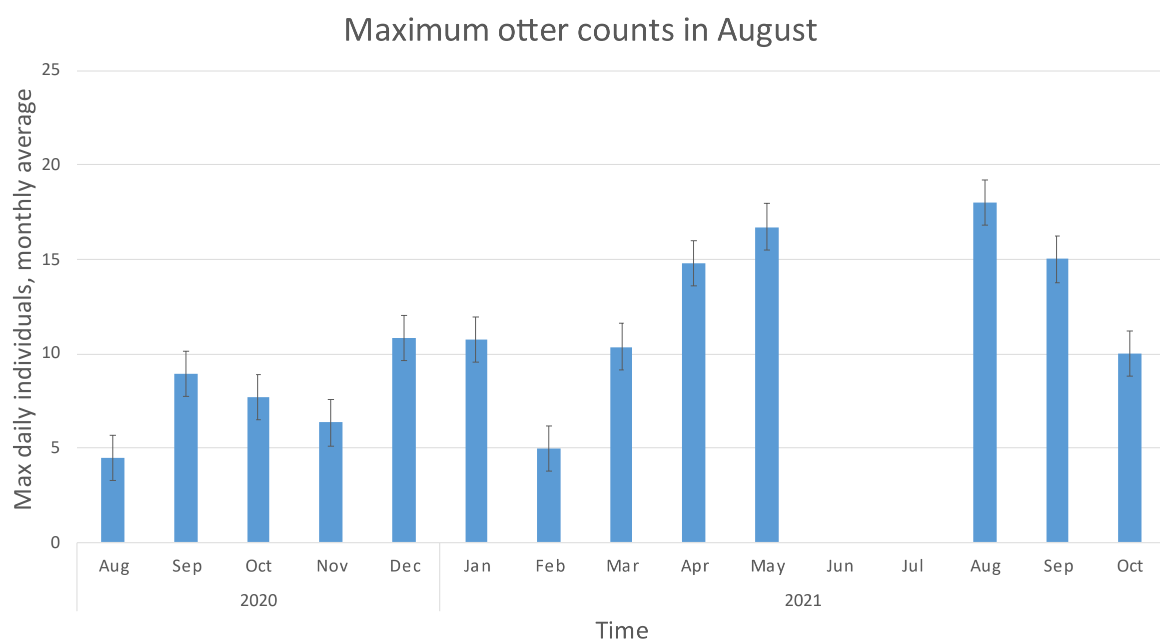


Figure 9. Otter counts by month.

Table 3. Otter change in behaviors due to various stimuli.

Incident #	Date	Reaction	Trigger	Activity	Distance (m)	Total Oters in Vicinity	Total Otters Reacted	Total Otters within 1000m
1	9/17/2020	Move	Construction (Visual)	Other	80	1	1	9
2	9/21/2020	Alert	Construction (Sound and Visual)	Excavating and filling	80	1	1	13
3	10/1/2020	Move	Construction (Visual)	Equipment moving closer	40	2	2	2
4	3/17/2021	Flush	Construction (Sound)	Tractors starting	300	1	1	4
			subtotal Construction			**5**	**5**	**28**
5	8/27/2020	Movement	Observer (Sound and Visual)	People only	100	1	1	4
6	8/27/2020	Flush	Observer (Sound and Visual)	People only	20	1	1	5
7	8/27/2020	Flush	Observer (Visual)	People only	20	1	1	5
8	9/22/2020	Movement	Observer (Visual)	Other	40	1	1	1
9	10/6/2020	Movement	Observer (Visual)	Excavating and filling	10	2	1	6
10	3/31/2021	Movement	Observer (Visual)	People only	80	2	2	2
11	4/13/2021	Flush	Observer (Visual)	Excavating and filling	20	1	1	1
12	5/11/2021	Movement	Observer (Visual)	People only	20	2	2	2
			subtotal Observers			**11**	**10**	**26**
13	9/22/2020	Movement	Visual	Tour boat	40	1	1	6
14	10/5/2020	Flush	Visual AND Sound	Kayak	20	1	1	3
15	10/21/2020	Movement	Visual AND Sound	Tour boat	10	1	1	4
16	10/22/2020	Flush	Visual AND Sound	Tour boat	10	2	2	9
17	11/23/2020	Flush	Visual	Kayak	20	2	2	3
18	5/10/2021	Flush	Visual	Kayak	1	1	1	7
19	5/20/2021	Movement	Visual AND Sound	Hydro bike	40	19	19	19
20	5/24/2021	Alert	Visual AND Sound	Paddle boarder	40	1	1	12
21	9/10/2021	Movement	Visual	Kayak	10	5	3	3
			subtotal Recreation			**33**	**31**	**66**
Total						**49**	**46**	**120**

Table 4. Abundance of otters by construction activity.

Construction Activity	Count
Excavating	77
Excavating and Filling	4230
Filling	256
Other	158
People only	118
Grand Total	**4839**

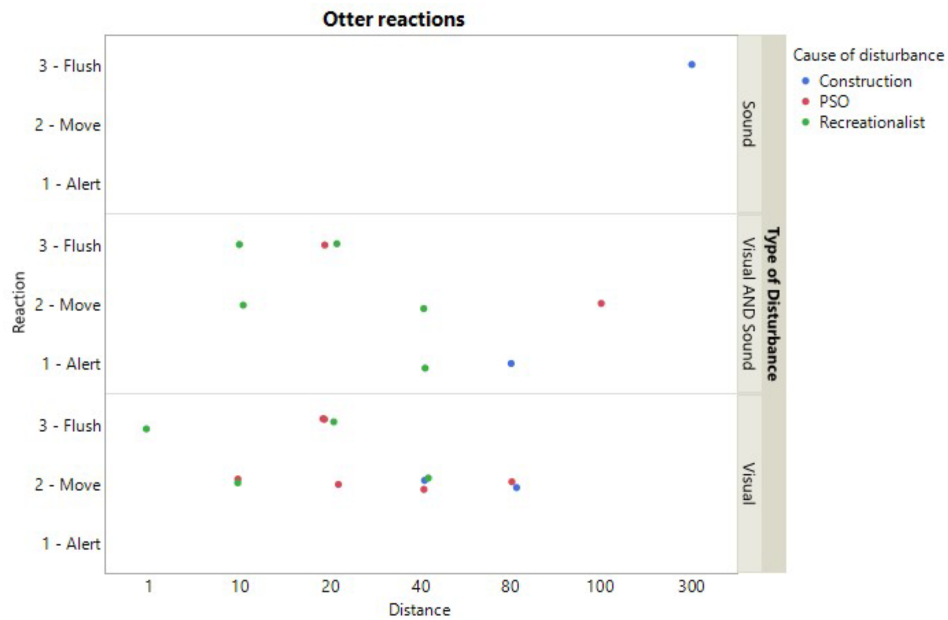


Figure 10. Cause and type of otter reactions by distance.

Discussion

Impacts of activities on pinnipeds

It appears that the impacts on pinnipeds was much less than originally estimated. They continued their regular activities. For example, harbor seal continued to move out into the bay to forage at night and haul out in the vicinity to rest during the day, regardless of construction activity. These findings are consistent with other marine mammal monitoring within Elkhorn Slough.

As mentioned above there were no shutdowns implemented. This is likely due to that fact the marine mammals in Elkhorn Slough appear to be habituated to noise and movement consistent with construction activities.

Recommendations

The Elkhorn Slough National Estuarine Research reserve implemented a robust and thorough monitoring program for monitoring marine mammal behavior during construction. It appears that takes estimate were extremely over estimated and it is our recommendation that future take estimates for construction projects in Elkhorn Slough be based on the data provided by these recent projects.

References

Fountain, M., Jeppesen, R., Endris, C., Woolfolk, A., Watson, E., Aiello, I., Fork, S., Haskins, J.,Beheshti, K., Wasson, K. Hester Marsh Restoration. Annual Report 2021. Elkhorn SloughNational Estuarine Research Reserve. Available fromhttps://www.elkhornslough.org/tidal-wetland-program/.